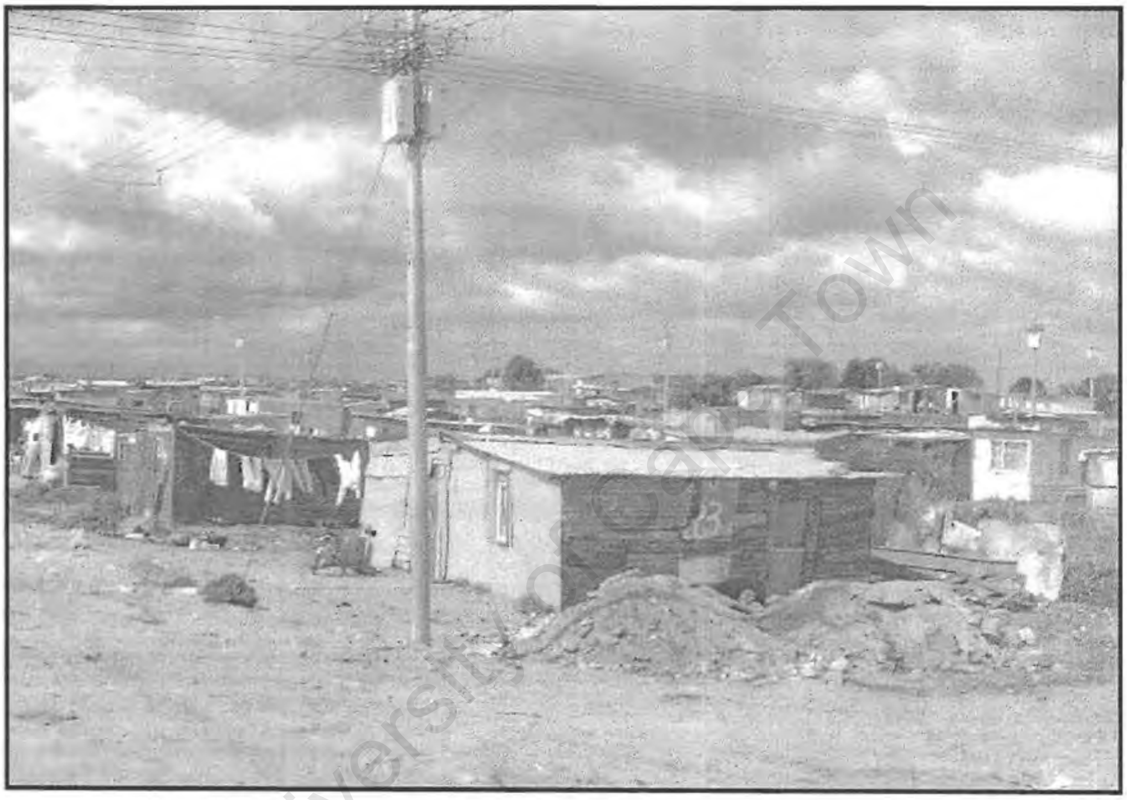
A REVIEW OF INFRASTRUCTURE SERVICES FOR THE UPGRADING OF SOUTH AFRICAN INFORMAL SETTLEMENTS



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EXECUTIVE SUMMARY

Informal settlements are rapidly growing around South Africa's urban centres. With the current housing policy unable to cope with the housing backlog, let alone the growth in demand, new solutions need to be found to improve the unpleasant, unhealthy and unsafe conditions in these settlements. Often, the only engineering interventions are 'emergency' services provided as a temporary solution until formal housing can be provided. While in-situ upgrading of informal settlements is becoming more widely practiced, there is still a lack of knowledge and expertise regarding the provision of infrastructure services in these settlements. Those services which *are* provided are simply a transfer of the same high levels of service used in greenfield low-cost housing projects. This approach ignores that fact that informal settlements are here to stay and that they are, by their nature, entirely different to other settlements and require innovative technical infrastructure solutions.

The aim of this thesis is to provide a review of the various options available for upgrading infrastructure in informal settlements and to assess the applicability of each of these in the context of South African informal settlements. A broader objective is to challenge the conventional development paradigm which centres on the provision of a 'package' of linked services according to a Level of Service Matrix. It is argued that this rigid categorisation of services and settlements oversimplifies the complexity of the technical and social choices that have to be made in the context of informal settlements. The hypothesis that is presented is that it is beneficial to treat each of the services independently in order to identify the criteria for selecting particular technologies, to provide sufficient options and flexibility to create real demand for infrastructure, and to challenge the traditional associations between certain services.

An analysis of each of the four main infrastructure services – Sanitation, Water Supply, Drainage and Access – has therefore been undertaken in four separate chapters. The method that has been used to review each service is to revisit the fundamental objective of each service by asking: "What is the fundamental objective of this service and how can this best be achieved?". From this starting point the options are then explored. Each chapter describes the conditions in informal settlements that affect the service, the infrastructure options available, past experience from local and international case studies, and the conditions required for their success in South African informal settlements. By using this method of

analysis, the issues that dominate the provision of each of the services are found to be quite different:

Sanitation: Theoretically there are many sanitation options available, but the challenging conditions in informal settlements reduce these considerably. It is clear that there is no 'best' option; the choice is based on individual socio-cultural acceptance of an affordable service, and operation and maintenance requirements.

Water Supply represents the most mature technology where a high level of service can be supplied in a flexible layout. The critical issue is thus the consumer/supplier interface over which payment is negotiated for a technical level of service that is acceptable to residents. The Free Basic Water policy has important implications for the service options available and the amount and method of payment.

Drainage is linked to the site rather than to the people living on the site. Drainage interventions are driven by elimination of risk and the site-specific analysis of the runoff characteristics.

Access is a service that is community oriented and needs to be looked at in the context of existing movement patterns as well as the social networks and economic livelihoods base of the community. Conventional standards need to be re-evaluated according to the (mainly pedestrian) priorities of this new planning context.

What these very different sets of issues show is that it is, in fact, beneficial to treat the services collectively, and that the Levels of Service approach is an inappropriate planning tool. The unique conditions experienced in informal settlements often require unique solutions. Revisiting the fundamental objectives of a service illustrates the necessities that need to be fulfilled as well as areas where trade-offs can be made. It is only through this disaggregation of services that engineering conventions can be questioned and standards can be revised. Engineering efficiency and technical convenience must not dominate socio-economic factors if upgrading interventions are to be sustainable. The service-specific approach introduces sufficient flexibility to gauge real demand for services and to avoid implementing 'blueprint' solutions. This thesis illustrates that upgraded informal settlements represent a new form of spatial development that require new technical solutions and a re-evaluation of the conventional engineering approach to service provision.

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GLOSSARY OF TERMS AND ABBREVIATIONS

ADU	Automatic Dispensing Unit (for water supply)	
Blackwater	Wastewater from flush toilets	
Camber	Uniform sloping of both sides of a road away from a central crest. Inverse camber involves both sides sloping towards a central trough.	
CBR	California Bearing Ratio. A strength test for road materials based on the ratio of a measured penetration force to a standard force.	
CMIP	Consolidated Municipal Infrastructure Programme published by the South African Department of Provincial and Local Government	
Crossfall	Uniform slope across a road to assist with road drainage	
du/ha	Dwelling units per hectare	
DWAF	South African Department of Water Affairs and Forestry	
Favela	A Brazilian informal settlement. Generally more formal than South African informal settlements	
FBW	Free Basic Water	
Greenfield development	The construction of residential dwellings and associated services on a previously uninhabited site	
Greywater	Household wastewater from washing and cleaning	
Informal settlement	"a group of dwellings where the families are illegally occupying the land on which they are settled, where there is no formal layout plan and the land is either unserviced or minimally serviced" (Abbott and Douglas, 2003).	
LOS	Levels of Service	
MAPET	Manual Pit-Latrine Emptying Technology	
Material Classification	C4	Cemented natural gravel
	G6	Natural gravel (min. grading modulus of 1.2)
	G7	Gravel/soil (min. grading modulus of 0.75)
	G9/G10	Gravel/soil (no grading modulus required)
PAWC	Provincial Administration of the Western Cape	
Ponding	The accumulation of water into puddles and ponds on the ground surface	
RDP	Reconstruction and Development Programme	

Red Book	The South African *Guidelines for Human Settlement Planning and Design* compiled by CSIR for the Department of Housing. It is the most current national guideline on the planning and design of engineering services.
ROEC	Reed's Odourless Earth Closet
Roll-over Upgrade	An upgrading project in which a settlement is temporarily relocated to a nearby area while the site is prepared for development. Once services have been installed, the residents move back onto the original site.
SUDS	Sustainable Urban Drainage Systems
Sullage	see Greywater
UCT	University of Cape Town
VIP	Ventilated Improved Pit
WSA	Water Supply Authority
WSP	Water Service Provider
WHO	World Health Organisation

Chapter 1

INTRODUCTION

Background to the problem

This thesis aims to explore the role that infrastructure plays in the upgrading of informal settlements and will consider the various physical forms that this infrastructure may take.

Informal settlements are unpleasant places to live. They are generally unserviced, unsafe and unhygienic and no one would live in them through choice; yet they remain a ubiquitous symbol of developing cities. People live in these settlements because they are either unable or unwilling to enter the formal housing market. Hence the motivation for this thesis comes from problems with housing, and not with informal settlements *per se*. The rapid growth of informal settlements in and around urban centres in South Africa is a testament to the current housing crisis, with the provision of new housing falling far short of demand. The current housing backlog in Cape Town alone is 240 000 units and growing at a rate of 8000 units per annum, with around 90 000 informal dwellings in the Metropolitan area (Obree, 2003:1-10).

Since 1994, the South African government's housing policy has been based on the provision of single-storey houses on fully serviced plots, usually located on the outskirts of cities. A once-off, household-based capital subsidy is used to fund both the house and the basic infrastructure, but residents still incur considerable capital and running costs. Both the amount and type of housing provided are grossly inadequate for the needs of the urban poor. Thus, informal settlements are the only option for urban dwellers failed by the formal land/housing market.

It is unlikely that informal settlements will be eradicated through adequate state housing provision in the short- to medium-term in South Africa, and indeed in developing cities worldwide. The number of people living in informal settlements continues to grow daily, and South African informal settlements house between 10 and 20% of the urban population (Abbott and Douglas, 1999). It is therefore necessary, and increasingly urgent, to address this problem and to develop strategies for their upgrading and development.

The physical infrastructure (roads, water supply, etc) is a critical element of human urban settlement. To date however, because informal settlement upgrading is a relatively new concept in South Africa, most interventions in informal settlements have consisted of providing basic standpipes and communal toilets as a temporary measure to improve health conditions. In most cases, this provision of 'emergency' services is driven by a policy that continues to see informal settlements as temporary; it is believed that everyone will eventually move into a formal house. This approach is also influenced by the lack of expertise and knowledge as to what form infrastructure in informal settlements should take. As upgrading slowly becomes recognised as a form of development in its own right (and this is gradually beginning to happen in South Africa) then the tendency is to transfer the standards and technologies used for formal developments and adapt them to suit informal settlement conditions. This approach ignores that fact that informal settlements are, by their nature, entirely different to other settlements and introduce constraints that may render these technologies inappropriate. It also ignores alternative approaches that have been used successfully elsewhere in the developing world that may be applicable in South Africa.

There are now a wide range of options available for infrastructure provision to informal settlements that have been used and tested in pilot schemes around the world. There are also many different, and often opposing, views on the best approach and what 'appropriate' technology to use. This thesis aims to review these options in order to address the lack of information in this field and to contribute to a more strategic and long-term approach to the development of informal settlements.

History of infrastructure provision and the emergence of 'Levels of Service'

Infrastructure history can be traced back to Roman times, but the infrastructure services in the form that we know them today really developed during the industrial revolution and the urbanisation of Europe and the United States in the mid-nineteenth century. This infrastructure boom was largely a response to increased water usage and the threat of cholera from inadequate sanitation, as well as the need to transport goods and resources more quickly and easily. Infrastructure provision therefore developed out of a need to satisfy social and economic needs; the need for water, the need for health, the need for safety, and the need for travel and trade.

The increasing wealth in these industrialised areas eventually allowed for infrastructure to be provided as part of the formal planning process for new land and housing development. This process of planning the infrastructure for new developments had two consequences. Firstly, the whole process of infrastructure provision could be regularised and the most efficient services, based on previous experience, could be implemented. The success of small-scale projects led to local specifications, which in turn were developed into national standards. Although only occurring much later in South Africa, this process can be observed in the development of national standards and guidelines such as *Town Planning and the Establishment of Townships* (Transvaal Provincial Administration, 1965), *Guidelines on the Planning and Design of Township Roads and Stormwater Drainage* (SAICE, 1976) and later the "Blue Book", *Guidelines for the provision of engineering services for residential townships* (DCD, 1983). The second, and more important, implication is that this process underlay a shift in thinking about the rationale for services. As technology improved, services began to be seen as ends in themselves, and not as a means of fulfilling basic needs. Their primary objective became the need to provide a greater degree of 'user convenience' (Abbott, 1993). For example, water is provided to households at sufficient pressure and quality to enable almost any use, flush toilets provide a convenient disposal site for many unwanted household wastes (not just excreta), and roads are tarred to the house boundary to enable the continuation of the hardened surface right through into the garage, if one so wishes. Standards enforce these perceptions of the functions of infrastructure services and divert attention from their original purposes. It is these standards, or a reworking thereof, that are being applied to new developments in South Africa and form part of the dominant development paradigm.

This thesis will show that, when faced with a new form of settlement that has not undergone the same path of development, user convenience is not a helpful or necessarily feasible starting point. The dense, crowded and unhealthy conditions in unserviced informal settlements require a revisiting of the fundamental objectives of services to find viable solutions to the problems of servicing these areas. Too often the high standards of the developed world are imposed upon low-income settlements for lack of alternatives and result in unsustainable and inappropriate systems.

Affordability is the greatest constraint to providing conventional infrastructure in low-income settlements. The high cost of providing conventional services in low-income areas has meant that the service standards have had to be reconsidered (Cotton and Franceys, 1991:6). This led to a debate over how to effect the lowering of standards. Cotton and Franceys, following the incremental housing model first developed Turner in the late 1960s, propose to first provide a *basic* level of service* which could be upgraded to higher levels when the means became available. Subsequent levels were then defined as *intermediate* and *full* (or ultimate). This progression has been termed 'incremental upgrading' (Cotton and Franceys, 1991) or 'progressive improvement' (Chougill et al, 1993) and is intended to be the responsibility of residents or the community, with assistance from authorities. The following table details the technical options for infrastructure.

* defined as that which satisfies the basic needs of each sector

Table 1.1 Technical options for infrastructure (Cotton and Franceys ,1993:131)

Service	Objectives	Technical options: Increasing service level through upgrading →		
Drainage	Safe disposal of sullage; rapid disposal of stormwater	Soakage pits Lined drains from water points Earth storm drains	Lined sullage drains Lined road drains All drains lined	Open drains covered in cluster Piped drains
Roads	Pedestrian and vehicle access to all houses at slow speeds	Profiled and compacted earth roads	Profiled and compacted gravel roads Water bound macadam roads Bituminous surfacing	Bituminous macadam pavement Concrete pavement
Water	Potable Water within reasonable distance	Water point per 200 people for 20 litres pc	Water point per cluster Yard connections	Metered household connections In-line water storage Solar water heating
Sanitation	Safe disposal of excreta	Household improved pit latrines Household off-set pour flush latrines	Communal septic tanks Reduced cost sewerage	Conventional sewerage
Solid Waste	Adequate removal and disposal of solid waste	Communal bin within 100m	Increased number of communal bins Street corner collection	Kerbside or household collection
Power	Economic power consumption; Future power line installation	Allowance for improved cooking stoves; Clearance maintained between plot boundaries and access routes for overhead lines	Security street lighting One amp semi-conductor fuses Full street lighting Five amp semi-conductor fuses	Household energy meters

Although this method of upgrading was meant as a community-based means to access affordable infrastructure, it has been adopted by governments and other development agencies to assist in selecting levels of service for low-cost housing projects. In South Africa the matrix has been institutionalised as the Levels of Services (LOS) Matrix. There are many forms of this matrix, but a commonly used one is that from the *Guidelines for the provision of engineering services in township settlements* (DCD, 1983). A simplified example of this type of matrix is shown below in Table 1.2. There is a distinct 'vertical' emphasis on the grouping of the services. The adoption of the notion of 'levels' of service is appealing because it simplifies the task of selecting low-cost infrastructure. Instead of having to consider the demand and required level for each service, one just has to select which of the three levels (basic, intermediate or full) is applicable to a certain community. This decision can be based on anything from income levels, to location, or type of settlement. Once a level has been selected, all the associated services are implemented as a 'package deal'. The potential for upgrading exists, but is usually left to the community to undertake. The LOS approach has dominated service delivery in South Africa.

Table 1.2 Typical Levels of Service (LOS) Matrix

	BASIC	INTERMEDIATE	FULL
WATER SUPPLY	Communal standpipe within 250m	Yard tap	House connection
SANITATION	VIP latrine	Septic tank with soakaway	Waterborne sewerage
ROADS	In-situ material; formed only	In-situ material; gravel surface	Pavement layers with surface
DRAINAGE	Unlined channels	Lined channels	Kerbs, channels and pipes
SOLID WASTE	Communal skip	Kerbside collection	Door-to-door collection
POWER	High-mast lighting	Prepaid 40 Amp supply	Metered 60 Amp supply

The physical, social and economic conditions in informal settlements are undeniably complex. By grouping all services, some quite unrelated, one is making certain assumptions about the needs, priorities and physical conditions in a certain settlement, or even in informal settlements as a whole. This thesis therefore challenges the concept of 'Levels of Services' on the grounds that it does not deal with these complexities. A further problem is that the LOS approach associates services in a group to the extent that they are viewed as necessary for, or inseparable from, one another. The alternative to this approach is to look at each of the services individually. There are two reasons for this alternative approach. Firstly, to identify the issues that determine whether the service is appropriate or not, and secondly, to determine the physical form the infrastructure should take. There are numerous technologies and approaches to each service that vary from being totally inadequate to providing ultimate user convenience. One would struggle to place these options under the three categories of basic, intermediate and full. This is not to say that for one particular service these levels do not apply, but they do not necessarily refer to a 'package' of linked services. The table below illustrates the revised approach to urban services, with a far more 'horizontal' emphasis, exploring the options within each service.

Table 1.3 Revised matrix for evaluating urban services

	Increasing cost and convenience
WATER SUPPLY	Basic ⟹ Full
SANITATION	Basic ⟹ Full
DRAINAGE	Basic ⟹ Full
ACCESS	Basic ⟹ Full

This thesis proposes that in order to review the service options available for use in South African informal settlements, it is necessary to abandon the notion of Levels of Service and to treat the services independently. There are some undeniable links between services at the practical level of design and construction, but it is proposed that at the level of planning and decision-making it is beneficial to analyse them separately. This hypothesis stems from the broader planning methodology for the in-situ upgrading of informal settlements that has been developed at the University of Cape Town (UCT) (Abbott et al, 2001; Abbott and Douglas, 2001). This methodology forms the theoretical basis for this research.

Background to the UCT upgrading methodology and its key elements

The current approach to informal settlement upgrading outlined in the methodology is the result of a five-year research project undertaken by the Department of Civil Engineering at UCT. The project included a review of case study material and previous conceptual and theoretical analysis of in-situ upgrading projects (see Abbott et al, 2001) and documented experience from a large local pilot project in Gugulethu, Cape Town called New Rest (see Abbott and Douglas, 2001). The objective was to find whether a sound theoretical approach existed that could be applied to South African informal settlements. The findings of the study motivate that a policy of in-situ informal settlement upgrading is urgently needed in South Africa.

The work undertaken at UCT is aimed at providing a holistic alternative approach to upgrading informal settlements in-situ with as little social and physical disruption as possible. The method-based approach is based on the integrated planning approach used in the *favela* upgrading programme in Belo Horizonte, Brazil, but incorporates the economic and social development on which the Sri Lankan Million Houses Programme was founded. The international research into the upgrading of informal settlements and the pilot project at New Rest were used to develop a new methodology from first principles.

What it proposes

The primary objectives of this upgrading methodology are economic and spatial development. The following are some of the key elements of the approach: (Abbott, 2002a,b; Abbott and Douglas, 2003)

- Reduction of vulnerability linked to social exclusion
- Community-Government partnerships
- Various levels of decision-making
- Focus on urban design rather than urban planning
- Integration of the settlement and the surrounding areas by using "soft boundaries"
- Building on existing spatial relationships within the settlement
- The basic spatial unit is no longer the erf, but rather the individual dwelling
- Minimum relocation of dwellings
- Infrastructure does not drive the upgrading process, but rather supports it.

What the implications are for infrastructure provision

The last bullet point mentioned above is the issue on which this thesis will focus. The UCT methodology calls for a new approach to the planning and design of infrastructure. The rationale behind infrastructure supporting the upgrading process is that infrastructure constitutes only one small part of the informal settlement development process, albeit an important one. This involves a break away from the conventional tried-and-tested project cycle in which infrastructure is designed first and drives the rest of the process. This design procedure for greenfield sites is still the most common approach in South Africa, and often adapted to fit informal settlement planning. However, this conventional approach to service delivery has already been shown to be inappropriate for the upgrading of informal settlements, and was a reason for the failure of sites-and-services schemes in the 1970's and 1980's (Lim, 1987; Choguill et al, 1993). Hence the drive towards developing alternative approaches, such as the incremental upgrading approach advocated by Choguill et al (1993, 1994). This is not necessarily the only new approach to upgrading infrastructure, and the methodology developed at UCT explores the issue from first principles. The most effective way to illustrate the differences in this new approach to the design of services is to compare it to the greenfield approach. The characteristics of a *greenfield* housing development that define the services are the following: (Abbott and Douglas, 2001:15)

1. The design is carried out in accordance with specific codes or guidelines.
2. All physical services tend to be designed together, and retain that linkage through the project cycle into construction and even maintenance.
3. There is a strong linkage between the roads and the stormwater, both in terms of stormwater generation and integrated design
4. Services move out from the individual erf, which is seen as the point of delivery and collection

The services are designed together both for economy and ease of construction. This is possible as no erven or dwellings are defined, and the physical services are able to influence and, if the site conditions demand, even dictate the site layout. For the in-situ upgrading of informal settlements there are existing dwellings on the site, and thus the approach needs to change completely. The *new approach* to infrastructure servicing results in the following changes: (Abbott and Douglas, 2001:16)

1. The services are disaggregated. The design tends to follow a two-stage process, dealing first with the settlement as a whole and only later moving down to the level of the individual dwelling.
2. Stormwater and roads are disaggregated, as they now have different functions. Stormwater becomes an element of physical risk, which has to be addressed in the initial analysis of the site. Access now moves from being an engineered issue to being much more a planning issue.
3. The two-stage design requires much greater flexibility in the design of the water and sanitation systems when coupled with a minimum relocation policy, particularly with respect to the latter.

4. All infrastructure should be viewed in terms of a collective function and an individual function. Each service must then be demarcated at some point (or points) between the two.

The disaggregation of services is motivated above in terms of the individual functions of each service, but is also beneficial for two other reasons. Firstly, it allows the services to be introduced into the upgrading process at different points, as is required by the methodology (Abbott and Douglas, 2001:85). Secondly, it enables a flexible implementation programme that allows for a range of different affordability / expenditure patterns. The points made above refer to the broad implications that the methodology has on infrastructure. The more specific implications for some of the services are as follows:

Drainage

Drainage now primarily concerns risk minimisation and management as flooding may necessitate relocation. Roads and drainage no longer have the same close relationship as roads take up much less area and thus do not play such a large role in stormwater generation and collection (Abbott and Douglas, 2003).

Access

Roads are replaced by movement networks, which form multi-functional social spaces. The movement corridors follow existing paths and tracks as much as possible. Non-vehicular traffic dominates over vehicular traffic.

Water Supply

Water reticulation is already the most flexible of all services and disaggregating of service delivery allows this flexibility to be retained in order to follow the development pattern.

Sanitation

New approaches to sanitation developed over the last two decades provide a much greater flexibility to this service than was the case in the past. This lessens the role that sanitation plays in site formation and layout, and enables it to play a more supportive role.

The potential benefit of this disaggregation of the individual services, and the new approach to each of the services outlined above, form the hypothesis that this thesis aims to explore.

Objectives of this thesis

The general objectives of this thesis are to:

- Investigate the validity of the hypothesis proposed by the UCT methodology: that it is beneficial to treat each of the infrastructure services separately for analysis and planning

- Provide a thorough review of all available technology and current approaches to the four main infrastructure services (sanitation, water supply, drainage and access) in informal settlement upgrading and/or low-income developments in order to substantiate the concept that services should be treated separately

- Identify the key issues for the design of each of these four services that must be considered to establish appropriateness in a South African context

- Describe the conditions that are required for each technology or approach to succeed in upgrading projects in South Africa, as well as the constraints that may cause them to fail

Method of research

The basic form of this thesis is a review; however, it is intended to be more than an assessment of the literature on informal settlement upgrading. It is rather a contextual analysis of this literature and other upgrading experience under real South African conditions. In order to cover the available literature and to analyse it in a local context the following procedure was followed:

- An initial literature review of the history of informal settlement interventions and the emergence of in-situ upgrading as a recognised approach was undertaken. This investigation situated the UCT methodology in the wider upgrading debate. This initial review was necessary as a starting point to appreciate the different approaches to upgrading, but because of the technical nature of this thesis and the amount of other literature consulted, this review has not been included here.

- An extensive literature review was then undertaken of international case studies of upgrading and reports regarding infrastructure provision. This was not restricted to developing countries, but included technologies from developed countries that may be applicable in South Africa.

- The local conditions and experiences in South African informal settlements were then investigated. This was achieved by consulting the few published local case studies, consulting professionals working in this field, and through personal experience of four informal settlements in Cape Town.

- Two short international study visits also formed part of this research. A visit to the UK was undertaken to speak with professionals working with infrastructure in the development field. Much of the research and design for internationally-funded upgrading projects in the Indian sub-continent is performed in the UK and the experience of these people was a valuable source of information. A visit to Brazil enabled a different perspective. Brazil has a long history of favela upgrading and the approach is very different from elsewhere in the world. During this visit, interviews were held with researchers, engineers, local authorities and informal settlement residents. Four upgrading projects were visited and local literature on upgrading was consulted.

The information gained from the literature reviews, interviews and site visits was then processed and structured to provide as thorough a review of the options for infrastructure upgrading as possible. From this review, conclusions were drawn based on the hypothesis described above.

Scope and limitations of the thesis

The research and analysis will only cover the services outlined above, namely: sanitation, water supply, drainage and access. Any reference to 'services' or 'infrastructure services' will be limited to these. A fifth service that may be considered as important as the others is solid waste management. Solid waste management is considered fundamental to the upgrading process, but is more of a *system* or process than an *infrastructure* service. It also does not significantly alter the spatial layout of a settlement. It is acknowledged that there are important connections between solid waste and other services and these are noted and discussed where applicable. Power supply is another notable omission in the definition of services. The reason for this is that in South Africa, electricity is provided by a separate parastatal utility, Eskom. During the upgrading process, electricity is usually supplied separately from other services. This can be seen in Eskom's recent electrification campaign in informal settlements which should serve as an example for the delivery of other services.

The scope of each infrastructure service will be discussed under each section and is restricted to that part of the service that is located on the site. Cotton and Tayler (2000) refer to this as 'tertiary' or 'local' infrastructure. The degree to which bulk infrastructure affect the services provided will only briefly be discussed. In South Africa, bulk infrastructure is planned and funded as part of the Municipal Infrastructure Investment Program and is beyond the scope of this thesis. In many cases it is assumed that, because of the location of informal settlements in or around cities, they have reasonable access to bulk infrastructure (treated bulk water supply, wastewater treatment plants, sewage mains, electricity supply, stormwater drains). The infrastructure for each of the four services will be considered from the dwelling up until the settlement boundary.

A very important point to note here is that settlement upgrading is *not* primarily a technical issue. It is a very complex negotiation of social, economic, cultural, political, spatial, technical and environmental factors. There is, however, a point at which technical considerations have to be integrated into the wider informal settlement upgrading development process. It is at this point that this research intends to contribute to the UCT upgrading methodology. It is thus assumed that a number of steps in the upgrading process have occurred, including participatory planning, ensuring access to livelihoods and obtaining security of tenure.

The context in which the service options will be analysed is informal settlements in South Africa's urban centres. These comprise a vast range of climatic, geological, social and physical characteristics. Settlements on the Cape Flats may be characterised by flat sites, sandy soils, a high water table and winter rainfall, while those in Durban have typically steep slopes, excessively drained soils and a subtropical climate. In contrast, those in Gauteng are characterised by clayey soils with dolines and intense summer rainfall. Densities range between 14 and 300 dwelling units per hectare (du/ha) and sizes between 1 and 100 ha (Abbott and Douglas, 2002). This shows that a wide range of conditions have to be considered when evaluating technology, but in most cases the settlements will be generalised as far as possible.

Because of local experience and lack of published material from elsewhere, most of the South African case studies will be from Cape Town. Similarly, the experience of Brazilian upgrading practice will feature prominently in the international case studies, although examples from as wide a sphere as possible have been included.

Cost is a factor that cannot be separated from any analysis of technology, particularly when it concerns low-income communities. It is often the deciding factor when any choice is offered. Because of the discrepancy in technology transfer, local material supply and cost, skills, and labour costs between countries, it is not possible to make a meaningful quantitative cost-estimate of each service option. Instead, the various options will be comparatively assessed using cost information gained from the literature and experience.

Thesis Outline

This introductory chapter serves to introduce the topic and to motivate the reasons for this research. It describes what this thesis aims to achieve and how this is to be done. The body of the thesis has been divided into four distinct chapters, dedicated to each of the services that are being assessed:

Chapter 2 - **Sanitation**
Chapter 3 - **Water Supply**
Chapter 4 - **Drainage**
Chapter 5 - **Access**

The chapters have been ordered in this way because of the traditional links between water supply and sanitation and between roads and drainage, but there is no other significance beyond this (e.g. the order in which they must be implemented or the importance in the upgrading process).

Although there is some cross-referencing between chapters, this is limited and an attempt has been made, as far as possible, to treat each chapter separately. This is because once the individual infrastructure services are explored separately, the issues that arise are quite different. As a result, the structure of each chapter is also quite different, although there are also some common features. Each chapter describes the technical options available, including those that are presently preferred for informal/low-income areas. The constraints present in an informal settlement context are described and then the technical options are discussed. Conclusions specific to the individual services are drawn at the end of each chapter. Chapters 2 and 3 focus more on the technical options, while Chapters 4 and 5 focus more on the approaches to these services. This is a result of the nature of the services and issues that come to the fore in analysis. The final chapter (6) has two components. Firstly, it draws broad conclusions from the discussions on each of the four services. Secondly it returns to the hypothesis posed by the UCT methodology and assesses whether the research was able to fulfil the original objectives.

Chapter 2

SANITATION

2.1 INTRODUCTION

The low-cost sanitation debate has had a long history in the development sector. Numerous technical options are available, yet the selection of an appropriate sanitation option remains highly problematic. In South Africa the debate has been given renewed status with the proposal of a Free Basic Sanitation Policy (DWAF, 2002). Sanitation has already been established as a basic right in South Africa and current policy requires that the very poor be given access to a free basic level of service (RSA, 2001:30). The target that has been set is that "...by March 2010 all South Africans must have access to a basic minimum level of service" (ibid:18). The aim of this chapter is to investigate what sanitation is meant to achieve, what form it could take, how it can be implemented, and what issues must be considered when selecting a sanitation option.

Objective of sanitation

Through a review of sanitation literature, the common objective of providing sanitation systems can be said to be:

To create a healthy and clean environment through the safe collection, storage and disposal of excreta

The link between health and sanitation has been conclusively proven and relates mainly to gastro-intestinal faecal-oral diseases, helminths, and diseases carried by insect vectors (See Feachem et al, 1977; Cairncross and Feachem, 1983; and Mara, 1996a). This link is not obvious to the consumers, however, with the result that the health focus is often an imposed objective. Consumers usually have very different motivation for desiring sanitation services. These reasons are usually convenience, privacy and prestige (Reed, pers. comm.; Mara, 1996a; Holden, 2001). This view was reinforced by research into user perceptions undertaken in India, Mozambique and Ghana (Saywell and Cotton, 1998). Reed believes it is risky to promote sanitation on health grounds, because as soon as an externality (of which there are many in informal settlements) causes a decline in health, or no visible improvement in health takes place, the sanitation system will be judged to have failed (Reed, pers. comm.).

There has recently been a large international drive to promote household hygiene and health education along with sanitation services. It is not possible to achieve the health benefits associated with sanitation services without a simultaneous improvement in water supply, health services, education and solid waste collection. The South African government has acknowledged this and it forms a large part of the *White Paper on Basic Household Sanitation* (RSA, 2001). It is recognised that all these aspects of health and sanitation are integrated, but the scope of this chapter is limited to the physical form of the sanitation infrastructure that can contribute to improvements in health and living conditions.

It may be argued that a sanitation system must first fulfil the health objective, with convenience, privacy and prestige (which usually result in higher cost), being catered for later. This may be so, but if these three less important, but very real needs are not catered for, there is no motivation to use and support the system. The system will fail and no health improvement will be realised. This important factor, that of sustainability, means that convenience, privacy and prestige, should become secondary objectives of any sanitation system. The users then need to trade these off against affordability to find an appropriate solution.

What is appropriate sanitation?

Pickford (1995:4) defines appropriate sanitation as:

> *"that which meets the needs of people in the best possible way in relation to the resources available and other aspects of the local situation".*

The requirement to fulfil the health objective is obvious, and any system that does not do this is deemed inappropriate. The health objective is achieved, firstly, by ensuring humans do not come in contact with fresh excreta, and do not handle it until pathogens are destroyed. This period is between 3 and18 months (Feachem et al, 1977 and Mara, 1996a) depending on the moisture content and temperature of the container. Secondly, insect vectors and other vermin need to be excluded from any excreta storage receptacle. The secondary objectives can be fulfilled to varying degrees, depending on the amount that users are prepared to spend on the system, but the system should at least provide the *option* of convenience, privacy and prestige.

Almost all sanitation proposed in the literature fulfils the health objectives (if operated correctly), but many are not sustainable. Sustainability in this context is linked to three factors; social acceptance, technical design, and affordability.

Social acceptance

Social acceptance is largely dictated by whether the toilet is inside or outside the house and whether the toilet flushes or not. It also relates to cultural practices of a particular community, as well as whether the system fulfils expectations. The issue of expectations is a highly politicised one in South Africa. The impact that apartheid had on service provision to poor (black) communities has meant that now huge demands are being made on the new government to address the inequalities. This is a theme that is common in all the services discussed in this thesis. Espinosa and Rivera (1994, quoted in Wall, 2000:31) stated,

> *"...many low-income households are reluctant to invest in dry latrines when they know of the flush toilets used by middle and upper-income groups – even if each uses more water in a flush than their entire daily water consumption. 'Alternative' technologies are often viewed by low-income groups as 'second-class' and it has proved a challenge to the technical teams to overcome such attitudes."*

This is obviously a world-wide phenomenon, but the political history that caused these inequalities in South Africa makes the problem even more acute.

Technical Design

The system should be robust enough to function despite misuse and to require minimal maintenance. The system must be simple to construct, operate and maintain, so the responsibilities that are often assumed by the authorities can be taken over by the users.

Affordability

This relates to both the capital and the operation and maintenance cost of the system. Affordability is not just a question of "who pays", but rather "who pays for what", because systems are frequently split up into different sections with different stakeholders paying for different sections. It is important to detail all the costs involved with a system in order to provide an equal basis for evaluation, particularly when on-site systems are being compared to sewered systems. It is difficult to quantitatively compare costs of systems because of the split between external and internal costs, and institutional and private responsibilities. Other factors that complicate costs are subsidies, local labour input, site conditions and surrounding infrastructure. Good relative cost estimates for the various types of sanitation system are given in Palmer Development Group (1993), van Ryneveld (1995) and Hardoy et al (1990), but there is a shortage of more recent cost analyses. An aspect of affordability that is as important as ability to pay for sanitation, if not more so, is what people are *willing* to pay for sanitation, instead of whether they are *able* to pay (van Ryneveld, 1995). This is a better indication of likely cost recovery than other indicators like income levels and therefore motivates a demand-responsive approach.

The method of assessment given by the South African *Guidelines for Human Settlement Planning and Design* give much the same criteria as the three mentioned above. In discussing the selection of a sanitation system, the guidelines state that the system should: (CSIR, 2000:10.8)

- Not be beyond technical capability of community for operation and maintenance
- Not be beyond financial capability, both capital and operating
- Take into account water supply
- Consider future upgrading, if likely
- Operate despite misuse
- Require as little maintenance as possible
- Take training of community into account
- Be able to be locally built
- Consider local customs
- Be compatible with local institutional structure
- Consider existing housing layout
- Consider environmental impact

Outline of this chapter

The purpose of this chapter is to assess the sanitation options available for the in-situ upgrading of South African informal settlements. The introduction has defined the objectives of sanitation systems and indicated what issues need to be taken into account when assessing them. It is believed that the characteristics of informal settlements, and particularly those in South Africa, present a number of constraints that affect the choices available and how these choices are made. The next section will outline these characteristics in order to further define the problem specific to South African informal settlements.

A summary of the research trends in sanitation will then be given to provide some background on the sanitation debate and indicate the direction of current research. The available sanitation systems then need to be classified in order to give structure to the descriptions of each system that follow. These descriptions are not meant to be technically comprehensive, but intend to show how each system operates, what their most common application is, and what the advantages and disadvantages are.

The following section will then discuss each of the technical options by relating them to the sanitation objectives and the characteristics specific to South African informal settlements. This discussion will highlight their strengths and weaknesses in an informal settlement context, and describe the conditions necessary for their success in this environment. From this discussion conclusions will be drawn about the sanitation systems and the issues involved in upgrading sanitation in South Africa.

2.2 PROBLEM DEFINITION AND BACKGROUND TO THE SANITATION DEBATE

Constraints to the provision of sanitation in informal settlements

There are three primary constraints that are experienced in informal settlements that may be more severe, or different to those experienced in other development projects; lack of space, lack of resources and location on marginal land:

Lack of space – Informal settlements, and particularly infill settlements in urban centres, are dense by nature; typically 70-150 du/ha (Abbott and Douglas, 2002). They may not be as dense as some 'slums' in other developing countries like India or Brazil, but South African informal settlements generally comprise single storey dwellings, with minimal shared public space around them, so a density of 120 du/ha is believed to be the maximum permissible for in-situ upgrading (Abbott and Douglas, 2002:2). There are usually main access tracks into the settlement, but most of the area is served by narrow footways. Any sanitation system must recognise this constraint, particularly where an improvement in housing is going to take place, in which case the available space around the houses is going to be reduced further. The density in urban areas means that the perceived needs (in terms of privacy and convenience) are a lot higher than in rural areas because people live much closer together (Mara, 1996a:165).

Fergusen (1996) states that international experience has shown that non-sewer sanitation solutions in urban areas seriously threaten health and the environment at densities greater than 100-150 *people* per hectare. Other research indicates that space is not necessarily a constraint. Saywell and Cotton (1998:47) report that "results from the household survey indicate that for the users, absence of a household latrine is more a function of poverty than available space on the plot." Space cannot, therefore, be assumed to be a reason for not having sanitation at all, but it does inhibit the *type* of sanitation system chosen.

Regulations for the maximum density for on-plot sanitation vary from 23 dwellings per hectare (Jamaica), to 250 dwellings per hectare (Indonesia). The minimum plot size for on-site sanitation in India is 26 m^2, although none of these regulations seem founded on reasoned argument or evidence (Saywell and Cotton, 1998:48). Saywell and Cotton conclude by saying,"there is little indication that plot size is associated with particular operational problems."

Box 2.1 Position on communal toilets

Position on the use of communal toilets in informal settlements

If space is perceived to be a problem and waterborne systems are not viable, then a common solution has been to provide a communal service. It is the opinion of many authors of literature in this field (see Marais, 1971; Mara, 1996b; Cotton and Tayler, 2000) that communal toilets are unsatisfactory to users, unless provided to a very small, willing group (of approximately four households), or the toilets are privately run (e.g. those run by the Sulabh International Social Service Organization in India). Communal systems are often badly maintained and cause conflict among users. There is also a greater opportunity for vandalism (Fig. 2.1) There are numerous cases of residents or 'landlords' locking communal toilets to prevent certain groups from using them. Individual toilets allow greater health benefits, more privacy, convenience and status, and are likely to be properly used and maintained.

The South African government has taken a bold step in the *White Paper on Basic Household Sanitation* by saying that the minimum acceptable basic level of sanitation is a toilet facility for every household (RSA, 2001:5). This appears to mean that the government no longer supports the construction of communal toilet facilities. This thesis strongly supports individual toilets to each household, regardless of the system chosen. Communal toilets will therefore not be considered as an appropriate sanitation solution unless in exceptional circumstances and with the full support of the residents.

Fig. 2.1 The fate of communal toilets: A cluster of communal toilets, complete with water-borne sewers, provided in Masiphumelele settlement, Cape Town. The toilet doors and pedestals have all been removed.

Lack of resources – Informal settlements are low-income areas with high rates of unemployment. The skills base from which to draw is small and the levels of education are generally low. This means that residents have little to bring to the negotiating table when dealing with local authorities and choosing sanitation options. The social survey by Saywell and Cotton, mentioned above, showed cost to be the single greatest contributing factor to the lack of adequate sanitation in the areas surveyed. "Poverty, and/or the inability to save funds to invest in longer term sanitation facilities are key constraints" (Saywell and Cotton, 1998:48).

Location on marginal land – Informal settlements are often situated on land that has no other functional use (see Satterthwaite, 1993). This may be because it is in a flood-prone area, in a servitude, on an old landfill, or on very steep or unstable slopes. Local examples of this are the two adjacent informal settlements of New Rest and Kanana in Cape Town, which are situated on a main water pipe servitude and an old landfill respectively (see Graham, 2001). The tendency for informal settlements to be situated in low-lying areas is problematic, both for on-site and off-site systems. Saturated ground limits the effectiveness of soakaways and pits that require infiltration, and sewers that begin in the lowest areas will require pumping at some stage, to transport the waste to treatment facilities, raising the cost of the system considerably. The location of settlements on marginal land provides significant constraints on the choice and design of sanitation systems. Because the site conditions will vary from settlement to settlement, this issue needs to be dealt with on an individual basis.

Assumptions about South African urban dwellers

Technology choice is made in the context of a set of assumptions. These include assumptions about ground conditions, housing density, frequency of use, workmanship, institutional strength, funding, level of water supply, and 'education' provision (Wall, 2000). Some of these assumptions like density, institutional strength, funding and water supply will be dealt with explicitly later on in this review. Others, like ground conditions, will not be dealt with because of the general nature of the review and the lack of focus on one particular area or settlement. Assumptions that need to be stated explicitly here are those about the cultural practices of urban South Africans that may be different from other cultures, and have significant impacts on the type of sanitation selected.

To use the terminology of Mara (1996a), urban South Africans are 'sitters' and not 'squatters'. They prefer to sit on a pedestal to defecate, rather than squatting, which is widely practiced in the Middle East and much of Asia (Alcock, 1999:39). The implication of this is that a pedestal needs to be provided on all sanitation facilities, which increases cost, and rules out some technologies that are specific to squatting (like the basic Sanplat squatting plate discussed later).

The second point, again using the terminology of Mara (1996a), is that urban South Africans are 'wipers' and not 'washers'. They use solid anal cleansing materials (usually toilet paper, often newspaper, and occasionally rags, cement bags, corn cobs, sticks and stones - Alcock, 1999) instead of water as used by other cultural groups elsewhere in the world. Note that these two assumptions do not necessarily apply to the Muslim and Hindu populations of South Africa, but these ethnic groups do not form any significant proportion of low-income informal settlements.

The final point is that there is an aversion to handling excreta in any form. Urban South Africans can be described as 'faecophobic', as opposed to 'faecophillic' nations like China and Vietnam, where excreta is collected and used as a valuable resource. The implication of this is that residents will be resistant to a system that involves handling of excreta, even after significant decomposition (CSIR, 2000; Alcock, 1999).

An evaluation of on-site sanitation systems in three low-income areas in South Africa (Bernhardt Dunstan & Associates, 1998) exposes some important cultural perceptions and practices:

- Many people believe children's faeces are harmless and therefore children are free to defecate in the open, when in actual fact they contain higher pathogen loads than adult faeces.
- There was a large misunderstanding of technology, resulting in only the simplest pit latrines functioning as intended.
- There was a general lack of hygiene education in these areas.
- The systems, varying from unimproved latrines to low-flush aqua privys, were all perceived by the users to be inadequate. Water-borne systems were desired.
- People believe they have inferior, second-rate systems in comparison with those enjoyed by (wealthier) urban people.
- There was no attempt to relate product to affordability and the payment principle was ignored or neglected.

Summary of research trends in sanitation

During the Water and Sanitation Decade of the 1980s, the World Bank's Technical Advisory Group (TAG) and other international aid agencies sought to implement more appropriate solutions in World Bank development projects (See Kalbermatten et al, 1982). This led to significant research into sanitation technology and the promotion of the VIP latrine in Africa and the pour-flush toilet in India. These two technologies were seen as likely to succeed because they were culturally acceptable solutions. Later, condominial sewerage was also promoted in Latin America. Because of the large financial backing in these projects, these solutions were implemented on such a large scale that they now are viewed by many to be 'standard' low-cost solutions. This seems to go against the philosophy and intention of the World Bank, both then and now which was/is to promote range of alternative sanitation solutions. Other areas in sanitation research include the following:

Settled sewers, or solids-free sewers were introduced in Zambia in the 1950's and Australia in the 1960's. The system is now used in the USA, Thailand and Japan as well, and has been researched in South Africa by the CSIR since 1989 (du Pisani, 1998).

Condominial sewerage is viewed by some to be the most significant recent breakthrough in sanitation technology (Mara, pers. comm.) The system was developed in Brazil in the 1980's. There have been many variations of this system applied in other countries, and the technology is probably one of the fastest-growing types in the world. These systems will be referred to as simplified sewers in this thesis.

Another area of research has been 'ecological' sanitation. This consists of non-waterborne systems that store excreta on site for reuse. This technology has been used for centuries in countries like China and Vietnam, but more sophisticated designs have been developed in Sweden and South Africa (See Winblad, 2001 and Enviro Options, 2002). A more recent addition is the urine diversion pedestal.

The lowest-cost solution to come out of research and development is the SanPlat system, which was developed in Mozambique and Malawi in the early 1980's, and is being widely implemented in other countries in Africa. The system consists of a domed latrine slab over a pit with a tight-fitting lid.

Since the 1990s, more research has been based on the non-technical setting in which the technology is placed (Wall, 2000:22). Recently, very little has been written regarding the design of sanitation options. Far more focus has been placed on the provision of choice, method of implementation, dissemination of information, cost recovery, and operation and maintenance (Cotton, pers. comm.; Mara, pers. comm.). As Bernhardt Dunstan & Associates (1998:46) reported,

> *"...technical issues are but a small part of sanitation. The most important issues today are social, economic and political: these dominate, but of course need competent technical input."*

With this in mind, this chapter does not intend to reproduce the technical discussion around sanitation options of the 1980s. Instead it explores the social, economic and political issues that arise around each of the options in the very specific context of the South African informal settlement. Therefore, although technical in content, this analysis will deal with many of the more social aspects of sanitation.

Classification of Sanitation Systems

A widely used classification system that was developed by the World Bank during the Sanitation Decade in the 1980's, separates all systems firstly into on-site, off-site, or both on- and off-site systems, and then into whether they are wet (water is used for flushing) or dry, as shown in Fig. 2.2.

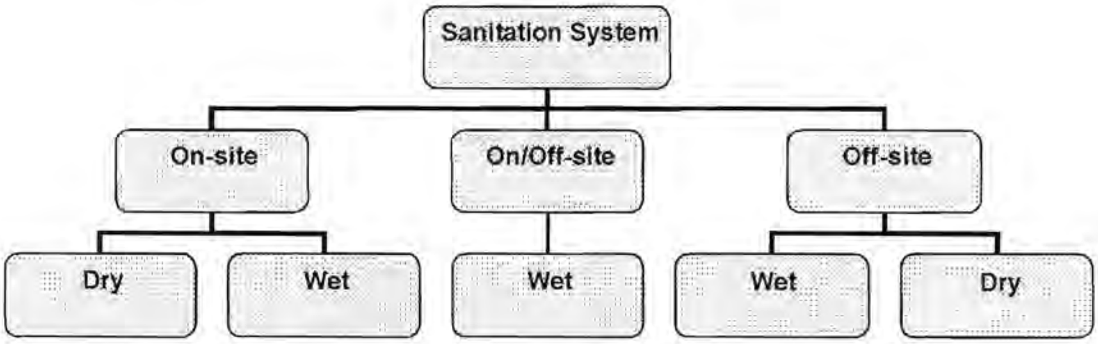

Fig. 2.2 The World Bank classification of sanitation systems (Kalbermatten et al, 1982)

The on-site systems generally comprise a pit or tank that degrades excreta in-situ, while the off-site systems involve collection of waste or a piped system. This classification leads one to believe that the primary decision factor in choosing a sanitation system is whether there is space for an on-site pit/tank or whether transport is required. In a dense urban settlement, some form of transport is almost always required, even though it may be infrequent pit-emptying, because of the space constraints and the health implications of storing excreta on-site. The classification of on- or off-site therefore becomes an indistinct definition and the removal frequency of excreta forms a continuum between emptying after a few years, or instant transport.

The classification process developed in the 1980's is no longer appropriate. Priorities have changed and it is no longer a simple matter of deciding whether on- or off-site sanitation is required. Hence it is proposed here that the primary decision factor be changed to whether the system is wet or dry (i.e. includes water or not). This is far more crucial because it is affected by levels of water supply, cultural practices, and ground conditions. The differentiation of wet and dry systems marks an important historical shift in the approach to sanitation with the introduction of flush toilets, but even then the systems were still on-site (draining into septic tanks). Developments since the introduction of wet systems have all taken water as the primary carrying medium of human excreta, for granted. This distorts the perception of what form adequate sanitation should take.

The reversal of the classification method (see Fig. 2.3) may not seem to be a particularly significant change, as the same four categories result, but it is important when deciding on appropriate alternatives for a specific user group or site conditions. For simplicity, the central column in the previous model has been eliminated by considering solids interceptor tanks with soakaways and with sewers as separate systems.

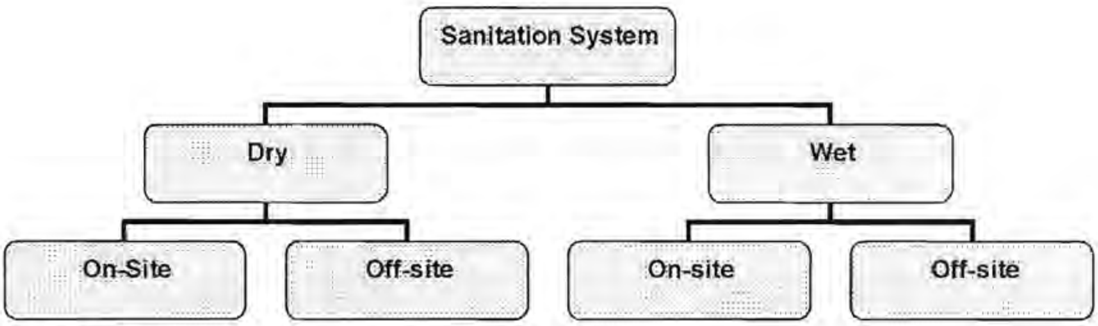

Fig. 2.3 The revised classification of sanitation systems

The options

From the literature, the list shown below (Fig. 2.4) of the available sanitation options was produced. Not all of these are seen as appropriate, and this is discussed in the following sections. Variations of a particular system (e.g. urine diversion variation of the composting toilet) are included in the generic headings and discussed in those sections. The most rudimentary forms of open defecation and unimproved pits are not discussed here.

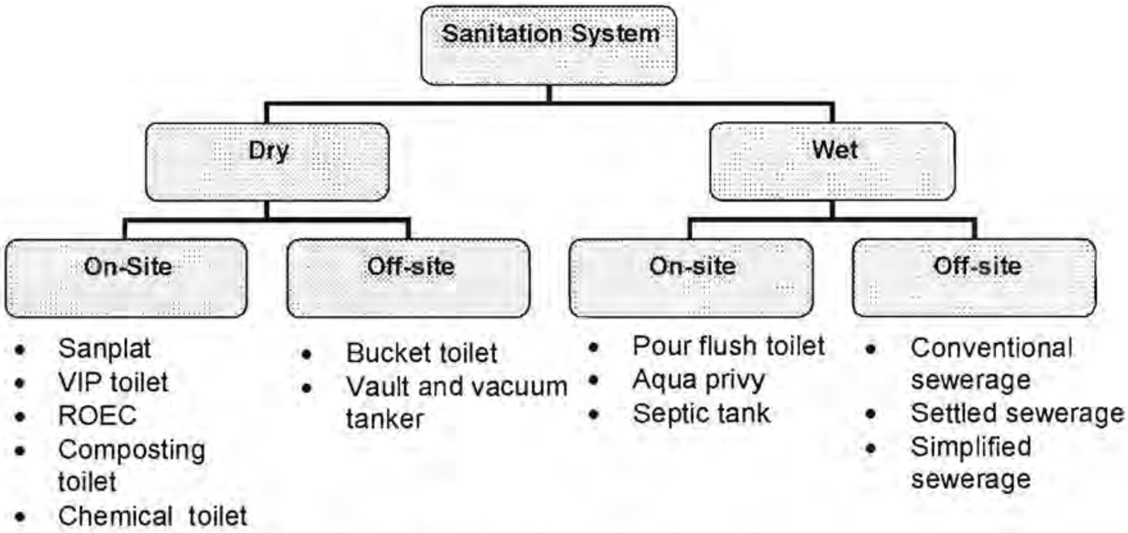

Fig. 2.4 List of sanitation systems under revised classification system

Each sanitation option will be discussed briefly to describe the main characteristics of the system, how it functions, what conditions are required and qualitatively how much it costs. The categories will be discussed from the left-hand column (dry, on-site) to the right hand side (wet, off-site), as this generally represents a progression from the simpler, cheaper solutions to the more complex, expensive options.

2.3 DRY ON-SITE SANITATION SYSTEMS

The SanPlat latrine slab

This simple system is based on ideas developed in Mozambique and Malawi between 1979 and 1989 (www.sanplat.com). Research has been undertaken in Sweden and the system is now promoted in Sweden and Swaziland by LCS ProMotion International AB. The system has been successfully implemented in many African countries and is being promoted in South Africa by the Mvula Trust.

The system consists of an unreinforced, domed squatting plate, which is placed over a pit. The plate has a keyhole drop hole and raised footrests (Fig. 2.5). The tight-fitting lid helps control flies, mosquitoes and odour, while the smooth sloping surface aids cleaning. The system is designed for squatting, but a pedestal can be added if required. The system can be adapted to a VIP latrine or a pour flush toilet. The pit is not intended to be emptied, and once the pit is full, it is covered over and the slab is rolled to a new site. Local manufacture is encouraged and build-it-yourself kits and manuals are available. This is the cheapest 'improved' sanitation system.

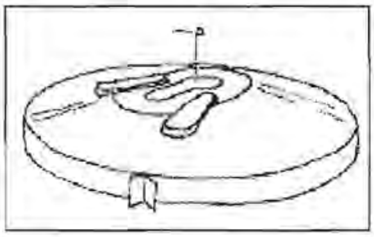

Fig. 2.5 A basic SanPlat latrine slab with tight-fitting lid (Source:www.sanplat.com)

Improved pits

The Ventilated Improved Pit (VIP) latrine was developed in the 1970's at the Blair Research Institute in Zimbabwe and the Reed's Odourless Earth Closet (ROEC) was developed in South Africa in 1944. The main differences between the two systems are that the ROEC pit is bigger and offset from the pedestal/squat hole, then linked by an inclined chute (Figs. 2.6 and 2.7). The greatest benefit of an ROEC is that the contents of the pit cannot bee seen by the users and it is possible to place an ROEC indoors (Winblad and Kilama, 1985:51). There is also no danger of anyone falling into the pit. It does, however require more space. The rest of this discussion will focus on the VIP latrine because it is a more well-known system and widely covered in the literature. All comments, however, are applicable to both, as the ROEC can be seen as a variation of the VIP latrine.

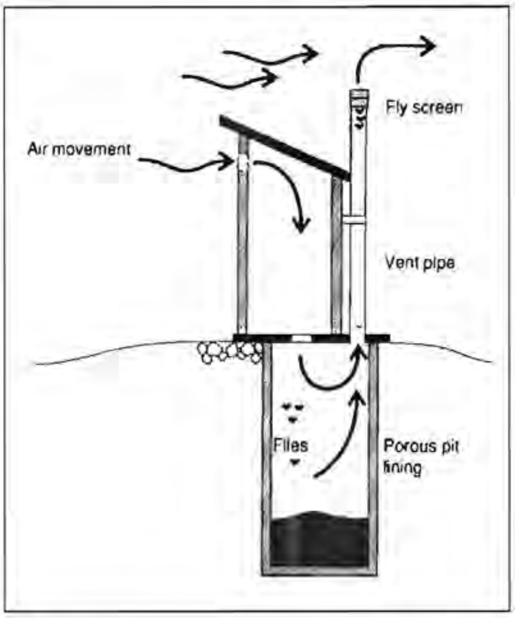

Fig. 2.6 A ventilated improved pit (VIP) latrine (Source: Cotton et al, 1995:19)

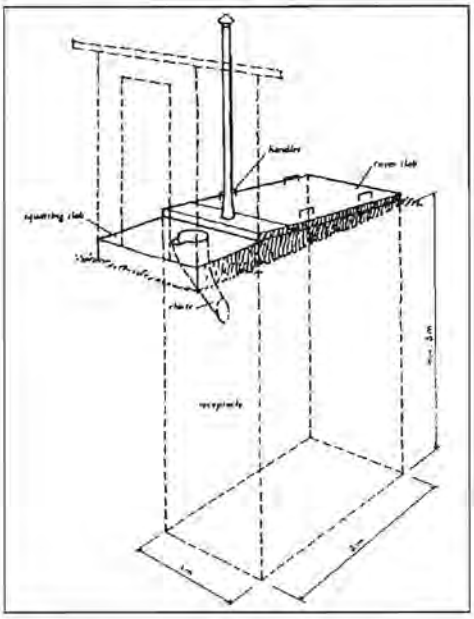

Fig. 2.7 Reed's Odourless Earth Closet (ROEC)(Source: Winblad and Kilama, 1985:52)

All the variations of the VIP latrine work on the same basic principle of a reinforced concrete slab containing two holes, placed over a pit. The first hole is for waste deposition, and the second hole is for a vent-pipe capped with a mesh fly screen. Air blowing across the top of the vent pipe causes a vacuum, drawing air into the pedestal/squat hole, through the pit, and up out the vent pipe. The ventilation controls flies and almost completely eliminates odours. The superstructure can be made of any material, but needs to be kept as dark as possible to prevent flies from exiting the pedestal/squat hole. Numerous designs for VIP latrines are given in Bester and Austin (2000).

Solids accumulate in the pit and degrade anaerobically, while liquid waste percolates into the surrounding soil. Pits can be used in areas with a high water table, and the wet conditions in the pit even improve degradation, but stimulate mosquito breeding. In this case, the slab can be raised to provide storage above ground level. In dense areas where there is no space for relocation, pits have to be manually or mechanically emptied. Using a double pit system prolongs the life of the pit and makes emptying safer. The pits are used alternately and the second pit is used, while the first full pit decomposes for at least a year. An important feature of a double pit system is that the dividing wall between pits has to be sealed to prevent the migration of liquid from the fresh pit. Use of pits is not advised in very dense urban areas, and where ground conditions are unsuitable (Kirke, 1984). The VIP latrine is a simple, robust, hygienic system and although more expensive than the SanPlat, is still one of the cheapest sanitation systems available.

Composting Toilets

Composting toilets have existed in Asian countries like China and Vietnam for centuries, where excreta are viewed as valuable resources (Winblad and Kilama, 1985). Composting is based on a sound environmental principle with a 'closed-loop' of nutrients being returned to the earth. For this reason it is often referred to as 'ecological' sanitation.

Composting toilets are similar to pit toilets, where excreta are stored in containers below the pedestal/squat hole (Fig. 2.8). The main difference is that in composting toilets, conditions are created that stimulate aerobic breakdown of waste, so that the degraded material can be used as fertilizer and soil conditioner. The containers are usually smaller than VIP latrine pits and above ground (for frequent, easy removal). Double compartments are almost always provided for extended composting time. The composting process requires that the correct quantities of material be maintained in the vault. Organic matter needs to be added to the vault frequently to maintain the correct carbon:nitrogen ratio.

A variation of the composting toilet is the urine diversion system, which uses a special pedestal to separate urine and faeces (Fig. 2.9). This process improves the composting process and less organic matter needs to be added to the faeces. Ash and wood-shavings are often added. High temperatures in the vault desiccate the faeces. The urine can be diluted with water and used as an excellent fertilizer (Jonsson, 2001). Six months of storage is required for the urine to be used and 6-12 months of storage is required for the faeces to become safe, depending on the conditions in the 'dry box' (see Cairncross and Feachem, 1983). There are three social issues that need to be addressed when operating a urine diversion system. Firstly, men have to sit down to urinate (or a separate urinal has to be provided). Secondly, the system is sensitive to abuse and toilet paper cannot be added to some systems, so it has to be disposed of separately. Thirdly, the users have to be comfortable with the manual removal and reuse of the composted product.

Some sophisticated single-unit versions have been developed, like the Multrum (Sweden) and the Enviro-Loo (South Africa) (Fig. 2.10). These options are relatively very expensive, but simpler double-vault composting toilets can be built more cheaply.

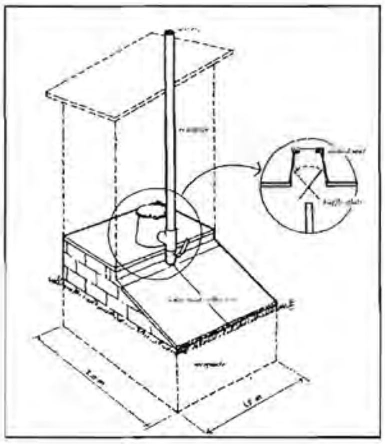

Fig. 2.8 A composting toilet with double compartments for alternating storage (Source: Winblad and Kilama, 1985:32)

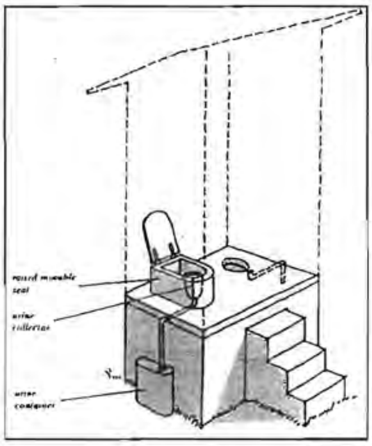

Fig. 2.9 A composting toilet with a urine-diverting pedestal (Source: Winblad and Kilama, 1985:23)

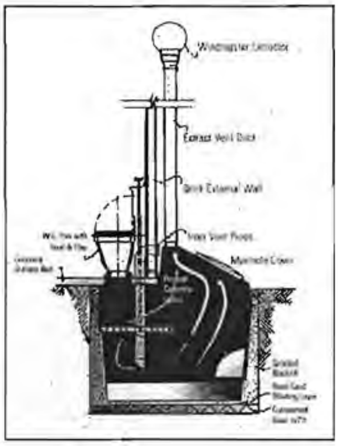

Fig. 2.10 The sophisticated Enviro-Loo (Source: Stewart Scott, 1998)

Chemical Toilets

Chemical toilets are prefabricated plastic units that are mobile and are frequently used as a temporary or emergency solution (Fig. 2.11). The small vault beneath the pedestal contains a combination of strong chemicals (including, inter alia, formalin, an emulsifier, a coloured dye and a powerful perfume) to digest excreta and control odours (Alcock, 1999:51). The system either uses a dry flush or a recirculation of the chemicals to clean the pan. The party digested waste is removed by a vacuum tanker (or the holding tank is removed manually and replaced) and taken to a wastewater treatment plant. Initial capital costs are high and chemicals need to be added at regular intervals.

Fig. 2.11 A chemical toilet in Kliptown, Gauteng (Source: DWAF, 1999)

2.4 DRY OFF-SITE SANITATION SYSTEMS

Bucket Toilets

Bucket toilets (Fig. 2.12) were common throughout the world prior to water-borne systems (McGarry, 1977:254). Excreta are deposited into a container, which is removed (with or without a lid) for disposal, frequently onto land or into watercourses. Either the container is replaced by a new one, or the old bucket is emptied and cleaned (although often not) and replaced. Where bucket systems are still in use, collection usually takes place once or twice a week.

The capital costs for a bucket system are low, but the running costs are high, but this depends on the frequency of collection and method of disposal. Bucket toilets are generally the least hygienic of all sanitation systems, and are often implemented as temporary solutions.

Fig. 2.12 A bucket toilet typical of those supplied to informal settlements in the Western Cape

Vault and Vacuum Tanker

Small household vaults are used in China, Japan and many other parts of Asia where excreta are removed frequently for use in agriculture (McGarry, 1977:258, Pickford, 1995:75). The watertight vaults can be used in areas with a high water table, or where the risk of pollution migration is high. The excreta are not safe to handle manually and are usually removed from the vault by a tanker fitted with sliding-vane or liquid ring vacuum pumps (Mara, 1996a:88). These tankers come in various sizes depending on the type of settlement and access requirements. The tankers are also used to empty pit toilets and septic tanks. Tanks are emptied every 2-4 weeks (Cairncross and Feachem, 1983:127; McGarry, 1977:258), but this can be less frequent with bigger vaults.

Recently, smaller alternatives to big vacuum tankers have been developed. The Manual Pit-Latrine Emptying Technology (MAPET) was developed by WASTE Consultants in the Netherlands for use in the informal sector of Dar es Salaam, Tanzania (Fig. 2.13). It consists of a cart fitted with a 200*l* drum, a piston hand pump and an air hose. The cart is manually transported and operated and is effective in accessing dense settlements with narrow access ways (WASTE website, 2002). The 'Vacutug' was developed in Nairobi by UNCHS (now UNHSP) for use in low-income settlements in Nairobi, Kenya (Fig. 2.14).

Fig. 2.13 A MAPET being used in a narrow access way in Dar es Salaam, Tanzania (Source: Mara, 1996a:90)

Fig. 2.14 "The vacutug consists of a robust carriage supporting a 500 litre capacity tank and a suction pump. A petrol engine provides power for the pump and for locomotion. At the latrine, a hose is lowered into the pit and is connected to the input valve of the tank; the pump is connected to the engine and sucks the effluent into the tank. The engine is then used to move the vacutug to an approved disposal point such as a main sewer where the hose is connected to the output valve of the tank for discharging." (UNHSP website, 2002)

The vault and vacuum tanker system is not strictly a 'dry' system as small amounts of water can be added to clean the bowl. If a ventilation pipe is installed, then the toilet becomes a ventilated vault version of a VIP latrine. Once a water seal is added, however, the system becomes an aqua privy or pour-flush toilet. If a low-flush or sullage–flush cistern is added, with a U-bend pedestal, the system is known as a conservancy tank, but still operates the same way as a dry vault. Emptying becomes easier with an increase in liquid, but needs to be more frequent. The most critical factors when considering this system are the size of tank versus frequency of emptying, and the access needed for the removal vehicle. A vault is less expensive than a septic tank and more expensive than a VIP latrine. The operation costs depend on the size of the tank and the vehicle used. A vault can fairly easily be upgraded to a flushing system with a settled sewer.

2.5 WET ON-SITE SANITATION SYSTEMS

Aqua-Privies

The aqua-privy consists of a watertight tank located directly under the pedestal/squatting plate. A 100-150mm diameter vertical drop-pipe extends approximately 100mm below the liquid level in the tank to form a crude water seal (Fig. 2.15). The seal controls odours, flies and mosquitoes and is maintained by adding small amounts of water to the tank. The solids sink to the bottom of the tank where they are anaerobically digested. A weir can be provided in the pit to prevent surcharging, over which the liquid waste drains and percolates into the surrounding soil. Greywater can be directed into the privy to maintain the seal, but then the overflow (into a soakaway or solids-free sewer) must be able to handle this increased flow. Once the tank is full it has to be desludged (see vault and vacuum tankers).

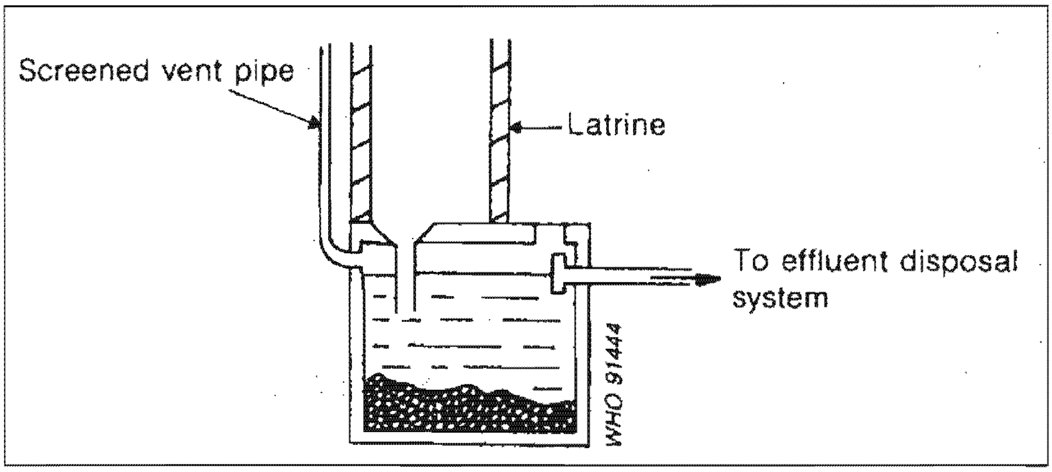

Fig. 2.15 An aqua-privy (Source: Franceys et al, 1992)

The system works well in Asian countries where water is used for anal cleansing, but where there is no culture of adding water to toilets, or where water is scarce, the seal is often broken and flies, mosquitoes and odours become a problem. This also happens if there is a leak in the tank. Having a shared tank or connecting privies in series helps to maintain the seal. The aqua-privy is a relatively inexpensive system, but no more so than its successor, the pour-flush toilet with a U-bend water seal, which is a definite improvement in terms of reliability.

Both aqua-privies and pour-flush toilets can be fitted with a low-flush or sullage-flush cistern. These two systems, along with low-flow septic tanks are sometimes referred to as low-flow on-site sanitation systems (LOFLOs).

Pour-flush (PF) Toilets

Pour-flush toilets are widely used in the Indian Sub-continent and in the Far East where water is used for anal cleansing. The system usually consists of a squat pan situated directly over, or offset from, a soakage pit. The pan contains a shallow water seal (20-30mm), which eliminates odours flies and mosquitoes. Where the pit is off-set, it is connected to the pan by a small diameter (75mm) pipe. This allows for great flexibility in the position of the pit and the toilet can even be placed indoors.

The pour-flush toilet requires very little water (1-3 litres per flush) to clean the bowl and maintain the seal. The ground conditions need to be able to handle this amount of water. If the ground is not suitable, then a solids-free sewer connection can be made. The toilet can also be upgraded to contain a low-flush cistem, but this increased volume of water will probably also require a sewer outlet. In Brazil, a pedestal version of the pour-flush squat pan has been developed and can also be upgraded to a low-flush cistern.

Single pits require mechanical emptying as the fresh excreta is not safe to handle, but twin pits can be provided, which can be used alternatively and emptied manually (see Mara, 1996a:63) (Fig. 2.16). The twin-pit pour-flush toilet has been widely adopted by aid organisations for use in dense settlements in India (Winblad and Kilama, 1985; Cotton and Tayler, 2000). The pour-flush toilet is not appropriate where bulky anal cleansing material is used (Mara, 1996a:62). Pour flush toilets are cheap to construct and maintain, and in some cases may be a slightly cheaper option than a VIP toilet.

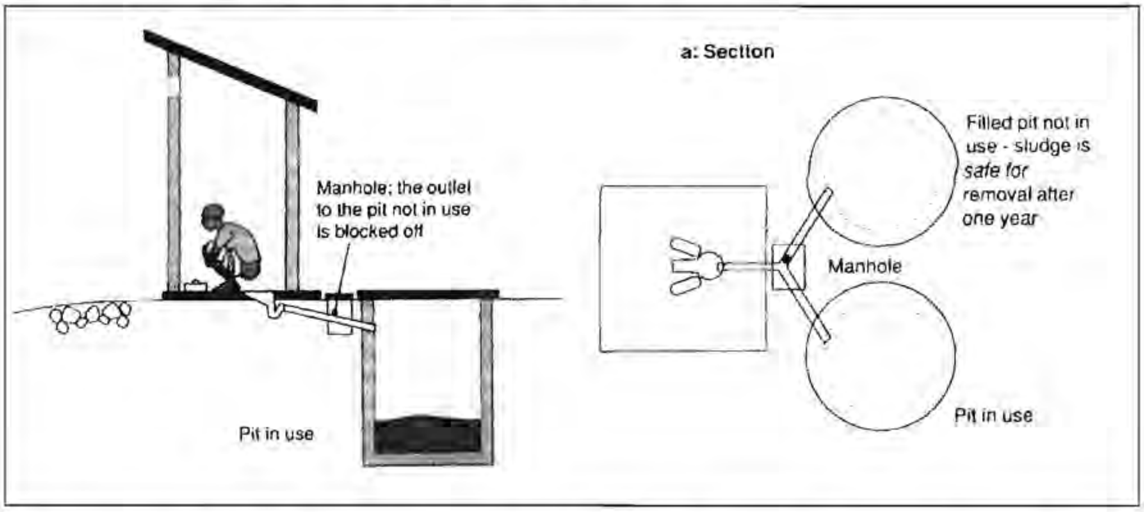

Fig. 2.16 A pour-flush latrine in section and plan showing off-set, dual pits (Source: Cotton and Tayler, 2000:4.90)

Septic Tanks

A septic tank is a watertight tank that obtains waste from the pedestal or squat pan through a standard volume or low-flush cistern. In practice, the arrangement and complexity of septic tank varies greatly (Cotton, pers. comm.), but they function in much the same way. The most common arrangement is a two-compartment tank with baffles in front of inlet and outlet pipes (Fig. 2.17).

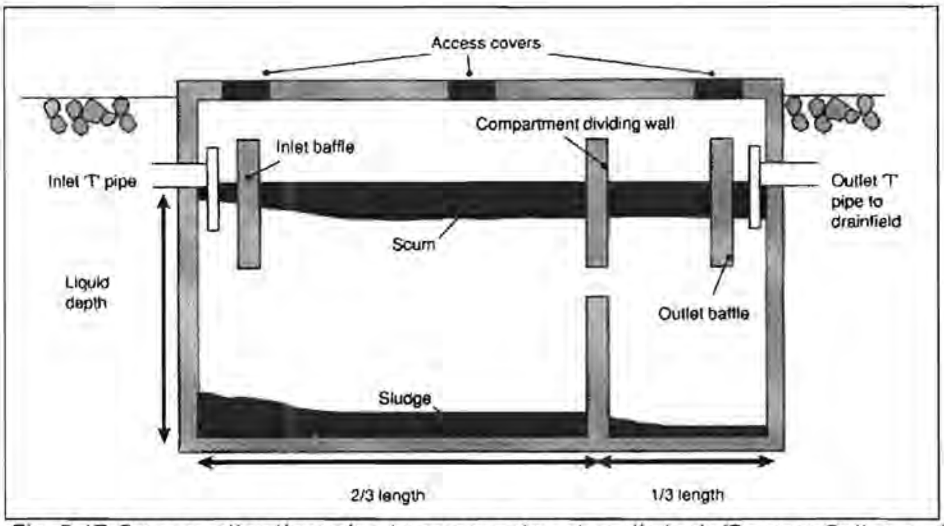

Fig. 2.17 Cross-section through a two-compartment septic tank (Source: Cotton and Tayler, 2000:4.99)

The purpose of the septic tank (also known as interceptor or conservancy tank) is to separate and partly digest the solid fraction of the wastewater as a form of primary treatment. The solids settle to the bottom of the tank where they are anaerobically digested. The liquid and suspended solids fraction forms a middle layer, while a layer of scum forms on the surface. Scum is prevented from clogging the outlet by means of a baffle and T-junction. The liquid is drained off to a soakaway or drain field. If the soil conditions are unsuitable, then the tanks need to be connected to settled (solids-free) sewers. Septic tanks form a requisite part of any new settled sewerage system.

The tank needs to be desludged mechanically (depending on the size and usage), every 1-5 years (Mara, 1996a:73), which obviously requires access for the desludging vehicle. The retention time for liquid in a septic tank is typically 1-3 days (Cotton and Tayler, 2000:4.94) and it may therefore still pose a health hazard. The disposal of this effluent is the most problematic aspect of septic tank operation (ibid:4.94). Newspaper can be added to the system, but other foreign objects will cause the malfunctioning of the system (Alcock, 1999:59).

Septic tanks are relatively expensive to install and require open space for wastewater percolation (unless a solids-free sewer is used). The operation and maintenance costs can be as high as those for conventional sanitation, particularly if the system is misused (Reed, pers. comm.). A septic tank requires at least an on-plot water supply and preferably a house-connection. Greywater can be added to the system. Septic tanks enable a high level of hygiene and convenience and the toilets can be placed indoors. The system is the most appropriate to upgrade to a settled sewerage system.

2.6 WET OFF-SITE SANITATION SYSTEMS

Conventional Sewerage

This term refers to the water-borne system used extensively throughout the developed world. The term is, in fact, a misnomer, as the majority of the world's population do not have access to waterborne sanitation (WHO, 1997), even though it is viewed by many as the only 'acceptable' solution. In South Africa, 51.9% of the population have access to this level of sanitation (Statistics SA, 2003). It comprises a pedestal with a water seal and a low-flush or full-flush cistern (7-20 litres). The sewer network uses large diameter-pipes (>150mm) designed using a philosophy of minimum self-cleansing velocity. Manholes are usually placed at regular intervals along the network and at all changes in direction. The effluent is either directed to wastewater plants for treatment, or disposed of directly into watercourses or the sea.

It is not necessary to describe or analyse this system in detail as it is well documented and well know throughout the world. General opinion in the sanitation field is that this system is conservative in design and wasteful of water, as well as being costly to install, operate and maintain (Cairncross and Feachem, 1983; Winblad and Kilama, 1985; Mara, 1996 a and b). The system is also too rigid in nature to conform to the flexibility requirement of the upgrading methodology. Conventional sewerage is also not particularly robust. Even in instances where waterborne sewerage can be afforded, breakages and blockages due to lack of maintenance can cause more serious health problems, and cost more to fix, than many more basic systems.

The purpose of presenting all the various sanitation options in this chapter is in order to find an *alternative* to conventional water-borne sewerage, as it is unaffordable to low-income groups. The advantages and disadvantages of this system will therefore not be discussed in detail, but conventional sewerage will be used as a comparison to assess the performance and benefits of alternative systems.

Settled Sewerage

This system consists of a low-volume cistern and pedestal connected to some type of on-site interceptor tank (or septic tank) to separate the liquid and solid fraction of the sewage stream. The liquid effluent then flows into a small diameter (40-100mm) sewer (Fig. 2.18). The internal functioning of the interceptor tank has been covered in the section on septic tanks.

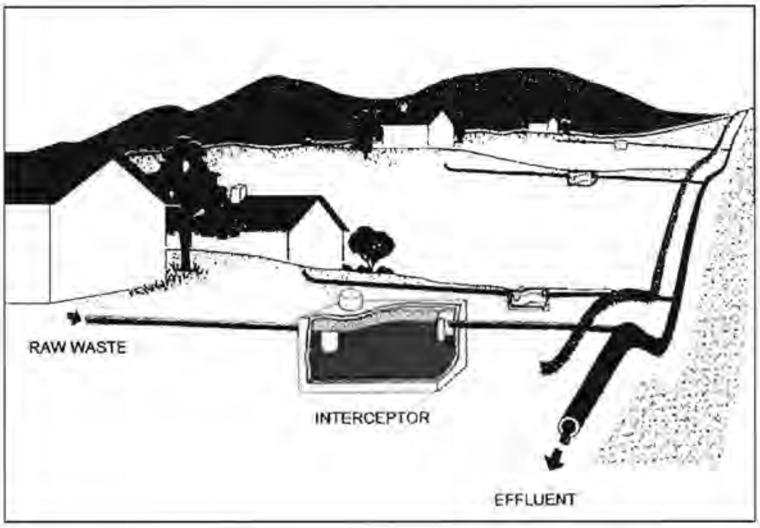

Fig. 2.18 A schematic diagram of the arrangement of a settled sewerage system (Source: du Pisani, 1998)

Settled sewerage, in various forms, has been successfully implemented in Australia, Brazil, Nigeria, Pakistan and Zambia (Reed, 1995:78), as well as on a small scale in South Africa (du Pisani, 1998). It is also known as solids-free sewerage, septic tank effluent drainage (STED) systems, or in some cases shallow, small-bore or small diameter sewerage, but these latter terms could also apply to simplified sewerage.

This system has many advantages over conventional sewerage, while still achieving the same level of convenience. The tank attenuates flow peaks and can also intercept inappropriate materials, although these may cause the malfunctioning of the septic tank. Because there is no transport of solids in the pipes, the flush volumes can be lower. The elimination of solids from the sewers has a large impact on the pipes. The pipes do not have to be designed for self-cleansing velocities and can operate under a combination of gravity and pressure flow. This results in smaller pipe diameters, which can be laid at shallower depths and flatter gradients with simple inspection covers instead of manholes.

A septic tank is relatively expensive to install as a new system, but significant savings can be made if some type of septic tank exists on the plot. Space is required to locate the interceptor tank and at least an on-plot water supply (but preferably a house connection) is required. It is usually cheaper than conventional sewerage because of the smaller pipes and shallower excavation depths.

Simplified Sewerage

This system was first developed by José Carlos de Melo in Brazil. It has now been established as the standard sanitation system in many parts of Brazil and is being introduced in other countries like Columbia, Bolivia and Pakistan (Mara, pers. comm.). The term 'condominial' is often used for the back-yard layout, while 'simplified' or 'shallow' sewerage are used for the front-yard or side-walk arrangements (Fig. 2.19). For simplicity and to avoid confusion with settled sewerage, the term 'simplified sewerage' used here will incorporate all of these.

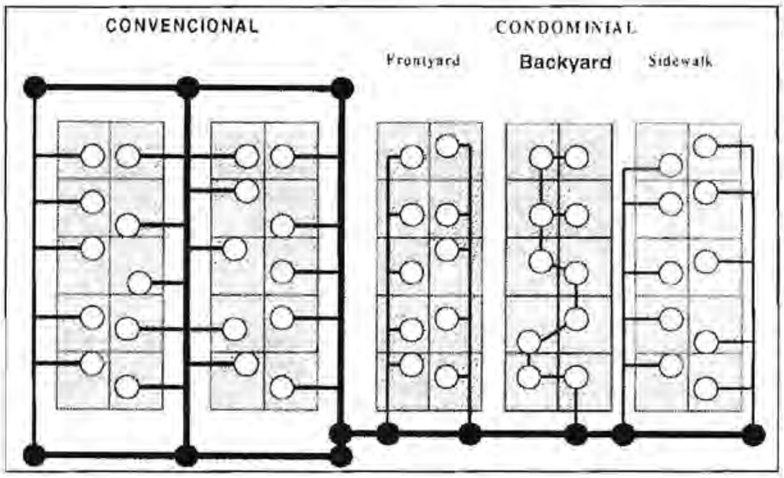

Fig. 2.19 The difference in layout between conventional sewerage and the different versions of condominial (simplified) sewerage (Source: CAESB, 1999)

The system developed out of a need to supply a sanitation system on a large scale at a lower cost than conventional water-borne sewerage, with an acceptable level of convenience. It sought to do this by stripping the conventional system down to its hydraulic basics (hence the term 'simplified' sewerage). Simplified sewers are designed either on the *self-cleansing velocity* or *minimum tractive tension* principles. In both cases this results in smaller pipe diameters (50-100mm) laid at shallower gradients than conventional sewers (1:167-255, instead of 1:150). In the upper reaches of the network, solids are transported in a sequence of deposition, transport, deposition, which is more efficient in small diameter sewers. The more rational design saves costs through less materials and shallower excavation depths. Not laying the sewers under roads, as in conventional systems, also reduces costs. Another important difference is that expensive manholes are replaced by simple junction boxes or cleaning inlets, placed only as frequently as necessary (Fig. 2.20 and Fig. 2.21).

Fig. 2.20 *Simple junction boxes replacing large manholes at changes in direction (Source: Mara, 1996a:132)*

Fig. 2.21 A cleaning inlet on a simplified sewer (Source: Mara, 1996a:100)

The technical aspect only accounts for half of the simplified sewerage system. The other half is the implementation and management process, which is very community orientated and has been stated as the reason for the success of simplified sewerage on a large scale in Brasilia, Brazil (CAESB, 1999). For operation and maintenance, the system is divided into 3 sections: the house connection (from the toilet to the feeder sewer), the feeder or 'lane' sewer (collecting each household's wastewater), and the public trunk main or 'collector' sewer (into which all the feeder sewers flow).

A common arrangement in Brasilia is that the house connection is the responsibility of the house owner, while the feeder sewer is the responsibility of those residents using a particular branch. The residents decide the layout of the sewer and can assist in construction. They either appoint a lane representative or a contractor to handle maintenance of the sewer. The local authority can be responsible for maintenance, but this is more common with the front-yard or sidewalk versions where access is easier. The responsibility for construction, payment and maintenance of the collector sewer and rest of the bulk network is the responsibility of the local authority, although costs can be recovered through tariffs. This is by no means the only management structure possible and a number of management options are available.

A disadvantage of the system is that it does not handle foreign objects and solid anal cleansing material very well. The small diameter sewers also mean that when sewers do block, the sewerage will back up the system quicker than usual, causing problems much further up the line. A further factor is that the sewers are designed with a very low peak flow (1.8 times Dry Weather Flow), not making any allowances for stormwater to enter the system, which inevitably happens at some point in the network (Tayler, pers. comm.). Simplified sewers require high rates of initial connection to function correctly, and also require a high level of community buy-in and cooperation for the decentralization of management responsibility to work. An in-house water supply is preferred, although UNCHS (1986a) reports functioning systems with water consumption as low as 25 l/c/day from a carried water supply.

The capital cost of the system is generally more expensive than on-site systems, but less than septic tanks and conventional sewerage. Studies have shown that at densities greater than 160 people/ha, the capital costs of simplified sewers can be cheaper than those of on-site systems (Mara, 1996a:110). Savings of 20-50% can be made on the capital and operating costs over conventional sewerage (Bakalian et al, 1994). The operating costs of simplified sewerage are about two and a half times higher than VIP latrines (Pegram and Palmer, 1999:38).

2.7 DISCUSSION ON SANITATION SYSTEMS IN AN URBAN SOUTH AFRICAN CONTEXT

The general characteristics of each sanitation system have been described in the previous chapter. This chapter assess those systems against the specific conditions and constraints found in dense urban informal settlements in South Africa, as outlined in the introduction. The technologies will also be assessed on how they cater for the UCT upgrading methodology described in Chapter 1. This, however, is not a major constraint as the only limitations that the methodology places on the choice of sanitation are that:

- It must be able to follow the existing layout
- It must be flexible enough to cope with changes in layout
- The design should not be heavily dependent on the other services
- A choice of management and payment options must be available to the users
- It should promote community-government partnerships

Through the description of the various sanitation options, it was obvious that some systems may be more applicable and appropriate in South Africa than others. Without wanting to come to any premature conclusions, the order in which the systems will be discussed has been rearranged. This is in order to deal only briefly with those systems that are quite obviously less applicable, and then to investigate the more viable options in some depth. In all cases the conditions that will be necessary for the efficient functioning of these systems in an upgrading context will be discussed.

Bucket Toilets

Bucket toilets are not an appropriate sanitation option because they do not fulfil the primary health objective. Studies done both internationally (McGarry, 1977; Saywell and Cotton, 1998) and locally (PDG, 1993) have shown that bucket toilets are unsatisfactory to users. The more specific problems with the bucket system are summarised by Palmer Development Group (1993:36) as being:

- The fact that flies are not prevented from reaching faeces in the bucket;
- lack of provision for preventing odour release; and
- risk to the health workers who need to handle open buckets on a regular basis.

The system also requires efficient management and high operating costs. Despite these factors, 4.1% of South Africans, almost all of whom are informal settlement residents, are still served by bucket toilets (Statistics SA, 2003). The government has taken a proactive stance on the eradication of bucket toilets and this is one of the primary objectives of the *Draft White Paper on Water Services* (DWAF, 2002).

Chemical Toilets

The high capital and operational costs makes chemical toilets unsustainable as a permanent sanitation option. The toilets are also sensitive to misuse and can be complex to operate. Chemical toilets are particularly useful when an immediate, portable toilet is required either for a function or for emergency services to refugees, but are not suitable for permanent use in informal settlements.

Aqua-privies

Aqua-privies are inexpensive to install, but the most problematic feature is the maintenance of the water seal. If enough water is not added, or if the tank leaks, the seal is broken resulting in the flies, mosquitoes and odours associated with an unimproved pit. The watertight tank means that a high standard of construction (or an expensive prefabricated tank) is required. Any pit system, and particularly wet pits like aqua-privies or pour-flush toilets, result in ground contamination and possible pollution of ground water. They are therefore not applicable in areas with high water tables.

There is no obvious advantage of an aqua-privy over a pour-flush toilet, and pour-flush pedestals can be manufactured or supplied relatively inexpensively. Therefore if an inexpensive, low-volume water seal is desired, it is recommended that a pour-flush system be used instead of an aqua-privy.

Pour-flush Toilets

Pour-flush toilets are widely used in the Indian sub-continent where they have filled a niche for low-cost sanitation. Their success has much to do with the simplicity of operation and construction, the minimal space requirements in dense informal settlements and cultural practices of the users. The most important cultural differences are that the users of pour flush toilets in Asia are generally 'washers' (using water for anal cleansing), and 'squatters' (preferring not to use a pedestal).

'Washers' bring water to toilets (or have a supply inside the toilets) as a matter of course, thus no extra water is required to maintain the water seal and clean the bowl. In South Africa the situation is different and the 1.5-3 litres of water need to be taken to the toilet specifically for flushing in addition to toilet paper/newspaper used for anal cleansing. This requires effort and is likely only to be done if there is a reliable on-plot or in-house water supply. It is very unlikely that water will be fetched from a communal standpipe every time someone uses the toilet. Without water the pour flush toilet soon becomes fouled, blocked and unhygienic.

The second point is that most pour-flush toilets in the world are constructed with squat pans. A pedestal version of the pour-flush toilet has been developed in Brazil, but this is more expensive and requires a greater flush volume (Fig. 2.22). There is no knowledge of this technology yet being used in South Africa. The pedestal version (and the squat-pan version) can be upgraded to a cistern flush system, eliminating the need for water to be brought to the toilet. The cistern for the pedestal version uses 5 litres per flush (Mara, 1996:60), which certainly requires an in-house water connection and is equivalent to low-flush conventional water-borne systems.

Fig. 2.22 A pedestal version of the pour-flush toilet (Source: Mara, 1996a:59)

An additional factor is that pour-flush toilets, even with low flush volumes, require favourable soil conditions for the percolation of liquid through the sides of the pit. Mara (1996a:6) recommends that pour flush toilets are "...unsuitable if bulky anal cleansing materials are used, if a minimum of 5 l/c/d of water for flushing can not be relied on, or if incomes are extremely low and subsidies are unavailable."

Nevertheless, if sewers are prohibitively expensive, a reliable water supply is available and ground conditions are adequate, a pour-flush toilet is a convenient compromise between a pit and a water-borne system. A VIP latrine can easily be upgraded to a pour-flush toilet, and it in turn can relatively simply be upgraded to a settled sewer system.

Composting Toilets

The composting of human excreta is definitely the most long-term sustainable (in the greater sense of the word) solution because no environmental damage is caused, the nutrient cycle is completed and precious resources are not wasted. It is argued here, however, that in terms of short-term sustainability, the system is bound to fail in the informal settlement environment. What is meant by short-term sustainability is the day-to day functioning of the system to achieve both the primary and secondary objectives. Most of problems with this system relate to the operation of the toilets and are given below.

The concept and process involved in composting are fairly complex and may not be well understood by the users. Extensive education programmes may be necessary to explain the concepts and ensure correct operation. The system is fairly high maintenance and users have to know what can and cannot be put into the toilets. Because of the conditions required for the biological processes, the system is sensitive to misuse.

In a dense urban informal settlement there is little incentive to produce compost. Agriculture is practiced in informal settlements, but on a small scale. The small amounts of compost that are produced at long intervals may not justify the effort required to operate a composting toilet. The biological processes may also take longer than expected. In the only known case study of composting toilets in a South African informal settlement, 30 *Enviro Loos* were installed in the Elias Motsoaledi settlement in Johannesburg (Stewart Scott, 1998). The toilets performed well and were accepted by the community, but after 12 months there was "little evidence of biological activity…and the composting processes [were] not well advanced" (ibid:20). This was due to the fact that the moisture content in the toilets was high, where newspaper was used it degraded very slowly, and because the high temperatures expected to destroy the pathogens were probably not attained. The lack of decomposition meant that the 'compost' had to undergo further treatment before it would be safe for use on gardens and fields. This seems to negate the purpose of the composting toilet and similar results could have been achieved in a simple pit.

Composting toilets also require the manual handling of the decomposed material. No matter how decomposed the compost is, it is still perceived to be human waste and, as mentioned in the introduction, the handling of this is objectionable to most urban South Africans. The excreta in the toilet is also visible through the pedestal because the vaults are generally smaller than pits, so users have to be comfortable with this for the system to be accepted. It is likely that composting toilets will be viewed as being too similar to the highly unpopular and unacceptable bucket system.

The urine diversion variation of the composting toilet may experience all of the problems mentioned above, with the addition of the following:

Urine diversion systems do not permit the addition of anal cleansing material, so provision has to be made for disposal into a container alongside the toilet. It may be possible to change users' behavioural practices, but this leads to a less hygienic situation with added odours, than if the material was disposed of into the toilet. Superstitions also exist around the use of soiled material for witchcraft (Holden and Austin, 1999).

Because of the arrangement of the pedestal, it is not possible for men to stand up and urinate into the bowl, without wetting the 'dry box'. Unless an expensive separate urinal is provided, men have to sit down to urinate. This may not be agreeable to some men on cultural grounds. Although Holden and Austin (1999) reported that this perception was overcome in their rural pilot project in the Eastern Cape, it is anticipated that considerable resistance may be met in urban areas.

The final problem noted by Holden and Austin was that the users of the urine diversion system would not use the diluted urine as a fertiliser, and it was directed to a soakaway. This adds to the point made earlier about the lack of incentive to compost, resulting in another potentially harmful 'waste' product that has to be disposed of somewhere.

The issue of cost has not yet been raised here. Simple composting toilets are relatively inexpensive and because of the shallow depth of the vault, may be easier to construct than a VIP latrine. Both 'wet' composting systems and urine diversion systems (to a greater degree) require some skilled labour for construction. The more sophisticated, prefabricated and commercially available systems are prohibitively expensive for use in informal settlements. The *Enviro Loo* mentioned in the case study above cost over R5 000 per unit to supply and install (Stewart Scott, 1998:8).

Mara (pers. comm.) argues that composting toilets were developed for low-frequency use in environmentally sensitive areas. They do not function properly with heavy, day-to-day use as they have been expected to do in developing countries where they have been implemented as the only form of sanitation (like in Dar es Salaam). Kalbermatten (2001) feels that composting toilets are not feasible in most situations in developing countries, as they require more attention in operation than the user can provide.

In order for composting toilets to be a viable option in an upgrading project, the recipients must be fully aware of the processes involved and the maintenance required, as well as have a strong desire to compost. This may be applicable in a small community of market gardeners, or for an environmental group, but on the whole it has been shown that composting toilets are complex to operate and do not sufficiently achieve the secondary objectives of convenience and prestige to make them acceptable on a large scale.

Septic Tanks

Septic tanks are an expensive solution to implement as new, and can even be more expensive to construct and operate than conventional sewerage (Reed, pers. comm.). Septic tanks must be constructed by skilled people and preferably supervised to ensure the tank does not leak and will operate correctly. The cost of a septic tank is increased by the necessity for and in-house water supply and the increased volumes of water that are typically used.

One of the major reasons for septic tanks being problematic for informal settlements is the space constraint. The tank itself does not require significant space and the toilet can be placed indoors, but the soakaway or drainfield requires sufficient area to percolate safely. This is one of the reasons why Mara (1996a:73) states that septic tanks are "...generally not an option for low-income areas...". The percolation also requires suitable soil conditions, which will exclude its use on certain sites.

A septic tank offers the same convenience as other water-borne sanitation systems, but the problem of solids is not a case of 'flush and forget'. The sludge that builds up at the bottom of the tank has to be removed periodically. South African case studies show that there is a poor history of tank emptying and outlet maintenance of septic tanks (PDG, 1993:38; Norris, 2000:21). Sludge overflowing from septic tanks can cause a serious health hazard on the surface, usually very close to the dwelling. Septic tanks are sensitive to abuse and foreign objects cause the system to malfunction. If no maintenance is going to take place, then a vault or a pit are probably better options, and cost less to install.

The conditions necessary for implementation of septic tanks, therefore, are sufficient open space in the settlement, access for desludging vehicles, and dry, permeable soil. Septic tanks are only preferred above a ventilated vault if residents desire the convenience of a full-flush system. It is recommended that if septic tanks are to be used, then they should be constructed in as many dwellings as possible to familiarise the entire community with the operation of the tanks and to promote regular desludging of the tanks. If septic tanks already exist on the site, the upgrading of the system to a settled sewer is a feasible option and may enhance operation of the septic tank. It also eliminates the need for space to construct a soakaway. In South Africa there are not many, if any, septic tanks already installed in informal settlements (as is the case in India).

Settled Sewerage

Settled sewerage developed out of a need to solve the problems of on-site systems with insufficient capacity, and to find a lower cost alternative to conventional sewerage. It is thus similar to simplified sewerage, as the two systems aim to achieve the same level of convenience at roughly the same cost. There are some important operational differences between the systems that are introduced by the solids interceptor tanks. These will be discussed below whilst comparing the two systems.

It has been mentioned above that settled sewerage is a viable option for upgrading of on-site systems where waterborne sanitation is desired and some type of solids interceptor tank or septic tank exists. As a new system though, the capital costs are high and may possibly be higher than conventional sewerage. In dense conditions, the capital costs for simplified sewers are probably less.

The advantage of the system is that it can, in some cases, be cheaper in both capital and operational costs than conventional sewerage. Where an existing treatment plant is not available, treatment facilities can be simpler. The cost benefits are also greatest where population densities are low (du Pisani, 1998:31). This is why the system is well suited to rural areas where treatment facilities are part of sanitation provision. The biggest advantage that settled sewerage has over simplified sewerage is that it is able to intercept solid anal cleansing material. Although this is not ideal for digestion in the septic tank, it will reduce the amount of blockages in the sewer if the system is abused.

A disadvantage of the system is that it combines on-site storage with off-site transportation and unfortunately is prone to the problems of both types of systems. Septic tanks will malfunction if not desludged, resulting in short-circuiting and failure to digest material. In two low-income countries, Zambia and Pakistan, where settled sewerage has been installed, desludging of the interceptor tanks has proved a problem (Vines, 1991 cited in Reed, 1995). The sewer system also has to be maintained and blockages will occur if the interceptor tank malfunctions and solids enter the small sewers. Du Pisani (1998) reports disadvantages of settled sewerage relating mainly to access to the septic tanks, cost of emptying the tanks and lack of understanding of the system by users. The different types of maintenance required means that strong institutional capacity (and good community relations) is necessary.

There are currently 21 settled sewerage schemes serving 16 000 erven in South Africa (du Pisani, 1998), but these schemes all seem to be in rural areas and small towns. The success of these systems in a dense urban environment is not well known. Du Pisani does note that: (1998:11)

> *"densification on existing erven may eventually make it difficult to reach the tanks for emptying, as well as lead to overloading of tanks and consequent odour problems. Furthermore, the tanks will eventually not provide adequate settling time for solids as the number of users increases, and the pipework may not accommodate the increased flows".*

It is interesting to note that du Pisani recommends the serious consideration of low-maintenance systems like VIP latrines where communities have a poor record of payment for services. The study by du Pisani also highlighted the problem of expectations. When interviewed, South African users of settled sewerage systems accepted the system as having the same level of convenience as a conventional systems, but "were still adamant that a raw sewerage conveyance system was better" (du Pisani, 1998:11).

Settled sewerage can be viewed as an evolutionary step in the development of a cheap alternative to conventional sewerage. For dense urban settlements, however, the evolution can be said to have progressed beyond settled sewerage to simplified sewerage. The system may have some advantages over simplified sewerage in theory, but the operational and maintenance problems experienced with the interceptor tank in particular, makes simplified sewerage more attractive.

Vault and Vacuum Tanker

There are essentially three aspects to the applicability of this system to informal settlements. The first is social acceptance of the system. This is a fairly simple question of whether a pit-type toilet is acceptable to users and whether it represents a sufficient improvement from their previous sanitation system. Odours in particular may be a problem if the toilet is to be incorporated into the dwelling. The social acceptance of a vault toilet needs to be assessed on site. The remaining factors are access for emptying, and the cost and institutional arrangement for emptying.

The problem of access is obviously site specific. In dense informal settlements it is unlikely that all dwellings have an access-way large enough to accommodate a large vacuum tanker. Mara (1996a:88) believes that access is not commonly a problem as some tankers can pump up to 100m horizontally. Pickford (1995:53) notes that Brevac tankers with high performance liquid ring pumps specifically designed to empty pits can lift 80% solids at a head of 64m through a 100mm diameter pipe. An alternative to using a high performance pump is to use a smaller vehicle. The MAPET system, described earlier, is the smallest known emptying vehicle, but the lack of storage space may cause a problem. Far more attractive is the Vacutug (also described previously) which has considerable capacity and can access the most rugged footways. The cost of imported vacuum tankers can make this system uneconomical, particularly if spare parts have to be imported as well. It is, however, likely that the municipalities in South African urban centres have at least one vacuum tanker. The question then is whether they have the time, staff and money to service informal settlements as well as their usual duties. The frequency of desludging depends on the capacity of the vaults, but because of the different rates of emptying, the tanker would have to be available most of the time. The possibility of importing technology like that of the Vacutug could mean the opportunity for reducing costs through local manufacture and privatisation of the emptying service. The small scale and low-skilled nature of the work has much potential for entrepreneurship and management of the service among the community.

In order to eliminate some of the odours associated with a vault toilet, a ventilation system like the one used on a VIP latrine is recommended. Because of the high operational costs involved in emptying a relatively small vault, the only instance when a ventilated vault system is likely to be more appropriate than a VIP latrine is where groundwater table is high, or if the threat of groundwater pollution is serious. The vault and vacuum tanker option therefore depends on the community acceptance of a vault toilet, the emptying technology employed and the institutional capacity to regularly empty the tanks. As with septic tanks, it would be preferable if a large number were installed at once to familiarise residence with the system and facilitate regular emptying. It is recommended that alternative technologies like the Vacutug be further investigated, as they may have a large impact on the cost and applicability of this sanitation option.

The SanPlat latrine slab

The squat-hole version of the SanPlat latrine slab is not applicable in South Africa because of cultural practices mentioned above. A modified SanPlat for use with a pedestal has been introduced by the Mvula Trust, but it has not yet been widely applied

(Holden, pers. comm.). The hole in the SanPlat is designed to seal with a tight-fitting lid, but it is not known how this is achieved with a pedestal version.

The domed SanPlat, when incorporated into a VIP latrine, could result in cost savings due to the elimination of reinforcing steel, and the sloped surface makes cleaning of the latrine slab easier. The slabs can be cast in a casting yard and rolled into position, allowing a much faster construction time than a rectangular slab which has to be cast in-situ. A VIP latrine that has been has been developed in South Africa using similar technology to that of the SanPlat is the Phungalutho Toilet (Devan, 1997). The Phungalutho Toilet includes an offset, domed pit cover and is cheaper to construct than a standard VIP latrine. Alcock (1999:79) reports that these toilets were not popular in one rural pilot project, but no reasons for this were given. The use of the SanPlat is not recommended in its most basic form, but there is definitely a place for it in the evolution of the VIP toilet design. The conditions necessary for the implementation of an adapted SanPlat are the same as those for VIP latrines, discussed below.

VIP Latrines

VIP latrines are cheap and robust systems. The technology is well known and the toilets are simple to construct using local labour. The only technical difficulty comes in adverse ground conditions. In loose soils, the pit has to be lined which raises the cost. In areas with a high groundwater table the pit can be raised above ground, or sealed as a ventilated vault (see above and Box 2.2). Mosquitoes are a problem with wet pits and various remedies have been suggested, like mesh traps, kerosene and polystyrene balls (Mara, 1996a:35). Operation of the system is simple, but some user awareness training may be necessary to ensure optimum operation.

The issue of groundwater pollution is often raised as an argument against on-site systems. This, although a consideration, is not viewed as being a serious problem for two reasons. The first is that groundwater is not a widely utilized water source in South African urban areas where almost all water is piped. Secondly, a certain amount of attenuation and adsorption takes places within the soil, and it is far better to confine contaminants in the soil, than on the ground surface (Mara, 1996a:50). A common view in South Africa is that the impact of VIP latrines on groundwater has been overstated (Jackson, 1995; RSA, 2001). If VIP latrines are used, then a separate method of sullage disposal is required.

Box 2.2 An innovate South African VIP solution

An innovative solution to the problem of leaking pits has been developed by South African company Ballam-Waterslot (Pty) Ltd. They produce prefabricated, ribbed polyethylene tanks that are fitted complete with a vent pipe and "polypedestal" assembly (www.ballamwaterslot.co.za). The tank is light, cheap and durable and is claimed to be ideal for informal settlements.

Fig. 2.23 The VIP tank and "polypedestal" assembly produced by Ballam-Waterslot (Pty) Ltd. (Source: www.ballamwaterslot.co.za)

A number of studies have shown the VIP latrine to be a technically sound solution, even in dense urban areas (PDG, 1993; Mara, 1996a; Bester and Austin, 2000), provided that it is correctly constructed, operated and maintained. The main constraint is therefore not technical, but the social acceptance of the system.

The VIP latrine has a much stigmatised status in South Africa as a second-rate solution for black (mainly rural) communities, while wealthy white communities enjoy waterborne sanitation. The VIP latrine is not seen as a great improvement over a bucket or an unimproved pit – the two predominant forms of sanitation in South African informal settlements. The only factor that could convince communities to adopt VIP latrines is cost, particularly if local authorities have shown reluctance to subsidise sanitation facilities. Some physical constraints like steep slopes or lack of treatment facilities might also make water-borne systems prohibitively expensive.

The advent of free basic sanitation may also put strong political pressure on promoting the VIP latrine as a basic urban sanitation option. The equitable share and housing subsidies are already stretched in providing free basic water and a VIP latrine may be the only affordable sanitation option. The only sanitation system explicitly mentioned in the *White Paper on Basic Household Sanitation* (RSA, 2001) is the VIP latrine. There is a strong emphasis that only the most basic sanitation system sufficient to achieve the health objective should be provided to those without sanitation, and thus a VIP latrine would seem the logical solution. The *Draft White Paper on Water Services* (DWAF, 2002), which outlines the free basic sanitation policy in more detail, also implies that only basic, on-site options will be considered. "In most instances, waterborne sanitation should not be regarded as a basic level of service" (ibid:34).

A case study by Palmer Development Group (PDG, 1993) of VIP latrines in Bester's Camp informal settlement near Durban shows that communities only accepted VIP latrines as a medium-term solution on the condition that the possibility of upgrading to waterborne sanitation was not eliminated. PDG go on to recommend that "...the VIP option be seen as an up-gradable option and that communities be assured that they will not be locked into a certain level of service without the possibility of upgrading" (ibid:34). This may be an attractive selling point for a VIP latrine, but the practicability of implementing such an upgrading is debatable. In view of the renewed capital outlay required to upgrade to a settled sewer (or conventional sewerage if possible) and the structure of the once-of capital housing subsidy in South Africa, an upgrade to an improved system seems unlikely.

With regard to the emptying of pits, it is often suggested that an alternating twin-pit system is used (Bester and Austin, 2000; CSIR, 2000; Cotton and Tayler, 2000). From experience in Pakistan, it has been seen that users often do not know what the two pits are for (Tayler, pers. comm.). Once both pits are full, they either relocate the toilet, or use the free space above the settled contents of the first pit. In view of this, it may not be justifiable to spend the extra capital cost in providing a separate pit when its use cannot be guaranteed. It may be better to construct a permanent single pit and have it mechanically emptied every 3-5 years. This cost is not unreasonable and the pit is guaranteed to be emptied as it is unusable when full. This arrangement may also be more acceptable to the users because of the 'faecophobic' tendencies of urban South Africans and their reluctance to empty the degraded contents of a pit manually.

The ROEC has not been discussed under a separate heading as it is seen as a variation of a VIP latrine. The large pit of a ROEC is not appropriate in confined settlements, but one feature of the ROEC should be considered for use in all VIP latrines; the simple inclined chute can be installed in both an offset and direct pit and would eliminate the unpleasant sight of excreta in the pit. Disadvantages of the chute are that it can become soiled, toilet brushes attract flies, and water is required for cleaning (Pickford, 1995:61). An added improvement, found on the Sopa Sandas latrine in India, is a steel flap to prevent the movement of vermin (Winblad and Kilama, 1985:30; Pickford, 1995:69). An improvement suggested by Alcock (1999:30) is the installation of a water seal. This, however, would effectively make the system a pour-flush (or cistern-flush) toilet with a wet pit. The problems associated with this have been discussed previously and this improvement is generally not recommended.

Simplified Sewerage

The simplified sewer system developed out of a need to find a cost-effective solution to sanitation in dense urban slums. This indicates that it is likely to have more relevance in South African informal settlements than other options that were either developed in rural, low-density areas, or high-income developed countries. One of the most attractive features of the system is that it is flexible in its layout and can weave between dwellings in confined areas. The network no longer has to be confined to straight road layouts. An implementation methodology used in Brasilia, Brazil, is to construct the collector sewers only once the final levels of the feeder sewers are known (CAESB, 1999). This means that the final plan is only developed after continual adjustments are made during construction, in an integrated process.

Further advantages of the system are that it can be implemented in ground conditions (such a rocky ground, a high water table, steep or unstable slopes) that may exclude any other type of sanitation option. The system is also suited to high densities, and actually *requires* high densities to ensure optimum flow conditions. Pegram and Palmer (1999:41) recommend that simplified sewers may be a preferred option for densities greater than 35 du/ha.

Simplified sewers may prove more expensive than most on-site systems (although some studies show otherwise), but the cost savings over conventional sewerage are great. A number of useful suggestions for reducing capital costs of the system are given by Reed (1995). What is important here is that the same level of convenience is achieved and the users' inevitably high expectations are met.

Choice is another important feature of simplified sewerage systems. The system lends itself to flexibility in layout, construction, management and payment options. A strong emphasis in Brazilian literature is placed on community management and maintenance of the feeder sewers. This helps to reduce costs and to promote greater ownership of the system. The effectiveness of this strategy in practice is not entirely convincing because these management systems have been shown to disintegrate quickly without support (Tayler, pers. comm.; Abiko, pers. comm.). In South Africa, as Pegram and Palmer (1999:9) point out, the devolution of maintenance responsibilities for block feeder sewers to residents is unlikely to work because of a number of reasons, namely:

- poor relationships with authorities;
- lack of skills;
- residents not willing;
- blocks do not affect everyone;
- authorities are not geared towards servicing intermediate options; and
- operation and maintenance are not political or institutional priorities.

They continue to state that, "the viability of delegated management of sewer systems has not been tested in South Africa, and there may be significant cultural and political resistance" (Pegram and Palmer, 1999:44). If authorities take responsibility for the maintenance of the system, this affects the system in a number of ways. A 'front-yard' layout is more suited to external maintenance, while the cheaper 'back-yard' option is more suited to maintenance by the users. Abiko (pers. comm.) points out that in Brazil, the backyard version is not favoured because residents build their houses over pipes and manholes. The operation and management arrangement is a critical constraint to the sustainability of simplified sewerage, but besides the provision of guidelines, can only be dealt with at a community level.

One of the biggest problems facing the possible implementation of simplified sewerage in South Africa is the use of solid anal cleansing materials. Toilet paper is the only material that the narrow sewers can handle, and anything else will block the system. The sewers are also likely to block if litter is thrown into toilets or inspection covers. A case study where this problem was highlighted is that of the provision of conventional waterborne sewerage in Mdantsane in the Eastern Cape (PDG, 1993). Here a reason for the high rate of system failure (apart from poor construction) was the use of newspaper, rags and between community representatives and the local authority. The pilot scheme was funded, designed and constructed entirely by the community and an NGO, The Homeless People's Federation, with technology transfer during exchange visits to the Orangi Pilot Project in Karachi, Pakistan. The lane sewer was connected into a large public collector sewer nearby. The local authority did not accept the standard of construction and the illegal connection into the collector sewer. The system was disconnected and the local authority began implementing a conventional system using part of the housing subsidy. The simplified system never operated and the community then waited for conventional sewerage. This case study proves the desire of some communities to construct and maintain their own systems, but a lack of motivation and momentum prevailed once the local authority intervened. The second lesson was that communities need to liase with local authorities (who have the power to halt the project) in order to gain acceptance.

The implementation of simplified sewerage on any significant scale will require an adoption of new standards for sewers in South Africa and a review of design procedures. Either a lower minimum velocity needs to be applied, or the tractive tension method needs to be adopted in order to reduce the sewer diameters. In addition to these design changes, there needs to be a change in implementation procedures as well. Much of the success of the system in Brazil seems to be due to the capacity of the staff at the water and sewerage companies and their relationship with the communities. This has come about through a wide acceptance of the system and the use of appropriate technologies. A positive attitude towards the system and encouraging environment for implementation is essential on the part of the service providers.

Furthermore, a significant transfer of skills must also take place, mainly in the technical capability of the sanitation authority, and those with the responsibility of constructing and maintaining the system. The optimal arrangement seems to be a multi-disciplinary team within the water and sanitation service provider that includes technical and social expertise and covers all aspects from community negotiation to construction and maintenance. This type of arrangement would only be possible if the technology was taken to scale.

Most of the materials and products for construction and maintenance of simplified sewers are available in South Africa. The type of maintenance equipment required depends on the type of junction boxes constructed, or perhaps vice versa. The prefabricated PVC inspection units produced by Tigre SA (see Fig. 2.24) may make construction easier and possibly cheaper, but requires jetting equipment for cleaning. If rodding equipment is stones in the toilets because residents could not afford toilet paper. A more constructive suggestion made by Mara (pers. comm.), is to subsidise the cost of toilet paper in low-income areas, coupled with an extensive user awareness programme. Mara also recommended the subsidisation of soap to fully realise the health benefits of sanitation.

A further problem with the system is that it requires high rates of initial connection to ensure enough flow volume to transport solids through the sewers. Pegram and Palmer (1999) suggest the system is only viable if a connection rate is above 75%. If the connection rate is lower than this and the system blocks, other users will be discouraged from connecting and the system will never function correctly. One way to counteract this is to begin constructing a small part of the system first which can be used immediately and demonstrate the system to other residents. As other residents see the functioning system and the benefits that it brings, they will also connect. In this way a real demand for the service is created.

Illegal connections to the system can also cause problems, as the quality of the connection is not guaranteed and foreign matter could enter at these junctions. The extra flow could also cause the sewer to surcharge. An example given by Tayler (pers. comm.) from Cambodia is of residents trying to connect 200mm conventional house connections into the 100mm simplified sewer. Tayler also identified a problem with simplified sewer caused by stormwater. He believed that the low peak factors are not adequate to cater for the inevitable ingress of stormwater through the system. This can only be overcome by ensuring a high quality of workmanship, reducing the number of inspection covers, or providing larger sewers.

Simplified sewers require a reliable supply of water in the form of at least an on-plot connection. Examples from Pakistan show that simplified sewers can function with carried water supplies, but this would not work in South Africa for the cultural reasons discussed in the introduction to this chapter. An existing wastewater treatment works is also a prerequisite for the viability of a simplified sewer system, preferably with a nearby bulk sewer network into which the collector sewers can discharge. Fortunately this is not a major problem in South African urban centres where sewer networks are widely distributed.

The only known attempt at implementation of simplified sewers in a low-income environment in South Africa was made in Kanana, a peri-urban settlement outside Vereeniging, Gauteng (Huchzermeyer, 1999b). It failed because of political conflict used, as is currently the practice in South Africa, then more expensive conventional manholes need to be provided at regular intervals.

Fig.2.24 A prefabricated PVC junction box (Source: Tigre S.A, undated)

The flexibility of payment options is also a feature of the system. This mainly relates to which stakeholder pays for what part of the system. It is strongly advocated in the literature that residents fund their own house connections. The lane sewers can then either be funded by a residents' group, or costs can be recovered through a connection fee or through monthly tariffs. It is generally the practice in Brazil that the water and sewerage authority pays for the bulk and collector sewers, while operation and maintenance costs are recovered through monthly tariffs. Reed (pers. comm.) warns about underestimating the cost of a house connection as it may be as much as the per capita cost for the rest of the system.

It is interesting to note that Pegram and Palmer (1999:43) recommend that the capital cost of the internal infrastructure (including feeder sewers and house connections) be paid for by national grants, with the remainder being paid for by residents in the form of a connection fee, or labour contribution. The government or local authority should also cover the cost of any health, hygiene and awareness campaigns to promote the system. Even if the government does fund the construction of the system, operation and maintenance costs are not covered by these grants and need to be recovered to ensure sustainability. Pegram and Palmer recommend delegated management responsibility for the feeder sewers, with other operational costs being recovered through an increase in the water tariff, or a monthly flat rate added to a rent or rates bill.

The linking of simplified sewerage charges to water rates is effectively applied in Brazil as a means of cost recovery. It is much easier to enforce as non-payment results in the disconnection of the water supply and residents will much sooner pay for water than for resumed sewer maintenance (that may not even directly affect them). The poor record of payment for services in South Africa is a huge problem for sanitation because even if the capital costs are covered, the sustainability depends on recovery of operational and maintenance costs. Palmer Development Group (1993:31) therefore recommends that "full waterborne sanitation should only be installed where residents are able to afford the full maintenance and operation cost of the system".

After a thorough analysis of the costs involved in providing simplified sewerage, Pegram and Palmer (1999:43) were able to conclude that simplified sewerage provides a financially viable and efficient alternative to conventional sewerage, even in low-income areas. This thesis proposes that the success of simplified sewerage depends not on its tested implementation in low-income areas and informal settlements, but in its across-the-board adoption as a standard replacement for conventional sewerage, as is the case in Brasilia. The Brazilian experience has shown that there is no loss in functionality, and costs are significantly lower. If simplified sewerage is adopted on a large scale in middle- and higher-income areas, then the skills and institutional capacity will be in place to implement the system in lower-income areas where there are more externalities likely to affect the sustainability of the system. It will be difficult to prove the applicability of a system in informal settlements, with the most adverse of financial, social and physical conditions, if no institutional support is present.

There are a number of problems associated with the implementation of simplified sewerage in South African informal settlements, but as a whole, the system has been shown to be a cheaper, viable and socially acceptable alternative to conventional sewerage. Mara (1996a:111) goes as far as to say that simplified sewerage may be "...the *only* technically feasible, economically appropriate and financially affordable sanitation option available for high-density, low-income areas". Even if this is the case, Tayler (pers. comm.) warns that simplified sewerage must be appropriate for function and location and each situation must be treated separately so that it does not become just another 'blueprint' solution.

2.8 SANITATION CONCLUSIONS

This chapter has shown that the issue of low-cost sanitation in South Africa is complex with no obvious, simple solutions. A number of sanitation systems have been discussed, and all have certain advantages and drawbacks and require certain conditions to succeed. It is the intention of this chapter to illustrate what these conditions are, particularly in the context of South African informal settlements, and how the choice of sanitation option should be informed.

The impact of the proposed free basic sanitation is as yet unknown, but if it is implemented it will undoubtedly affect the provision of sanitation in informal settlements. Establishing sanitation as a basic right is a positive step, and may provide the political will necessary to sustain adequate systems that has been absent in the past. The policy is likely to cause a resurgence in the promotion of VIP latrines as a sanitation option because of cost constraints. Experience warns against standard, across-the-board solutions, but at least the option is available for a basic system that has been shown to achieve the intended health benefits.

In terms of the upgrading methodology defined at UCT, the most flexible sanitation systems are on-site solutions, followed by simplified sewerage, which is able to fit the dynamic upgrading model. These, as has been shown, all have their individual benefits and disadvantages and are more appropriate in different situations. Simplified sewerage is a promising, cheaper alternative to conventional sewerage, but has some institutional issues to overcome.

The important issues that can be drawn from this chapter are:

- The health requirement of any sanitation system is non-negotiable and should be expected and maintained in any sanitation system. Complimentary hygiene measures are required to guarantee the health benefits of sanitation.

- The secondary objectives of convenience, privacy and prestige must be traded off against the *operation* and *maintenance* costs for a particular system, of which the users should be made fully aware. The capital costs are far less important, particularly if the system is to be subsidised.

- It must be acknowledged that South African urban dwellers are 'sitters' and 'wipers', and are 'faecophobic', which has the effect of limiting the number of sanitation options that are actually available.

- Changing the primary classification to whether as system is 'wet' or 'dry' raises important environmental and long-term sustainability issues, while the classification of on- or off-site relates more to responsibility and cost.

- The institutional arrangement must be clear and efficient to ensure sustainability. Responsibilities must be made clear. Both users and the service provider must approve of the system.

- Residents must have knowledge of the operation and management of a chosen system, as well as the complimentary hygiene practices. No sanitation system is maintenance-free.

Although technical options have been presented here, the choice of sanitation system is a social, political and financial one. The decision to be made is ultimately one by the users, and the system(s) provided must respond to a real demand. The choice must, however, be supported by a good technical appraisal. There are certain technical preconditions for the functioning of individual systems and these have been presented in this chapter. The more social aspects of sanitation choice and the potential problems associated with these have also been highlighted here.

Chapter 3

WATER SUPPLY

3.1 INTRODUCTION

The intention of this chapter on water supply was initially to limit this discussion to the technical issues encountered in water supply to informal settlements. After a review of the literature it became clear that it is not possible to ignore national and even international debates around water supply in developing countries, as they have profound effects at local level and on the type of service provided. The first part of this chapter will therefore briefly describe these debates and then show how these have manifested in government policies that directly affect service provision in informal settlements. The ways in which the choice of service can be affected include the degree to which the capital costs of an improved system are subsidised, how the amount used is regulated and how payment is made. The chapter will be concluded by a discussion on the various water supply options available and their appropriateness in an in-situ upgrading context.

Objective of water supply

The requirement for water as a basic human need is now clearly understood and well documented in the literature, as are the health benefits through washing of clothes and bathing (See Cairncross and Feachem, 1983: Hardoy et al 1990). The objective of water supply comprises three aspects: quality, quantity and reliability. The objectives given in the literature are all very similar and can be drawn together to give the fundamental objective of water supply to be:

To provide everyone with access to an adequate amount of good quality water for drinking and personal hygiene on a permanent and regular basis

The more specific objectives implied in the above are:

Quality: The water must be free from pathogenic organisms and chemical contaminants in concentrations greater than prescribed limits (see DWAF, 1996). Included in quality are the more subjective characteristics of colour, taste and odour.

Quantity: The World Health Organisation (WHO) recommends a minimum daily consumption of 50 litres per capita per day (l/c/d). In South Africa the basic minimum is access to 25 l/c/d, but the target for urban areas is 50 l/c/d.

Reliability: The ultimate objective would be to provide a constant 24hr service. If this is not possible, then consumers should know exactly when water is available. South African regulations state that no consumer should be without water for more than seven days a year, supplied from a source of raw water which is available 98% of the time, not failing more than once in 50 years (DWAF, 2001a).

Background to water supply in informal settlements

It is estimated that 7 million people (15%) of the population are without adequate water supply (DWAF, 2002), the majority of whom live in informal settlements. Many informal settlements in South Africa have been supplied with communal standpipes for 'emergency' supply. With lack of resources and insufficient political will to upgrade settlements further, this arrangement has become permanent.

The South African government's Reconstruction and Development Programme (RDP), begun in 1994, specified the minimum level of service as an unregulated communal standpipe placed no further than 250m from any dwelling (CSIR, 2000). This has been the level provided in many rural schemes, and in some (temporary) urban schemes (Fig. 3.1). The RDP greenfield developments in urban areas comprise concrete block houses fitted with an in-house water connection (Fig. 3.2) or yard tap (Fig. 3.3) and waterborne sewerage. In areas where water has not been formally provided, residents rely on water kiosks, water vendors, or public water tankers. Surface water in urban areas is generally highly polluted and not suitable for domestic use, although it is often used in the absence of an alternative supply. Groundwater accounts for 14% of exploitable water in South Africa (Palmer and Eberhard, 1994:5.1), but is not abstracted in any significant quantity in urban areas.

Fig. 3.1 A communal standpipe in New Rest informal settlement, Cape Town

Fig. 3.2 An 'RDP' house with metered, in-house water supply and water-borne sewerage

Fig. 3.3 A yard connection attached to a sewered toilet block in a 'sites-and-services' type development

The systems described above that are provided to low-income residents are fairly basic but there is no shortage of technology in the South African water sector. High-income areas and industry have access to the most sophisticated of systems and South Africa is at the forefront of development in prepaid distribution systems. These have begun to be implemented in low-cost housing and upgrading projects.

Scope and limitations of this chapter

In terms of bulk infrastructure, the major urban centres in South Africa have large storage facilities, treatment works and comprehensive reticulation networks. The majority of urban centres are covered by the reticulation networks; the exceptions being the many unserviced informal settlements. Palmer and Eberhard (1995:42) note that the good availability of bulk water is fairly typical of South African urban areas as a whole. Because the informal settlements that are being dealt with are situated within these urban centres, an available bulk water supply is assumed. Water quality will also not be dealt with, as the South African water quality standards are high by international standards and strictly enforced, resulting in a high quality of urban water supply. Few complaints about quality are received in the urban centres.

The significance of the link between water and sanitation is the subject of ongoing debate (Wall, 2000). Some case studies show that demand for sanitation goes up if water supply improves, while others show that sanitation facilities provided along with water fail because of lack of real demand (ibid:30). It is acknowledged here that both water and sanitation have an undeniable link to health, along with many other factors. The connection also extends to the extent that some sanitation options rely on certain levels of water supply, and if the sanitation level exists, then it is necessary for the water supply to be complementary. There is, however, some flexibility in matching certain levels of water supply with other levels of sanitation. This leads to the view that sanitation should not be the primary decision factor for the selection of water supply technology, and vice versa. The more important factors are what users desire, what they can afford, and what the service provider has the capacity to provide, all in sustainable manner. It is around these key factors that the delivery debate focuses. In terms of the UCT methodology for in-situ upgrading, this thesis proposes that for analysis of technology, design of the system and management options, the two services may be considered separately. The results of this proposition are discussed in Chapter 6.

The issue of greywater is inseparable from that of water supply and must be considered simultaneously. All the water that is supplied to a site and not consumed (which is most of the water) must be disposed of in some manner. There are three basic alternatives for the disposal of grey water:

- If the volume supplied to the site is low enough, the wastewater can be absorbed by the surrounding environment without causing a health risk. Seepage pits and soakaways can be constructed for this purpose, but in some cases the ground conditions may not allow for this.

- If waterborne sanitation is provided, then this is usually used as a convenient method of disposing of greywater, although it does increase the flow that has to be handled by the waste treatment works.

- If neither of the above conditions apply, then some form of drainage system has to be put in place. This type of drainage system would cater for greywater and stormwater and will be discussed further in Chapter 4 – Drainage.

Most of the technology described and case studies cited in this chapter will be local. The reason for this is that the water sector in South Africa is fairly advanced and much research has been undertaken, particularly by the Water Research Commission, on new technologies and on water policy. International examples will be brought into the discussion wherever possible.

3.2 THE INTERNATIONAL WATER DEBATE

There are three core issues that dominate the international water debate, not only in developing countries, but in the developed world as well. These are:

- water as a market commodity versus water as a basic right;
- the privatisation of water services (particularly in developing countries); and
- management of water as a scarce resource.

The debates are complex, ongoing and largely unresolved. This section will therefore briefly outline the major arguments insofar as they affect South African water policy and water supply to informal settlements. Understanding what contemporary thinking on these issues is important, as they affect the attitude of WSPs towards servicing the urban poor, as well as the specific technologies chosen for water provision.

Water as a market commodity versus water as a basic right

Water is often treated as a market commodity because of the fact that as soon as it is transported from a source to the consumer a cost is incurred; a cost that has to be borne by someone. In urban areas where uncontaminated sources are often far away, and where local sources usually have to be treated, the cost is often high. It is rarely the case that consumers can extract uncontaminated water for themselves. This is why it is often argued that, although people should not have to pay for water as a 'free' natural resource, they should bear the cost of the convenience of having it treated and transported to their homes.

This view has been strongly articulated by international lending agencies since the failure of many programs in developing countries to recover costs. One of the highly-influential 'Dublin Principles' adopted at the United Nations' World Conference on Water and the Environment was that "Water should be recognised and treated as an economic good" (UN, 1992). These principles have been included in many national water policies, including South Africa's (see DWAF, 1997). Some organisations insist on full cost recovery (World Water Commission, 2000; Serageldin, 2000; Asian Development Bank, 2003), while other authors state that the price of water should be set at the marginal cost to cover operation and maintenance (Palmer and Eberhard, 1994). The recent literature emphasises a demand-driven approach to achieving cost recovery through assessing how much users are willing and able to pay (see Cairncross, 1990; Cotton and Tayler, 2000; Bos, 2001).

The treatment of water as a market commodity has come under much criticism because of the ethical issues of commodifying a 'good' that is essentially a basic human need. Jaglin (2002:234) observes that "widespread poverty obstructs the strict enforcement of market principles and taking this on board has become a strategic element of successful reforms." This has led to water being viewed as somewhat of a right, up to a certain quantity, but this in turn leads to questions of "How much is enough?". The definition of 'basic' has been carefully determined by various international organisations like the WHO, and amounts to around 40-50 l/c/d. The strong movement towards access to water being treated as a basic right argues that no one can be denied access to this basic supply because they cannot afford it, or because the areas that they live in is 'unserviceable'.

How this right is ensured to the poor leads to a further debate on subsidisation of water supply. Many argue that subsidies are the only chance the poorest residents have of obtaining the 'basic' amount of water (Goldblatt, 1998; van Ryneveld, 1995). Full cost recovery places too heavy a burden on the poor, who end up paying more per kilolitre for their water than any other consumers (Cairncross, 1990; Cotton and Franceys, 1991). These subsidies can be in the form of direct government grants, or by cross-subsidising the poor from other consumers in the sector. Others argue that subsidies only benefit those that are already receiving services and that they threaten the expansion of the supply network to those who are most desperately in need (Smith, 2000).

The privatisation of water services in developing countries

Privatisation is becoming popular with aid agencies for application in developing countries. European companies that already operate well established systems in Europe are looking to expand to developing countries, particularly in South America (Marvin and Laurie, 1999). It is believed that private companies can provide the service with greater efficiency and less political interference governments (Cairncross, 1990:117). Privatisation has not answered some vital questions like how services can be extended to the poor and what happens to the water supply when the supplier goes bankrupt. Due to the expertise present within private operators, more sophisticated systems may be possible, but the advantages of this are not particularly relevant in an informal settlement context. Administratively, privatisation may overcome corruption and lack of resources and skills that may occur in large public authorities, but may fail because of inadequate regulation (Eberhard, 1999:8). Wall (2000:45) also states that "...private sector provision of infrastructure services can be positive if the regulatory framework is well defined and is enforced." At some higher level, there has to be sufficient capacity within a public authority to regulate a privatised system. A strong argument for the privatisation of water is that it can introduce competition to a sector that is often run as a monopoly. Competition then results in a more efficient service in order to keep costs as low as possible, and this saving may or may not result in cheaper tariffs to the consumer.

A number of cases in South America (e.g. La Paz and Cochabamba, Bolivia; Buenos Aires, Argentina) and Africa (e.g. Guinea and Gambia) have highlighted the failure of privatisation to benefit the urban poor (Marvin and Laurie, 1999; Hall and Lobina, 2002; Hall et al, 2002). These have reinforced a trend that strongly resists privatisation on the grounds that it is exploitative of the poor. This debate has had a definite impact in South African water policy.

Managing water as a scarce resource

The scarcity of water is becoming an increasingly important on a global level, but is most pressingly felt in dry, developing countries. In developing countries, however, the provision of a basic water supply to the poor usually takes precedence over water conservation. Conservation is considered an accepted principle in most water projects, in particular with regard to reducing losses, wastage and excessive consumption. These issues will be considered throughout this chapter, but mainly concern industry and high-income consumers. Bulk water supply issues like finding new sources and building dams are national issues that are beyond the scope of this discussion.

The situation in South Africa

Water as a basic right or market commodity?

Jaglin (2002) accurately describes the difficult situation that sub-Saharan African governments are in; trying to reconcile free-market policies with the universal provision expected of accountable, democratic governments. This is evident in the tentative steps taken in South Africa towards a revised tariff policy. In 1994, the new, democratic government made a number of promises to correct the previous discriminatory practices. These were set out in the *Water and Sanitation Policy White*

Paper (RSA, 1994), whose basic intention was equity in distribution. It stated that everyone has a right to a basic water supply. It did not, however, abandon the contemporary thinking on cost recovery and included the two principles of "Water has an economic value" and "User pays":

> *"The basic policy of Government is that services should be self-financing at a local and regional level. The only exception to this is that, where poor communities are not able to afford basic services, Government may subsidise the cost of construction of basic minimum services but not the operating, maintenance or replacement costs."* (RSA, 1994:21)

The poor were thus still required to pay for the service. The policy includes the provision for a 'life-line' tariff, but this was to be set at a local government level. An important feature of the White Paper was that it conceded that residents in marginal areas (i.e. informal settlements) are also entitled to basic services.

In 1996, the South African Constitution recognised the right for all citizens to access to a sufficient water supply (RSA, 1996). This raised questions about whether water could still be treated as an economic good and whether those who could not afford to, should pay for water (Macdonell, 2001). The 1997 *White Paper on a National Water Policy for South Africa* reaffirmed the right to water for basic needs, but placed emphasis on pricing water to ensure efficient and productive use. It is notable that this document makes the first mention of a *free* life-line tariff for basic water provision. This tariff would apply to a limited number of government projects and it was not specified how this would be implemented. The 1997 *Water Services Act* and the *National Water Act* (1998) follow in a similar vein from the 1997 White Paper, insisting on access to sufficient water and a life-line tariff, but remain vague about what the life-line tariff is and whether it means free basic water.

Subsidisation has always been a part of post-apartheid South African water policy. Through the use of case studies, van Ryneveld (1995) and Goldblattt (1998) show that people living in informal settlements will never be able to afford the full cost of water services. With this in mind, and because of the undeniable fact that in the long run total costs have to equal total revenue, there has to be some form of government subsidy, or subsidies across sectors. Eberhard (1999:5) believes that financial trade-offs like cross-subsidisation between services (along with their economic and social implications) lie at the heart of water tariff policy. Some may argue that subsidisation does not reflect a sustainable service, but the status of water as a basic need and the current inequity in the South African water sector may be used to justify subsidisation. It is clear that during this period the government was trying to maintain a sustainable service and expand the network while still serving the social cause and keeping political promises.

In 2000, after a serious outbreak of cholera in KwaZulu Natal due to water cut-offs, DWAF took a bold step in announcing the Free Basic Water (FBW) policy. With the advent of this policy and the legal backing of the Constitution, access to a basic water supply was firmly established as a right in South Africa. It is also viewed as such by a large percentage of the population. This right forms one of the guiding principles of *the Draft White Paper on Water Services* (DWAF, 2002). An outline of the Free Basic Water policy, what it entails, and its implications for types of service provision are given in the next section.

Privatisation of water in South Africa

Jackson (2000) provides a concise overview of the advantages and disadvantages of privatisation in South Africa. Reference is made to the two major private water contracts operating in South Africa, those in Nelspruit and the Dolphin Coast. Jackson's argument strongly favours privatisation on a concession contract basis, but acknowledges that the success of private supply depends on carefully negotiated contracts and a firm regulatory authority to maintain accountability. South Africa began privatisation of water services in 1992, but through to 2000 only six private contracts have been awarded to multinational companies (Hall et al, 2002). Pressure on the government, largely from labour unions, resulted in a policy change and the 1997 Water Services Act states a preference for public sector provision of water. This preference arises from two primary concerns: (DWAF, 2002)

- the concern that the profit motive will result in unaffordable services and lack of focus on servicing people without access to basic services; and

- the concern for the loss of public sector jobs.

Since 1998, DWAF has shown a greater intention to keep water services in public hands, motivated by the need to protect and promote the public interest. The 2002 *Draft White Paper on Water* Services states:

"Water is an important social good...and hence water assets that serve the public should be owned by the public, that is, by the water services authority that is responsible for the provision of services to the citizens in its area or government." (DWAF, 2002)

Privatisation of water services is therefore unlikely in the near future in South Africa. There are, however, other forms of private sector involvement that are promoted by the govemment and that can result in a more efficient system. The most common form of private sector participation in South Africa is service contracts (Ramsay, 2000:154). This entails contracting portions of the work such as engineering design, construction, meter reading or billing out to private contractors. This is an efficient way of augmenting the capacity of a local authority, without compromising the advantage of a single owner and administrator of the system. An efficient billing and tariff collection system increases willingness to pay, and consumers may be more inclined to pay tariffs to a private contractor, rather than to a government authority.

Water as a scarce resource

South Africa is a water scarce country with an average rainfall of 500mm, significantly less than the world average of 860mm (RSA, 1994). In addition, the rainfall is also very unevenly distributed over the country, making expensive inter-basin transfer schemes necessary. The scarcity of water has become a growing concern and steps are now being taken at local and national level to reduce consumption and make water supply networks more efficient (RSA, 1997). The conservation of water resources is, however, a national issue and its importance in the water debate depends on the environmental priorities of the government and international pressure. It is an over-arching concern in any water supply scheme, but cannot be dealt with adequately on the scale of this discussion.

3.3 THE FREE BASIC WATER POLICY

The Free Basic Water policy was the culmination of a long debate in the late 1990s about subsidising basic services in South Africa. Subsidies that were diverted to the water companies and not at the consumers directly had the effect of keeping water tariffs artificially low, and benefit all consumers and not specifically the poor. The South African government has moved away from these higher-tier subsidies to a more specific third tier (local authority) subsidy that is more accurately targeted at the poor. The Free Basic Water policy was announced in September 2000 and is likely to have a large impact on the way water is supplied in informal settlements and upgrading projects.

> *"The primary intention of the policy is to ensure that no one is denied access to a basic water supply because they are unable to pay for the service. Underlying this is the recognition that supply of water at a 'basic' level assists in alleviating poverty, improves community health and frees women from drudgery"* (DWAF, 2001b:2).

To date, 59% of the population (including 42% of the total poor population) are receiving free basic water (DWAF, 2003). The political pressure driving the implementation programme, as well as the large impact that the policy has on the daily lives of the poor, means that the policy will be an integral part of water supply in South Africa for some time to come. It is therefore in this policy environment that the service options will be discussed later in this chapter.

What the policy entails

The policy states that poor households must be provided with 6 000 litres (6kl) of safe water per month free of charge. The volume was calculated by taking the WHO minimum standard of 25 l/p/d for an average household size of 8 people for a month. The 6 kl volume is not explicitly stated as the absolute minimum, but is a recommendation that local authorities may modify according to local conditions. The policy is structured in such a way to "...ensure access to free basic services for the poor and only free basic services to all if the local authority can afford it." (DWAF, 2001b:10). The policy has been set at national level, but it is local government that has the mandate to implement the policy. It is therefore local authorities that have discretion over how much water to provide free, and those with scarce resources may decrease this amount.

The intended recipients are poor households, but no formal definition is given as to "how poor is poor". In order to avoid a strict definition of poor, only one of the methods (the targeting method) defines a benchmark income, while the other two methods avoid any classification. The three methods of implementing FBW have a significant impact on the physical infrastructure provided in an upgrading scheme. These methods are:

- rising block tariffs;
- targeted credits; and
- service level targeting.

Rising Block Tariffs

Rising block tariffs are used extensively around the world to create a more equitable tariff structure. They generally aim to increase the consumption of those using less than 50 l/c/d (for health reasons) and discouraging the use of more than 200 l/c/d (Eberhard, 1999). In the case of the FBW policy the rising block tariff has the first block (0-6kl) set at zero cost. Obviously this subsidises all consumers, not only the poor, and additional measures need to be taken. The higher blocks then have to be set at such a level to recover revenue lost from lowest-tier consumers. This method is independently sustainable as long as there are sufficient high-level consumers to 'subsidise' the poor within the supply area of a WSA. The minimum proportion of high-level consumers (using >20kl/month) for this to occur is approximately 30% (DWAF, 2001b), which will apply in most urban centres. If this is not the case, then external funding needs to be introduced. This type of cost recovery also requires all levels of user to be serviced by the same WSP to allow the cross-subsidisation. Fortunately this is usually the case in areas that include urban informal settlements.

Targeted credits

Targeted credit is the option most specific to the poor, but involves identifying who qualifies for the subsidy. Those who qualify (usually households with an income of less than R800/month) then get a credit on their water bill for the first 6kl consumed. They are still expected to pay for consumption in excess of this amount. This method does not have to apply to privately billed connections. Coupons can be issued for water kiosks or mechanical prepayment systems, and electronic prepayment systems can be set to provide the first block free. The verification of income is often a difficult process. There are other methods of identifying the poor, including geographical divisions, housing quality and level of education, but these can be inequitable (Sussens and Vermeulen, 2001). Targeting is a sensitive issue because of the stigma attached to being labelled 'poor'. This system is similar to the indigent policy that has been used in schemes around South Africa, but these tend to be smaller schemes where the administration of the system is easier. In large urban areas the task of identifying the poor and applying credit on an individual basis may be prohibitively difficult.

Service Level Targeting

This method involves limiting consumption through physical constraints to excessive consumption or through regulated flow, caused by a specific level of service. Examples of these are an unregulated standpipe, where household consumption is rarely greater than 6 kl/month (200 l/d) because the water has to be carried, or a limiting system like the yard tanks used by Umgeni Water. Prepayment systems can also be set to limit consumption. Service Level Targeting does not require billing or debt collection and therefore reduces administration considerably. In many cases it would be uneconomical to bill consumers who consume less than 6 kl/month. The regulated flow reduces the risk of users consuming more water than they can afford. It does, however, restrict users who may require more volume per month (in a large household for example) and this, some may argue, is unethical.

In reality it is likely that in urban centres a combination of service level targeting and rising block tariffs will be used in order to ensure that the poor with both metered and unmetered supplies have access to free basic water. Sussens and Vermeulen (2001:131) stress that there must be flexibility in the use of these options must remain at a local level.

Criticisms of the policy

South Africa's FBW policy has been criticised internationally by those in the water sector because it is perceived as a financially unsustainable model. In addition to this problem, there are also other important issues that need to be addressed for the policy to succeed. The FBW implementation policy document identifies 4 major constraints to its implementation, namely: (PDG, 2001a:5)

a) *financial*: how to ensure sustainability
b) *socio-political*: how to establish co-operation amongst stakeholders
c) *institutional*: how to develop the required organisational capacity
d) *technical*: how to choose the appropriate technical and service level options

It is the final point – technical service level options – that this chapter aims to address, but the other issues will be mentioned briefly here. One of the most serious financial concerns is that the loss of revenue in the system will compromise the expansion of the water supply network to unserviced areas. FBW may be equitable for those who have access to a water supply, but does not explicitly cater for those without it. This may result in the FBW policy benefiting the urban poor, but not the 'poorest of the poor' - usually those in informal settlements. The onus is on local authorities to prioritise those without access to water supply, and this should possibly be done before free water is supplied to all serviced consumers. The problem of unserviced urban areas is growing rapidly and needs to be urgently addressed.

A further financial concern is that illegal connections result in unaccounted for water that is not budgeted for in the FBW scheme (Tanner and Abbott, 2001:20). This may lead to the un-sustainability of the system. Sussens and Vermeulen (2001) reiterate that water losses through vandalism, unauthorised connections or normal leakage could threaten the viability of the FBW policy. Reduction of number of paying customers in any one system (because of FBW) means that the cost of any water losses has to be borne by the smaller pool of paying customers or by the water utility. The FBW policy does not contain any mechanism for recovering the cost of lost water in supplying free basic water.

The socio-political aspect of the policy deals with how the public receive the service. It is easy for users to misinterpret the message of 'free basic water' as 'free water', particularly when it has been used by politicians for political gain. Concepts like rising block tariffs and credit on water accounts can be confusing to consumers. An important concern is that the wealthy should not benefit from the policy more than the poor (if at all). Monitoring of the effects of the policy needs to take place to ensure that this does not happen. Another social question is whether the FBW policy is entirely equitable. Users may complain that their households are twice as big as others, and that they should therefore get more free water. Households as large as 16 members are not uncommon in South African informal settlements. Tanner and

Abbott (2002:18) note that these inequalities are difficult to prevent, as there is no sure way of fairly and accurately measuring household size.

Institutional capacity is a major constraint to the success of the FBW policy. The administrative complexity introduced by the policy could prevent local authorities from implementing the system, as they are not required to do so if they can show that it is not financially feasible. The policy could also reduce incentives for efficient maintenance because the users are not contributing to the income of the Water Service Provider (WSP). In order to counteract this, the Water Supply Authority (WSA) may withhold funding to the WSP if service is not of a good enough quality.

Technically, the provision of FBW has a number of effects on the level of service provided. These are discussed later in this chapter. The method of implementation also introduces some technical constraints on the supply system. For example, in order for rising block tariffs to be implemented, all user connections have to be metered.

Results of the policy

The limited reports that have been published on the implementation of the FBW policy show mixed results. The FBW message, as one would expect, has the tendency to increase expectation for water service provision and level of service. This is why the system has been the most effective when there has been an associated improvement in the level of service and a concerted effort to improve cost recovery. Cases have been reported where the FBW policy has had a positive effect on cost recovery because users have no excuse not to pay for consumption in excess of 6 kl/month, due to claims of poverty or on health grounds (Tanner and Abbott, 2001).In some cases the opposite has happened and payment for services has reduced. The George Municipality reports that after the FBW policy was introduced, payment dropped from 94% of users to 87% (PDG, 2001b). There was no official communication to users explaining how the tariff structure would work.

Due to the fact that the price elasticity of demand is much higher for the poorest urban residents than for the more affluent, the FBW policy is likely to increase water consumption by these users. This is consistent with the objective of increasing the consumption of users previously using less than 50l/c/d. FBW also has the potential to reduce the administration burden of collecting charges, as long as the user stays below the 6 kl/month level. If a block tariff system is adopted, however, then the high cost of water in the higher tiers could discourage consumption by middle- and high-income users, thus curbing overall consumption. Durban Metro Water reported that after the introduction of rising block tariffs, the number of consumers moving from the middle to the lowest block rose sharply (PDG, 2001a). This did reduce the administrative load, but had serious implications on the financing of the scheme because income dropped disproportionately to the decrease in volume consumed.

It is important that users therefore have the *option* of using only this amount or less. If a high-pressure connection is provided to the household with waterborne sanitation, it may be difficult to use below 6 kl/month, and the user may pay for water that he/she does not want as a result of the technology provided (Tanner and Abbott 2001:25). A study of consumption in Durban, however, showed that households with waterborne sanitation could stay below 6kl/month, but that this required careful household-level water management (PDG, 2001c). A complementary measure to the implementation of FBW, as was done in Durban, is to introduce an awareness campaign on water-saving measures.

In the 3 years since its inception, the FBW policy has spread slowly to all of the metropolitan regions in the country. It is still regarded with much scepticism by the WSPs and the influence that it has on cost recovery and the sustainability of water supply in poor areas has yet to be determined. In order to asses the effect that the FBW policy has had, or will have, on water services provision, the different distribution systems and cost recovery methods will now be described.

3.4 DISTRIBUTION SYSTEMS AND COST RECOVERY METHODS

The previous sections have described the policy environment within which the upgrading of water supply in informal settlements must take place. This section will provide a brief description of the types of water distribution systems available for upgrading informal settlements and the associated payment methods. The traditional method of classifying water supply systems is to group them according to the 'level of service', having between three and five groupings from 'rudimentary' to 'full service' (see Department for Community Development, 1983; Cotton and Franceys, 1991; DWAF, 2000). Here four levels will be used to describe all the distribution systems currently available. The levels indicate an increase in quantity, pressure, access or convenience:

Rudimentary: Non-piped sources that generally fall below the DWAF 'basic' standards for adequate water supply

Basic: Communal piped sources with sufficient access to achieve a minimum acceptable level of water supply.

Intermediate: On-site piped supplies that represent any increase in convenience above that of a basic supply

Full: The ultimate level of convenience with water piped under pressure directly into the dwelling.

Table 3.1 Water distribution options

Rudimentary	Basic	Intermediate	Full
• Direct abstraction from rivers • Wells and hand pumps • Vendors • Public tankers • Water kiosks • Concession sales from individual houses • Communal standpipe with limited access	• Communal standpipe within a set distance to every dwelling	• Yard taps • Yard tanks • Roof tanks	• House connections

Rudimentary Systems

Vendors

Water vending is the private commercial sale of water in containers, usually from the back of light delivery vehicles. This takes place in areas that do not have access to any public supply of water. Caimcross and Kinnear (1988, quoted in WELL, 1998) estimate that 25% of the population of third world cities buy water from vendors (this definition of 'vendors' probably includes kiosk and tankers). The vendors charge more for water than public utilities, but yet do not make large profits. This is because of the high cost of transporting water and the small scale of the service. There is an undeniable economy of scale in the water sector, creating a natural monopoly in which a public utility, with a large reticulation network, can always provide cheaper water than private sellers. In water scarce countries, price is very sensitive to any change in supply and it is those purchasing water from private sellers (usually the poor) who are affected by these price increases first.

Public Tanker

This is a system whereby water is supplied by the local authority by means of a large water tanker, which visits an area on a regular basis. The tanker then fills up residents' containers. The service is usually (but not always) provided free of charge and is often used as a temporary service, or in emergency situations, like during a cholera outbreak. Tankers are often used in unserviced rural areas.

Water Kiosk

Water kiosks are stalls provided with piped water, from where water is sold to residents in designated volumes (usually 25l). The kiosk is operated by entrepreneurs, or by residents elected by the community. The connection to the kiosk is metered and the kiosk owner pays the WSP for the water used. Profits need to be added to the price of water to make the kiosk viable, so the cost of water is generally high. For kiosks to function efficiently, economic factors like thresholds and profits for vendors need to be well understood (Palmer and Eberhard, 1995). A balance needs to be found between distance people are prepared to walk, and the threshold population required to provide the kiosk owner with sufficient income. Palmer and Eberhard recommend 1 kiosk per 100 households. This means that in order to keep walking distances low, kiosks are more suited to high-density areas.

Concession sales from individual houses

Concession sales are similar to water kiosks, but sellers are able to run other business, or just combine the sale of water with the duties of a householder to supplement income (Palmer and Eberhard, 1994:8.9). It is often the case that the community water committee identifies an individual to operate standpipe and collect money for the volume consumed.

Box 3.1 Note on Rudimentary Distribution Systems

Rudimentary systems are not often considered as options in upgrading projects, and are widely considered to be inadequate (WHO, 2000). The reasons for this have been alluded to above, and are mainly related to cost and equity. Numerous studies have shown that the cost of water from kiosks and vendors are between 20 and 50 times more than public supply (Kakebeeke and Van Wijk, 1998 quoted in Goldblatt, 1998; Lovei and Whittington, 1991:9 quoted in Rogerson, 1996; Jaglin, 2002). The economies of scale and the cost of transporting water mean that the most efficient form of water supply in urban areas is through reticulation. The non-piped systems will therefore not be considered for use in upgrading informal settlements, but have been mentioned here because they are present in many existing settlements. Although they are very efficient at filling the void were no official water provision exists, they are unsuitable for a long-term supply. The remainder of this discussion will focus only on piped supplies and the various methods of cost recovery from these systems.

Basic Systems

Communal standpipes

Communal public standpipes supply water to millions of the world's poor and are the most common form of 'formal' water supply in South African informal settlements. Public standpipes have been implemented on a large scale as part of the Reconstruction and Development Programme (RDP), which stipulates that a standpipe within 250m of every dwelling was the basic minimum for water supply. The *Guidelines for Human Settlement Planning and Design* (CSIR, 2000:5.7.7) state that in densely populated areas a maximum distance of 100m and a walking time of 2 minutes are preferable. Public standpipes are generally provided with concrete plinths and some provision for drainage, but the designs vary considerably. The standpipes can have a single or double outlet (Fig. 3.4), or a number of taps in series.

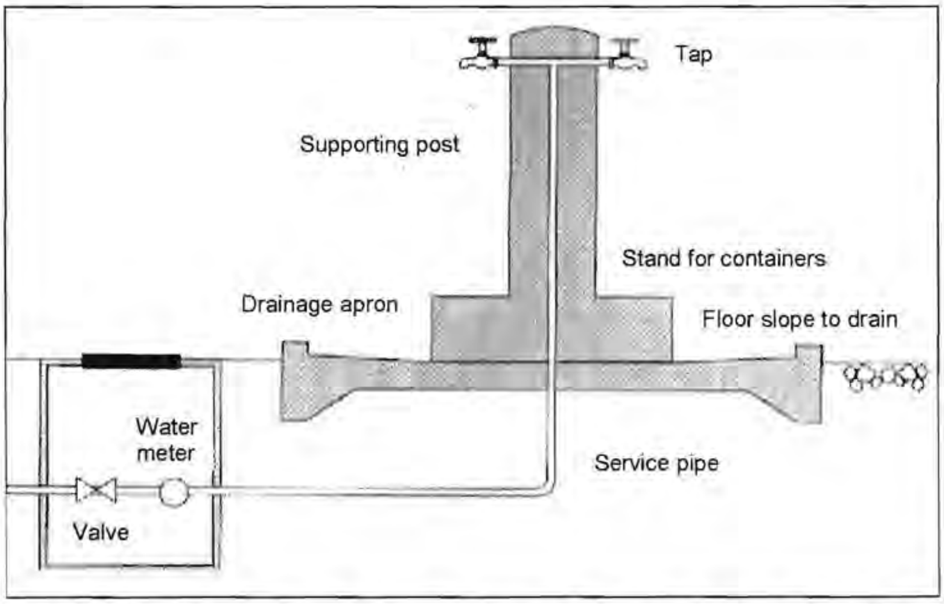

Fig. 3.4 Typical layout of a double outlet standpipe and concrete plinth (Source: Cotton and Tayler, 2000:4.43)

The standpipes found in informal settlements are most often provided through political pressure as an 'emergency' or temporary supply. These connections tend to be uncontrolled (except by pressure), unmetered and often provided free of charge. The average cost of each standpipe is R1800, with the typical consumption from these standpipes being 4 kl/household/month (CMIP, 2001) (but this varies depending on the distance from the dwelling to the standpipe). These standpipes, more often than not, are poorly maintained and frequently broken. Where payment *is* expected for water from public standpipes, the mechanisms used are described briefly below:

Flat rate tariff: All households in the area pay a fixed monthly rate. This can vary according to household size, but does not take into account distance from the standpipe. The tariff can also be collected as part of other levies.

Metered standpipe with shared payment: Standpipes are placed on the premises of individuals who are then responsible for the water bill. They can either sell the water at a profit (similar to concession sales) or split the bill equally. The payment can also be based on the size of each household. The idea is that each 'water group' manages their own account and resolves disputes internally. There are no examples of this in South Africa, but there are in Malawi (Palmer and Eberhard, 1994:8.9). When families get their own private connections, they just withdraw from the system. The standpipes are available at most hours of the day.

Manual Coupon System with Water Bailiff: (Lima, 2001) Consumers purchase coupons from the WSP or participating agent and exchange these for water at public standpipes. Coupons are used instead of cash for security reasons and because coupons can only be used to purchase of water, but it was found that coupons are easily lost. Manually operated taps are easier and cheaper to install, repair and maintain than any of the automatic dispensing units, but the cost of the water must incorporate the cost of paying the bailiff. Extra administration is created through the sale of coupons. The bailiff is usually only available at certain times of the day. The standpipe is metered and consumption is reconciled monthly with coupons collected. The bailiff is then compensated with a salary or through sales commission. Various problems can arise with the bailiff selling water illegally or not treating all customers equally. Lima Rural Development Foundation (2001) reported on several of these schemes in rural and peri-uban areas in KwaZulu Natal.

Automatic Dispensing Units (ADUs): Automatic dispensing units are fairly recent technology in South Africa, but are already widely used. There are two types of automatic prepayment systems used in South Africa; the electronic tag /card system and the mechanical coin/coupon systems. The electronic system operates through the user purchasing an electronic tag or encoded card, which is used to operate the standpipe. The tag/card is inserted into the standpipe unit and water can be drawn up to the available credit. The valve on the standpipe closes when the tag is withdrawn, and the user is only debited for the amount of water withdrawn. Credit is bought from an electronic vendor, which can be at the WSP offices or at a local shop. The tag costs R25 – 50 and is reusable (Lima, 2001). There are various models of electronic prepaid systems designed and manufactured in South Africa and have been used internationally (see Fig. 3.5). A list and description of many of the systems available is given in DWAF (1997). User information is stored both at the dispensing unit and the vending point. This information is then collected and stored on a central database, from where water balances and demand assessments can be performed. Some of these prepayment systems are capable of vending to both water and electricity (Conlog, 2002).

Fig. 3.5 One of the many types of prepaid standpipes available in South Africa (Source: www.citizen.org)

The other types of prepaid standpipes are mechanical systems that use either tokens or coins to operate. Lima (2001) describe a mechanical ADU, developed by a company in KwaZulu Natal, that has no electronic components and works like coin operated slot machine. Hazelton and Kondlo (1998:5.12) describe the Thelamanzi Mechanical Pre-payment meter, which uses the public water supply to fill a large storage tank. Inside the storage tank is a smaller tank fitted with a simple float valve. The user empties the smaller tank into their container by inserting a plastic coupon which falls into a padlocked collector box. The float valve then reopens and the inner tank is refilled.

Intermediate Systems

Yard taps

Yard taps consist of basic single standpipes placed within the plot boundary of individual dwellings. This has been the standard level of service for sites-and-services schemes. Cairncross (1990) promotes the yard tap as an acceptable level of service at which most of the health benefits associated with water supply can be achieved. The average capital cost of this system in South Africa is R2100 per connection, and yard taps result in a typical consumption of 11 kl/household/month (CMIP, 2001). If no waterborne sewerage is provided, drainage for wastewater around the tap is essential. A yard tap can be located on the wall of a toilet if waterborne sewerage is provided (see Fig. 3.3), but should not be a condition for obtaining waterbome sewerage, or vice versa. These connections are usually metered and conventionally billed, but can also be prepaid units. Some argue for an unmetered connection with a flat-rate tariff.

Yard tanks

The yard tank system was pioneered in South Africa by Durban Metro Water and Waste and the CSIR. The tank that is used can be either plastic or ferro-cement, but Macleod (1997) shows that a white plastic tank made in a two-layer process helps keeps the water temperature down to 25°C. The tanks can be a variety of shapes and sizes, but are usually cylindrical with a storage capacity of around 200l (Fig. 3.6). A large household can have more than one tank. The distributed storage that yard taps provide means that demand peaks are reduced and sometimes eliminated in the reticulation network. Yard tanks are also capable of operating under low pressures. This means that an existing standpipe network can be upgraded into a yard tank system. There are essentially three different types of storage system, depending on how flow is regulated and how payment is made. These are manually operated, trickle-feed and regulated systems.

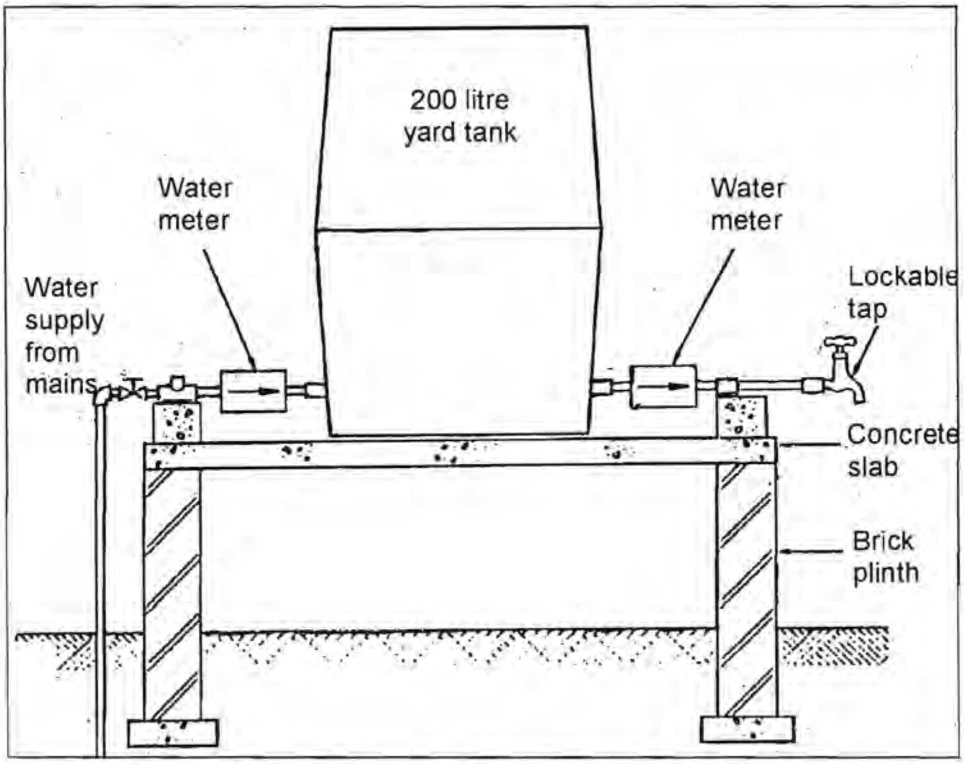

Fig. 3.6 Design diagram for a manually operated or regulated yard tank (Adapted form Hazelton and Kondlo, 1998:5.6)

Manually Operated Yard Tanks

This system is also known as the 'Durban tank' system and the following description is taken from Macleod (1997). The reticulation to the tanks consists of 25mm diameter polypropylene pipes laid along access routes in the area. At appropriate intervals a manifold connects to the reticulation. The manifold contains a supply meter and a shut-off valve in one section, and a control valve for each of the 20 household connections that can be made to the manifold. The householders then connect to the manifold using 20mm diameter pipes leading from their household tank, which is placed on a plinth. A float valve controls overflowing of the tank. The outlet contains a valve that prevents the tank being emptied while it is being filled. Each household pays a fixed tariff to the water authority every month to stay connected to the system and to obtain a fixed monthly supply. Proof of payment is then given to a water bailiff who is charged with the operation of the system (usually one bailiff per 200 households). The bailiff opens the valve in the manifold, supplying the paid-up household with a full tank of water each day. The tank is filled under full pressure from the reticulation and therefore the filling process does not take very long. Users are not able to obtain more than a tank's volume of water per day. Volume of supply can, however, be increased by changing the tank size and increasing the monthly tariff. As part of this system the bailiff has a standpipe installed on his/her property from which they can sell water to residents who do not have a tank installed. The water is sold at a price that promotes the use of a tank system.

Trickle-Feed Yard Tanks

The trickle-feed system has a similar arrangement to the manually operated system, but with a different mechanism for regulating the water supply and consumption (see Fig. 3.7). A small rectangular tank is fitted to the inside of the main tank. The main reticulation feeds into this tank and this inlet is controlled by a float valve. The outlet to the tank is a small orifice, which effectively regulates the flow into the main tank because of the fixed hydraulic head. The water can only flow into the tank at the same rate as flows out of the small orifice. The main tank can be any shape or size, as long as it is fitted with a trickle-feed box (Tipping and Scott, 2001).

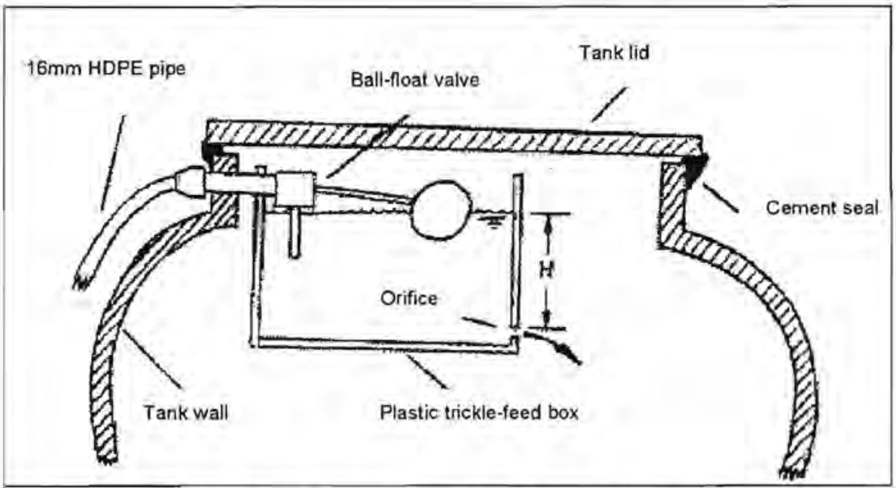

Fig. 3.7 The flow regulating mechanism inside a trickle-feed yard tank (Source: Tipping and Scott, 2001)

The tank can be used constantly throughout the day, but the volume consumed is limited to that which can be supplied by the orifice. The rate of supply can be supplied by either enlarging the orifice, or by adding another orifice. The lid of the unit obviously has to be locked or sealed, so that only the WSP can modify the orifice. The household pays a fixed monthly charge, which is usually based on an estimated average consumption according to the orifice size and not on the maximum possible consumption. The system is designed for low to medium consumption and can supply 500l/day regardless of the shape of the demand curve (Hazelton and Kondlo, 1998:5.2).

Regulated Yard Tanks

The regulated yard tank system is essentially the same as the trickle feed system, except that the pressure and volume of water supplied to the tank is controlled from a point on the reticulation, and not from inside the tank. This prevents users from bypassing the trickle-feed box and gaining an unlimited supply. The 'equity' valves placed at control nodes on the supply network allow for the supply to be shut off if the monthly flat rate tariff is not paid. The volume supplied can also be adjusted at this point by changing the size of the equity valve (DWAF, 2000:18). This system has not yet been tested in South Africa. The Consolidated Municipal Infrastructure Plan (CMIP, 2001) estimates the average capital cost of all yard tanks to be R1400 per connection, with a typical consumption of 6 kl/household/month. Cost estimates done by DWAF (2000) show the regulated system to be the cheapest, followed by the trickle-feed system and then the manually operated tank. The capital outlay for a yard tank is 30% less than that for a full-pressure house connection (Stephenson et al, 2001:28).

Roof Tanks

Roof tank systems are simply an upgrade of a yard tank system in order to obtain water inside the dwelling at a higher pressure than a yard tank. A similar result can be achieved by placing a yard tank on a stand next to the house. These systems are sometimes referred to as 'medium pressure' connections. The added cost of roof tanks is due to the effort and extra material required in placing the tank in the roof, and the internal reticulation required to supply water to different rooms in the dwelling. An obvious prerequisite of this system is that the dwelling is sturdy enough to support the considerable weight of a roof tank. Yard tanks are easily upgraded to roof tanks provided there is sufficient pressure in the reticulation network.

Two types of roof tank are described by DWAF (2000). The first is a regulated system that operates in the same way as the regulated yard tank. The second is a manually operated roof tank, but is not filled daily by a water bailiff. Instead, water is supplied at full pressure to the roof tank and is metered conventionally by water bailiffs. Supply is unlimited and users are charged according to consumption. This system is in fact similar to a conventional house connection, but water is only supplied at roof pressure and the distributed storage and consequent reduction of peak flow allows for cost savings in the reticulation design. The administrative costs are the same as for a full house connection. It is proposed that roof tanks that operate in the same way as the trickle-feed and manually operated yard tanks are other options, but these are not described in the literature.

Full service

Individual House Connections

Full-pressure house connections to individual dwellings are the standard level of water supply in middle- and high-income urban areas of South Africa. These systems are well documented and well understood, so will not be described here in detail. Supply is theoretically unlimited. The CMIP (2001) estimates the average capital cost of a house connection to be R2500 with a typical consumption of 25-40 kl/household/month. The only variation in these systems is in the payment mechanisms, and thus the main issue here is how water is billed and paid for. There are three common methods of payment: conventional metering, fixed monthly tariffs, and prepaid metering.

Metered house connection with conventional billing

This is the most common arrangement for individual connections in South Africa. It involves an individual meter, which is placed on the property boundary and manually read on a monthly basis. Monthly accounts are then sent to the users, who are charged a fixed connection fee as well as for estimated usage based on the previous month's consumption. Water supply can be disconnected at the meter for payment defaulters. A variation of centralised billing is hand-held meter reading, with on-site processing and billing (Hazelton, 1997:232). This eliminates much of the administrative cost associated with centralised, off-site billing. Another option mentioned by Hazelton is self meter reading and billing with centralised payment.

Unmetered house connection with fixed monthly payment

Palmer and Eberhard (1994:8.11) report that this method of billing is relatively widely used in South Africa. This situation often arises where meters do not function and conventional metering has collapsed. Authorities require some form of cost recovery, and so resort to the most administratively simple system, but which is also potentially inequitable. Case studies have shown that a flat rate levy is no easier to collect than a metered account payment. The cost of keeping meters operational is eliminated, but water losses cannot be monitored. New legislation states that all private connections need to be metered and the government therefore intends to phase out this service option (DWAF, 2001a).

House connection with electronic pre-paid meter

Household prepaid water meters are similar to the more familiar prepaid electricity meters. There appear to be many different systems of prepaid water meters that have been tried in South Africa. All systems use an internal electronic unit that displays the amount of credit available to the user. The credit is bought in the form of a card or coupons at a vendor, which can be the WSP, a dedicated vendor, or a local shop. The water is supplied at full pressure to the house connection until the credit has been used up. Some systems then have a mechanism to shut off the water supply until further credit is bought. Other systems, such as the one described by Palmer and Eberhard (1994:8.11), are integrated with the prepaid electricity supply and the electricity is shut this off instead of the water supply. The water supply continues, but displays negative readings. The electricity is only reconnected when the water debt has been paid. The reasons for cutting off electricity are that a water solenoid valve is expensive, and because of health reasons. Another practical consideration is that users are more likely to reconnect electricity before water.

Prepayment meters avoid the necessity of meter reading and billing and can accommodate a number of tariff structures, including a rising block tariff. The metering device can also regulate the volume supplied. Meters are not entirely tamper-proof and can be bypassed. The prepaid concept for electricity supply has worked well in informal settlements in South Africa. Cost recovery is ensured and consumers are able to link their consumption to affordability in real time.

3.5 IMPLICATIONS OF THE FREE BASIC WATER POLICY FOR WATER DISTRIBUTION OPTIONS

The FBW policy has different implications on the various water distribution options, depending on the institutional capacity of the WSP and the FBW implementation method used. Sussens and Vermeulen (2001) provide a fairly comprehensive list of the service options, their application in water supply systems, and how suitable they are for the application of FBW. This data is presented over the page in Table 3.2. From the table, the following points can be noted:

- Unmetered communal standpipes do not pose a threat to the policy as they are appropriate for service level targeting. However, they are low cost options that may be unacceptable to many consumers. A meter fitted to each standpipe would help to check that the standpipe is distributing sufficient free water, or that it is not distributing more free water than the policy allows, either through abuse or leakage.
- Service level targeting dictates that water from communal standpipes should be free and thus there is no longer need for systems like water kiosks or manual coupon systems with bailiffs.
- A very important result of the FBW policy is that prepaid communal standpipes are no longer required. This has major implications as much money has been spent on the development of these systems. The capital and operational cost of the prepayment meter is not justified if no payment for the water needs to be made.
- The yard tank option accommodates the FBW policy well, as the amount of water consumed can be limited to 6 kl/month. Alterations can be made for a greater consumption, but still at a constant consumption, so a fixed rate can be applied. Of the three systems, the regulated system has the greatest advantages.
- The advantages of the roof tank are not related to the FBW policy, but to other factors like the convenience of pressure and capital costs of the system.
- Yard taps are considered together with house connections because they have to be regulated in the same way. A rising block tariff would usually apply, except when users may qualify for any available targeted credit.

Table 3.2 Assessment of service options under the FBW policy (Source: Adapted from Sussens and Vermeulen, 2001:132)

Service Description	Application	Suitability for 'free basic water'
Communal street tap: Tap shared by a number of consumers	While mainly used in urban areas their widest application has been in rural areas where this has been the most common service level provided under water supply programmes over the last decade.	A low cost option well suited to providing water to poorer consumers. It is seldom that consumers would use more than 6000l per hhold/month and therefore this service level is well suited to service level targeting.
Prepaid communal street tap	This option has been introduced recently in a number of areas with mixed results.	If up to 6 kl is to be provided free then the need for a pre-paid meter falls away as no payment is to be made.
Low pressure trickle feed yard tank: Tank, typically 250 litres, located in yard with flow control device in tank. Permanently connected to network.	Yard tanks have a major benefit in that they provide a restricted supply at a fixed monthly charge. They also allow for a cost effective reticulation design. No bailiffs required to open manifolds, but the tank can be easily bypassed.	For a 'free basic water' policy yard tanks are an important service level as they provide a relatively high restricted flow service level (less than 6kl/month)/. Typically the tariff for the tank would be set at zero. This fits in well with all the poverty relief options.
Low pressure manually operated yard tank: *A tank filled from a manifold on a daily basis.*	Has the same benefits as the trickle feed tank with the following exception: the daily manifold opening is labour intensive. However, tank cannot be bypassed.	As for the trickle feed tank, there is wide application for this type of service in a 'free basic water' context.
Low pressure regulated yard tank: A tank with a regulator at a node on the reticulation.	Similar to a yard tank but does not require opening of a manifold. Bypassing of the tank brings no benefit to the consumer and therefore is not a problem.	As for other yard tank options, this is well suited to a 'free basic water' initiative.
Medium pressure manually operated roof tank: Unregulated metered flow to tank on roof directly from reticulation.	Has limited application as a service between normal metered supply and yard tanks. Main benefits relate to saving on reticulation costs. May be a good upgrading option.	No particular benefits: needs metering, billing and credit control systems.
Medium pressure *regulated roof tank*: A roof tank version of the low pressure regulated yard tank.	This option is also based on having regulator at the reticulation node. Therefore it allows for restriction of flow without the risk of bypassing.	This is well suited to a 'free basic water initiative'. It allows a relatively high service level with limited flow volume.
Full pressure conventional house connection	The 'yard tap' is also included under this category. This is the highest level of service but it requires an effective metering and billing system to function properly.	Generally has to be integrated with a 'free basic water' initiative. If used with service level targeting it would be assumed that those having it can pay cost reflective tariffs. If the poor have access to this service level a rising block tariff or credit system is required.
Full pressure prepaid house connection:	Pre-paid metering avoids the necessity of reading and billing. Non-payment is not an issue but tampering can be a problem.	Most prepaid meter systems provide for rising block tariffs with a zero first block. In this case they are suited to a 'free basic water' initiative.

The suitability to the FBW policy, as listed in the table, deals mainly with whether a system can be adequately regulated or not. What has not been considered is whether regulation and physical restraint on the volume that a user can consume is equitable and justified. This will be discussed in the next section.

Service level targeting introduces questions around the compatibility of basic systems with sanitation (Tanner and Abbott, 2001:6). The lower levels of water supply generally exclude waterborne sanitation, and on-site systems carry the possibility of greater health risks. The improvement in health conditions due to increased water use may be lost due to inadequate sanitation facilities. On-site water borne systems may only be compatible with a 6 kl/month water supply if careful water management is practiced. Unregulated systems can also be abused to gain more water, through tampering with the system or making illegal connections.

The FBW policy also excludes the provision of water from vendors and kiosks, unless targeted credit is used and coupons are distributed. These services could be included in service level targeting, but then there is little incentive to run these stalls and the system is open to abuse.

3.6 THE CONCEPT OF THE CONSUMER/SUPPLIER INTERFACE

Introducing the concept of a consumer/supplier interface

Traditionally, the considerations when planning and designing a water supply system to a low-income area have mostly been technical and supply-driven. They include the following:

- Minimum acceptable level of service to reduce cost (because residents can afford very little)
- Demand, pressure and minimum acceptable flow rate, which are all linked to the sizing of the system
- Cheapest and most efficient reticulation design
- Associated level of sanitation
- Fire-fighting requirements
- Maintenance requirements
- Elimination of theft, vandalism and illegal connection
- How to ensure/enforce cost recovery

These parameters can all be calculated or ascertained fairly accurately with no community consultation at all. When analysing systems that do fail, however, one realises that incorrect calculation of these parameters is not the main cause. The actual reasons have far more to do with the needs and expectations of the consumer and their relationship with the service provider. This provides the motivation for a shift in the focus of water supply planning considerations to a demand-driven approach. From the discussion in this chapter, it is clear that the constraints to implementing the FBW policy and the conditions necessary for the success of water supply systems in informal settlements all converge at a point. This point is the consumer/supplier interface. The concept of a consumer/supplier interface is a defining feature of water supply that is not present in the other services, and is a feature that has not been given adequate attention in the technical specification of water distribution services. What will be illustrated below is how this concept can help to focus the issues surrounding water supply at a point and thereby deal with them in a manner that ensures a sustainable system.

Palmer Development Group discuss a similar idea when they discuss the factors that effect willingness to pay at the "customer-service provider interface" (PDG, 1998). The factors that their study highlighted included:

- communication between officials, councillors and customers;
- efficient delivery and adequate maintenance by the service provider;
- clear and accepted mechanisms for penalising non-payment;
- increasing the options available to customers;
- making a visible impact to improve services; and
- transparency in service delivery.

The idea of a consumer/supplier interface is both physical and conceptual. On a physical level it is the water distribution system; the point at which the consumer accesses the water and where it is measured/regulated. On a conceptual level it deals with those aspects mentioned by PDG, above; essentially the relationship between the stakeholders and the exchange that takes place across the interface. The supplier provides water of a certain quality, quantity and reliability, while the consumer is expected to pay for, and correctly operate the service. All the issues regarding the sustainability of the water supply system can be related to this interface. The key issues around the interface that that need to be assessed are:

- Location of point of delivery, and its implications;
- Regulation of the supply; and
- Method of payment by the consumer.

It is through these three interventions/systems that the relationship over the interface develops. Each of distribution option has a number of associated implications when each of these factors is considered, and it is these that determine the efficacy of a service, rather than the technical appropriateness of the physical infrastructure provided. The final decision as to what physical form this interface should take is based more on how the consumer views the service and whether the exchange over the interface is equitable and sustainable, rather than merely on the basis of cost and affordability.

Location of the delivery point

Location of the delivery point influences how much water a household can consume, and how convenient it is to use the water. It is probably the most important factor in determining how consumers perceive the supply system and its acceptability. The location also affects the equity of the system as consumers closer to public supplies have a better service than those further away. Whether a service is public or private has large cost implications to the service provider, both in terms of reticulation length as well as metering and billing.

The debate around location of the delivery point distinguishes between three general locations: communal, on-site (yard) and in-house supply. Although services at greater distances than the basic requirement of 200m do exist, most communal standpipes and other communal sources will be considered to be within this range. Roof tanks may added as a level between yard and house connections, but are considered here as an in-house supply.

Communal supplies within 200m of every dwelling

The history of communal supply is rooted in rural areas where water was traditionally fetched from a well or a spring. Although a chore, the water collection point was an important social meeting area where daily issues were discussed amongst women. The concept of communal standpipes in low-income areas has thus been imported from rural areas and expected to function in much the same way. With many of the first residents in informal settlements coming directly from rural areas and with the lack of any other level of supply, communities may originally have accepted these communal supply points.

With the increase of the age of the settlements and the intra-urban movement of residents, the culture of communal water collection diminishes. In the urban areas of Brazil, for example, which have a long history of informal settlements and third or fourth generation urban dwellers in these settlements, there is no culture of communal water supply (Abiko, pers. comm.). All new water systems that are installed are provided to every household. As the residents become more 'urbanised' they begin to expect higher levels of service. This is evident in an observed lack of congregation around water points and the lack of ownership in these communal facilities, which manifests itself in vandalism. The collection of water from a distant source is a heavy burden, mostly to the women in the community. In urban areas the opportunity cost of fetching water is higher than in rural areas, and this may be exacerbated by long queues due to low pressure, broken standpipes or insufficient water points to service the number of households.

For the service provider, communal facilities have a number of advantages. They are the cheapest service to install and can easily be relocated if necessary. Standpipes are simple to design and require no negotiation with a community, except perhaps around their location. Service level targeting is also the least administratively problematic method of implementing the FBW policy. There may, however, be a number of disadvantages for the service provider, including increased maintenance cost and poor (if any) cost recovery.

On-site supply

For the consumer, upgrading to an on-site supply results in a large increase in convenience, as consumption is no longer restricted by how much water can be carried. In addition to the convenience benefits, there is a proven increase in health. A study undertaken by the CSIR and the Medical Research Council in Khayelitsha, Cape Town showed that the water delivered to residents via standpipes was of a suitable quality, but became contaminated during the transportation and storage processes (CSIR, 2002). The study concluded that in order to protect the community from water-related disease, a private yard tap was the minimum acceptable level of service. Some type of outdoor flush toilet is possible with an on plot supply. Studies have shown that quantity may have more effect on health than water quality and the location of a water supply on the property can cause an increase in consumption by a factor of 2 or 3 (Cairncross, 1990).

It is also fairly easy to upgrade an on-plot standpipe into a house connection, provided the distribution network has been designed with sufficient capacity. This is an important difference between a communal supply and an on-site supply. With a communal supply residents are powerless (except through illegal connection) to alter the supply arrangements to suit their needs. With an on-site supply people are empowered to improve their situation and have the *choice* to leave their service as it is or upgrade it if they are able. In many instances where sites-and-services schemes have only provided on-plot standpipes these have been upgraded (formally or informally) into house connections. If on-site supply is provided, a very beneficial practice would be to provide residents with the skills necessary to convert their on-plot standpipe to a house connection themselves.

On-site supply may also have disadvantages for consumers. There are considerable added capital costs involved in obtaining the connection and the service level will result in higher consumption. There may also be a problem with disposal of wastewater from this concentrated source, particularly if the system leaks or breaks. With this location of the service, however, there is likely to be much greater ownership of the system and residents are far more likely to fix the problem. The outdoor tap is also open to abuse from passers-by.

For the WSP, the reticulation required for connections to every plot will cost significantly more than for communal supplies. The increased consumption also means that the supply cannot go unmetered and some form of cost recovery will be necessary. Although this significantly increases administration costs, there are advantages to this. The typical consumption from yard taps in greater than 6kl/month, which means that residents ought to pay for their water. An increased willingness to pay through satisfaction with the service can enable the WSP to recover some of their operation and maintenance costs.

House connections

An individual house connection is the ultimate level of convenience, preferred by most consumers. House connections enable waterborne sewerage in the dwelling and no water has to be carried in from outside. The house connection has the same disadvantages as an on-site supply in that consumption is significantly increased and residents may use more than they are able to afford. Greywater disposal is also necessary. The increase in convenience for the consumer between an on-plot and an in-house connection is not very great, but there are considerable cost and time implications in installing the internal plumbing, especially if more than one internal connection is to be made. It is these increased costs that discourage house connections from being universally fitted in upgrading schemes. Some sort of cost recovery is essential to make house connections financially sustainable.

The maintenance of house connections is more difficult for WSPs, but residents are usually expected to see to the maintenance of their systems themselves. The maintenance of the external reticulation is much the same as for an on-plot supply. The individual connection of a large number of informal dwellings to the water supply network may cause problems on a citywide scale. The water demand will increase dramatically and this could result in local shortages. In many settlements in Brazil where informal dwellings have house connections, roof tanks are fitted to compensate for the intermittent service caused by insufficient supply.

Regulation of supply

There is considerable pressure on WSPs to regulate the amount of water supplied and consumed, both for environmental and financial reasons. They need to account for losses in the system and minimise wastage. Costs also need to be recovered and in order to achieve this, the amount of water consumed has to be regulated in some way. There also needs to be some mechanism of enforcing payment for water, and this may incorporate restriction or disconnection of supply. Regulation is a key aspect of the FBW policy and should take place with any type of distribution system.

There are four main methods that can be used to regulate consumption:

- Service level restrictions
- Vending (including prepayment systems)
- Restricting daily supply
- Metering

Service level restrictions

This has been mentioned under the service level targeting strategy of the FBW policy and refers mainly to unmetered communal supply where consumers are physically restricted in the amount of water they are able to carry. This guarantees a certain level of consumption, but does not guarantee that wastage does not occur. The most wastage occurs from communal standpipes, which are frequently broken, left open or abused. Maintaining a certain level of service to physically restrict consumption is therefore an ineffective method of regulation.

Vending

The direct payment of a fixed volume of water for cash is a very certain and rigid method for regulating water supply. Cost recovery is ensured and residents may not consume more than they can afford. Consumers are able to equate consumption to affordability directly. A problem that has been identified is that kiosks can only be open for certain hours of the day (Hazelton and Kondlo, 1998:4.9). This is unacceptable to many users, which means that storage has to take place in the house, and water may be unavailable at critical times.

Prepayment is based on the same principle, where water is not provided on credit and therefore no debt is accumulated. Field evidence shows that prepaid systems have a good record of controlling wastage and reducing consumer debt (Macdonell, 2001:177). Macdonell suggests, however, that the severe reduction in consumption that prepaid systems have been proven to cause can compromise the objective of an improved water supply; health benefits and an improved quality of life. The argument is that if people are too poor, or for some reason they cannot afford the water or prepayment card, then they are prevented from having access to water. This is the reason behind certain types of prepaid systems being banned in the UK (McDonald, 2002). Users may also prefer to spend money on something else instead of water for hygiene. The FBW policy tends to reduce this problem, but it may still exist in large households where 'basic' consumption is far higher than 6 kl/month.

It must be recognised that prepaid systems 'depoliticise' rationing and disconnection. Jaglin (2002) makes the important point that because the disconnections are individual, the responsibility for payment becomes an individual issue. The community at large does not suffer from individual disconnection and there is less chance of mass protest. The cut-offs are done automatically and there are no authorities present to direct complaint. This is a huge advantage for the WSP, but is also a disadvantage for the individuals who cannot afford to pay for the prepaid water, even if the first 6 kl are provided free. Prepayment can be an inconvenience because the administration time is transferred from the WSP to the user. Vending may also unreasonably restrict access to sufficient water in times of emergency. Vending is therefore a drastic measure to ensure regulation and cost recovery and should only be implemented with full consent of the community.

Restricting daily supply

Restricting daily supply has become a popular method of regulation since the introduction of yard tanks. Yard tanks have proved successful in low-density rural and peri-urban projects, but have not been implemented on a large scale in dense urban informal settlements. There are a number of advantages and disadvantages to regulating flow by the use of a yard tank, and these vary depending on the type of tank used.

The largest advantage of yard tank reticulation is to the service provider. The simple, low-cost technology (HDPE pipes, float valves) can be easily maintained and replaced if necessary (Tipping and Scott, 2001:337). It also reduces administration of the system significantly. Individual meters are not necessary, reducing the cost of the installation. Savings are also made on meter reading, billing and accounting systems because flat rate payment is used for the fixed daily volume (Hazelton and Kondlo, 1998:5.1). This is an advantage to consumers because they pay a fixed amount each month and therefore are not subject to financial shocks. With the FBW policy this could amount to a guaranteed free supply of a fixed volume every month.

The tanks reduce peak demand in the supply network and thus smaller pipes can be used in a more economical reticulation design. The reduction in demand also means that the supply is more reliable and shortages are less likely to occur. Standpipe reticulation can be extended to tank systems as well (Tipping and Scott, 2001:337). The lower operating pressures that yard tanks use result in less leakages than full-pressure systems. The consumers do not pay extra for these losses, but do pay through the inconvenience of having shortages in supply (Hazelton and Kondlo, 1998:5.1). The small volumes used also mean that no special provision is necessary for greywater disposal (Macleod, 1997:290).

A major disadvantage is that each household is limited to daily maximum amount of water, typically 200 l/d (Njiru et al, 2001; Tipping and Scott, 2001), although a survey by Njiru et al found that 94% of households found this to be adequate. There were also complaints that the system does not allow for unusual demand during large gatherings like weddings and funerals. One way of overcoming these problems on a trickle-feed tank is to change the size of the orifice, or to install more than one tank in series.

The volume regulating systems are all outdoors and therefore water can be accessed by passers-by. In some cases residents have requested lockable taps (Tipping and Scott, 2001). Trickle-feed and manually operated tanks can be bypassed so that residents obtain an unlimited free supply (although at low pressures), but regulated yard tanks can not. Trickle-feed tanks need to be sealed in such a way that they cannot be tampered with. The reticulation up to the plot is also vulnerable to illegal connections, but vandalism of the outlet will be reduced because of private ownership and the location of the tank on the plot.

The low pressures and subsequent small-diameter pipes that are used for the reticulation are inadequate to provide fire flow and a separate network has to be installed. The low pressures mean that total losses due to leakage may be reduced, but leak detection by conventional methods is difficult (Hazelton and Kondlo, 1998:5.1). An important note is that the low volumes provided outside of the dwelling are not compatible with waterborne sanitation. Yard tanks are usually used in conjunction with VIPs (Macleod, 1997:290).

Limiting daily consumption by means of a yard tank is a very effective means of regulating consumption, expenditure and losses. If a community accepts it, then the system is well suited to the free basic water policy, but if it is not accepted then the daily restrictions may be seen to be unfairly restrictive. The systems are best suited to consumers with constant demand, but other sources need to be available at all times in case of unexpected demand. It has been shown in a case study that the FBW policy can compromise the viability of the manually operated yard tank because of lack of incentives for the water bailiff (Njiru et al, 2001). There are a number of technical problems associated with the trickle-feed tank, and DWAF (2000:32) concludes that of all the levels of service assessed, the low-pressure regulated yard tank provides the best value for money and suitability.

Metering

Metering is only a form of regulation if payment for water is linked to consumption and this payment is efficiently collected. Residents will only regulate their consumption from a metered connection if payment is enforced and penalties are applied. Metering on supply mains and on communal facilities is also important in regulating water losses and for accounting purposes during water balances. Under-reading of water meters is one of the largest causes of unaccounted for water, and accuracy of water meters decreases with age. They therefore need to be maintained for full cost recovery.

The DWAF Regulations (DWAF, 2001a) state that every new water connection and, after 2003, every old connection, must be metered. The local authorities do not seem to have the capacity to read and maintain all of these meters, and the cost to WSPs may be too great to achieve this goal. Service level targeting means that communal standpipes do not have to be metered, even though it might help for administrative purposes. Systems regulated by other means, like yard tanks, also do not require metering. The three systems in which metering plays an active regulation function are metered standpipes with shared payment, metered private yard connections and metered house connections.

Metered standpipes with shared payment have been strongly favoured as alternatives to communal standpipes as they are easier to administer and regulate (Hazelton and Kondlo, 1998). It can be seen that this system is open to abuse by the standpipe administrator – or alternatively they can be intimidated by other users into giving them water 'for free'. The user's payment is therefore related, but not directly linked to the consumption measured on the meter. Private metering on yard taps and house connections is more a means of billing consumers than of regulating flow. Users who can afford the capital costs of private connections should be able to afford the cost of the water and are often unconcerned with the amount of water used. For those users who *are* finding it difficult to afford the water cost are able, however to check their consumption on a water meter. Even so, they do not have a means, other than usage discipline, of curbing their consumption. Consumers in this situation are probably more likely to favour an electronic prepaid mater.

The most problematic aspect of metering and private billing is enforcement of payment and the penalising of defaulters. There are various options of enforcement available, the most common of which in South Africa is disconnection of the water supply. In Cape Town alone, close to 100 000 households had their water cut off for non-payment between 1996 and 2001 (McDonald, 2002). Disconnection is a highly politicised and controversial issue in South Africa and has many negative consequences. This was evident in Tafelsig, Cape Town when 800 disconnections for non-payment in September 2001 prompted a week of violence and rioting in the suburb (Ray, 2001). The disconnection of supply to payment defaulters creates resentment towards the WSP and reduces the number of end users. Those too poor to pay are not likely to be able to afford the reconnection fee as well as the arrears, but are stuck with their given level of service and no water supply at all. A more constructive approach may be the limitation of flow, but this may be an expensive and administratively tedious exercise. In Durban defaulters are given the option of paying their arrears, or having a flow-limiting device installed (PDG, 2001c). The device limits the consumption to 6 kl/month. The *Draft White Paper on Water Services* (DWAF, 2002) favours restriction over disconnection, but states that if disconnection must be used, an alternative supply must always be available.

Method of payment

Method of payment varies according to what service option is provided, which FBW implementation method is used, and how the supplier collects the tariffs. Other factors that need to be considered are how the community is organised, who the money is paid to, and who pays for which aspects of the system. This section will investigate how different service options are paid for and how this payment is enforced. Other than services that are provided for no charge, there are four broad methods of payment: private purchase per volume, flat rate payment, prepayment, and individual billing.

Non-charging for services

The FBW policy has had the result that much of the water supplied to the urban poor should be free of charge. Where previously this has applied only to some of the most basic communal standpipe facilities, it can now apply to higher-level services like yard taps and yard tanks. This is not to say that the users will not have to pay for the capital costs, as in almost all cases there will be an initial installation fee. There is also a major question about maintenance and the quality of the service.

Many believe that this is an unsustainable arrangement as non-payment inevitably leads to a poor quality service (Serageldin, 2000). Financially, WSPs are only able to provide the most basic communal standpipes without charging for water consumed, which leads to dissatisfaction with distance to the standpipes, queues at standpipes, and interruption of service when standpipes break. Although administratively simple because no billing or collection of payment needs to take place, there is also lack of incentive for the WSP to maintain the standpipes. This is the biggest question surrounding the FBW policy and it is yet to be seen whether the cross-subsidisation is efficient enough to allow completely free or even affordable water supply to the poorest of urban residents.

Direct purchase per volume

Although the private forms of direct payment (vending, kiosks, concession sales, and even tanker supply) are widely practiced in informal settlements, they have been shown to be unacceptable because of the high prices that are charged based on demand alone (see Box 3.1). It is the most certain means of cost recovery, but also has the greatest potential to exploit the poor. This method of payment could only exist in a highly regulated and subsidised environment. The public forms of direct payment include coin-operated standpipes and standpipes manned by water bailiffs, but these are also problematic due to vandalism, abuse, and difficulties of supplying free basic water. The FBW policy has also now made it very difficult to integrate this method of payment into a formal, public service and in all cases alternative payment methods associated with reticulated supply is preferable.

Flat rate payment

Flat rate payment can be used with nearly all of the supply options, including communal standpipes, yard tanks and house connections. The biggest issue with flat rate payment is that the cost has to be generalised to some extent across a user group. This means that low-volume users, who may be situated further from the supply point or have a lower quality connection, subsidise high volume users. Payment is also not directly linked to consumption and thus wastage is not discouraged. Macdonell (2001) argues that flat rate systems are only viable for communities with less than 200 households because larger communities lack the spirit for voluntary cross-subsidisation. DWAF (1997) concluded similarly, but placed the figure at 100 households.

For communal standpipes, it may be feasible to charge a flat rate to recover capital and maintenance costs, particularly if service level targeting assumes an average consumption of less than 6 kl/household/month. Flat rates are often collected by community-based organisations or local water boards. The flat rate may be easier to collect than an individualised rate, but there are serious problems with preventing non-paying residents from using the standpipe.

The flat rate that is charged for yard tanks is slightly different as it is directly linked to the regulated volume that can be consumed. This makes it equitable across households and easy to incorporate free basic water. There is occasionally confusion over payment for the consumption as users are billed for an estimated or maximum consumption instead of for actual consumption. The provision of free basic water tends to eliminate this problem.

Charging a flat rate for a house connection creates the same problems that are associated with a flat rate for standpipe use, but the inequities are increased. A case study from Swaziland showed this system failed because large households invited their friends and family to use the taps, so smaller households refused to pay (SWSC, 2002). Because of the large disparities in usage patterns between consumers with house connections, individual metering is necessary.

Prepayment

Prepaid meters simplify the commercial management of small consumers and provide users with a tool to control their expenditure (Jaglin, 2002:238). The biggest advantages are offered to the WSP. Administration costs are substantially reduced as metering, billing and collection of payment does not have to be performed by the WSP. These costs have not been eliminated, but merely transferred to the private sector in the form of prepayment vendors. This arrangement will only be more efficient and beneficial to all if sufficient incentive (profit) can be provided to the vendor, without making the water unaffordable. Prepayment also reduces likelihood of administrative error and fraud. The WSP is still required to recover the high capital costs of installing prepaid units, as well as the maintenance costs.

Tipping and Scott (2001:336) report that these systems have had limited success due to high installation costs, reliance on advanced technology and low water usage by the consumer. Hazelton (1997) stated that individual prepaid meters do not overcome the high unit costs associated with low consumption, but they are competitive with conventional billing. This would suggest that prepaid systems are applicable for house connections and yard taps where consumption is increased. It has been shown earlier that prepaid *communal* standpipes are not relevant under the FBW policy.

Prepayment systems also offer benefits to consumers. It allows them to link consumption with expenses in real time which reduces the shock of monthly billing, particularly in poor areas where cash flow is a constant problem. It also eliminates mistrust and misunderstandings of accounts. This would tend to suggest that prepaid systems are most suitable where relations between the community and local authority are strained. The disadvantage is that consumers have to purchase water in advance from a location that may be inconvenient to get to. A key issue is the minimum amount of credit that can be bought as cash flow may restrict the amount that a household can spend on water at any one time. Prepaid water meters also do not generate a willingness to pay, but rather enforce payment for water at a price that is not able to be negotiated after it is set (Tanner and Abbott, 2002:10).

Billing of individual connections

Individual billing can apply to shared standpipes or to private yard and house connections. The metering of all of these types of connections is seen as absolutely necessary (CMIP, 2001; Palmer and Eberhard, 1995; DWAF, 2001a), and thus billing based on consumption is the logical method of cost recovery. The benefit of this is that it is individualised and therefore equitable, but disadvantages are that it is administratively intensive and difficult to enforce payment. DWAF (2000:32) clearly states that "...operating costs are high and operational efficiency is low for most conventionally metered systems."

A study of this method of payment for shared standpipes found that some water debts are often high and officials have difficulty disconnecting where people claim to have paid (Hazelton and Kondlo, 1998:4.10). Because a different amount has to be collected from each 'water group' this system requires a high degree of organisation, both by authority and consumers. The system works best if the standpipe administrator knows and has a good relationship with those sharing the facility (Hazelton and Kondlo, 1998).

There are a number of difficulties encountered in using this method of payment for private connections (yard and house connections) in low-income communities and these tend to entrench a vicious cycle of poor services:

> *"In South Africa there have been difficulties with this arrangement in townships, both because of poor management and because of political resistance to paying for services. In the former case this leads to a situation where meters are not properly read and accounts are not sent out properly. In the latter case the accounts are simply not paid. Often the two factors are inter-linked with consumers being unwilling to pay for a service which is poorly rendered."* (Palmer and Eberhard, 1994:8.10)

Hazelton and Kondlo (1998) argue that owners do not mind receiving monthly bills and when they do not pay it is because of a cash flow problem. When short of cash, users sell water to ease the cash flow, but then have no money left to pay the bill at a later stage. This can be detected by rapid jumps in consumption. The poor may also find it difficult to physically make the payment to distant offices, although this can be improved if payment for water is incorporated with payment for other services like sanitation, solid waste collection and electricity. It has been argued that the high administrative costs of this system of billing are not justified for low volume consumers.

Despite these problems, individual billing is still the most common, and seen by many as the most efficient, means of cost recovery for house connections. There are a number of ways to improve the efficiency of billing and payment. Meter reading is often contracted out to private companies who are able to do it more efficiently (Palmer and Eberhard, 1994:8.10). DWAF (1997) found that for individual house connections, semi-automatic field billing and self-billing systems were marginally less expensive than electronic prepaid systems, which are in turn less expensive than conventional metered billing. The self-billing and field billing systems are not as versatile as the electronic systems as they are not suitable for shared connections.

3.7 WATER SUPPLY CONCLUSIONS

The South African government has affirmed access to a water supply as a basic right. A unique feature of the South African water sector is the Free Basic Water policy which is undoubtedly going to change the way in which water services are extended to the urban poor. There is also the commitment to public supply over privatisation, which means that the state still has a large role to play in service provision and policy issues. These policy developments are outlined in the *Draft White Paper on Water Services* (DWAF, 2002).

This chapter has investigated what the impacts of water policy might be on the form of water supply for upgrading informal settlements, and some recommendations on future action have been made. The discussion has focussed around the concept of the consumer/supplier interface, and how users and suppliers might negotiate an acceptable and sustainable service. Some of the more important observations from the discussion are given below. Rudimentary supply systems such as vending and water kiosks have been fairly conclusively ruled out as viable options, except for emergency supply. It has also been shown that prepaid communal standpipes are not applicable in a FBW environment.

The literature has generally discouraged the provision of communal standpipes. However, in order to provide FBW and not to discriminate against those who really can not afford to pay for water, it may be necessary to provide a bare minimum network of standpipes to distribute water free of charge. As long as a free basic service is available, the service provider is free to strictly regulate and enforce payment for higher levels of services. If communal standpipes are to be installed in informal settlements because of cost constraints in the WSA, a number of conditions should apply:

- The service needs to be reliable, with adequate pressure and as few interruptions to the service as possible.
- The number and location of the water points should consider not only the distance to each dwelling, but the density of dwellings as well (the Red Book recommends a standpipe within 100m of every dwelling serving 15-25 households).
- The system requires a relatively cohesive community who are able to take ownership of the service.

- The standpipes must be well maintained, possibly by a member of the community employed by the WSP, which will help to address misuse and vandalism.
- The system must be upgradeable because higher levels of service will be required in the future. Residents must be able to make their own house connections to the system if they are able to afford it. In order to do this, the distribution network needs to be designed to handle an increase in future demand.
- The water supplied must be provided free of charge. A flat rate may have to be charged for the maintenance of the system, but not for the volume consumed. A shared standpipe with group contributions towards maintenance may be an easier way of administering this.

There is a strong case for providing on-plot water supply to informal settlement residents, not as an intermediate level of service after a communal one, but as a basic level to be provided in the first instance in an upgrading project. The benefits include: convenience and the reduction of burden on women, health improvement, greater sanitation options, equitable pricing, and the ability to upgrade when able. If yard taps are provided, these can be individually billed or prepaid, depending on institutional capacity and preference. Yard taps also allow for shared usage, depending on the community dynamics. Of the yard tank options available, the regulated tank appears to be the most efficient and administratively simple. Yard tanks have emerged as a favourable option for a number of reasons. Some of these are given by Sugandree Muruvan of DWAF:

> *"A recent study indicated that although communal standpipes have a short-term capital saving, in the longer term, certain other higher levels of service have financial and other benefits. The most important finding was that for a marginal increase in capital cost, low pressure yard tanks that are far more acceptable and sustainable, can be provided. It was shown that the total long-term cost is cheaper than the present standpipe system. These systems also lend themselves to the implementation of a free basic water policy. They meter and/or control the volume of water so that people using less than the basic amount can get it free, whilst those using more have to pay. They are also less prone to vandalism and unauthorised connections and reduce the burden on women and children of having to carry water."* (Muruvan, 2002:175)

The ultimate level of water supply, an in-house connection, can not be expected or justified as a basic service, but is a convenience that must be paid for. If this level is provided in an upgrading scheme, then free basic water still applies, but the current step tariff environment will mean water will probably have to be paid for. In low-income environment, experience has shown that an unrestricted supply with individual billing is unsustainable and therefore a prepaid meter is probably preferable for both the user and the supplier.

The recommendations made above are by no means meant to dictate what levels of service and payment mechanisms should apply in upgrading schemes. They are rather intended to aid the decision-making process. In keeping with the demand responsive approach two key steps are:

1) **Assess the demand** from consumers for the different distribution options and payment mechanisms. Location of the service is probably the most important factor here. The type of regulation desired and/or required can be based on estimated consumption. Users may express a strong preference for a certain method of payment, and a definite willingness to pay for higher levels of service must be indicated before the service is provided.

2) **Assess the institutional capacity** on the part of the WSP. Their skills and competencies will have a large effect on what types of regulation and payment are most applicable. The ability to provide and maintain certain levels of service will differ from one area to another.

An aspect of water supply that has been stressed throughout the chapter is that of choice to the consumer. If a basic standpipe supply is provided in order to fulfil the government's commitment to providing FBW, then the WSP is given many more options for implementing higher levels according to demand and willingness to pay. It is important the consumers are able to upgrade their service and that they are not trapped into a particular level after the upgrading has been completed.

Chapter 4

DRAINAGE

4.1 INTRODUCTION

This chapter will investigate current approaches to urban drainage with the aim of informing the upgrading of drainage in informal settlements. It will be argued that the drainage problems experienced in informal settlements are unique due to the physical nature of the settlements. The first part of this chapter will identify these specific problems based on the fundamental objectives of urban drainage. It is these issues that any drainage intervention will need to address.

A review of the literature has revealed two main approaches to urban drainage and these will be presented in the second section of this chapter. What has been called the 'conventional' urban drainage method has been adopted from developed countries for application all over the world. Challenging this approach is the Sustainable Urban Drainage Systems (SUDS) approach which may be more applicable in the developing world, but is yet to be tested in these conditions. The appropriateness of these two approaches in an informal settlement context will be assessed later in the chapter.

The problem identification and the assessment of the two approaches will highlight a number of drainage issues in informal settlements that pose the greatest engineering challenges. In order to bring the drainage debate down to a more practical level, the physical characteristics of a number of settlements will be analysed. This analysis will provide the motivation for a new approach to local, low-cost drainage intervention based on the combined strengths of each of the approaches and the unique physical characteristics of the settlements. This new approach will then lead onto a number of proposed interventions.

Drainage of an area is affected by, and can affect, other areas in the catchment. Drainage systems should therefore ideally be planned on a catchment-wide scale; otherwise improvements in one area mean problems in another (Cairncross and Ouano, 1990). With in-situ upgrading, it is often not possible to alter the drainage characteristics of an entire catchment. There are, however, significant measures that can, and must be taken at a site level. This chapter will focus on measures that deal with local drainage issues in informal settlements, defined as all surface water up to the settlement boundary. It is understood that the local drainage methods discussed in this chapter will have to form part of an integrated catchment management plan.

Definition of urban drainage

Drainage is the process of removing unwanted water from an area. Urban drainage, as it will be defined here, deals with two different kinds of excess water; stormwater and wastewater (Butler and Davies, 2000). Stormwater is precipitation that travels along the surface (and to a lesser extent, subsurface) as runoff, and household wastewater consists of greywater or sullage from washing, cleaning and cooking, and blackwater from flush toilets.

Objectives of urban drainage

The primary objectives of urban stormwater drainage are to prevent or reduce the effects of flooding and to eliminate the inconvenience of inundation and associated health risks (Caminos and Goethert, 1978; UNCHS, 1986b; Butler and Davies, 2000). The objective of household drainage is to eliminate the spread of disease caused by pathogens present in the wastewater (Cairncross and Ouano, 1990).

The problems noted by Reed et al (2001:283) of poorly managed stormwater and wastewater include:

- small floods damaging roads and buildings causing disruption to lives and businesses
- pollution from overflowing latrines and sewers, causing faecal pollution and disease
- cross contamination of water supplies
- wet soils leading to ideal conditions for worm infections
- providing habitats for vectors (e.g. mosquitoes and snails)
- water pollution from diffuse sources (rubbish, animal faeces, air pollutants)
- erosion of water courses
- siltation of water courses
- inconvenience (e.g. wet feet in puddles)
- safety (e.g. physical danger of being washed away)
- landslides

The drainage problems experienced in urban areas are due to the impacts that urbanisation has had on the natural hydrologic cycle, increasing the risk associated with flooding. These impacts are well documented in the literature (e.g. Chow, 1964; Ward, 1967; Butler and Davies, 2000). Fig. 4.1, below, shows these effects on a standard hydrograph for a hypothetical catchment. Urbanisation generally creates impermeable surfaces in place of natural ground and vegetation. During heavy rainfall the peak flow rate is increased and arrives more suddenly than in undeveloped areas, increasing the risk of flooding. This is because there is less infiltration and the runoff is able to move faster over these hardened surfaces. Another important impact of urbanisation is that it contaminates the water when runoff comes in to contact with surface pollutants. This poses a threat to the receiving waters and the associated natural environment.

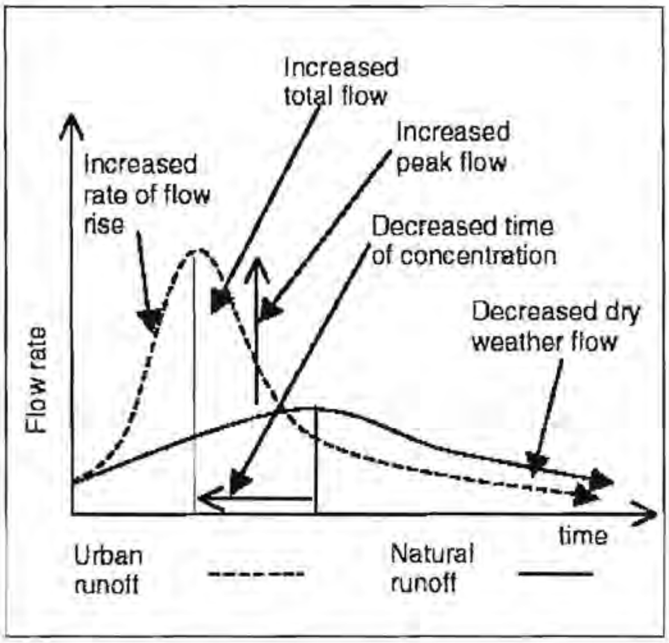

Fig. 4.1 The impact of urbanisation on a storm hydrograph (Source: Reed et al, 2001)

Integration of drainage with the other services

This review of infrastructure services seeks to assess each of the services separately in order to isolate their main objectives and key factors influencing design. The interrelationships between the services has to be acknowledged and drainage is the service that most affects, and is affected by, the other services. The interactions that drainage has with other services are discussed below.

Sanitation

Poor management of runoff can negate the health benefits achieved through the provision of sanitation. Flooded sanitation systems dramatically increase risks of faeco-oral infections within a settlement. Kolsky et al (1996:189) state, "Effective sanitation of *any* kind requires stormwater drainage" (emphasis added). Conversely, if no effective sanitation is provided, then faecal matter will end up in surface water and the drainage system provided will have to take this potential health hazard into account.

The development of waterborne sewerage was historically based on the use of stormwater to dispose of toilet wastes. The original 'sewers' were combined systems with pipes that deliberately carried both sewage and stormwater. Most new sewerage systems convey sewage and greywater only, but many of the older networks in the developed world are combined sewers. Around 70% of all sewers in UK, France and Germany are combined systems (Butler and Davies, 2000:17).The base flow from combined systems is treated, but untreated wastewater is discharged into watercourses during heavy flow. Even though most countries have moved away from combined systems, they have had a major influence on the development of piped drainage systems and the approach to drainage that is used in developed countries.

Water Supply

The supply of potable water onto a site introduces the aspect of household wastewater into drainage design. Blackwater from toilets has already been mentioned, but greywater from household activities will also need to be removed from a site. There are a number of methods of dealing with greywater. Where separate or combined sewers are provided, greywater is usually added to these. In some cases, separate pipes may be provided exclusively for greywater at a reasonable cost, but these have not been entirely successful because of the tendency for residents to 'illegally' connect sewer pipes to the greywater system (Cotton, pers. comm.). In many developing countries, greywater is disposed of in surface stormwater channels (Hardoy et al, 1992). Although not as pathogenic as blackwater, greywater may still pose a health risk if left to stagnate. Disposal on the surface is often the only option when drainage and sanitation are not provided and will only be acceptable if the soil is permeable and can accept all the greywater generated. DWAF (1999) states that off-site sanitation is required for greywater disposal at densities higher than 40 du/ha (which is the case in most informal settlements). Drainage can have an effect on the quality of water supply as well. Poor drainage can result in contaminated surface water entering water pipes, particularly when the supply is intermittent and pressure in the pipes is low. This is a reason for the frequent outbreak of disease during the monsoons in India (Kolsky, 1998). On-site water sources like wells and boreholes are the most susceptible to contamination by stormwater, but these water sources are uncommon in *urban* South Africa.

Access

Roads and stormwater are often considered to be integrated systems because of the important role that roads play in conventional stormwater systems, and because roads have to be drained to protect their structure. These two services have been deliberately separated here because it is felt that, although they have and impact on one another, the two objectives are fundamentally different. Roads are primarily related to access and movement, while the objective of drainage is to eliminate risk. Drainage is a function of the climate, topography and ground conditions, while access is dictated by existing networks, spatial relationships and social behaviour. The relationship between roads and drainage networks will be comprehensively reviewed in this and the following chapters.

Solid Waste

Solid waste collection is necessary for the correct functioning of any drainage system. Solid waste blocks drainage systems and either increases the frequency of flooding or increases the cost of maintenance. Open channels are often used as convenient areas to dump solid waste. In order for any piped drainage system, or even surface drainage systems, to work, some sort of solid waste management is required.

4.2 PROBLEM IDENTIFICATION: DRAINAGE IN INFORMAL SETTLEMENTS

Drainage issues in informal areas tend to be more severe than other urban areas. The reason for this relates largely to the poor location of the settlements. Informal settlements are often located on marginal land that is not viable for formal development. The location can increase the severity of drainage problems for three reasons:

Topography: sites too flat, too steep or in a natural basin/depression

Situation: on a river bank, bordering a wetland, on a flood plain or in an area with a high water table

Ground conditions: impermeable soils or unstable slopes prone to landslides

A second aspect that aggravates drainage problems is that fact that no provision is made for drainage before the dwellings are constructed. Water follows natural drainage routes and dwellings that are badly positioned may be affected by surface runoff. Irregular ground may result in ponding during prolonged rainfall, which introduces health risks (Fig. 4.2). If residents try to make individual efforts to improve the drainage around their dwelling then it may simply result in the problem being passed to another resident. As conventional drainage generally requires an intervention at site-level or beyond, it is difficult (and expensive) to address drainage problems after a site is established.

Fig. 4.2 Ponding caused by surface irregularities in Kanana informal settlement, Cape Town. Laboratory tests on water from this puddle revealed extremely high counts of faecal coliforms (Graham, 2001).

The impact of flooding on informal settlement residents is greater than others because of the greater vulnerability of their location and because they are less able to cope with shocks (Reed et al, 2001; Amis, 1995). Dwellings are susceptible to flood damage and often contain all the residents' possessions. Social networks are often confined to a single settlement and if all residents are affected, there is no external support. Residents take a long time to recover from the shocks that floods can cause. Numerous informal settlement flood disasters have been reported in the South African press. In August 2001 severe flooding on the Cape Flats forced 13 000 residents from 13 informal settlements to flee their dwellings (Cape Times, 2001). Informal settlements in other areas were also severely affected during floods in KwaZulu Natal in December 1999, in Johannesburg in February 2000 and in East London in August 2002.

The environmental problems caused by poor drainage are particularly acute in informal settlements because of the combination with a lack of other services. Lack of sanitation is the most serious of these. During flooding, runoff mixes with faecal matter and spreads across a settlement causing a risk of gastro-intestinal diseases like cholera, diarrhoea, typhoid and intestinal worm infections (Kolsky, 1998:1). Van Veelen and DWAF (1994, quoted in Ashton and Bhagwan, 2001:14) found that faecal pollutants from informal areas, originating from both toilets and refuse disposal sites, were the component of urban runoff posing the most serious threat to human health. If no provision is made for greywater disposal an unhealthy environment can also be created. A lack of solid waste collection is a problem in its own right, but this can be made worse if runoff spreads the waste around the settlement or into other areas (Fig. 4.3).

Fig. 4.3 A culvert blocked by solid waste in the Monnakato informal settlement, North West Province. (Source: DWAF, 1999)

Contaminants that enter the stormwater runoff from an informal settlement have a great influence on the rest of the catchment. The quality of the receiving surface water bodies is often severely affected. Problems of pollution from informal settlements have already been experienced in places like Midrand and Centurion (Ashton and Bhagwan, 2001) and Cape Town (Abbott Grobicki, 2001). It has even been stated that:

> *"Pollution form densely populated settlements is perhaps one of South Africa's most important, but most complex water quality problems"* (DWAF, 1999)

Pollution to surface water may thus be the prime motivating factor for upgrading informal settlements in South Africa. If informal settlements are to remain on a site where water quality problems are being caused, then the drainage is the first aspect of the site that is likely to be upgraded.

Identifying the causes of drainage problems

The problem of inadequate drainage in informal settlements is difficult to deal with because it is caused by many factors. Simply adopting an approach to urban drainage that has been used elsewhere avoids the necessity of examining the causes and effects of poor drainage specific to informal settlements. The purpose of this section is to clearly define these causes and effects and the extent to which on-site stormwater management can address them. The three primary objectives of drainage defined in the introduction are; to eliminate the physical risk of flooding*, to reduce the disturbance caused by inundation**, and to decrease the health risks associated with standing surface water. Table 4.1 details the effects, the characteristics and the causes of these three issues. The table has been structured in this way to progress logically from the very obvious effects of poor drainage, through the more specific characteristics of the problems, to finally identify some of the less obvious underlying causes. The causes will then be looked at in greater detail below. There is an obvious inter-relationship between the columns, but they have been separated here for simplicity.

* Flooding is defined here as a rapid rise in water levels resulting in dwellings being filled with water or washed away and people being forced to leave their homes because of a threat to their safety.

** Inundation is a less severe condition, where the dwelling is not flooded and people can remain on the site, but the public space is inundated and movement is restricted. The distinction is subjective, but based on severity.

Table 4.1 Effects, characteristics and causes of inadequate drainage in informal settlements

	Physical risks of flooding	Disturbance caused by inundation	Health risks of poor drainage / flooding
Effects	• Personal risk • Damage to property	• Restricts movement • Restricts transport of goods • Unpleasant living conditions	• Increases vulnerability of children to sickness • Aggravation of existing poor health conditions • Drowning
Character-istics	• Raised water levels • Fast, uncontrolled watercourses • Severe erosion/undermining • Landslides	• Impassable roads • Muddy areas • Unusable facilities • Smells • Ponding • Damp	• Pathogenic micro-organisms from sewage and greywater on surface • Disease vectors in stagnant ponds • Damp conditions
Causes	• External drainage problems • Location (watercourse, floodplain, basin) • Topography (too steep/flat) • Unusually intense rainfall on site • Lack of maintenance of on-site drainage	• Inadequate drainage • Lack of maintenance • Irregular ground level • Poor location of facilities/dwellings • Incorrect levels of hardened areas • Proportion of the site that is permeable • Water table/ degree of saturation	• Inadequate / faulty sanitation • Drainage not coping for low flows / greywater • Solid waste • Blocked drainage system (maintenance)

Physical risks of flooding

The rainfall that falls on the generally small sites of informal settlements is usually not sufficient to cause catastrophic flooding on its own. Severe flooding is caused by a number of extemal factors. These include:

- an accumulation of runoff from other areas in the catchment
- limited downstream drainage capacity
- lack of maintenance leading to blockage of the system downstream
- high downstream water levels
- a river bursting its banks

Reed et al (2001) propose that external flooding can be managed by:

- Building conventional, engineered flood defences
- Preventing development on the flood plain, allowing the river to flood naturally
- Adapting infrastructure and livelihoods to cope with inundation (e.g. raised pit latrines)
- Managing the catchment upstream to reduce the frequency and severity of flooding

Runoff from external sources is a major cause of flooding in informal settlements, but the management of this runoff cannot be expected to be performed on the site. Over and above the fact that there are significant local drainage problems in these areas, there is usually insufficient space and funding to deal with external flooding as well. Informal settlements thus cannot, and should not, receive runoff from other areas. What is therefore recommended is that, as far as possible, all flows from other areas be diverted away from informal settlements and be dealt with outside of the settlement boundary. This may be a major project on its own, but is seen as essential in solving the drainage issues in these problematic areas.

Eliminating external runoff allows the drainage for a settlement to be dealt with on a site level. An example of this type of action is in the New Rest informal settlement in Cape Town where a major cause of flooding was a stream running through the settlement that carried runoff from a number of adjacent areas. Prior to any upgrading work the stream was diverted around the edge of the settlement by means of a drainage canal, reducing the incidence of flooding and simplifying the drainage design for the area. The focus is thus on settlement-level drainage, but the downstream capacity of the larger stormwater network also has to be considered. It may have to be upgraded to accept increased runoff from an improved drainage system in an upgraded settlement.

The location of a settlement is also a significant factor in external flooding. This is perhaps the most controversial aspect of upgrading; whether a settlement should be allowed to remain on a site that is subject to physical risk. Encroachment into natural watercourses increases risk of flooding both to the resident and to the adjacent communities because of the restriction of the natural flow (UNCHS, 1996). The development of informal settlements along riverbanks is more of a problem than just that of danger to residents and risk of flooding. They cause serious environmental problems and pollution to water resources (Ashton and Bhagwan, 2001). Ashton and Bhagwan state that the general opinion in South Africa is that these settlements cannot remain and any further settlements of this type must be prevented.

The minimum relocation policy of the UCT upgrading methodology seeks to address the dilemma of whether to upgrade settlements in precarious positions. It states that dwellings that are in significant physical risk should, in consultation with residents, be relocated, but as far as possible dwellings should remain where they are, or be relocated to another position within the existing settlement. Fig. 4.4 shows an example of an informal settlement in Brazil that had to be relocated because of its location on a river bank. This settlement, Du Gato, on the banks of the Rio Tiete in Sao Paulo was prone to constant flooding and the municipality insisted that the residents be moved to formal, high-density housing further back on the site (Coelho, pers. comm.). The residents recognised that it was unsafe to live there, so built temporary wooden shelters until the authorities were forced into providing alternative housing. It is acknowledged here, that in extreme cases such as this it is necessary to relocate residents.

Fig.4.4 Favela Du Gato, Sao Paulo: Temporary wooden shacks built on the river bank

Another solution is to canalise the watercourse to prevent the banks bursting and to provide increased cross-sectional area for flood flow. Fig. 4.5 shows a case where this was done in a favela upgrading project in Sao Paulo. This follows the conventional approach to stormwater drainage, removing the runoff as quickly as possible. Canalisation can be dangerous where not designed correctly and is an increasingly unattractive option due to its environmental and aesthetic impacts.

Fig. 4.5 Canalization of a watercourse to increase storm capacity (Source: CDHU, undated:66)

Health risks of flooding

From the table above, it can be seen that the causes of health risks during flooding are mainly associated with the interaction between drainage and the other services. Sanitation is the most important of these and on-site sanitation needs to be designed with correct drainage in mind. Fig. 4.6 shows a stormwater control structure that was constructed by an informal settlement resident because his composting latrine was constructed with inadequate drainage (Stewart Scott, 1998). Sewered systems are less of a problem, but flooding can still cause pipes to break, or cause surcharges through stormwater entering the sewer system. With non-sewered systems, or systems that do not accept greywater, provision in the drainage intervention needs to provide for the constant low flows of household wastewater. Channels that carry greywater can be shaped with a parabolic cross-section or semi-circular invert to accommodate this flow

Fig. 4.6 A concrete bund built by the user of a composting toilet in Elias Motsoaledi township, Johannesburg, in order to keep out stormwater (Source: Stewart Scott, 1998:11)

The second cause of health risk is stagnant water bodies, mainly caused by surface ponding. Moist soil provides an ideal environment for the maturation and spread of worm eggs, and therefore poorly drained and unpaved areas can increase the risk of worm infection (Kolsky, 1998:2). Greywater that stagnates on the surface can contain pathogenic micro-organisms and can promote the spread of schistosomiasis (bilharzia) and malaria in certain areas by serving as a breeding site for disease vectors (Cairncross and Ouano, 1990). Ponding, combined with areas of unhardened, natural soil, also cause inconvenience and its prevention will be dealt with under the next heading. The health problems associated with local site-level drainage problems lead Parkinson (2002) to conclude that:

> *"Investments for smaller-scale infrastructure for drainage at household and community level, combined with health education – so that people understand the effects of poor drainage – may therefore be a more cost-effective means of improving problems associated with poor drainage than investments in large-scale flood alleviation infrastructure"*

This comment highlights the need to deal with some of the drainage issues, particularly those associated with health, at a site, or even household level. It has been shown that there is a strong link between health-related drainage problems and the provision of other services.

Disturbance caused by inundation

Kolsky (1998:1) helps to narrow the problem of drainage in settlements by separating wastewater into five different categories: local runoff, external runoff, ponds, sullage and toilet wastes. It has been shown that external runoff is best dealt with off site and should not be designed for in the local stormwater system. If adequate sanitation is provided with protection against flooding, and if some means of greywater disposal is provided, then toilet wastes and sullage can be separated from the debate. The two remaining drainage problems that contribute to the inconvenience of inundation are then ponding (including saturation of natural, unhardened surfaces) and local runoff not being drained quickly enough (from hardened surfaces, channels and movement routes).

Ponding is a function of:

- the proportion of the site that is natural ground;
- irregularity of the ground surface;
- incorrect design levels;
- misdirected drainage discharge;
- the level of the water table; and
- the lack of grade on a site.

Local runoff not being removed quickly enough is a function of:

- lack of grade on a site;
- insufficient capacity in conventional drainage systems;
- poor design and construction of drainage facilities;
- lack of maintenance; and
- lack of a suitable outlet.

This section has highlighted the need to address eternal runoff outside of the site boundary, and to provide complimentary services to ensure that the health benefits of adequate drainage are achieved. The causes of the remaining problems of rainfall and poor drainage around the dwellings have been laid out above. These are the specific issues that the proposed drainage system must focus on. The next sections will describe two approaches to solving drainage problems and then assess their ability to cater for the specific problems identified above.

4.3 THE CONVENTIONAL APPROACH

Basic philosophy

The conventional approach to drainage design is based on a philosophy of removing stormwater from a site as quickly as possible to a point downstream where it can join a natural watercourse or connect to a larger drainage network (Andoh, 1994; Reed et al, 2001). This essentially means shortcutting the part of the hydrologic cycle that would usually take place on the area taken up by the site. Precipitation as surface runoff is gathered as quickly as possible and disposed of at a convenient location. In addition to speeding up the section of the water cycle from rainfall to discharge, it also concentrates the water to single conduits, increasing both the volume and velocity of runoff.

The reason for doing this is that the problems of standing water and the inconvenience of water on movement routes is eliminated rapidly with little or no disruption to daily activities. Other negative effects such as erosion are reduced if water is channelled to run on impervious surfaces and in pipes. Much of the reason for diverting stormwater into closed conduits stems from the historical use of waterways as means of transporting sewage. This led to the formalisation of the polluted waterways into combined sewers. To reduce health risks and the unpleasant sight and odour of the sewage, these systems were closed and buried. Even today, when many stormwater pipes do not carry sewage, there is often ingress of sewage into the systems, which adds to the health risk of open or natural stormwater courses.

Conventional drainage systems are usually divided into major and minor systems. Minor systems cater for the runoff during normal rainfall and most storms, while the major system caters for flood conditions when the capacity of the minor system is exceeded. Major drainage systems consist of roads and road reserves, banks and floodplains along rivers, and other open spaces that act as retention facilities. The components of the *minor system* are shown in the following flow diagram (Fig. 4.7) and will be discussed below. This is a simplified representation of the process and does not cater for all possibilities.

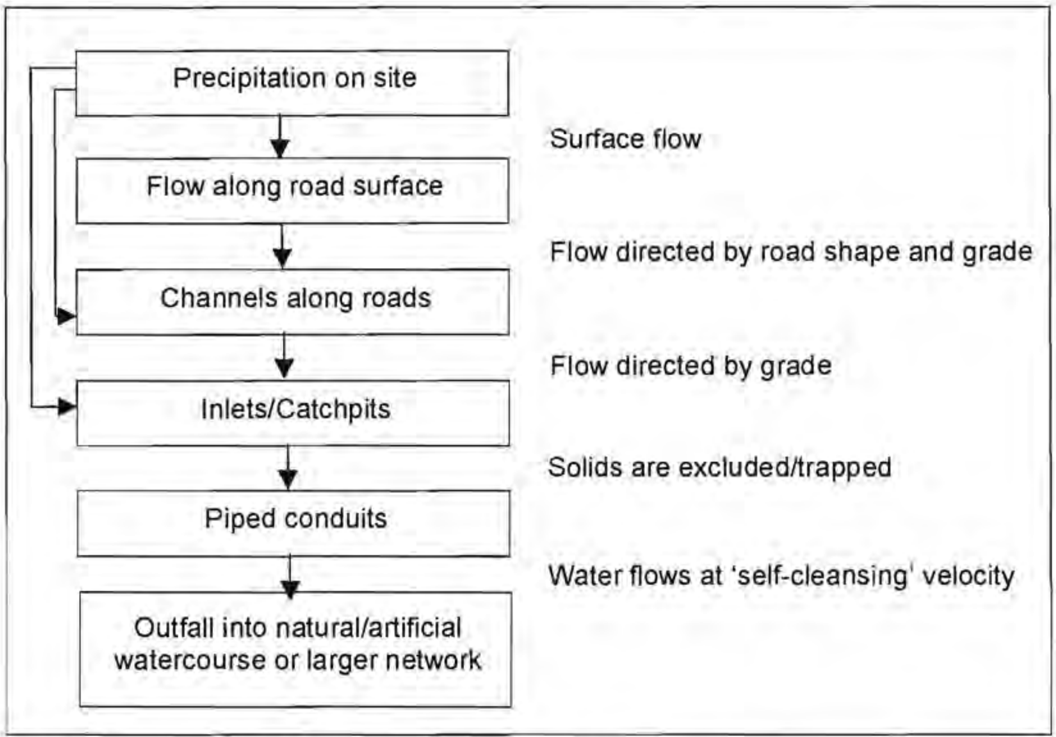

Fig. 4.7 Components and processes of the minor drainage system

Conventional drainage networks

Once precipitation falls onto formal urban settlements, roofs, gutters, pipes and paved areas are all intended to direct water towards road reserves as surface flow. This is often not explicitly designed for, but occurs as a function of the natural grade. Once on the (usually surfaced) roadway, the water is directed to channels on the sides of the road by means of camber or crossfall and the vertical alignment of the road. Kerb inlets and catchpits are provided at varying intervals along the channels depending on the capacity of the channel and the expected volume of runoff. The aim of the inlets and catchpits is to allow the maximum flow of runoff into the piped system, while minimising the entrance of solids. Much of the suspended solids in the runoff settle out in the catchpits (also called gully-pots or gullies).

The piped conduits then transfer the runoff at a 'self cleansing' velocity, which means that solids are kept suspended and blockages are minimised. The stormwater is conveyed as directly as possible to a suitable outfall. Manholes are provided at regular intervals and changes in direction in order to inspect and maintain the drains. In South Africa, conventional drainage systems are largely dominated by roads. They act as the primary means of stormwater collection and dictate the alignment of channels and pipes. Where channels or watercourses flow perpendicular to roadways, culverts are provided and the water is directed into the larger drainage system.

Drainage design parameters

It is not possible to predict how large the greatest flood in an area will be; it is also not economical to construct a system that will cope with the consequences of such a hypothetical flood. For this reason drainage systems are designed on the principle of accommodating all the floods up to a certain size. The size of the maximum flood to be accommodated is determined by trading off the capacity of the network and the associated costs and the costs of damage that is likely to be caused during flooding (CSIR, 1986). The size of a flood is given by the frequency or average period between which floods of the same size or greater occur and is called the return period or recurrence interval. For instance a 1 in 20-year flood will be exceeded, on average, once every 20 years and will be smaller than, for example, a 1 in 50-year flood.

The return period chosen for a certain area depends on the nature of the area and the risks posed by flooding. In South Africa, design flood recurrence for minor systems it is 1-5 years, while the interval for major systems in residential areas is 50 years (CSIR, 2000:6.7). Buildings are not allowed to be erected within the 1:50 year flood line, and the 1:100 year flood line is also required on plans to indicate potential flood hazards. In the UK the typical return period is 1-2 years for most schemes with 5 years being used in vulnerable areas (Butler and Davies, 2000:206). In upgrading projects in Pakistan, the return period is not calculated accurately because of lack of information, but is typically 1:0.5 years (i.e. an average of two storms a year flood the system) (Tayler, pers. com.). This is because of the extreme yearly events during the monsoon season that cannot be accommodated economically. Tayler and Cotton (1993) suggest a return period of one year or less for urban upgrading schemes, but one must bear in mind that they were dealing with the distinctive regional rainfall characteristics of the Indian sub-continent.

Drainage systems are designed to accommodate the peak flow expected at particular points within catchments during the return period. There are various methods to calculate the peak flows through drainage networks. Although the deterministic Rational and SCS methods are still used for minor works, they are largely giving way to the computer modelling of stormwater systems. Packages used include *SWMM* (and the different versions thereof), *Mouse* and *InfoWorks*. The event-based hydrology of the earlier methods has been replaced with continuous hydrodynamic simulation models in order to take account of rainfall history and saturation conditions (Armitage, 2003). The different drainage modelling methods will not be discussed here, but the intention of all of these packages is to model the actual rainfall, runoff and drainage processes as accurately as possible. A common feature of all methods is the need to characterise the catchment area in order to determine the amount of rainfall converted to runoff. The Rational method does this through a runoff coefficient, *C*. Although often treated simply as a function of the permeable to impermeable ratio of the catchment surface, the value of *C* also depends on slope, vegetated area, soil type and storage area. Models like *SWMM* have many more parameters that affect the volume of runoff, but these still need to be entered by the modeller, based on the characteristics of the catchment. Each program has protocols for entering these parameters, or alternatively default values can be used based on the land use in the catchment. Models also incorporate infiltration rates into the calculations using the Green/Ampt or Horton methods. An allowance for surface storage in local depressions is also made. The impacts of all these factors are then modelled dynamically. What is important to note is that the accuracy of the runoff model is determined by the depth of knowledge of a site.

The major drainage network

The use of a return period in the design of stormwater systems shows that the system will not be able to cater for occasional flood events. So what happens to the water when the rainfall exceeds the capacity of the minor system? The water will surcharge or overflow from the minor system into the major system. The first aspect of the major system is the roadway. Water from the road channels will overflow into the full roadway width. Depending on the type of road cross-section, this area should be able to handle a significant volume of storm runoff (see Chapter 5). In some cases the entire road reserve may be designed to carry stormwater.

The second aspect of the major system is the natural freeboard or flood plains from existing, or previously existing watercourses. These areas are usually wider than the natural channel in order to take a greater volume of water for a small increase in water depth. The practice of constructing buildings on floodplains has increased, particularly for informal settlements, and this is where a greatly increased risk of flooding occurs. During normal rainfall conditions, people may not see the function of the floodplain as a part of the major drainage network and may therefore assume that it is safe to live there. If these natural flood-bearing areas have been encroached upon, it is necessary to do one of the following: provide an alternative major drainage route, accommodate greater flow in the existing channel, or to relocate the people.

Adaptations to conventional drainage networks

There have been some adaptations to the basic form of these conventional drainage systems either for cost saving or for use in particular circumstances. The first of these is using the roadway as an open stormwater drain in periods of low flow and not just for major storms. The road-as-drain option is a simple adaptation of the conventional design philosophy to provide a low-cost option for developing countries. It may also be used in areas where there is insufficient rainfall to justify building separate drains. In this system, the side drains or subsurface pipes are replaced by kerbs and channels, central channels, or a dished road surface that is designed to carry water down the centre (Figs. 4.8 to 4.11). Water is kept off the travelled area by the road shape, but these systems do require a minimum grade to transport the stormwater. Once a sufficiently large area has been drained on the road surface, the water is directed into a conventional pipe network or a natural watercourse.

Fig. 4.8 A single-crossfall road with a simple roll-over kerb and side channel

Fig. 4.9 A conventional kerb and channel

Fig. 4.10 Two types of centre channel

Fig. 4.11 A cast in-situ dished road surface

The road-as-drain option offers the following advantages: (Kolsky, 1998:131)

- It provides natural surface water drainage for the housing between roads
- It is easier to sweep a road than to clean a drain
- It can eliminate the need for underground storm drains for substantial areas
- Even where underground drains are built, the roads can act as an effective major drainage system for managing the overflow from heavy storms.

Kolsky notes that the road-as-drain option can only be used for surface water and that greywater and sewage needs to be managed by other means. If sewers are not provided, then it is likely that both greywater and sewage will find its way into the system and the road-as-drain is excluded as an option. In South Africa, the road-as-drain option is widely applied as a cost-saving measure. It is most appropriate on smaller roads with moderate grade and a low return period for drainage design. The road surface material needs to be able to carry the flow without any adverse effect on its structure.

A second adaptation is the addition of retention and detention facilities as a supplement to the major drainage system. Since the application of the conventional design philosophy results in a distortion of the natural hydrograph (see Fig. 4.1), it was necessary to alleviate the flooding that is caused by bottlenecks in the drainage system. Where the minor system cannot handle the increased flow during the largest floods, it is beneficial to have an area that holds water for a period to reduce the flood peak. Retention ponds are designed to hold water temporarily during increased flow, while detention ponds draw water from the stormwater system until it can naturally dissipate. Detention ponds are usually wet most of the year, while retention ponds are usually dry and can therefore serve other purposes. Dry ponds are favoured because maintenance is cheaper than for wet ponds (Arnold, 2003). Retention facilities also often have a dual purpose as sports fields, playgrounds or car parks.

Other adaptations to the conventional systems have been applied in developing countries to save costs. These include silt and litter traps, and the construction of open and covered surface channels, which may be lined or unlined. The decision about whether to provide open or covered drains and lined or unlined channels is based on capital cost considerations as well as the cost and ease of maintenance. A further factor is safety, and in a number of low-income areas, residents place pressure on authorities because they are concerned about children falling into the polluted urban streams. If sanitation is not provided and the runoff is likely to contain faecal pollution it is essential for the stormwater drains to be covered, although in many poor areas in developing countries it is common for sewage to flow into open drains alongside the road. Butler and Davies (2000:464) provide a summary of the advantages of open channels and closed drains, below:

Advantages of open channels:

- They are cheaper to build as they are simpler and shallower than closed pipes
- Blockage with refuse and washed-in sediment can be more easily monitored and cleaned out
- They use available head more efficiently
- Mosquito breeding is easier to control than in closed drains

Advantages of closed drains:

- They do not take up surface space
- The risk of children falling into them is reduced
- Possibility of vehicles damaging drains is reduced
- Sediment entry can be minimised (in principle)

This section has given a brief introduction to the philosophy, design and components of conventional drainage systems. The applicability of conventional drainage in informal settlement upgrading will be discussed in section 4.5.

4.4 AN ALTERNATIVE APPROACH – SUSTAINABLE URBAN DRAINAGE SYSTEMS (SUDS)

Background to SUDS

The conventional method of urban drainage has proved to be effective in many areas, but also has some serious disadvantages. These mainly relate to the fact that the conventional method simply transfers the flooding problem to a point downstream, with serious environmental consequences. As a reaction to this, an alternative design philosophy for urban drainage was introduced, calling for a paradigm shift away from the conventional philosophy of the rapid removal of stormwater towards the replication of natural drainage patterns (Andoh, 1994). This approach was seen as a 'prevention rather than cure' approach to urban flooding.

The design philosophy that was developed in the UK has been called Sustainable Urban Drainage Systems (SUDS). A similar approach is used extensively in other countries like the US and Australia where it is called Best Management Practices (BMPs). BMP is a fairly broad approach dealing with best practices in urban management in order to limit non-point source pollution (Heaney et al, 1999) and is therefore not limited to stormwater drainage. All the SUDS concepts are incorporated in BMPs, however, and only SUDS will be discussed in this chapter.

The word 'sustainable' in the title reveals that the focus of SUDS is largely ecological, and seeks to fulfil the objectives of 'sustainable development' by not having an adverse impact on the environment. The proponents of SUDS contend that urbanisation negatively effects the environment through disrupting the natural hydrologic cycle. Conventional urban drainage does little to address this and may even make the impact worse by increasing flood peaks, introducing pollutants and creating the need for artificial water treatment at the end of the system (Butler and Davies, 2000).

Basic Philosophy

The basic SUDS philosophy is to reproduce the pre-development hydrograph by increasing infiltration and decreasing runoff. The runoff from an area should be no greater than the runoff prior to development and should not result in any downgrading of downstream watercourses or habitat (Martin et al, 2001). The conventional philosophy of removing stormwater as quickly as possible is replaced by a stormwater management system that deliberately slows that path of runoff so that the natural processes of infiltration and evaporation can take place.

The objectives of SUDS are also different from those of conventional drainage. Conventional drainage predominantly serves the single purpose of flood control, while SUDS place an equal emphasis on stormwater quantity (for flood control), quality (for reuse and environmental health) and the amenity value of the drainage areas (Martin et al, 2000:14). The philosophy behind SUDS is neatly captured in the following diagram (Fig. 4.12) of the management train and its three tiers of control.

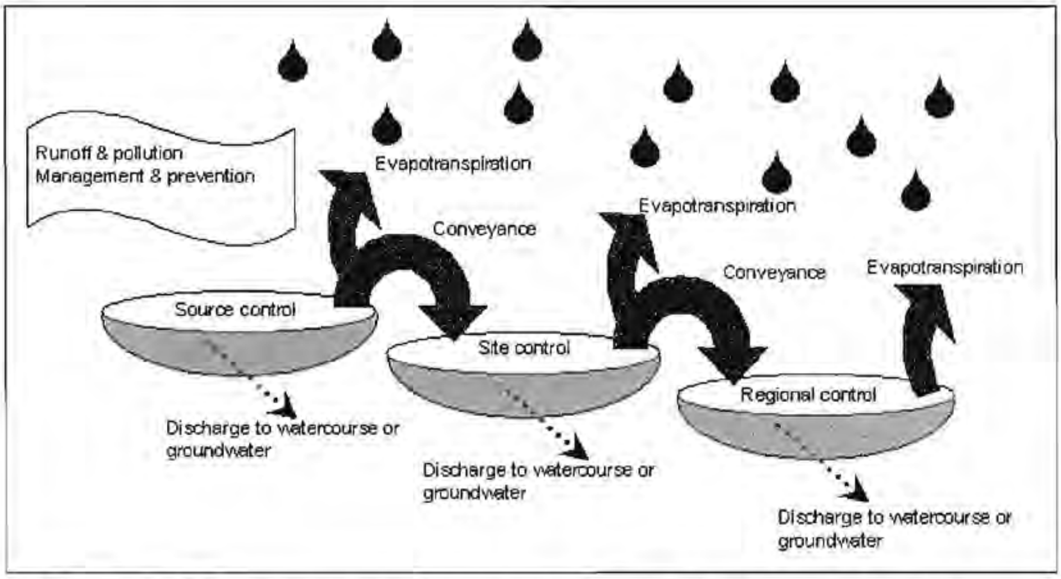

Fig. 4.12 The SUDS Management train (Source: www.ciria.org/suds/suds_management_train)

The first step in the management train is 'source control', which is defined as the storage, treatment and local re-use of rainfall at its point of impact, before it would reach the traditional piped drainage system (Andoh, 1994; Butler and Davies, 2000). The concept of source control is used to enforce the 'polluter pays' principle in which those responsible for pollution or poor drainage management will feel the effects themselves. Promoting infiltration at the point of rainfall also reduces pollution of groundwater because the further runoff is allowed to travel in urban areas, the more polluted it becomes.

The next two steps in the management train, 'site' and 'regional' controls, manage rainfall drained from several sub-catchments and therefore deal with runoff on a catchment scale (Martin et al, 2000). Runoff need not go through all the processes, but it is more advantageous to avoid short-cutting and to deal with the runoff as locally as possible. In all stages, infiltration and evapotranspiration are encouraged. The SUDS philosophy is by no means new, as it is simply a return to natural drainage processes. It does, however, use some innovative technical methods to achieve the desired drainage patterns.

Methods used to achieve sustainable urban drainage

The numerous techniques that make up SUDS are classified by CIRIA (2002) into 5 categories:

- Preventative measures
- Filter strips and swales
- Permeable surfaces and filter drains
- Infiltration devices
- Basins and ponds

These 5 methods are briefly described here, but for a more detailed explanation, consult CIRIA (2002) or Martin et al (2000). All the information in this section was obtained from these two sources.

Preventative measures

These are measures to prevent pollution and minimise excessive runoff at the source of the rainfall. They include minimising paved areas and interconnected hardened surfaces, responsible disposal of liquid wastes, road sweeping and rainwater harvesting and reuse.

Filter strips and swales

Filter strips (Fig. 4.13) are gently sloping vegetated areas that slow down runoff to promote infiltration and reduce erosion, and filter out solid pollutants. They can be incorporated into any vegetated area on a site. Swales (Fig. 4.14) are long, shallow, vegetated channels with a slight grade to transport water. They also to promote infiltration and filtration of pollutants and can contribute to flow attenuation.

Permeable surfaces and filter drains

Permeable surfaces include grassed or gravelled areas, porous paving blocks (Fig. 4.15), grass reinforcing, and paving blocks with spaces between them for infiltration. They are an alternative to hard space that increases runoff. Permeable pavements must be laid on a permeable base and subbase in order to function correctly. The water that flows through the surface either infiltrates into the ground, or is trapped by a waterproof layer and directed to an outlet. Filter drains (Fig. 4.16) are trenches filled with course aggregate to drain roads and other impermeable surfaces in a diffuse manner. The water enters the top or side of the trench and filters down to where it can infiltrate the surrounding soil or be collected in a perforated pipe. They are similar to conventional subsoil drains for roadways, but accept water directly from the surface, rather than draining the surrounding soil. Filter drains can also be constructed along the base of swales, providing extra storage and attenuation.

Infiltration devices

Other infiltration devices not mentioned already include conventional soakaways (or 'French drains') (Fig. 4.17), infiltration trenches and infiltration basins (Fig. 4.18). They work by enhancing the natural capacity of the ground to store and drain water. This is done by providing a more permeable material than the surrounding soil and directing surface runoff or roof water into this facility. It is stored there until it has time to percolate into the surrounding soil. Infiltration trenches are linear soakaways. Infiltration basins attenuate flow by ponding water on the surface. All of these methods depend on the infiltration capacity of the surrounding soil.

Basins and ponds

Basins are storage areas that are free of water during dry weather conditions and include flood plains and detention basins. Ponds contain water most of the year round but are able to take more water when it rains. They include balancing and attenuation ponds, retention ponds and wetlands. The main function of basins and ponds is to attenuate surface flow and reduce the flood peak. They are therefore found at the end of the management train and collect runoff from large areas. They also act as passive treatment systems by promoting sedimentation, absorption by vegetation and biological activity. Wetlands are specifically used for this reason.

Fig. 4.13 A filter strip on a road verge

Fig. 4.14 A broad swale

Fig. 4.15 Porous paving (Source: www.johnstonsmith.co.uk)

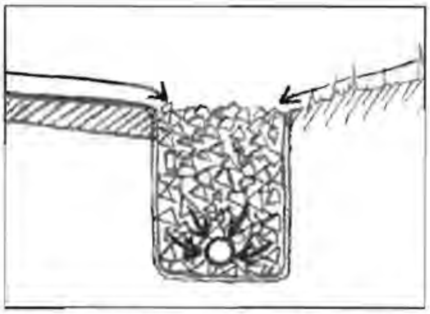

Fig. 4.16 Cross-section of a filter drain

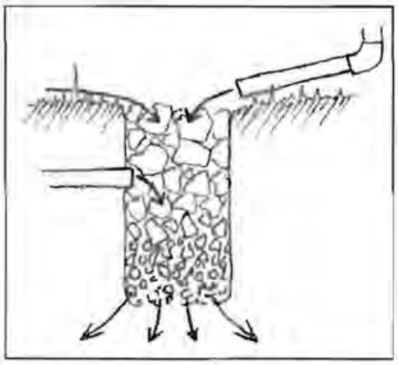

Fig. 4.17 Cross-section of a soakaway

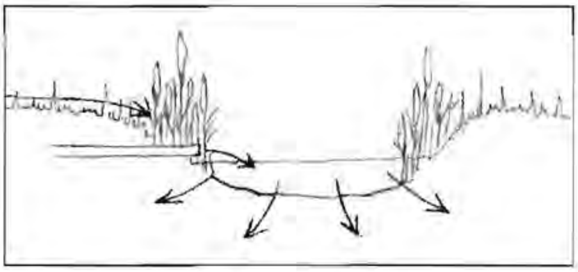

Fig. 4.18 Cross-section of an infiltration basin

Application of SUDS

In a review of the literature on SUDS devices, Pratt (2001) gives a comprehensive account of the application and performance of SUDS. It is noticeable that the review shows literature only from developed countries (including the UK, USA, France, Sweden Japan and Denmark) and focuses mainly on the environmental impact and pollution handling capacity of the SUDS devices. An observation from the review is that most of the devices used take up large amounts of space. SUDS are generally used on the periphery of urban areas and for new developments. It is relatively difficult to retrofit SUDS to existing development.

An example of the integrated application of a number of SUDS devices is in the Dunfermline Eastern Expansion Area in Scotland. Water flowing off the road surface gets channelled through a kerb inlet into a filter drain. From there it seeps into an adjacent swale. The swale also serves as a major drainage route, as any water overtopping the kerb will find its way into the swale. The swale widens towards the downstream end into a detention area before discharging into the natural watercourse. (Environment Agency, 2001)

The question remains as to whether SUDS are suitable for low-income countries. In order to establish this, pilot projects are about to be implemented in Uganda and Vietnam. These countries have been chosen because of the very different socio-cultural conditions. There are various aspects of implementation (space constraints, correct use, sufficient skills, etc.) that need to be tested before SUDS can be applied on a large scale in developing countries (Brian Reed, pers. comm.).

Benefits of SUDS

It is believed that SUDS are more sustainable than conventional drainage methods because they: (Martin et al, 2001:14)

- manage runoff flow rates, reducing the impact of urbanisation on flooding;
- protect or enhance water quality ;
- are sympathetic to the environmental setting and the needs of the local community;
- provide a habitat for wildlife in urban watercourses; and
- encourage natural groundwater recharge (where appropriate).

They do this by:

- dealing with runoff close to where the rain falls;
- managing potential pollution at its source now and in the future; and
- protecting water resources from point pollution (such as accidental spills) and diffuse sources.

A benefit of source control is that infiltration of relatively uncontaminated rainfall at source can help restore base flows in rivers and recharge aquifers (Parkinson, 2002:3). Rainwater harvesting can reduce the peak flows of runoff as well as the benefits of a supplemented water supply. With the introduction of SUDS, stormwater no longer needs to be directed in to foul sewers and the risk of cross connections is reduced (Environment Agency, 2001). A large benefit to areas using combined sewers in the UK is the reduction in flow through treatment plants. The extra capacity created by the omission of stormwater from these pipes enables future development to connect sewers to the existing networks.

The more natural hydrograph that SUDS produce is obviously preferable for managing flooding and enhancing the environment. A natural land feature that is dedicated to water storage and/or transport can handle large fluctuations in water volume, but a pipe cannot. When a pipe is full the water has to find another unplanned route (Environment Agency, 2001). The vegetated areas and standing water bodies that are created also provide amenity value to an area.

Reed et al (2001) point out that SUDS provide theoretical benefits for developing countries as well, but these have yet to be tested. Firstly, construction relies largely on simple earthmoving and can be performed by labour-based methods with minimal equipment and skills. Secondly, no expensive (imported) material is used and in some cases only local in-situ material may be necessary. Finally, the localised nature of the systems promotes the ideas of decentralisation and community management.
There are therefore many elements of SUDS that can be considered for use in the local drainage of informal settlements and their applicability in this context will be discussed in the next section.

4.5 ASSESSMENT OF THE TWO DRAINAGE PHILOSOPHIES IN AN INFORMAL SETTLEMENT CONTEXT

The previous chapters have described the basic principles behind the two dominant approaches to urban drainage, and identified the problems in South African informal settlements that they need to address. The SUDS approach arose as a reaction to the conventional approach and challenges its basic philosophy. The two approaches can thus be seen, to some extent, as competing alternatives, although SUDS often incorporate elements of conventional systems. The conventional system has, up until now, been the only option for improved drainage in developing countries, but now that an alternative exists, an assessment of the merits of each system must be made. This assessment will highlight the positive and negative aspects of both approaches, and in so doing, will begin to define a new approach to local urban drainage.

Discussion on the use of the conventional approach in informal settlements

There are several reasons why conventional drainage methods continue to be used throughout the world. They successfully achieve the objectives of removing stormwater from a site to eliminate inconvenience, damage to property and the health risk created by standing water. The vast amount of research and development in this field has enabled the design of these systems to be both hydraulically and economically efficient.

Conventional drainage systems have also been widely applied in developing countries. In Brazil the general approach to upgrading favelas is to remove the stormwater as quickly as possible from the large areas of 'hardened' surfacing that are typical characteristics of these areas (Abiko, pers. comm.). No attempt is made to attenuate the flow through infiltration. This is done for a number of reasons. Firstly there is the problem of siltation in manholes and pipes when runoff carrying suspended material seeps into pipes. Secondly, surface runoff would cause intense erosion because of the typically steep grades involved. This can threaten the stability of houses and slopes, destroy roadways, and expose manholes and other services. The conventional systems are very effective at eliminating these problems, but result in greater pollution and siltation problems that have to be dealt with in the lower end of the catchment.

When one looks at conventional drainage and its design process in an informal settlement context, however, there are four assumptions made by this approach that may not be valid. These assumptions are that:

- the rapid removal of stormwater is the most effective method of flood control;
- the site has a favourable slope or has been shaped to facilitate runoff towards certain points prior to development;
- roads are the primary drainage elements; and
- pipes are clear of obstructions.

The basis of these four assumptions and their applicability in informal settlements is discussed below:

Rapid removal of stormwater

The SUDS approach is based on the belief that the rapid removal of stormwater is an undesirable solution, transferring the flooding, erosion and pollution problems to a point further downstream. The disruption of the natural hydrologic cycle negatively affects the environment and increases the peak flow that needs to be accommodated by the drainage system. Other problems that have been identified with conventional drainage are that the runoff cannot be utilised, aquifers are not replenished, the systems are expensive and maintenance is difficult (Reed et al, 2001).

Ashton and Bhagwan (2001) conclusively show that informal areas are worse polluters of urban waterways than formal residential areas. Fast-flowing surface water transports solid waste, organic matter and other pollutants into the nearest drainage inlet where they either block the pipes, or get transported to a watercourse or the sea. Conventional drainage does nothing to attenuate the flow of pollutants into receiving waters. This is probably why Ashton and Bhagwan (ibid:15) come to the surprising conclusion that the provision of additional infrastructure to low-cost, high-density urban developments (i.e. informal settlements) does not improve the pollution problem, but may actually result in increased contamination of other area. This may indeed be the case if conventional drainage methods are used. Thus, the rapid removal of stormwater may not have all the intended benefits when applied to informal settlements.

Sites with favourable drainage prior to development

Conventional drainage systems have been developed in first world countries where planning practices are understood and adhered to. These planning practices have drainage as a high priority before any use is made of an area. Sites with unfavourable topography are either filled or graded to achieve a constant slope. This ensures that a general 'natural' drainage to a common collection point will occur as part of a drainage 'master plan' independent of any additional drainage measures implemented. It is very rare that drainage measures are retrofitted to existing developments. It can be done, but is very expensive.

It is for this reason that when physical drainage infrastructure (kerbs, channels, inlets, pipes) are designed, it is assumed that water will naturally find its way from the point of rainfall to a road or other runoff collector via surface flow. The levels of these collectors are designed below the surrounding ground level to facilitate this movement, but between the collector and the point of rainfall the runoff is left to follow whatever surface grade exists.

In informal settlements the situation is very different. The topography of the sites is often highly unfavourable and residents generally make no attempt to shape the ground surface before constructing dwellings. If the site is flat or in a depression, the runoff follows the natural ground slope and ends up pooling in low spots around the site. On steep slopes the water will be disturbed by the construction of dwellings and might follow a new path that could flow into the dwellings. It is very difficult to address these drainage problems with conventional drainage methods because there is no drainage 'master plan'. This is the reason why roll-over upgrading has been popular with engineers. Residents are moved temporarily off a site while the whole area is graded to alleviate drainage problems before they move back again. This, however, is often not a socially acceptable option and is not consistent with the principles of in-situ upgrading outlined in Chapter 1.

In an in-situ upgrade it is not always possible, for space reasons, to construct roads or drainage channels along the lowest area of a site. Even if this were possible, it cannot be assumed that all the runoff for a site will find its way to this low point because of the irregularity of the unshaped ground. Even with conventional drainage systems constructed in-situ in an informal settlement, ponding and flooding will occur. This problem highlights the need to consider runoff closer to its point of generation, and analyse what happens to it between this point of impact and its entry into a drainage network.

Roads as primary drainage elements

Roads are used as primary drainage elements in conventional formal settlements for the following reasons:

- Roads and road reserves make up a large portion of the public space on a site
- Roads are constructed before houses and it is therefore possible to design and construct roads at levels below the existing area and at a grade sufficient for transporting runoff
- It is cheaper to use the carrying and channelling capacity of a road surface than to construct separate channels and pipes
- Roads require their own drainage systems to protect the pavement structure and it do not require major alterations to enable them to carry stormwater from elsewhere as well
- The hardened surfaces on urban roads facilitate the fast removal of runoff
- The space taken up by water on a road does not affect the daily activities of the users for most of the year
- It is easier, for construction and maintenance reasons, to install stormwater pipes in the road reserve and thus it is logical for the inlet to be on the road edge where water can flow directly into the pipes

Most of these reasons make perfect economic sense for greenfield developments where the site is correctly graded, roads are constructed prior to the dwellings and conventional access standards are used with generous road widths and vehicular access to every dwelling. In informal settlements these conditions do not exist; in which case one must ask, "What happens if there are no roads?". If there are no roads, or if roads of minimal width are provided only to certain areas in the settlement, one must consider whether these are sufficient to collect all the runoff. If the site is not graded, then will the stormwater find its way to the roads or access ways that may be provided? Perhaps an alternative primary collection mechanism should be used instead? The constraints that are provided by in-situ upgrading at least force one to think about the role of roads in the management of stormwater.

Obstructions in pipes

Stormwater drains carrying the peak design flow are designed to flow just full (ignoring the slightly greater flow that is possible just below full) (Butler and Davies, 2000:215). The presence of solids and sediment in stormwater pipes is acknowledged, but not explicitly designed for. This is because, theoretically, large solids will be excluded at the inlet and any other solids will be transported by the flow in the pipe (ibid:315). Conventional design includes a 'self-cleansing velocity' at which sedimentation will be prevented and solids will be flushed from the system during a storm event. In developed countries it is also assumed that those solids not flushed out of the system will be removed during regular maintenance.

Kolsky et al (1996) undertook extensive research into the effect of solids on drainage systems in developing countries by investigating the condition of the upgraded drainage system in Indore, India. The conclusions of this research were: (Kolsky, 1998:130)

- Solids deposits in drains are substantial, and have a major impact on drainage capacity
- The theoretical concept of self-cleansing velocities is completely inapplicable to the size-distribution of solids (including construction debris and solid waste) likely to be found in many urban drains of developing countries
- Frequent flooding is inevitable where rainfall intensities are high, the surface does not drain naturally, and solid waste management is poor.

One can therefore not assume that solids are insignificant, or will be removed by flushing or maintenance. The lack of maintenance and solid waste collection is acute in informal settlements and a severe hindrance to the functioning of conventional drainage systems. Fig. 4.19 shows how solid waste can completely block catchpits if street sweeping does not take place. Mr Rod Arnold, Stormwater Manager for the City of Cape Town commented:

> *"Experience has shown that the nature of the areas being served has the greatest impact on required cleaning frequency, with flat, sandy, low-income, or commercial areas requiring far greater maintenance effort. Consequently, providing an underground system to the burgeoning low-cost housing suburbs in the Cape Flats is not sustainable without major injections of operating funds, which of course is not happening" (Arnold, 2003:3-18)*

Either these problems must be tackled concurrently with the installation of a drainage network, or an alternative form of drainage should be used that is less susceptible to blocking by solids.

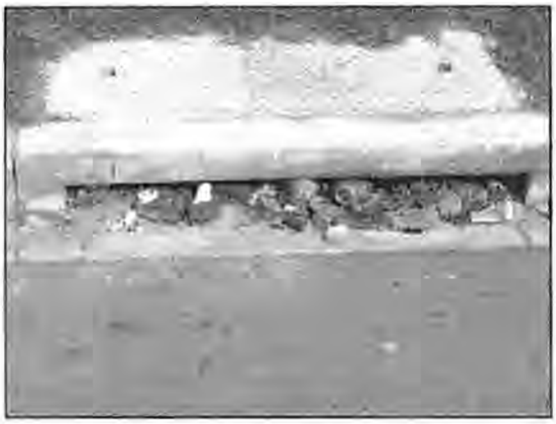

Fig. 4.19 Solid waste and sand blocking a catchpit in the upgraded section of Masiphumelele settlement, Cape Town

The adaptations that have been made to conventional drainage for use in developing countries have been firstly to reduce cost, and secondly to cater or a lack of maintenance. The overall philosophy, however, remains unchanged, and these open channels and road-as-drainage channelling mechanisms merely serve to aid the bigger objective of the rapid removal of stormwater.

Discussion on the use of SUDS in informal settlements

SUDS have challenged the basic philosophy behind conventional drainage systems as an attempt to offer a more sustainable approach. The re-introduction of the natural processes of infiltration and evapotranspiration counteract the negative hydrological consequences of urbanisation. Stormwater is seen as a resource and not as a burden. The concept of source control allows the reuse, as well as reducing runoff, reducing the pollutants in the surface and groundwater and recharging aquifers. Source control focuses at least part of the management process specifically on the scale of the site. A very important concept that is introduced by SUDS is that one does not have to rely on roads for the collection and routing of stormwater. SUDS use various other methods to trap and transport runoff. With SUDS, natural surfaces are preferred over hardened surfaces for dealing with runoff.

SUDS, like conventional drainage systems, were developed in first world countries. Problems are thus expected to occur when the philosophy and technologies are imported into developing countries. These anticipated problems are quite different to those experienced with conventional drainage systems in an informal settlement context.

The first and most restrictive issue is that of space. The effectiveness of SUDS is a function of the land available (Cotton, pers. comm.) Space is at a premium in informal settlements and therefore large open areas are generally not available for the creation of swales, basins, ponds and other infiltration devices. There is already a conflict between the huge demand for settleable land in informal areas and the land required for effective drainage. This is evident by the encroachment of informal settlements into waterways, or the establishment of settlements in areas deliberately designed as retention facilities.

Reed (pers. comm.) feels that the space constraints in developing urban areas are not a problem if the systems are properly designed. In this case the system has to make use of dual-space, dual-use facilities like sports fields acting as detention ponds. If pipes have to be used because of lack of space, at least the primary attenuation will reduce pipe sizes and therefore cost less. Many of the SUDS methods described in the previous section are macro-drainage features and may only need to be implemented outside the settlement boundary. They thus will not infringe on the settleable land.

The second issue is that of cost. Reed et al (2001) have pointed out that most of the SUDS techniques only require earthmoving and local materials. Some of the techniques like porous pavements and slope reinforcement, however, are likely to be more expensive than conventional techniques. This may not be the case in all situations; a study from Sweden showed that porous asphalt on roads and parking areas was 25% cheaper than conventional roads when all construction and drainage costs were taken into account (Pratt, 2001). If extra land is required for SUDS, then the cost of relocating residents must also be considered.

From a technical perspective, Butler and Davies (2000:416) point out some important limitations of source control:

- Limited application in dense urban areas where runoff problems are most severe
- Possible increase of probability of system failure (with the danger of local flooding) but with less severe consequences

- Onerous maintenance and regulation of a large number of facilities
- A possible rise in groundwater levels causing basement flooding or damage to foundations
- Possible contamination of groundwater

Institutional acceptance will be one of the greatest challenges to implementing SUDS in developing countries. The promotion of the system will be targeted at engineers, who are usually responsible for the design of such schemes, but not for the maintenance. It is not clear who should maintain the facilities because the systems are no longer a separate, engineered system, but instead form features that are extensions of the road verge, amenities, or multi-use facilities. Another aspect of implementation is the acceptance by a community of SUDS as an adequate alternative to conventional drainage and an understanding of how the systems work. SUDS are deliberately designed to *not* look like engineering structures and because of this they could be mistreated. Amenity areas in informal settlements do not have high value in these areas (for various reasons, including the great pressure on space for housing) and 'open' spaces are often built upon or used as solid waste dumps. If the purpose behind SUDS is not fully understood, then blockages caused by solid waste or other interference in the systems will counteract any attempt at site drainage.

A significant problem with the SUDS technology is that they rely heavily on the ability of the surrounding soil to accept the infiltration of runoff. This means that these systems will not work in impermeable soils and in areas where the groundwater table is high. Butler and Davies (2000:418) recommend that the base of the soakaway or trench should be at least 1m above the groundwater table at all times of the year. This is not possible in many informal settlements, such as those on the Cape Flats where the water table is at or near the surface for the duration of the rainy season. Other problems may be experienced in drier areas as many SUDS require vegetated areas to promote infiltration, reduce runoff velocity and improve water quality through filtration. Where vegetation does not grow easily, the direction of flow onto ungrassed areas may cause increased erosion.

4.6 MOTIVATION FOR A NEW APPROACH TO LOCAL DRAINAGE

To begin to find solutions to the drainage problems in informal settlements, this thesis has identified the causes of these problems and assessed the strengths and weaknesses of the two dominant methods of stormwater management in the South African context. A new approach is proposed by drawing elements from both of the two approaches, but based on a more site-specific analysis of runoff characteristics.

The first task in solving any drainage problem is to undertake the basic assessment of finding out where the water goes to when it rains. This may seem simplistic, but is often overlooked. Rainfall over an area can fall onto one of three generalised types of surface: roofs, permeable natural surfaces, and hardened impermeable surfaces. Conventionally, the division has been between permeable and impermeable areas, but roof area has been added to this analysis because its position adds another dimension to stormwater control (this will be elaborated on later). The critical issue here is how water is directed onto and disposed of from these areas. The way that the water behaves once it has hit these surfaces is quite different in each case:

Roofs are generally impermeable and should, in most cases, be sloped to facilitate runoff. The rapid runoff from roofs can fall either onto a permeable or impermeable surface area. Containment of this roof water is also an option, but not widely practiced in urban South Africa, and particularly not in informal settlements.

Water falling on *permeable surfaces* can do one of three things. It can infiltrate, it can pond on the surface, or it can run off to the most convenient route (possibly some form of rudimentary channel).

Impermeable surfaces can cause water to collect in a flat or depressed area, or cause it to flow off or along the surface to the lowest local point. From there it can be directed off the site, or it collects and backs up onto the site.

In order to motivate a new, site-specific approach to drainage, it is important to analyse the extent to which each of these processes is likely to take place. This will be done by taking two local case studies of informal settlements and by calculating the ratios of each of these three areas in terms of the total area of the site. A formal low-cost housing development in the same geographical area will also be used to illustrate differences, as well as a case study of an in-situ upgraded informal settlement in Brazil to compare the types of drainage interventions implemented.

New Rest, Cape Town

The informal settlement of New Rest consists of 1318 dwellings and approximately 4500 residents on a site of 18.8 hectares at a gross density of 70 du/ha (Abbott and Douglas, 2002). The average size and density of all informal settlements in the Cape Metropolitan Area very nearly match those of New Rest. It can therefore be said to be a typical settlement for this region. The analysis has been undertaken for the existing situation, as well as for the proposed upgrade in order to assess the impact on runoff that upgrading is likely to have. Upgrading was scheduled to begin in October 2002, but this analysis is based on preparatory engineering designs. A plan of the proposed upgrade is shown in Fig. 4.20. A December 2001 aerial photograph with a GIS overlay of the shack data and areal data was used to obtain the information on existing conditions.

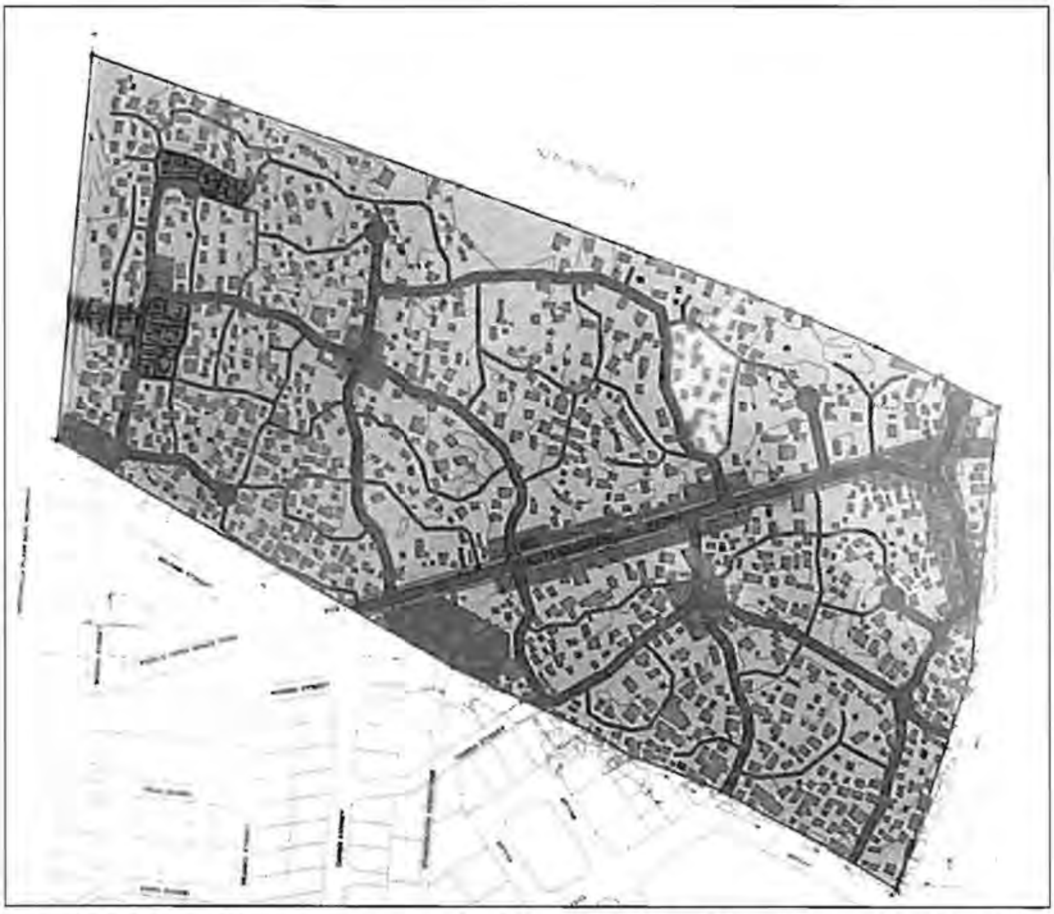

Fig. 4.20 A plan of the proposed upgrade of New Rest, Cape Town (Source: First Plan Town and Regional Planners)

An analysis of the ratios of the surface areas of the site produced the following results:

Table 4.2 Existing conditions in New Rest informal settlement

	Total area (ha)	% of total site
Roofs (dwellings, public buildings and toilets)	5.06	27
Hardened access ways	0	0
Natural ground	13.77	73

Approximate values were then calculated for a post-upgrading situation. In order to approximate a worst-case drainage scenario it was assumed that the planned roads and paths were surfaced and that dwellings were upgraded to an optimistic size and density of 50m² and 70du/ha respectively. This scenario results in the following division in surface area:

Table 4.3 Post-upgrading scenario in New Rest informal settlement

	Total area (ha)	% of total site
Roofs (dwellings and public buildings)	6.35	34
Hardened access ways	2.52	13
Natural ground	9.96	53

It can be seen here that the post-upgrading roof area covers an area similar to that of the existing site. The area of access ways is deliberately kept low because of the upgrading methodology (see Chapter 5 – Access). This can be compared to the area taken up by roads on greenfield developments, as shown in the Delft case study given below. Even after upgrading, the majority of the site is still natural, permeable surface.

Joe Slovo Park, Cape Town

Joe Slovo is a larger, denser settlement in Cape Town and is used again as a case study in Chapter 5. The settlement is far older and more established than New Rest. It is used here because upgrading of the access ways within the settlement has already taken place and thus more accurate calculations of surface areas can be made. The 29 ha site is a very desirable place to live because it is close to the city and therefore the density has been constantly increasing. The values calculated for roof area were based on areas covered by existing shacks, but it is assumed that because of the desirability of the area, the density is likely to remain high after upgrading. In order to obtain accurate values for relative surface areas, an aerial photograph from April 2002 was used (Fig. 4.21). The site is extremely dense at around 209 du/ha and thus problematic to upgrade. Even so, Caleb et al (2000) reported in 2000 that the settlement could be upgraded. Part of the upgrading plans involves de-densifying the area (MacGregor, pers. comm.), but because of its prime location it is likely that the site will remain very dense, even after upgrading.

Fig. 4.21 A close-up aerial photograph of Joe Slovo Park (Photographer: Bruce Sutherland, 2002)

The values below were calculated for the existing informal dwellings using a calculated average density and average dwelling area of 209 du/ha and 25m²/du respectively. The length and width of the existing tracks were taken as given by van Niekerk and Hugo (2002). The remainder of the site was considered to be natural ground.

Table 4.4 Existing conditions in Joe Slovo informal settlement

	Total area (ha)	% of total site
Roofs (dwellings, public buildings and toilets)	15.15	52
Compacted access ways	3.93	14
Natural ground	9.92	34

It can be seen that the roof area takes up considerably more of the site than in New Rest. Access roads are only provided around the cells and not to any of the internal dwellings. It can be seen from the photograph that the main tracks are gravel and not impermeable, but for a post-upgrading scenario it is assumed that they will be hardened. The impermeable surface area is almost the same as that in New Rest and the permeable surface area is significantly less. Like New Rest, the site is extremely flat and experiences severe ponding problems.

Delft South, Cape Town

The area that was analysed is a recent extension to the formal area of Delft South on the Cape Flats. The development is mainly residential, but in addition to the low cost housing, provision has been made for schools, crèches, places of worship and a business area. It can be said to be fairly typical of 'RDP'-type housing projects. For this analysis only the residential section of the development has been considered. The gross residential density of the area is 61 du/ha. The following results were obtained from data supplied by the planners of the scheme, Steyn Larsen City Planners and Architects in Cape Town:

Table 4.5 Existing conditions in Delft South

	Total area (ha)	% of total site
Roofs	19.07	18
Hardened access ways	32.06	31
Natural ground	53.18	51

Tamarutaca, Sao Paulo, Brazil

Tamarutaca is an example of a successful in-situ upgrading project in Sao Paulo, Brazil. The original 600-household settlement consisted of wooden shacks built precariously on the very steep site bordered by surfaced roads and serviced by a single surfaced road through it centre. These were then upgraded to multi-storey block houses on regular plots, all served by surfaced access ways. The change in ratios of surface areas was calculated from pre- and post-upgrading plans obtained for the project (Figs. 4.22 and 4.23), and the results are given below.

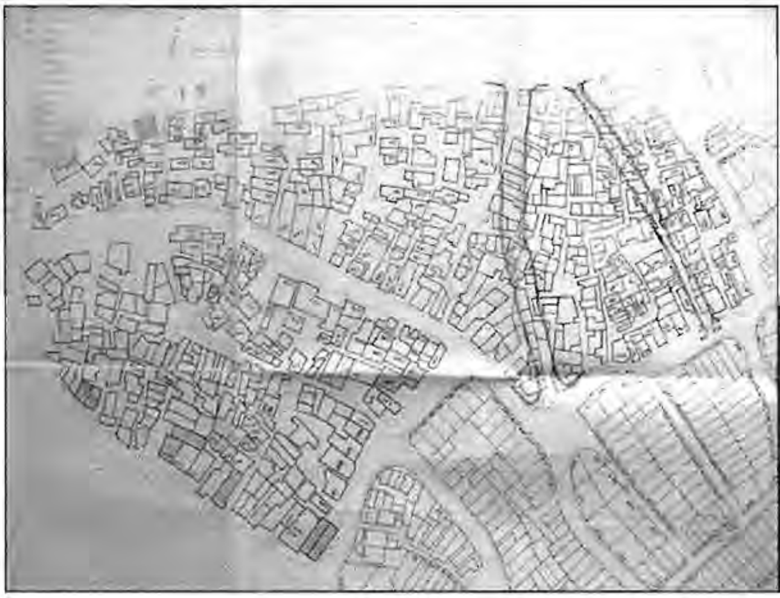

Fig. 4.22 Plan of the settlement before upgrading and a photo of the on-site conditions.

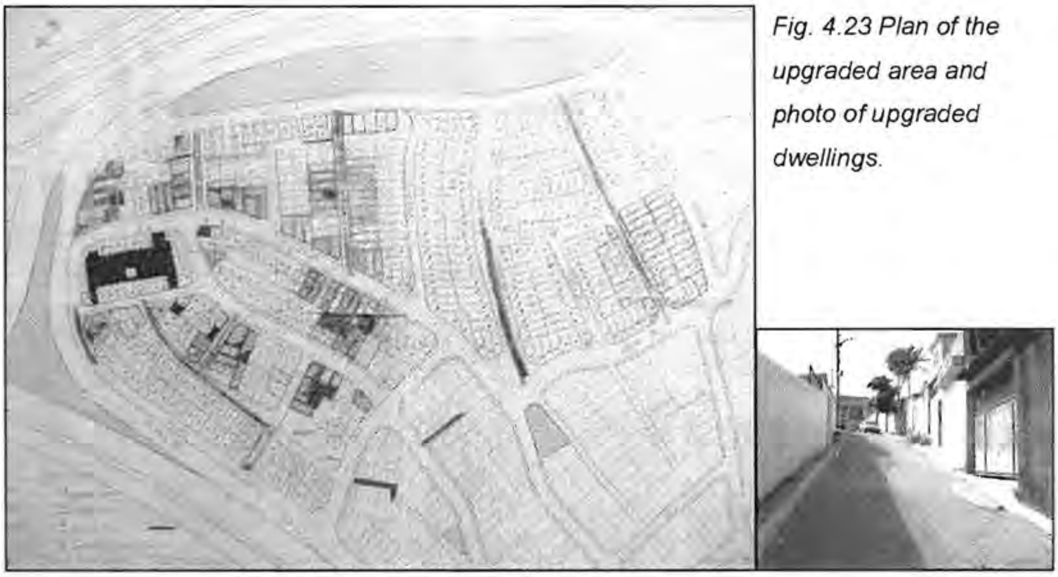

Fig. 4.23 Plan of the upgraded area and photo of upgraded dwellings.

Table 4.6 Pre-upgrading scenario in Tumarutaca

	Total area (ha)	% of total site
Roofs (dwellings and public buildings)	0.94	48
Hardened access ways	0.23	12
Natural ground	0.80	40

Table 4.7 Post-upgrading scenario in Tumarutaca

	Total area (ha)	% of total site
Roofs (dwellings and public buildings)	1.23	63
Hardened access ways (including sidewalks)	0.60	30
Natural ground	0.13	7

The most remarkable feature of this case study is the density of the housing, indicated by the proportion of the site covered by roof area. This is a characteristic of Brazilian informal settlements, and is a result of their tendency to build right up to the plot boundary. The other important feature is the near-complete hardening of the natural ground during upgrading. During a site visit it was observed that nearly all public space had been covered with concrete. The reasons behind this are partly related to the steepness of the site, and partly because of the Brazilian design philosophy. This has a dramatic effect on the hydrograph for the area, rapidly increasing the volume and speed of the runoff.

Significance of the case studies

Table 4.8 Compilation of all the results on settlement areas

	New Rest (existing)	New Rest (post)	Joe Slovo	Delft	Tamaru (pre)	Tamaru (post)
Roof area (%)	27	34	52	18	48	63
Hardened area(%)	0	13	14	31	12	30
Natural area(%)	73	53	34	51	40	7

There are no distinct trends observable in the above data, but there are some general points that can be made:

- In an in-situ upgrading project, the proportion of the site covered by roof area is likely to increase; this is due to both an increase in dwelling size and a more structured layout.
- The more established the settlement, the more dense it is likely to be and again the greater the roof area. Greenfield developments (like Delft) will have a far lower proportion of roof area than informal settlements (existing or upgraded).
- The area of hardened access ways is greatest in the most formal areas. Existing informal settlements may have no hardened area, while the New Rest plan shows that access can be provided without taking up significant areas of the site.
- With the exception of the Brazilian example, it has been shown that despite high housing densities, there is likely to be a significant proportion of the site remaining as natural ground.

The South African case studies only describe the conditions in two informal settlements in the same geographical area, and therefore cannot be used to generalise informal settlements across the country. There are, however, two important conclusions that can be drawn from them. Firstly, it has been shown that in the informal settlements there are significant proportions of roof area and natural ground. This validates the proposal to examine these areas separately; these may be the areas where on-site stormwater management should be focussed. Secondly, although the ratios of the areas after upgrading may differ from one informal settlement to another, they have been shown to be significantly different to Greenfield developments. The consequent difference in behaviour of the runoff is further motivation for treating drainage in upgraded informal settlements differently to that in new housing developments.

4.7 INTERVENTIONS

The Red Book (CSIR, 2000) only provides a basic guideline for drainage interventions in low-income settlements, and does not address stormwater management in upgrading projects. Most municipalities have their own, more specific design guidelines for these circumstances based on previous experience. The City of Cape Town has recently developed its own Draft Policy for the Provision of Stormwater Management Services to Informal Areas (City of Cape Town, 2003). The policy has two levels:

1) *Rudimentary service* for transient settlements, comprising unlined earth channels and pipe culverts under access routes, ground reshaping where possible, infilling, the creation of detention and infiltration areas, and the relocation of dwellings in trapped low areas.

2) *Basic service* for settlements likely to remain in their present form for more than 3 years, comprising as above but including lined channels, and reedbeds to improve runoff quality.

The level of basic service recommended for permanent settlements (2) concurs with the general findings of this chapter. The logic behind the additional interventions proposed in this section follows on from the previous section: if the nature of the settlement and the behaviour of runoff are different to those in areas where conventional drainage is applied, then the intervention should also be different. The issue of local drainage in informal settlements has been redefined here as a function of the ratios of the different types of surfaces. One must now look at how water on each of these surfaces can be managed.

Roof Management

The reason that roof area was calculated separately and not considered part of hardened surface is that roofs are the first point of interception on a site. Because they are impermeable and elevated above ground level they have the potential to effectively manage the rainfall that they intercept with minimal interference to daily activities. It has been shown in the case studies that roof areas could even make up more than 50% of the site area. The quantity of water that falls on these surfaces is significant and could reduce the volume of water that needs to be accommodated in formal drainage systems, as well as reducing and retarding the flood peak. A further advantage of harnessing runoff at this point is that it is relatively uncontaminated and can either be used in the household (for non-potable uses) or discharged into the ground without any threat of polluting groundwater.

SUDS have adopted the idea of roof management in the principle of source control, but the concept of rainwater harvesting has been practiced for many centuries - mainly for the purpose of supplementing water supply. It is only recently, in dense urban areas, that this technique has been seen considered for reducing peak flow (Parkinson, 2002), and rainwater harvesting is receiving renewed attention in the water sector for use in developing countries. In conventional drainage systems, water from roof gutters is channelled via downpipes into the piped stormwater system or into sewers. The water is not used or attenuated, but added to the total runoff from a site.

There are four methods that are proposed for the management of roof runoff, each with different costs involved. These are described below:

No intervention – diffuse runoff: (Fig. 4.24) This is the situation that occurs by default if no action is taken to manage roof runoff. This option is not desirable because it does not alter runoff patterns and can lead to inundation of the dwelling and ponding. Diffuse runoff is, however, better than a single stream of roof runoff that can cause erosion and undermining of dwelling foundations. There are two methods of promoting infiltration while reducing runoff and scouring from diffuse runoff. The first is to construct a narrow concrete apron under the roof eaves so that water splashes onto the surrounding ground. CSIR (2000:6.19) recommends an apron 1.5m wide to avoid the runoff affecting the foundations. The second method is to construct an infiltration trench under the length of the roof overhang and allow the roof runoff to fall directly onto the coarse filter material.

Gutter to soakaway: (Fig. 4.25) For this option a gutter is provided along the roof edge with a downpipe on one side. The downpipe discharges the roof runoff directly into a soakaway constructed next to the dwelling. This soakaway can also be used for greywater discharge.

Gutter and channel: (Fig. 4.26) This option is the same as above, except that an open channel (a gutter pipe, half a sewer pipe or a concrete channel) is provided from the base of the downpipe to a convenient communal discharge point. This discharge point can be a designated pond, a communal soakaway, a larger stormwater channel, or an access route designed to carry surface runoff.

Gutter to tank: (Fig. 4.27) This is the most expensive option, but involves storing the runoff for reuse. Water from a gutter is directed into a private or communal water tank. There are numerous materials and designs that can be used for the tank. The capacity of the tank depends on the size of the dwelling and the rainfall characteristics of the area. From preliminary calculations it has been shown that it may be possible to store water for a 1:1 flood event, but tanks would not be able to store all the roof runoff for many of the heavier storms so an overflow pipe would have to be provided in all cases. The discharge from this overflow also needs to be considered. The quality of the water would most likely not be good enough to drink, but could be used for other household activities.

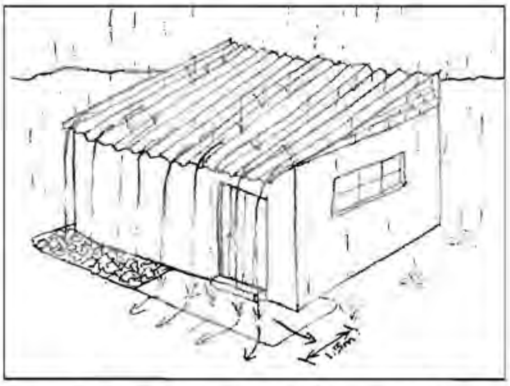

Fig. 4.24 Two options for diffuse runoff

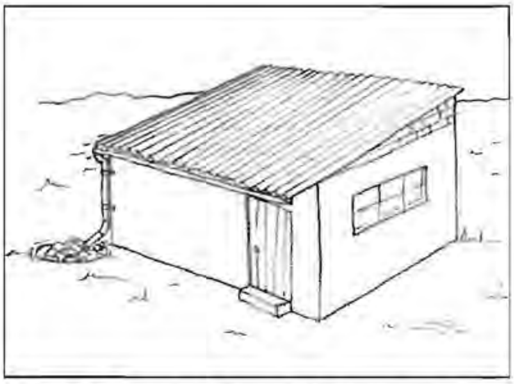

Fig. 4.25 Runoff from gutter to an on-site soakaway

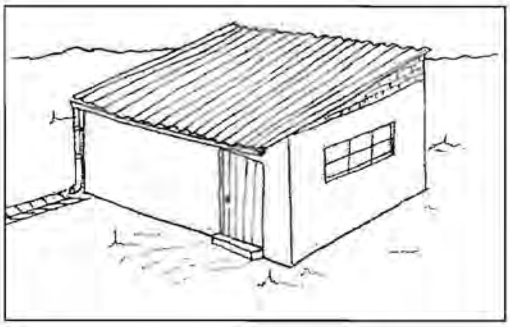

Fig. 4.26 Runoff from a gutter directed off-site via a channel

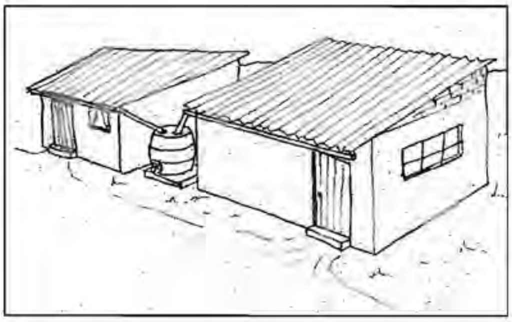

Fig. 4.27 Runoff from gutter to storage tank

Natural permeable surfaces

A note that must be made here is that not all natural surfaces are permeable. Experience has shown that much of the open ground in dense informal settlements is compacted by pedestrian traffic to such a degree that it becomes impermeable. For this reason many stormwater calculations assume these areas behave in the same manner as hardened surfaces. If natural areas are intended to promote infiltration they must be untrafficked, and may need to be broken up in upgraded areas. For permeable surfaces it is important to separate sites into two types: those where the groundwater table is high (say, between 0m and 1m from the surface) and those where it is low (>1m below the surface). These two cases have to be treated differently because infiltration is not effective where the groundwater table is high.

Areas with a low water table

In these areas infiltration should be promoted as far as possible by slowing the velocity of the runoff. The basic philosophy of SUDS applies here with source control being key to reducing runoff. Some of the SUDS techniques may not be appropriate because of space constraints, but many of the devices described earlier can be used. Soakaways should be used extensively on an individual dwelling basis to drain greywater and water from around the dwelling. Residents can easily construct their own soakaways out of cheap, readily-available material like builder's rubble and hessian. Surface ponding can be eliminated by directing runoff into swales alongside access ways and infiltration basins in open areas. Grassing these features helps to promote infiltration. In order to reduce the inconvenience of muddy areas, access routes must remain unsaturated. This can be done by hardening these areas, or by providing unlined channels alongside them. Unsurfaced access ways should not be used as infiltration areas.

Areas with a high water table

This classification includes areas that have impermeable sub-strata or impermeable soils that cause perched water tables and do not allow free drainage into the soil. Most of the informal settlements on the Cape Flats are subject to the problems caused by a high water table. As infiltration is not possible in saturated areas, an alternative method of stormwater management has to be applied. The saturated ground means that almost all of the rainfall is converted to surface runoff. One might think that it is best to remove it as quickly and directly as possible, but this results in higher flood peaks and all the problems that have been encountered with conventional drainage. The primary method of control on these areas should be on-site storage by means of retention and detention facilities. Storage does not reduce the volume of water during a storm, but does significantly reduce the peak flow by increasing the time of concentration. This counteracts the effects of channelling and hardening (Kolsky, 1998).

The main constraint to implementing this type of on-site stormwater management is that there may be insufficient space to do so. It is likely that with the high demand for land, naturally low areas have been built upon or they have been filled up and then built upon. Cairncross and Ouano (1990) warn that low-lying areas are important for storing flood waters until it has time to drain away and should not be built upon. This is reiterated by Kolsky (1998:32), who states that

> *"...land use changes which fill in large open areas that normally pond during rains will...reduce the storage within the system, and thus concentrate runoff discharge into a shorter interval at a higher flow."*

This shows that no matter what the demand for space, communities have to recognise that some areas are required to handle stormwater and reduce the risks of flooding. This designated land need not be one large pond and a trend is to create smaller, more frequent ponds, although Arnold (2003) notes that large regional retention facilities are preferable to numerous small ones from a maintenance point of view. A more efficient method is to construct a multi-functional retention area that can be used for other activities (e.g. a soccer field) during dry periods.

In New Rest, the water table is between 0m and 0.3m from the surface for most of the year and the area has had serious flooding problems. To deal with these problems, the proposed upgrading design directs all surface flow along access ways and earth channels into two small retention ponds situated near the main stormwater outfall (Avenant, pers. comm.). As a result, approximately 25 dwellings have to be relocated, but as flooding is a common occurrence and a very real risk to residents, they recognise the necessity to move. Similar problems have been experienced in Madras, India, where many of the sites-and-services schemes were built in low-lying water detention areas. One method of overcoming this was to dig part of the site deeper into which they could divert the runoff, and then live on the rest of the site (Tayler, pers. comm.).

A second foreseeable problem with on-site storage areas is that standing water bodies in informal areas have been shown to be both health and safety risk (see Feachem et al, 1980). Standing water traps windblown solid waste and can pose a drowning risk to children. These problems can be avoided, but require other services like sanitation and solid waste collection to be functioning correctly on a permanent basis. It is likely that a standing water body in an informal settlement will become polluted to some extent and therefore retention areas or wetlands are favoured over detention areas.

Hardened areas

The hardened areas of a settlement are made up of all formal road pavements and pathways, concrete courtyards, paved parking, and trade and recreation areas. The proportion of this type of surface in a settlement will increase to some extent as a consequence of upgrading. It has traditionally been desirable to have a large proportion of an area hardened because of the advantages that it brings (e.g. no muddy patches) and because of the perception of being more 'urbanised'. It is proposed here that hardened areas, in their traditional form, are undesirable from a drainage perspective because they increase flood peaks and pollution of receiving water bodies. It is likely that residents may disagree, as the inconvenience of muddy ground may seem more significant that the infiltration benefits of natural permeable areas. This is an important question and an area where a trade-off will need to be made.

Although the allocation of a large area of the settlement for access ways is discouraged (see Chapter 5), this does not mean that where access ways are provided they should not form part of the drainage network. On the contrary, it has been shown that the conventional engineering practice of using roads as drains is a very efficient way of channelling stormwater. It is recognised that this system is valid in an informal settlement context, both as part of the major and minor systems. Where access ways are designed to carry stormwater, they must always be constructed below the level of the surrounding ground. Roads above the surrounding land act as catchment dividers, while roads below the surrounding land act as drainage routes (Kolsky, 1998:52). Pavement level is another important factor that is more concerned with drainage and storage capacity than with road design (Cotton and Tayler, 2000:4.136).

On the other hand, a poor case has been made for the use of piped drainage in informal settlements. It has been generally accepted that solids deposits (silt or solid waste) is a huge problem in low-income areas and thus closed systems need extensive maintenance to function as designed. Butler and Davies (2000:458) believe that in most developing countries, conventional piped drainage is not an option, unless it is part of a simplified system.

Thus, an argument is made for increasing the volume of surface flow that can be accommodated on access ways and eliminating the need to provide subsurface drainage. This can be done by providing raised edges along hardened pedestrian paths, as has done in Brazil (see Fig. 5.9), and by providing kerbs on road edges. Kerbs increase road costs significantly, but this may be outweighed by savings on drainage installation and maintenance costs. Road cross-sections and grades required for transporting water are discussed in the next chapter. It is important that the community know that the access ways are intended to carry stormwater. A case where this was not apparent was in Joe Slovo Park. The gravel tracks on the flat site had been constructed with the minimum slope required to carry runoff. After construction of the tracks some of the residents cut perpendicular channels into the road surface to drain their own dwellings (MacGregor, pers. comm.). This action effectively counteracted any drainage function that the tracks could have performed and resulted in neighbouring dwellings being flooded.

If movement routes have to act as drainage routes as well, then they have to be surfaced to protect the pavement structure and to prevent erosion. Hardened surfaces need not be impermeable, however, and SUDS have shown the effective use of porous paving in a number of applications. The cost of these paving materials may be a prohibitive factor, but this is something that requires further investigation. Water ingress into the base layers of a road may be expensive to deal with, but for lightly trafficked areas, such as pedestrian pathways, market areas and play areas, it may not pose a problem. Porous paving can certainly be used to promote infiltration on other hardened surfaces such as market or recreation areas. Permeable pavements are particularly relevant in areas with a low groundwater table.

Other methods

There are other methods of reducing the risks of localised flooding that are not related to the three surface area categories. The first of these is to raise the floor level of the dwelling. A complementary measure to raising the site level is to locate the entrance on the downhill side of the dwelling. Many households already do this as a matter of course. In many of the cities in the Punjab region in Pakistan, it is standard practice to raise house plinth levels a metre or more above the natural ground level (Tayler, undated:3). Raising plinth levels may be an important step in addressing the fact that no land shaping is done before residents settle on a site. This could be implemented as part of the upgrading process, with a precondition for the construction of a house being that a site must be raised to a level that aids drainage. This method may cause problems, however, because of the incremental nature of housing improvements and the raising of levels on one site may worsen the flooding on another. In Joe Slovo Park, sand was provided along roads for residents in the lowest areas to build up their site levels. Unfortunately many of the residents along the roads edges laid claim to the sand and effectively built a barrier around the residential 'blocks', trapping the water inside and flooding the internally located dwellings (van Niekerk and Hugo, 2002).

4.8 DRAINAGE CONCLUSIONS

In the conventional greenfield project cycle, drainage is one of the first issues to be dealt with on a site. The site characteristics dictate which areas of a site are suitable for development and determine the scale of preliminary earthworks. The formal settlement layout is then designed and dwellings are constructed. The process of upgrading informal settlements in-situ would seem to reverse this process, but the problems created through not dealing with stormwater drainage at the outset have been shown to be substantial. The factors that exacerbate the drainage problems in informal settlements include the location of the settlement, the lack of a constant grade on the site, and the vulnerability of the residents to the shocks of flooding. This chapter has aimed to identify the drainage issues that are specific to informal settlements and to illustrate that these present unique engineering and planning problems that require innovative solutions.

Drainage interventions are related to the elimination of risk. There are two levels of drainage risks; major physical risks of flooding and more minor risks related to health hazards from stagnant water and the inconvenience of inundation. The first level is essentially a planning issue and is one of the major determinants of whether a settlement is upgraded or not. There are certain cases where physical risks due to drainage (such as development below the 50-year flood line or on unstable slopes) are so severe that authorities are unlikely to negotiate the upgrading of a settlement. What this chapter has argued is that there are certain measures that can be taken before resorting to relocation. Under a minimum relocation policy, the preferred action would be to control runoff through the various methods described in this chapter, and thus enable dwellings to remain in their current locations. A prerequisite for this option is that external runoff outside of the site boundary is dealt with. This may require diversion of water courses or the upgrading of downstream drainage capacity. Thus local drainage problems can be isolated and dealt with at a site level. The next best option is to rearrange the dwellings within the settlement to eliminate the drainage risks and to provide space for drainage facilities. The need to maintain strategic low-lying areas for stormwater retention has been highlighted in this chapter. If these measures are not possible then the last option is to relocate the settlement.

The second level of risk deals with the more minor issues of health risks and disturbances caused by inundation. The health risks that have been outlined relate very closely to the provision of other infrastructure services, particularly sanitation systems and solid waste collection. If the water supply and sanitation systems are correctly constructed and solid waste collection is regular, then these services have little effect on runoff quality and the malfunctioning of drainage systems. Conversely, the surface drainage measures (such as the road-as-drain option) that have been promoted in this chapter actually *create* health hazards if these associated services are not provided. There are various household-level interventions that have been outlined in this chapter that residents can implement to prevent ponding and stagnation of water, particularly greywater.

The main focus of this chapter has been addressing the risks of inundation caused by ponding and lack of local drainage capacity. These are the risks that are typically addressed by the drainage 'master plan' in a greenfield development. It has been argued that the nature of informal settlements is different to conventional development, thus drainage interventions should be approached differently as well. The physical differences relate mainly to the fact that dwellings are present on the site and should be disturbed as little as possible, and that the proportions of different types of surfaces present in upgraded settlements are unlike those typical of formal developments. The two approaches to urban drainage, the conventional approach and SUDS, were assessed in order to question conventional drainage practices in this context and to find innovative solutions to these considerable challenges. In summary, the main points that have emerged from this analysis are:

- Roll-over upgrading is popular with engineers because drainage problems can be ameliorated or even eliminated, but is often a socially unacceptable solution. It is recognised that it may be necessary in extreme cases.

- A number of the assumptions that are made when designing conventional drainage systems were questioned and shown to be invalid in the context of informal settlements. These include the assumption of a constant grade prior to development, the major role of roads in the drainage network, and the regular maintenance of the drainage systems.

- The concept of source control introduced by SUDS is an important change in thinking about drainage systems, but there are some concerns about the cost and space requirements of some of these drainage systems. Source control is particularly relevant when dealing with site-level drainage control and where roads are not the major drainage elements in a settlement.

- There is a need to characterise informal settlements more closely than is conventionally done for greenfield developments through the various modelling packages. This leads to more individualised drainage interventions that can cater for the existing layout of the settlement, and the avoidance of implementing 'blueprint' drainage solutions in these areas.

- A number of interventions have been proposed as a step towards a new approach to localised, low-cost drainage. These interventions manage runoff between the dwelling roof and the settlement boundary and are based on the proportions of permeable area, impermeable area and roof area in the upgraded settlement. Runoff from roofs and off permeable areas may be significant in upgraded drainage systems.

This chapter has shown that there are two levels to drainage intervention; both of which involve the elimination of risk. Risk is considered first, with technical efficiency in design only coming at a much later stage. At a planning level, the physical risk of flooding may determine whether a settlement is upgraded or relocated. Once the decision to upgrade is taken, then the second level of risk elimination is far more specific and is essentially an engineering problem depending on the characteristics of the site. There are two aspects of settlement-level drainage that this chapter has aimed to highlight. Firstly, engineers are required to treat informal settlements individually and find innovative ways to overcome the additional challenges that an existing settlement pattern present. Secondly, there are a number of measures that households can take to ease the drainage risks around the dwellings. These measures may have a significant effect because of the large proportion of 'private' space that has been shown to exist in this settlement form.

Chapter 5

ACCESS

5.1 INTRODUCTION

Definition of Movement Networks

In previous township developments and upgrading schemes the term 'access' has been interpreted principally as access by road, and has dealt mainly with road layout and design (see DCD, 1983; Department of National Housing, 1994). In some cases pedestrian and cycle paths have also been included. In this section and in the upgrading methodology promoted at UCT (see Chapter 1), the concept of access by road has been replaced with access by movement network.

The concept of movement networks is introduced by the *Guidelines for Human Settlement Planning and Design*, which defines them as "public right-of-way networks, accommodating land-based movement by a range of movement modes." (CSIR, 2000:5.1.1). The guidelines elaborate further that:

> *"the role of a movement network in the daily operation of a settlement system is essentially to enable the convenient, efficient, affordable and safe movement of people, goods and services and, in doing so, satisfy the needs of a variety of users and facilitate the efficient operation of local space economies" (CSIR, 2000:5.1.3).*

The planning philosophy that is outlined in the guideline mentioned above will form the basis of this discussion on access. It lays out a framework for the development of appropriate standards and approaches to movement networks in the upgrading of informal settlements, but does not deal with any specifics. The new framework is also seldom applied in practice. The purpose of this chapter is to deal with the specific issues associated with the planning and design of movement networks in informal settlements. Only local movement networks within the settlement boundary will be dealt with; this excludes higher order movement networks, or aspects of public transport beyond the settlement boundary.

Functions of Movement Networks

The functions and objectives of movement networks are to:

- gain convenient access to, from, and between dwellings;
- access work opportunities, shops and other social services;
- provide access for emergency, maintenance and commercial supply vehicles;
- provide meeting and playing areas for residents and children;
- assist in the drainage of the settlement;
- integrate the settlement into the surrounding urban fabric;
- provide a convenient location for reticulated services (stormwater, water and sewerage pipes, telecommunication cables); and to
- transfer loads from the surface into the surrounding material.

It can be seen that the functions are much broader than those traditionally associated with roads which involve the movement of people and goods from point A to point B. There is a noticeable shift from the purely technical functions of roads to an emphasis on the role that movement networks play in the livelihoods of the residents. Included in this is the fact that the spatial division of settlements invariably created by access ways is very important in defining spatial and social relationships. It is these and other factors that are often not considered in conventional residential street planning and design.

There are, however, crucial technical aspects of movement network design that remain. These include ensuring that all required loads are carried for the entire design life of the access way so that the route is always functional. Another aspect of the technical design includes the integration of other services with road design. Roads are traditionally associated with all the reticulated services, and therefore play an important part in their layout. Stormwater drainage and roads are also conventionally designed together because the concept of 'road-as-drain' is standard practice where surfaced roads are provided. Under this drainage philosophy the movement network plays a large part in the transfer of stormwater, either by surface flow or by the accommodation of stormwater pipes. This thesis has deliberately separated access and drainage. It is felt that movement networks (including roads) should first fulfil their access objective before their role in drainage should be considered; these functions are independent of each other.

Focus of this chapter

This chapter will identify the access requirements for upgraded settlements and review the options available to service these needs. A major part of this chapter will be an analysis of the current minimum standards for access in South Africa because it is these that dictate the affordability of basic services. The argument that is followed here is that current standards are conservative and inappropriately high for the unique conditions that arise in informal settlements. These conditions include the existing layout of tracks and dwellings, low car ownership (and consequently unconventional traffic loading), poor ground conditions, and a premium placed on space. This chapter divides the standards that need to be (re)assessed into two parts: Access Standards and Design Standards.

Access standards, which are discussed in the first half of the chapter, refer to the extent to which different vehicles and services are accommodated in different areas of the settlement. These considerations are expressed through the standards for layout (such as the minimum distance to a certain road type) and minimum road width. This section challenges the perceived necessity for vehicular access to all dwellings and will motivate the proposed reduction in access standards based on in-situ conditions and international case studies. The implications of these proposals for service provision, the accommodation of emergency vehicles, and maintaining the social function of access ways, will then be discussed. From this discussion a number of critical factors for the design of access ways will be identified and a series of recommendations will be made.

Design standards refer to the standards applied to the physical form of the movement networks. The latter half of the chapter examines how the unique loading and conditions in informal settlements may influence the technical design of movement networks. The transfer of loads, and subsequent design life of a road, are often considered by engineers to be the primary design factors, but the fundamental assumptions behind the structural design of roads are hardly ever questioned. This section will assess the standards for access way geometry, the options available for pavement structure and surfacing and finally, the interaction between roads and drainage. This will serve to identify a range of options most appropriate to informal settlement conditions. The chapter will be concluded by a summary of the recommendations for both the access standards and design standards for the upgrading of movement networks in informal settlements.

5.2 ACCESS STANDARDS

Current access standards and practices in South Africa

The Consolidated Municipal Infrastructure Plan states that there is currently no national policy defining the basic level of service for roads in South Africa, but that the Municipal Infrastructure Investment Framework refers to "all-weather access to within 500m of the dwelling" as a basic level (CMIP, 2001:23). This is a very low level of access and would only apply to rural areas. In urban areas the situation is very different.

For current greenfield housing projects in urban areas in South Africa, the accepted norm for access is to have a surfaced road serving every dwelling. According to the old Red Book, the lowest class of road in low-income areas should have a minimum recommended width of 3.4m and a minimum reserve width of 8m (where cables, sewers and stormwater pipes are not required in the reserve) (Department of National Housing, 1994:2.6). This document, which is still the basis of much of the engineering work carried out in South Africa, makes little mention of non-vehicular access ways. Those that are mentioned briefly are pedestrian and cycle tracks alongside roads or unsurfaced 'tertiary ways' in developing communities (ibid, 1994). These access guidelines are clearly aimed at serving the more wealthy areas in the city with high car ownership and make very little, if any, adjustment for low-income areas with low car ownership.

The standards set out in these guidelines are often followed, even though they have subsequently been revised (CSIR, 2000). In an interview, a local engineer stated that in practice, the standard minimum road width used in new developments is a 5.5m carriageway in a 10.5m road reserve (2.5m on either side of the carriageway). Provision is made for private vehicles to access every dwelling and parking for vehicles is provided either on the road edge or on the road shoulder. If private car ownership is low, the standard of vehicular access to every dwelling is maintained, but is motivated on the need to provide access for emergency vehicles.

The formal roadways are also used to accommodate the reticulated services (water supply, sewerage, stormwater, electricity and telecommunications) (Fig. 5.1). These are conventionally laid under, or adjacent to the roadway, or in the road reserve (CSIR, 2000:5.1.12). The reason for this is that it is cheaper to lay these services in straight lines with the minimum number of junctions, and because there is space for construction. The services are also situated in public space so they will not be obstructed and are easy to access for maintenance, especially in emergencies. The wider a road reserve is, the straighter and more cheaply services can be laid. Sewers and stormwater pipes that are laid in straight lines are also easier to clean. With conventional roads it is also possible to provide door-to-door solid waste collection with a large compacting vehicle.

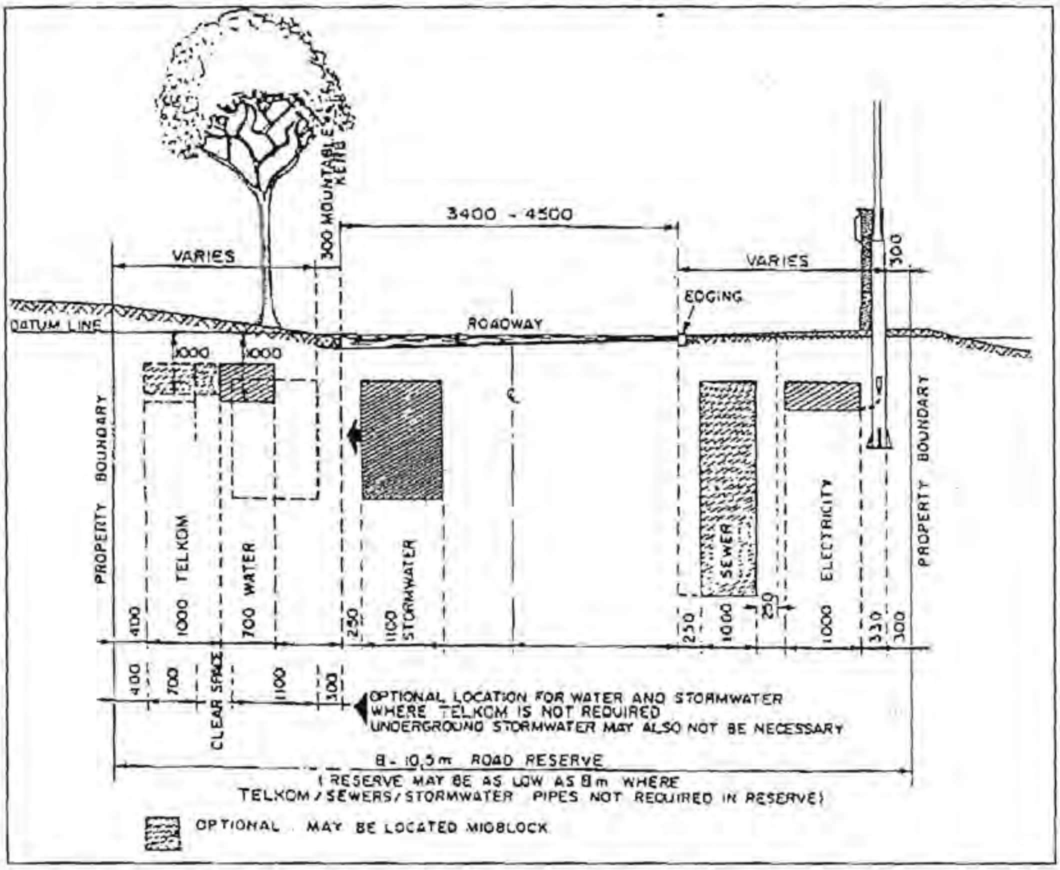

Fig. 5.1 The conventional location of services within a road reserve (Source: Department of National Housing, 1994:15)

The updated Red Book (CSIR, 2000) acknowledges the rigid, conservative standards of the previous guidelines and adopts a more flexible approach. The guideline mentions a need to provide 'adequate' access to all erven within a site, but what constitutes 'adequate' is under debate:

> *"In some instances, due to steep topography or low levels of car ownership (especially in in-situ upgrade developments), 'adequate' is interpreted as being a relatively short public pedestrian pathway leading from a public road"* (CSIR, 2000:5.1.11)

This statement provides the framework for the relaxation of access standards in informal settlement upgrades, but no specific design details are given. The guideline remains vague and hence engineers have no technical basis on which to implement a reduced standard of access. This chapter will examine whether providing only pedestrian access to some dwellings is 'adequate' and will present case studies of instances where this level of access has been successfully implemented.

Existing conditions in informal settlements

The previous chapters have described the dense and irregular nature of informal settlements. Where access differs from the other services is that even in the most basic, unserviced informal settlement an informal network of paths and tracks will exist. These existing movement networks *cannot be ignored*, and should form the starting point of any access upgrading in a settlement. The existing networks are usually complex and, although often not deliberately created, they are highly functional and communicate more about the access needs of the residents than any social assessment or external analysis could. Payne (2001:11) observes that in informal settlements:

> *"...the poor have created their own urban environments which reflect their own social and cultural priorities and are financed by various local methods. Studies of these areas have demonstrated that they are invariably more efficient in using land, more economically dynamic and more socially responsive than areas developed according to official norms."*

An externally imposed layout that ignores the existing roads and pathways will not be the most efficient one. A common indicator of how efficient a movement network is, is the Pedestrian Route Directness (PDR) ratio, which indicates how direct a path between any two points in a settlement is by dividing the distance travelled by the straight line distance (Randall and Baetz, 2001). An informal pathway will almost always provide the most direct route given the existing layout of the dwellings. The route could be made more direct by moving some dwellings, but under a policy of minimum relocation (see Chapter 1), this is not often desirable. Turner (1980) finds that the irregular layout that is a result of a minimum relocation policy is socially and economically preferable to a reorganised regular layout. In many cases residents agree to move their dwellings to improve road or pathway alignment, and this is where some flexibility is introduced.

Rationale for promoting pedestrian access in informal settlements

Possibly the main reason for the typically high standard of access in new South African housing developments is the origin of the engineering design standards. The South African design standards have all been imported and adapted from either British or American design codes (see SAICE, 1976 – a document almost exclusively based on American standards). The relevance of these to low-income developing areas is understandably distant for two reasons. Firstly, these standards have been based on high levels of car ownership and high traffic volumes. Secondly, the concept of designing an access network and implementing services *after* the establishment of dwellings on a site was irrelevant to the development ideology that was current when these guidelines were drafted. Admittedly, in an attempt to save on costs, the imported standards have been adapted for local conditions, but maintain the basic principle of roads catering for predominantly motorised transport.

The reality of the spatial layout in informal settlements is that providing conventional vehicular access is extremely problematic. The rationale for providing a lower level of access, in the form of pedestrian pathways to some dwellings, is based on issues of cost and space (which are inseparable in this context) and low car ownership in low-income areas. The general view in the literature is that it is not necessary to provide full vehicular access in low-income areas (Turner, 1980; Kirke, 1984; Cotton and Franceys, 1991; Payne, 2001).

Providing conventional access to every dwelling is also either prohibitively expensive, or takes up a large proportion of the funds available for upgrading. In a typical greenfield housing project in South Africa, around 50% of the budget for services goes towards road construction. Access to every dwelling, with a standard minimum reserve width, is treated as an absolute and therefore has to be allocated a certain part of the project funds. Where funds are limited (which is in almost all cases), savings are made on the surfacing, pavement layers, kerbing or other infrastructure services. In fact, cost savings are tried everywhere except on the access standards themselves. If lower standards of access were acceptable, then cost savings could be made and a higher quality pavement and surfacing could be provided, resulting in greater durability. Alternatively, more funds could be available for the dwelling construction.

A second aspect of cost is that of the opportunity cost of space in informal settlements. The land, which is often close to city centres and employment, is very valuable and this is reflected in the typically high densities of these settlements. The space required for vehicles is not available and the disruption caused by the creation of wide reserves is inconsistent with the minimum relocation policy of an in-situ upgrade. Cotton and Tayler (2000:4.129) state that a balance must be struck between:

- desirable planning standards which may specify large access widths, thereby taking up valuable land; and
- the need to adopt small plot sizes and high housing density to cope with the demands for shelter.

Caminos and Goethert (1978:274) point out:

> *"...the most frequent cases of land waste are in public streets. Comparative studies of urban areas indicate that, as a rule, the layout of old sections is compact and economical in the use of public land when compared with sections more recently developed".*

One of the major indicators of efficient allocation of space is the percentage of the area used for roads. The percentage of the area used for access in informal settlements can be as little as 5%, while greenfield developments may use as much as 30% (Abbott et al, 2001:86). In the Philippines, some upgrading projects have reduced the area used for movement networks down to 20% (Kirke, 1984:239). Payne (2001) reinforces that as much land must be used for private use (i.e. housing and informal trade) as possible, and this should ideally be above 60% of the total area. "The most effective way of achieving a high proportion of land in private use is to design roads and rights of way to minimise the area of land required" (ibid:9).

In informal settlements it is known that private car ownership is very low. In Cape Town, the figure for private car ownership in black households (unfortunately equated with low-income groups) was 5% in 1994 (Van der Reis and Lombard, 1995), while Behrens (2002) states that only 3% of members of low-income households (earning <R1800/month) have access to private vehicles. Where there is little chance of a family owning a car, it may not be necessary to use valuable space to provide access and parking for vehicles. Visitors may be able to park in main roads or cul-de-sacs a short distance from the dwelling instead.

If a conservative figure of 5% is taken as an estimate of the percentage of residents in informal settlements that own cars, and even if this figure increases to 10% after upgrading, this still means that the number of dwellings that need to be provided with vehicular access is very low. It is accepted that some type of formal access is required in a settlement for emergency vehicles, supply vehicles and taxis. When these considerations, which are discussed below, are taken into account there is almost certain to be access to 10% of the dwellings along these formal routes. Therefore, the number of dwellings supplied with vehicular access will far outnumber the actual number of households that own private vehicles. The roads may not pass by the existing dwellings of car owners, but tenure in informal settlements is sufficiently flexible to facilitate internal movement that will allow car owners to be located along formal roads. This can take place through a process of negotiation. An example of this is in the upgrading of Tamarutaca in Sao Paulo, Brazil. In this project, 60% of the plots had vehicular access. An in-depth social study was performed to determine which residents owned, or intended to own vehicles. These residents were then allocated plots alongside the vehicle routes (Coelho, pers. comm.).

The issue of community expectations of high levels of service is raised in all the sections of this thesis, but is probably the most acute with access. This is because roads are such a visible indicator of improvement in living conditions, and 'blacktop' surfaced roads are seen as the only acceptable standard (Wright, pers. comm.). Political promises also raise these expectations as politicians wish to rally support through providing a high level of service. In most cases the cost of providing conventional surfaced roads is more than residents can afford, and thus funds are sought from other sources. Often pressure is put on authorities to provide these high levels of service as part of the upgrading schemes.

However, the spatial consequence of high levels of access, mentioned above, may be far more real to residents than a higher cost. The construction of more roads at a higher standard means that more people have to relocate or leave the settlement altogether. This was the reason why residents in the New Rest informal settlement in Cape Town agreed to a lower standard of access for the proposed upgrading project (Abbott, pers. comm.). In this case, vehicle access was only provided to within 50m of every dwelling, while the rest of the settlement was serviced by pedestrian pathways (see Fig. 4.20).

International precedent for reduced access standards

The concept of pedestrian access to dwellings is by no means new. Prior to the introduction of the motorcar, villages and even cities were built around pedestrian access. Examples of this are Old Jerusalem in Israel, York in England and Florence in Italy (Fig. 5.2). Even after the advent of the motorcar and the large rise in private vehicle ownership, these planning philosophies of high densities and limited access have been maintained in some places. The preservation of pedestrianised movement networks has not, however, been a feature of Anglophone planning, which abandoned the pedestrian emphasis and developed cities around accommodating the motor vehicle; most noticeably in the United Kingdom and the United States. This is the planning philosophy on which South African planning codes have historically been based.

Fig. 5.2 Examples of pedestrian streets in the centres of the ancient towns of Jerusalem, York and Florence. (Sources: www.travel-notes.com; www.hbp.usm.my/conservation; N Graham)

With the resurgence of the environmental movement and concerns over pollution from motor vehicles, there has been an international shift towards the promotion of public over private transport. This is coupled with huge congestion problems that discourage travel by private vehicle. Hence the idea of "car-free" housing has emerged in Europe. These types of developments are commonplace in Holland and Germany and the first car-free development in the UK was recently built in Slateford, Edinburgh (Islington Council, 2001). This shows that pedestrian access to residential areas is not a sub-standard solution for housing in the developing world and can be acceptable (and even desirable) in the developed world as well. There are even some local examples from Cape Town where space constraints have forced dwellings in higher-income areas to have only pedestrian access (Fig. 5.3). This questions the objections to pedestrian access on safety grounds.

Fig. 5.3 Pedestrian-only access ways in high-income areas of Muizemberg, Simonstown and Clifton, Cape Town

Pedestrian-only access has also been used in low-income situations internationally. Payne (2001:10) describes three recent examples of reduced levels of access used in informal settlement upgrading (see Box 5.1). An example where pedestrian movement was *not* catered for, to the detriment of an upgrading project, was in the settlement of George in Lusaka, Zambia. Only 4 and 6m-wide roads were provided which required a significant number of dwellings to be demolished and allowed high vehicular speeds. A tighter network of pedestrian and cycle tracks was proposed, but never constructed. An assessment of the project concluded that the network of footpaths would have resulted in a safer pedestrian environment and less disruption to the settlement (Schlyter, 1981:34).

Box 5.1 Reduced access standards in upgrading projects (Payne, 2001:10)

"In the Kampung Improvement Programme (KIP) in Indonesia, rights of way as small as two metres were accepted for short distances and three metres was routinely used for local access routes. These included drainage channels of nearly half a metre on each side and a two metre wide carriageway intended for access by pedestrians and those on bicycle or motorbikes. Since these were the most common forms of transport, and the new routes were in any case wider than had existed previously, people considered the new routes perfectly adequate. In many cases, residents placed flowering plants and even small trees in tubs above the drainage channels, so that when moving along the paths, it appeared as though one was in a park, rather than a high-density inner-city housing area.

In another example, planners involved in the upgrading of a Palestinian refugee settlement in East Wehdat, Amman, Jordan, worked with the local community to regularise the existing circulation network, so that services could be installed without removing existing houses or residents. In fact, by readjusting plot boundaries slightly, it was possible to insert a number of additional plots, which were sold to help reduce the unit costs of providing services. Again, the rights of way of access routes was narrow and in some cases less than two metres. However, this created echoes of the traditional Middle Eastern urban environment in which the minimum width of a road was defined as one in which a fully laden camel could pass. Of more practical relevance, however, was the fact that the narrow roads provided maximum areas for their plots and protection from the elements. On a deeper psychological level, the environment reflected traditional cultural values towards the built environment, and was only possible because the planners worked with, rather than for, the community.

A third example is that of the Orangi Pilot Project (OPP) in Karachi, Pakistan. Here, the existing layout of narrow lanes restricted options for the installation of public services. However, this was turned into an advantage in that residents agreed to co-operate in digging trenches and laying pipes along the lanes and maintaining the pathways. As a result of their efforts and the NGO directing the project, over 600,000 people benefited from the provision of sanitation services."

A final example of pedestrian-only access is given by Turner (1980) in a plan for an upgrading project in Manilla, Philippines. Fig. 5.4 shows a block of informal dwellings surrounded by existing, unpaved roads. The area is then formalised by defining plots around existing dwellings with minimum movement of the structures. The spaces between the 'plots' are then filled in with paving to provide pedestrian access to every dwelling, and the peripheral road is paved (Fig. 5.5). The pedestrian paths are highly irregular but maintain a minimum width throughout and vehicles are restricted to the surrounding formal road. Only 14 of the 124 dwellings had to be demolished as a result of this form of upgrading. The final diagram (Fig. 5.6) shows how the areas can be serviced by laying pipes along the narrow pedestrian pathways. Fire hydrants are placed at regular intervals on the edge of the block. A very similar method of 'in-fill' upgrading is used in the favelas of Brazil, with the only difference being that each dwelling is individually serviced as opposed to the communal services shown here. This layout can serve as a viable and practical model for providing formal pedestrian access and accommodating infrastructure and emergency services in informal settlement upgrading projects.

Fig. 5.4 A plan of a block of informal dwellings from Manilla, Philippines (Turner, 1980:259)

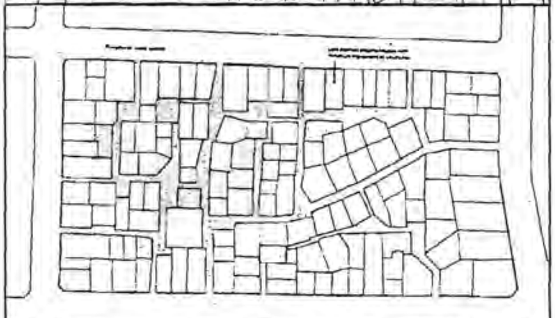

Fig. 5.5 The regularization of the area through establishment of plots and construction of hardened pedestrian access ways (Turner, 1980:260)

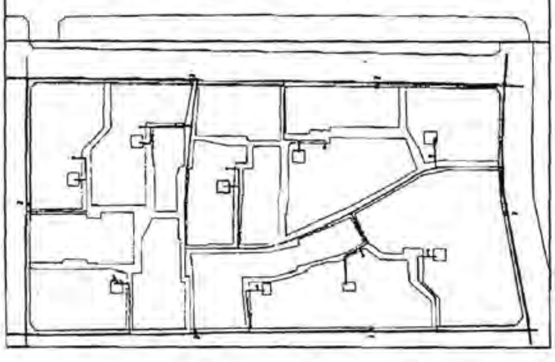

Fig. 5.6 A plan for servicing the area with communal water supply, toilets and fire hydrants (Turner, 1980:263)

5.3 IMPLICATIONS OF A REVISED STANDARD OF ACCESS

The proposal for a movement network based on providing some dwellings pedestrian access only, challenges conventional planning standards. A lower level of access to dwellings has many implications for service delivery and the way systems operate in residential areas. By taking a very practical, empirical view of how these systems function, an estimate of the necessary width and frequency of these access ways will be obtained. The systems that will be discussed are related to the functions of movement networks identified in the introduction to this chapter. These systems are:

- service delivery (infrastructure services, solid waste collection, and goods delivery);
- public transport;
- the social function of the movement network (recreation, socialising, trading, etc.)
- collective utility points; and
- access for emergency services.

Implications for service delivery:

Space for the location and maintenance of services

The location of reticulated services in roadways is both the cheapest and most convenient method of service reticulation. If conventional roads are not constructed within a settlement there are two options for the location of services. They can be placed in private property (Fig. 5.7) or constructed along narrow pedestrian lanes, as in the upgraded favelas of Rio de Janeiro, Brazil (Fig. 5.8) and in Orangi, Pakistan (OPP, 1995).

Fig. 5.7 Favela Vidigal, Rio de Janeiro: An example of services placed perpendicular to the access way in private space. Two sewers and a set of hydraulic steps for stormwater flow have been constructed alongside the pedestrian access to the dwelling on the left. The water supply pipes are just visible on the wall of the dwelling.

Fig. 5.8 Favela Vidigal, Rio de Janeiro: PVC water supply pipes, poorly covered with concrete, are located along the edges of this stepped pedestrian pathway. The larger pipe is a sewer that discharges into a collector sewer running down the centre of the pathway. Sewer manholes are located on the landings of the stairway at ± 20m intervals. Stormwater flows along the surface of the steps.

The location of services on private land gives a more flexible layout, but is problematic. Firstly, more changes in direction are likely to be required to avoid dwellings and secondly, maintenance is difficult. This has been proven in Brazil where the maintenance of 'backyard' sewers failed because authorities could not gain access and in some cases dwellings had been constructed above the manholes (Abiko, pers. comm.). Caminos and Goethert (1978:103) show that narrow backyard service lanes can turn into unsafe rubbish dump areas and decrease the overall quality of the area. Service lanes should therefore, as far possible, run past the front of dwellings and incorporate the services within the travelled way.

The second option of using pedestrian lanes for the location of services has been widely adopted in upgrading programmes because it is the only public space available for services without demolishing dwellings. The question then becomes, how much space is required for the services? This obviously depends on the form that the services take, but if stormwater flow is kept on the surface, and telephone and electricity cables are kept overhead, the only space required is for water pipes, sewers and sewer manholes (if waterborne sewerage is provided). This has effectively been achieved in upgrading projects in Brazil, where concrete pedestrian pathways 1-1.5m wide accommodate surface runoff and conventional sewer pipes, as well as sewer manholes (Figs. 5.8 and 5.9). An innovative system of incorporating water, sewage and stormwater into pedestrian paths has been developed in Rio de Janeiro (Fig. 5.10).

Fig. 5.9 Sete de Setembro, Sao Paulo: An edge has been added to this 1.4m-wide pedestrian pathway to increase its stormwater carrying capacity, while waterborne sewers run down the centre. Note the right-angle bend in the path to fit between existing dwellings.

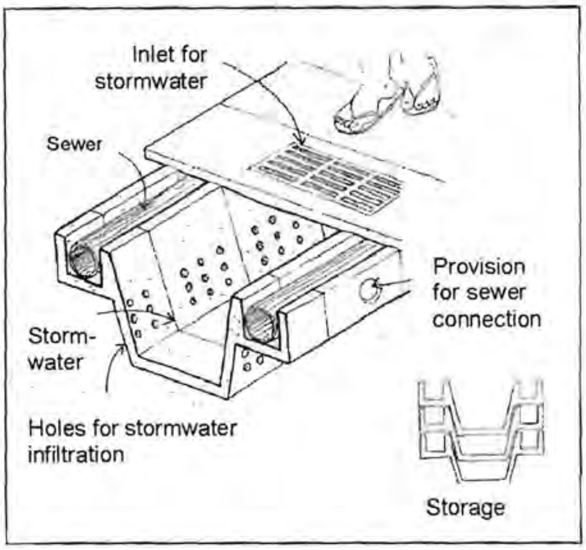

Fig. 5.10 An innovative design for a pre-cast paving block that incorporates water, sewage and stormwater under the travelled way (Source: Duarte et al, 1996).

Conventional widths for water and sewer trenches in South Africa are given as 0.7m and 1.0m respectively and a clear distance of 0.25m between the sewer trench and other services is required (Department of National Housing, 1994). Drainage inlets for manholes are typically 1.5m wide (CSIR, 2000:7.23). To reduce the space required, galvanized steel water pipes can be laid on the surface along the sides of pedestrian lanes, as is fairly common practice in upgrading schemes in Pakistan (Tayler, undated:6). Space for maintenance of these services is obviously important, but where vehicles are not required for this, an access width of 1.5 - 2m should be sufficient.

Placing services in narrow pedestrian access ways means that there will be more changes in direction than if placed in a road reserve. The extra costs caused by added junctions in the reticulation are insignificant when compared to the amount of space saved by not providing wider access ways. Kirke makes the important point that:

> *"the opportunity cost of developable urban land is often the largest single element of project costs. Thus a small percentage reduction in land retained for non-revenue-earning public use (especially circulation space) will represent a far greater cost saving than any which may result from decreases in infrastructure costs..."* (Kirke, 1984:235).

The reduced loading on smaller pedestrian access ways means that savings will also be made on the excavations and cover necessary to protect services. Tayler (undated:5) provides the example from the North-east Lahore Upgrading Project, Pakistan where concrete sewers in narrow lanes were laid with a minimum cover of about 250mm rather than the 900mm required for those under conventional roads.

If upgraded areas are provided with some form of on-site sanitation, access for vacuum tankers will be necessary. These vehicles need not park directly adjacent to the dwelling, but need a fairly direct route for a suction pipe. These pipes can operate over a distance of up to 100m. Alternatively a smaller vehicle like the MAPET could be used, which only requires a pedestrian pathway (see Chapter 2).

Solid waste collection

Conventional access provision enables door-to door or kerbside solid waste collection, even if the means do not exist for it when the project is designed. Door-to door collection may be the ultimate level of service, but there are other waste collection options. There are four general solid waste collections options used in South African residential areas:

1. Community-based refuse collection service
2. Skips/ containers / swivel drums
3. Conventional black bag with municipal collection service once a week.
4. Conventional, wheeled "Otto Bin" with municipal collection service once a week

Community-based collection involves manual collection and deposition at a central collection point for the local authority to remove. The service often includes street sweeping and litter picking. This model has been widely adopted in South Asia (Ali and Cotton, 2001), but mainly on an informal basis. Waste collectors collect waste by hand or in carts. The collection vehicles are usually small or modified to gain access to narrow lanes. This type of collection is not affected by the use of narrow pedestrian access ways, and is probably most suited for a pedestrianised movement network.

The provision of communal skips is common in low-income areas in South Africa. Residents are required to dump their waste in the container which is then collected by a heavy vehicle. Pedestrian lanes will not affect the transport of waste by residents, but the placement of the communal skips is important. The skips need to be placed alongside access roads that are able to accommodate heavy vehicles and should be within 100-150m of every household to encourage residents to use them (Behrens and Watson, 1996; Cotton and Franceys, 1991). It must be noted here that communal skips are not a favourable option. They often overflow or are surrounded by waste, which causes unpleasant odours and nuisance.

The third option refers to door-to-door collection of black rubbish bags, which are placed in compacting trucks or into large trailers. Pedestrian walkways will prevent door-to door collection with conventional waste compacting vehicles, but this option is not excluded by because alternative vehicles can be used. Simple handcarts or bicycle carts can be used to collect and transfer the black bags to a central collection point or to a large compacting vehicle waiting at the nearest access street. In Rio de Janeiro, Brazil, the state waste collection company, COMLURB, has developed specialized "micro-tractor" waste collection vehicles to access the narrow alleyways of the favelas. In addition to this, some settlements have a small compactor on site to reduce the volume of waste (Cavallieri, pers. comm.).

The fourth option of conventional "Otto Bins" is the only one excluded by pedestrian pathways, as these need specialised compacting vehicles to lift and empty the bins. With the exception of this option, there are still a variety of ways that solid waste can be collected from informal areas provided with pedestrian pathways. There is scope for community management of the collection as well as the development of innovative technology.

Access for supplies and building materials

A possible motivation for providing a high standard of access in an informal settlement upgrade is the need for access for supply vehicles. An upgrade is usually associated with a simultaneous improvement in housing. Heavy housing materials need to be delivered to the site and there is only a limited distance that one can expect them to be carried. There are also many informal businesses situated within the settlements and these need to be stocked. It would seem reasonable to expect a supply vehicle to be able to drive right up to the shop entrance.

The question of the proximity of the delivery of building materials is one of convenience, and may not need to be delivered to each individual site. Double handling of building materials increases the cost of construction (Cotton and Franceys, 1991), but is less of an issue when labour intensive construction is used, as is the case in the housing sector in South Africa. Cotton and Tayler (2000:4.129) argue that in predominantly residential areas, access to every dwelling by large vehicles is unnecessary, but access of small vehicles like carts, rickshaws and bicycles is desirable. In South Africa, the use of these sorts of small vehicle is not very common, but there is scope for innovation. Wheelbarrows are widely used for transporting building materials and these must be accommodated, preferably by a hard, all-weather surface. Pedestrian access ways must also be wide enough to carry wide objects like standard-width corrugated iron roof sheeting, furniture, geysers, etc. Where access for delivery vehicles is provided, it should be at least 3.1m wide with minimum radii of 6m on turns (Cotton and Franceys, 1991:51).

The location of shops in an informal settlement is generally very logical and market-determined. One finds that the majority of commercial ventures are already located on the edges of settlements or along the major movement routes to attract the most passing trade. It is these routes that are likely to be upgraded and thus businesses will not have to move in order to obtain deliveries. Those personal services that do not require deliveries and much passing trade (e.g. hairdressers, crèches, etc) can be located elsewhere in the settlement. Again, the flexibility of tenure referred to previously will allow those businesses that are isolated to relocate along the major routes.

Implications for public transport

Residents of informal settlements are low-income earners and private car ownership is low (see Van der Reis and Lombard, 1995; Behrens, 2002). Public transport therefore plays an important role in fulfilling their need for mobility outside of the settlement (Botha and Pienaar, 1995). Public transport is actively promoted over private transport by the national government (RSA, 2000) and the Red Book states that road design should not only accommodate the use of public transport, but actively encourage its use (CSIR, 2000:7.1). The UCT upgrading methodology contends that any upgrading scheme must be accompanied by a simultaneous improvement in the public transport facilities. Public transport is promoted for informal settlement residents for a number of reasons including the high cost of private vehicles and the lack of space for the associated facilities. Public transport infrastructure is beyond the scope of this thesis, but public transport considerations do have a significant effect on the internal movement networks.

The internal access ways must make provision for pedestrian access to the nearest bus stops, taxi ranks and train stations. Planning guidelines recommend the location of railway stations 1.6km apart (with a walking threshold of 800m) and bus stops at 400m apart (CSIR, 2000). The separation of taxi ranks is somewhere between these two values. An upgraded movement network need not provide access for buses and taxis to all points within the settlement. Taxis generally operate between public transport hubs and do not enter into residential areas, but taxis can theoretically pick up passengers along any access route with a suitable width and surface. A survey of South African informal settlements showed that a common feature in all the informal settlements was the close proximity of a large distributor road (Babamia and Mkhacane, 1995) and most informal settlements are located where they are precisely because of access to public transport.

If one assumes the maximum time residents find it acceptable to walk to a public transport facility as 10 minutes at an average walking speed of 1.5 m/s (CSIR, 2000:7.5), this equates to a distance of 900m. This would then be the maximum acceptable distance from any dwelling in a settlement to public transport access, but shorter distances would obviously be preferable. A walking time of 5 minutes, or 450m, is a reasonable estimate of the average acceptable distance to the nearest public transport link. As taxis usually service the entrances to settlements, only the largest of settlements, with dwellings more than 450m form the entrance, will require internal access for taxis or buses to reduce the walking distance. In settlements smaller than this, pedestrian walkways will be sufficient to provide access to public transport facilities.

Implications for the social function of the movement network

The social function of the movement network refers to the spontaneous use of the public space by residents for activities for which they are not necessarily designed. These include space for children to play, meeting places, outdoor cooking areas and space for informal traders. If it is acknowledged that rights of way in informal settlements are not primarily for vehicular movement, but for pedestrian movement and other activities, then it is perhaps these activities that will dictate the dimensions of the access ways and the division of space.

Pedestrian pathways are generally narrow and therefore not suitable for the types of activities described above. There is, however a need to allow these 'non-movement' activities in areas where formal roads are not provided. One method to facilitate this is to have an occasional widening of the pedestrian pathways. For a rough idea of dimensions, a street vendor may require 2-3m of space between the travelled way and the adjacent dwellings and a square space of 10m x 10m may be sufficient for children to play games. It is recommended that these areas be 'hard space' to enable use in wet weather, and that they be formally demarcated in some way to prevent the erection of dwellings on these sites. Frequent, small, open spaces such as street junctions or small squares are more likely to be intensively used and maintained than occasional large parks that require external management (Payne, 2001:9). This means that instead of dedicating large areas as recreation areas and providing access separately, smaller multi-functional areas become a part of the access ways themselves (Figs. 5.11 and 5.12).

Figs. 5.11 and 5.12 Upgraded settlements in Sao Paulo and Rio de Janeiro, Brazil, where hardened spaces were provided as recreation areas with playing equipment, benches, steps and vegetation. In many projects the recreational areas were created before any of the infrastructure was provided to prevent invasion of the open land (Source: M Carrilho Arquitatos, 2000:206 and N Graham).

Implications for access to collective utility points

Collective utility points are those areas in low-income settlements that provide communal facilities for community activities and services that individuals may not be able to afford. These include public telephones, post office boxes, services for public trading areas, communal standpipes and public toilets. The types of service provided will differ in each settlement, depending on location and community needs. Where provided, these services need to be located within walking distance of all dwellings, and also have access for service vehicles. It is common for such utility points to be associated with public transport nodes, or other commercial activity.

Table 5.1 Recommendations for the spacings of collective services (CSIR, 2000)

Utility	Walking Distance	Threshold
Standpipe	100m (2 min)	15-25 dwellings
Postal services	250m (5 min)	200-1000 dwellings
Public telephone	200m (4 min)	(not given)
Solid waste skip	100m (2 min)	100-150 dwellings

From Table 5.1, the only implication that these utilities have for the form of the movement network is that vehicular access should be provided within 100m of every dwelling, provided there is sufficient density. Communal toilet facilities have been disregarded in this thesis (see Chapter 2) and therefore the only public toilet facilities that would be necessary would be those around transport stops or large markets. There is no need to have a threshold distance to a public toilet if they are only intended to serve the public area.

Implications for emergency vehicle access

The issue of fire in informal areas is extremely serious (CSIR, 2000:5.8.3). It is related to access for two reasons; the need for easy access by emergency vehicles and the function of access ways as fire breaks. Numerous reports have been published regarding lives that have been lost and the thousands of people left homeless and destitute during shack fires in South African informal settlements (Bank, 2001; Bekker, 1997; DiMP, 2002). Two case studies of such incidents are provided in Box 5.2. There are a number of reasons why fire is so much more of a risk in informal areas than in other more formal residential areas. Firstly, the dwellings are made out of highly flammable materials with a large proportion of wood. Secondly, the densities are high and fire can spread quickly across the small spaces between dwellings. Thirdly, there is prolific use of paraffin stoves for cooking in areas unserviced by electricity, which pose a major fire hazard.

Fire engines have trouble accessing informal settlements which delays response time and increases the fire risk. An average fire engine has a length of around 6.1m and a width of 2.5m. This requires a fairly wide access way and minimum radii of 12.8m on bends (CSIR, 2000). There are also often problems with gaining access to fire hydrants and obtaining sufficient flow when hydrants are located. The required proximity of a fire vehicle to a fire is dictated by the fire-fighting methods employed. The Red Book distinguishes between two types of fire-fighting vehicles: heavy vehicles with 90m of hose that require wide, surfaced roads, and smaller vehicles carrying 30m of hose that can access gravel tracks. They therefore conclude that where frequent fire hydrants are not provided, every dwelling should be within 30m of a gravel road, or within 90m of a surfaced road. An alternative fire-fighting method is to use water cannons that are mounted on top of fire engines that are capable of shooting 6000l/min over a distance of 70m. These have proved very successful in fighting informal settlement fires (DiMP, 2002).

Box 5.2 Two case studies of informal settlement fires and the proposed solutions

In one of the worst shack fires in South Africa, over 1000 dwellings were destroyed in Duncan Village, East London in July 1996 (Bank, 2001). The fire was started by a paraffin stove and the reasons given for the extent of the destruction were high densities, flammable building materials, lack of water and water pressure, lack of telephone access and lack of access for emergency vehicles (Bekker, 1997). In a second case in Joe Slovo Park informal settlement in Cape Town, a fire destroyed 980 dwellings in November 2000. The fire spread rapidly due to heavy winds and 4500 residents were left homeless. The reasons given for the devastating fire were identical to those given for Duncan Village.

The solutions to the risk of fire in Duncan Village were to de-densify the area and to implement firebreaks at least 3m wide enclosing blocks of approximately 30 dwellings. Above-ground, tamper-proof fire hydrants were also proposed (Bekker, 1997). A similar process of de-densification was implemented following the disaster in Joe Slovo Park. Firebreaks of 8m were constructed in a regular layout around the settlement. These breaks enclosed "fire-proof cells" of between 47 and 267 dwellings with an average of 112 dwellings per block, although the desired ratio was 60 dwellings per block. The resultant net density was 192 du/ha (van Niekerk and Hugo, 2002) (see Fig. 4.21). Tracks of 5m for access for emergency vehicles were created by hardening the centre of the firebreaks. Electricity was installed in the settlement, both to reduce the risk caused by paraffin stoves and as an incentive to encourage relocation. New water mains were provided with 16 hydrants located strategically around the settlement (van Niekerk and Hugo, 2002).

...box continued

A year after the devastating fire of 2000 another fire broke out in the same area of Joe Slovo Park but was confined to a single cell by the firebreaks, significantly reducing the damage potential (MacGregor, pers. comm.). The total number of fires was brought down from 23 in 2000 to 11 in 2001, with the number of dwellings being affected being reduced from 1248 to 182 (van Niekerk and Hugo, 2002).

There are many international examples of upgrading projects where space constraints have forced authorities to accept that emergency vehicles will not be able to access every dwelling. The common view in the literature is that access to every dwelling is not necessary, as long as a minimum distance to a vehicular access point is maintained. Cotton and Franceys (1991:47) state that emergency vehicles do not need access to every dwelling as the pumps on fire engines carry 90m of hose and patients can be carried short distances to ambulances. For a local reference, Dewar and Uytenbogaardt (1995:54) recommend that emergency vehicles should be able to get within 80m of all dwellings in order to be accessible with a fire hose. Kirke (1984:239) recommends that for emergency vehicle considerations every dwelling should be within 75m of a vehicular road. The Red Book acknowledges that it is not necessary to provide emergency vehicle access to every dwelling, but that distances should be short enough for easy stretcher bearing and to be reached by fire hoses (CSIR, 2000:3.10). The recommended distances for fire fighting, stated above, which vary from 75 to 90m, also seem reasonable for stretcher bearing. It must be noted that in many *formal* residential units such as high-rise flats, large complexes or those areas shown in Fig. 5.3, access by ambulance to every unit is not possible and patients have to be carried effective distances of up to 75m.

The Joe Slovo Park case study in Box 5.2 shows that firebreaks are vital and effective in reducing the fire risk in informal settlements. The firebreak function of access roads in informal settlements has a different effect on the design of a movement network. Instead of placing a restriction on the distance between every dwelling and a formal access way, the firebreak function requires a minimum width of access way and a maximum number or density of dwellings within the enclosed blocks. This requirement the may supersede the threshold distances and the width requirement for service provision and thus form the dominant design input for upgraded access ways.

5.4 RECOMMENDATIONS FOR A REVISED STANDARD OF ACCESS

This section has provided motivation for a lower standard of access based on the conditions and needs experienced in informal settlements. This proposed movement network for upgraded settlements fits into a new access hierarchy with pedestrian access ways as its lowest level. The access requirements of the services discussed above will inform the structure of the access hierarchy, the maximum distance to each level of access, and the widths of these access ways. These recommendations for revised design criteria are presented below.

Proposed hierarchy for upgraded settlements

The upgrading projects studied generally have hierarchies that consist of 3 or 4 levels from a two-lane public transport through-route to a narrow pedestrian pathway. A common hierarchy in low-income settlements is to have a main trunk route through the site with smaller distributors accessing the housing clusters or blocks (Cotton and Franceys, 1991:47). Pedestrian walkways then connect each dwelling to the local streets. Such a three level hierarchy was used in a local upgrading project in Besters Camp in Inanda, Durban:

> *"The approach in Besters camp was particularly innovative for South Africa as it did away with vehicular access to every dwelling. The reason for this was that vehicular access was only possible to very few sites; firstly because very few dwellings were located alongside existing movement routes and secondly because the site was extremely steep - some areas with slopes as steep as 1 in 2.5. The access hierarchy consisted of roads (3.6 - 4.5m wide), lanes (2.5m wide) and pedestrian footpaths (1m). The circulation network was essentially a pedestrianised one, although roads and lanes could accommodate vehicles. The roads, lanes or footpaths served as boundaries to residential 'blocks' consisting of 20 to 40 dwellings. Access to sites from roads or lanes was mostly via footpaths (in areas with gentle slopes) or steps (in steeper areas). Within each block, there was no system of private rights of way that provided pedestrian access to each individual site. People moved relatively freely within blocks (as they had done before the upgrading). Some pathways were aligned along site boundaries, whereas in other instances, people would walk across neighbours' sites to get access to their own site."* (van Horen, pers. comm.)

The proposed upgrading plan for Mshayazafe, also in Inanda, built on experiences from Besters Camp and also provided only pedestrian lanes (3m wide) to every plot. The plan (Fig. 5.13) shows four clearly distinct levels in the local hierarchy, a bus route (15m), taxi routes (10m), residential access roads (6m) and the pedestrian lanes.

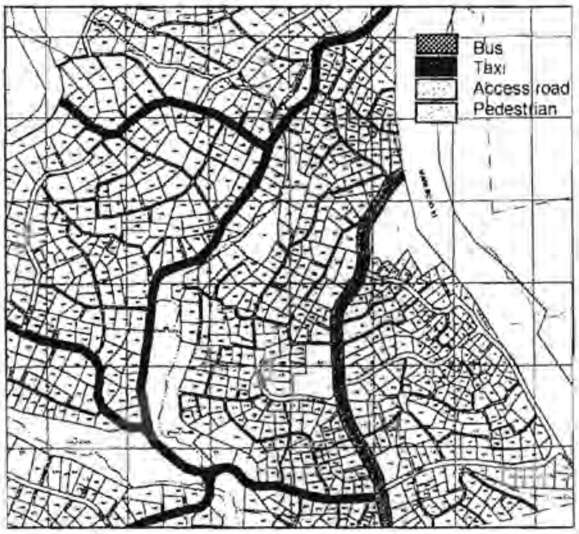

Fig. 5.13 A plan for a proposed upgrade of the Mshayazafe settlement in Inanda, Durban. The bus route is shown in red, the taxi routes in black, the residential access roads in purple, and the pedestrian lanes in blue (Source: Behrens, pers. comm.)

In the case of the upgrading of New Rest informal settlement in Gugulethu, Cape Town, no public transport routes have been planned, as the site is relatively small and the main transport hubs are on the edge of the settlement. A two-level hierarchy for internal access has been used. The vehicular service corridors will be 6m wide and have been provided to within 50m of every dwelling. This means that only ±20% of the dwellings will have vehicular access (Fig. 4.20). The rest of the settlement will be served by 2m-wide pedestrian footways. The pedestrian pathways will not serve every dwelling, but will define blocks of 10 to 40 dwellings.

From this discussion it can be seen that the hierarchy depends on the size of the settlement, but should cater for all the modes of transport used. It is proposed here that for the majority of upgrading schemes a three-tier hierarchy consisting of the following levels should be appropriate:

- **Primary access routes** or through routes catering for buses, taxis and fairly high vehicular use (where necessary)
- **Main access routes** that provide circulation within the settlement and can accommodate emergency vehicles
- **Pedestrian pathways** that enable access to individual dwellings or 'short-cuts' between main access routes

Maximum distances to vehicular access

The need for emergency vehicle access (primarily fire engines) emerges as the critical factor when considering the maximum permissible distance from any dwelling to a point of vehicular access. Other concerns like distance to waste skips, public transport and collective utilities are superseded by this requirement. The literature has shown that a distance of 75m to every dwelling seems acceptable for emergency vehicles. This is compatible with fire fighting techniques as water canons can reach up to 70m and the 90m of hose should be able to traverse 75m between the dwellings. The guideline of 30m provided by CSIR (2000) for smaller fire fighting vehicles is something that should be considered and may result in the pedestrian access ways being designed to accommodate these smaller vehicles for a certain distance into each 'block', to assist with fire fighting.

If Kirke's recommendation of 75m is taken as a reasonable guideline, the existing pathways that are selected for upgrading to main access routes can be a distance of up to 150m apart, provided that formalised pedestrian access is provided in between. In many cases, the existing network is likely to convey much about the access needs and the required distribution of higher-order access ways. In determining the frequency of access roads, the fire break function must be considered, especially if the "fire-proof cell" model used in Joe Slovo Park is applied. In addition to the width of the firebreak, the number of dwellings that are enclosed is also a major fire-mitigating factor. This depends on the dimensions of the 'block' enclosed by the main access routes and the density of the settlement.

A hypothetical block that has side dimensions of 150m results in an area of 2.25ha. It is not proposed that a grid layout be imposed on informal settlements, but this is the easiest method of conceptualising a layout in which each dwelling is less than 75m from a vehicular access road. If one assumes an average density of 73 du/ha for South African informal settlements (Abbott and Douglas, 2002), then each block would contain around 164 dwellings. The density in informal settlements can obviously be much higher than this, up to 300 du/ha, but Abbott and Douglas (ibid) propose that it is not viable to upgrade settlements with densities greater than 120 du/ha. A density of 120 du/ha would mean a 150m x 150m block of 270 dwellings. If a fire broke out within this hypothetical block, between 160 and 270 dwellings could be destroyed. Smaller blocks are preferable as the damage caused by fire is minimised, but this cost must be weighed up against the extra infrastructure cost of more frequent vehicular access ways. It must be remembered that the proposed upgrading process for South Africa includes electricity provision and the replacement of flammable housing material will be replaced by more permanent structures, thereby reducing the fire risk significantly.

Width of vehicular access ways

The next important parameter to determine is the width of the main movement routes through a settlement. The issue of width probably causes the most controversy when conventional design standards are challenged. Behrens and Watson (1996:128) make the important point that road reserve dimensions are a planning output, rather than an input. It is in this light that appropriate access way widths will be evaluated. Under this heading, the widths of the first two levels of the proposed hierarchy will be discussed; those of the public transport routes and the main access routes. Pedestrian pathways are discussed in the next section.

Because any public transport routes that are planned for a settlement will carry the bulk of the vehicular traffic, they will most likely be fairly conventionally designed. These public transport routes require sufficient width for two passing buses and a safe area on the shoulder or adjacent sidewalk for pedestrians. This equates to two lanes of 3.7m each (CSIR, 2000:20) with a space of 1.2m on each side for pedestrians resulting in a road reserve of at least 10m. These dimensions would maintain the firebreak function of the access way and accommodate speeds of around 40-60 km/hr.

The width of the second level of access way in the hierarchy is likely to be more contentious because the primary function of these routes as vehicular streets has been abandoned in favour of pedestrian-dominated, multi-use areas. These movement corridors are intended to be pedestrian rights of way, and therefore vehicles should only be permitted at low speeds. Speed is controlled by short road lengths, narrow widths or traffic-calming measures. For this reason it is not necessary to provide more than a single lane for vehicles. Passing/Parking bays should be provided at no less than 50m spacings (CSIR, 2000:7.20), unless there is some other widened area available. Because pedestrians will be using these routes most of the time, the width should allow a pedestrian to safely pass a moving vehicle at all times. The narrowest lane width recommended by CSIR (ibid:7.20) is 3.1m, which gives 0.25m of clear space on either side of a 2.6m-wide (heavy) vehicle. Cotton and Tayler (2000) recommend a similar 3.5m minimum for light local traffic. For passenger cars with a width of 1.8m (CSIR, 2000:7.4), a 3.1m lane width will only give 0.65m of clear space on either side and a sidewalk may be necessary. The sidewalk may be integrated with the roadway or provided at a different level, but it is recommended that the travelled way be kept as narrow as possible to reduce vehicle speeds. Road reserve width also seriously affects sight distances, and although vehicle speeds are anticipated to be low, this needs be kept in mind.

In the upgrading of the George settlement in Lusaka, Zambia, 6m-wide tarred bus routes were provided and 4m-wide gravel roads were provided to every 25 dwellings for emergency vehicle access (Schlyter, 1981:32). In an assessment of the upgrade, Schlyter concludes that standard of access was good enough to serve the emergency access function, but the roads were too wide and encouraged high vehicle speeds and resulted in unnecessary demolition of dwellings (ibid:34). In Brazil, the lowest level of vehicular access way in upgrading schemes has been observed to be around 3m wide, often with no additional road reserve because of dwellings built right up to the road edge. In some places where existing dwellings restrict space this value has been narrowed even further to around 2.5m (Fig. 5.14). Although access for fire vehicles is considered in design, the risk of fire in these upgraded settlements is far less than in South Africa because of the building materials used.

Fig. 5.14 A very narrow lane in Vidigal, Rio de Janeiro, Brazil

In informal settlements it may be the case that access way width is not dominated by the need to accommodate a large amount of vehicles, or by the need to accommodate services, as it has been shown that only limited space is required. It may rather be dominated by the need to provide firebreaks. The issue of widths required for firebreaks is far more difficult to determine than calculating the widths required for vehicles. There is very little literature regarding standards for firebreaks, and any recommendation has to be made empirically. Environmental conditions play an important part in the spread of fire and flat, windy areas (like the Cape Flats) will require more space for firebreaks than in other areas where the reserve width may be narrower (CSIR, 2000). The case study in Duncan Village (Box 5.2) shows that 3m was specified as the minimum firebreak width. Cotton and Franceys (1991:48) note that an access width of 3m gives an increased protection as a firebreak. The 8m width for the tracks that were implemented in Joe Slovo Park was chosen empirically and based on the conventional minimum road reserve width (Van Niekerk, pers. comm.). This width included the space considered necessary to accommodate services as part of a planned upgrading scheme. It has been shown that these 8m-wide tracks have significantly reduced the spread of fire in the settlement, but one cannot say whether these firebreaks are unnecessarily wide. The wider the track, the less the chance of fire spreading, but this must be balanced against the cost of providing wider reserves and the value of the land required to do so.

The approach to the upgrading of Joe Slovo Park is a very important departure from conventional planning practice. It is the first known case in South Africa where access ways sufficiently wide for vehicles were provided, but with vehicular access not being the primary function of the corridors; in this case the primary function was to act as a firebreak. It is felt that this is the first step in revising access standards according to the most relevant and pressing needs of an area, and not simply designing to accommodate motor vehicles or the uphold the planning status quo.

Width of pedestrian access ways

These routes are meant to exclude vehicular traffic and therefore only need to accommodate services and the free passage of pedestrians and cyclists performing daily activities. The discussion on implications for service delivery showed that a width of 1.5m is generally the minimum required for water and sewer pipes as well as sewer manholes or drainage inlets. For the areas around the dwellings, only the smallest diameter pipes will be required for water and sewerage (where provided). The wider the pathways are made, the fewer junctions that are necessary in these pipe networks and the cheaper the services are to construct.

For daily activities, the most restrictive design case is probably going to be two pedestrians carrying large items passing each other. Alternatively one could consider a cyclist passing a pedestrian carrying a large rubbish bag. Cotton and Franceys, (1991:48) consider 1m (or 1.4m including a side drain) to be the minimum width for pedestrian pathways, but suggest that for two bicycles to pass or two people with bags one requires 1.6m. Kirke (1984:239) quotes a figure of 1.5m for the minimum width. The South African standards for footways and bicycle paths are 1.5-2m and 1.5-3m respectively (CSIR, 2000:7.23). It has been noted that the pedestrian pathways must also accommodate large items of furniture, such as a double bed or a cupboard. If small vehicles like hand carts or "micro-tractors" are used for solid waste collection then these vehicles should also be accommodated.

As with the main access routes, the pedestrian pathways also fulfil the 'social' function of the movement network and thus should be variable in width with regular widening of the hardened area. If pathways are greater than 2m in width there is a likelihood that they will be used by vehicles to gain access to dwellings. This needs to be prevented as heavy vehicles will damage the pathway structure. In addition to the restricted width, vehicles can be excluded from the pathways by means of bollards, kerbs or other barriers. It has been suggested that in denser settlements the pedestrian access ways should be widened to allow small fire vehicles to get within 30m of every dwelling. If this is the case, then the structure must be adapted for this purpose, or all other traffic must be excluded by temporary bollards.

From this discussion it can be seen that a reasonable width for the pedestrian access ways between dwellings and the main access routes in a settlement is between 1.5 and 2.5m. The pathway width should be greater in places to accommodate recreation, socialising and trade.

5.5 DESIGN STANDARDS

Design standards refer to the technical and structural input into access way design. These enable the travelled way to perform the function of transferring loads, resisting erosion and facilitating run-off. In this section, design standards are discussed under four headings: Geometry, Surfacing, Pavement Structure, and Access and Drainage. Similar to the access standards mentioned in the previous chapter, the historical design standards for roads have been based on accommodating the motor car, and may therefore be unnecessarily high for situations of low traffic volumes. When constructing roads, a trade-off is made between the capital cost of construction and the operation and maintenance costs during the design life of a road. Risks are involved with simplified and non-conservative designs, and the costs associated with these risks could be great. Because local authorities are largely responsible for the maintenance risk of a pavement, they are likely to insist on high design standards. The new Red Book acknowledges that:

> *"Standards have also been very conservative, with the use of low-risk pavements with concomitant high construction cost. A shift in emphasis has occurred and service provision to the whole spectrum of development levels now needs to be considered."* (CSIR, 2000:8.1).

This section will therefore investigate the function that access ways in informal settlements have to perform and then assess what design standards are appropriate for this function. The design standards for access ways are based on the function and location of the route, the vehicles expected to use the route, and the design life of the pavement. It has been shown in the previous section that the dominant mode of transport in informal settlements is walking. There is, however, the need to provide access to other types of transport in certain areas of the settlement and the physical elements of these access ways must be able to accommodate these vehicles. In the previous section, a three-tier road hierarchy was proposed, consisting of primary access routes, main access routes, and pedestrian pathways. It is not felt that it is necessary to discuss the design standards for the public transport routes, as the minimum requirements for these roads will generally conform to existing design standards and alternative standards will not be applicable. Only the main access routes and the pedestrian pathways will be dealt with here. They will be discussed separately under each of the four headings because of the very different load conditions and design criteria for the two types of access way.

5.6 GEOMETRY

As road width was considered in the previous section, only vertical and horizontal alignment of the travelled way will be discussed under this heading. Horizontal and vertical alignment are designed to compliment each other to provide improved safety and appearance (Underwood, 1991:223). The Red Book considers road curvature (horizontal alignment) and road gradient (vertical alignment) the aspects of road design that have the greatest impact on the efficiency of service reticulation (water supply, sewers, stormwater, electricity) (CSIR, 2000:5.1.12).

Vertical alignment

The two components of vertical alignment are vertical curvature and gradient. Vertical curvature is concerned with road safety and the aesthetics of a route. For short residential streets with low vehicle speeds the curvature is not a dominant design input. The gradients of access ways are mainly concerned with drainage, but there are also practical considerations like construction methods and the steepest grades that motor vehicles can handle. These issues are discussed for the two types of access way.

Main access routes

Most countries have some type of national guideline specifying the maximum and minimum road gradients. In South Africa the new Red Book provides the most current guidelines. In flat areas a road with sufficient crossfall or camber could have a grade of 0%, but this is not recommended and as a general rule the preferred minimum is 0.5% (CSIR, 2000:18). The minimum gradient for road edge channels (usually coinciding with road gradient) is specified as 0.4% in order to reduce sediment deposition from runoff (ibid:6.15).

For residential streets the maximum recommended gradient is 12% and on sections shorter than 50m the gradient could be increased to 16% (CSIR, 2000:7.17). It is difficult to construct conventional roads with grades >12%. Steeper roads should be constructed out of concrete, brick or interlocking road stones (ibid:7.18). Roads as steep as 20% have been constructed in some residential areas, and as many informal settlements are situated on steep slopes, it may be necessary to increase the maximum slope permitted. If the road gradient causes the velocity of runoff in roadside channels (where provided) to exceed 3m/s then design measures need to be implemented to dissipate energy (ibid:6.15). Gravel surfaces are subject to scour where runoff speeds exceed 0.6 to 1.0m/s, which is achieved at slopes of 7 to 8%.

Pedestrian pathways

Where pedestrian pathways are designed to carry stormwater, the gradient considerations are much the same as for roads. Pedestrian access ways have the advantage that much steeper slopes can be built on because steps can be used. The case study of Bester's Camp, Durban showed that steps were used for areas of the site with slopes as steep as 1 in 2.5 (40%) (van Horen, 2000). The use of steps obviously prohibits disabled access or use by wheeled vehicles and has serious implications for the aged or infirm. However, in adverse physical conditions some compromises have to be made. On the steep slopes of Sao Paulo and Rio de Janeiro, the use of steps in upgrading projects is extensive (Fig. 5.15).

Fig. 5.15 Pedestrian steps in upgraded settlements in Sao Paulo and Rio de Janeiro

Horizontal alignment

The constraints provided by in-situ upgrading and a minimum relocation policy mean that the layout of the access ways is likely to be far more irregular and curved than in new developments. The result of this is that construction costs for the access way and the reticulated services are markedly increased. However, in a pedestrian-dominated environment, it is preferable to minimise long, straight road lengths to reduce vehicle speeds and increase pedestrian safety. Although horizontal alignment has more to do with safety than drainage, the drainage aspects are worth mentioning here as the layout of the movement network affects how they interact with the drainage network. Longer roads should be aligned to follow contours as far as possible (although drainage is not the only reason for doing this). "Streets that cross contours at an angle, or even perpendicularly, pose the most drainage problems"

(CSIR, 2000:8.2). Roads must not be built across or along drainage paths where possible, and if they are then adequate alternative drainage measures need to be constructed (Caimcross and Ouano, 1990).

Main access routes

Safety is particularly important in dense residential areas with multi-use streets. In the context of low-income residential areas, the issue of safety can be simplified because the roads can be designed for reduced vehicle speeds. Lower order roads are usually designed to achieve maximum desired speeds of only 15-40 km (Department of National Housing, 1994:5.14). This reduces the need for skid resistance and stopping sight distance considerations. Safety then becomes a factor of sight distances at intersections, the ability to control speed at intersections (humps, etc.), and the provision of a safe area for pedestrians to pass moving vehicles. In some projects in Brazil, where dwellings are built right up to the plot boundary on the road edge, safety is ensured by constructing narrow roads that only allow slow vehicle speeds and by providing at least 300mm of raised sidewalk alongside the roadway. Roads in favelas are designed for speeds of around 25-30 km/hr (Minas Gerais, 1992). Slow vehicle speeds also mean that radii on curves can be reduced to a minimum and curves can be suited to the existing layout (Fig. 5.16).

Fig. 5.16 Roads in upgrading projects that have had to accommodate the existing settlement layout (Source: M Carrilho Arquitatos, 2000: 139)

Pedestrian pathways

One of the benefits of providing only pedestrian access to some dwellings is that they can be constructed to suit almost any existing layout. Pedestrian paths can be constructed with bends of 90° or sharper (see Fig. 5.9). Where sharp bends are included in the layout of these paths, sufficient width must be provided to manoeuvre large items like furniture. Where pedestrian pathways meet vehicular access routes, sufficient sight distance should be provided to prevent children from running in front of cars. The layout of the pedestrian paths must be directed by the residents, as these routes will often be used to delineate property boundaries.

5.7 SURFACING

The purpose of surfacing on access ways is to protect the underlying structural layers from wear, erosion and damage from infiltration of water. It also facilitates the fast transport of stormwater and provides a hard surface for movement in all weather conditions. Finally, the surfacing should also enable a smooth, comfortable ride for vehicles. Surfacing is closely linked with the structure of a pavement and for lower level access ways the surfacing and structural components of the pavement may be the same material. In lightly trafficked areas the sealing and drainage function of surfacing may be more important than resisting wear or adding to the structural integrity of the pavement.

The current South African guidelines in the Red Book suggest that under certain conditions it is acceptable and even advisable not to surface the lowest level of road (CSIR, 2000). 'Unsurfaced' refers to gravel wearing courses, ferricretes, calcretes, shales, grass or compacted in-situ material. These types of surfaces are favoured over hard surfaces because:

- less capital outlay is required;
- they are quicker and easier to construct;
- road failure can be relatively easily repaired;
- local materials can be used; and
- the roads can easily be upgraded.

The main reason for using a gravel or similar surface is cost. It is often the case that residents' priorities lie in the other services and there is little money left for access way construction. Unsurfaced movement routes can also be used as a temporary measure until more funds are obtained. There are, however, many disadvantages to using unsurfaced access ways. These include:

- frequent maintenance required;
- dust during dry periods;
- slippery, muddy surfaces and potholing during wet periods;
- corrugation if inadequate compaction and low cohesion;
- higher vehicle operating costs;
- erosion by stormwater runoff; and
- siltation and blockages caused in drainage systems.

Although cost effective in terms of capital cost, the chief characteristic that discounts the use of gravel roads in upgrading projects is that they require constant maintenance - a service that cannot be guaranteed in a low-income environment. It has been shown in the previous chapter that movement routes are a very effective means of transferring stormwater in dense urban areas. This is not possible with unsurfaced access ways. Other problems are those of dust, erosion and siltation. There is also a significant stigma placed on gravel roads associating them with an inferior rural solution and it is likely urban community will resist the proposal of a gravel road. It is therefore concluded that, unless they are temporary, or financial constraints exclude all other options, access ways without a hardened surface are unlikely to be appropriate for upgrading in urban areas. The remainder of this section will deal with the 'hardened' surfacing options for the two types of access way.

Surfacing options for main access routes

'Blacktop' surfaces

The conventional surfacing for vehicular access routes in urban South Africa is some kind of flexible 'blacktop' surface. This could be a 'spray and chip', an asphalt, or a slurry type surface. The details of the composition and construction of each of these types of surface can be found in the literature (see CSRA, 1986; SANRAL, 1987; SABITA, 1992; SABITA, 1994; COLAS, 2002), and only the advantages and disadvantages of each type will be discussed here.

Spray and chip surfaces are relatively cheap and easy to apply. They have a 6 to 10 year lifespan in residential areas (Cotton and Tayler, 2000:4.140). They are water resistant and offer no contribution to the structural strength of the pavement. A disadvantage for the use of single seal spray and chip surfaces for multi-use residential access ways is that they produce a very rough surface. The access way is intended to serve as an extension of the living/recreational area and hence a smooth surface is desired. A double seal is better than a single seal, but asphalt or concrete surfaces are most suitable for this purpose because of the smoother surface, but are considerably more expensive. Asphalt is water resistant and adds structural strength to the pavement. Recent guidelines have described methods of hand-laying asphalt in a labour-intensive process for the construction of minor roadways (SABITA, 1994).

Concrete surfaces

Concrete pavements (if constructed properly) are more durable than other types of pavements. They are, however, 30-40% more expensive than conventional 'blacktop' pavements (Wright, pers. comm.). There are concrete roads in Gugulethu, Cape Town, that have lasted 50 years, and although they have lost surface fines and the aggregate is exposed, they still carry loads adequately. A well-constructed concrete pavement is relatively low-maintenance, but once damaged they can be difficult to repair or reinstate (e.g. if service trenches need to be dug after pavement laying) (Cotton and Tayler, 2000:5.154). Concrete pavements are more suitable stormwater carriers than granular pavements or unsurfaced roads because they are not easily eroded or infiltrated and little damage can be done to underlying layers. The joints, however, are always a problem in terms of water ingress, damage to the subbase, loss of support to the slab edges, and finally failure (Wright, pers. comm.).

A large problem in South Africa is the perception of concrete pavements. Communities do not want concrete roads as they view them as substandard and they are seen as the action of the old apartheid authorities – advantaged communities had very few concrete or block paved roads. There is a preconceived idea of what a good road looks like and this includes a 'blacktop' surface (Wright, pers. comm.).

Block and brick paving

Concrete block paving is widely used in South Africa for parking areas, sidewalks, courtyards and private roads, but is not often considered for low cost applications because of its expense. Concrete block paving is 15-20% more expensive than conventional bitumen pavements, (Wright, pers. comm.). Experience from Pakistan has shown that brick pavements have the advantages of being durable, reasonably cheap and can be laid without expensive equipment by unskilled workers (Cotton and Tayler, 2000:4.141). Brick and block pavements are flexible, can adequately act as stormwater drains and can be laid on irregular routes. Brick and block paving is aesthetically attractive and is likely to be more acceptable than concrete access ways.

Where used on main access routes, block paving restricts vehicles to speeds of less than 50km/hr (CSIR, 2000:8.16), but this should be adequate in the residential context of upgraded informal settlements. For adequate riding quality all the blocks should be aligned and deformation of the underlying material should not occur. A major advantage of block paving is that an uneven surface can easily be repaired. Clay bricks are less durable than concrete blocks and although initially cheaper than concrete blocks, they may cost more over the life of the pavement because of maintenance costs.

Surfacing options for pedestrian pathways

The surfacing on pedestrian pathways does not require the same strength and durability as on vehicle access ways. They do, however, need a surface that can withstand erosion and carry stormwater if designed to do so. A further constraint on the surfacing chosen is that the pathways may be difficult to access during construction and the use of heavy vehicles may not be possible. Kirke (1984:239) believes that pedestrian pathways should be well compacted, not subject to flooding and be provided with at least a sealing coat to reduce dust. In South Africa it has previously been felt that the surfacing of narrow footpaths "would normally be in-situ material" (Department of National Housing, 1994:7.14). Even the more recent Red Book (CSIR, 2000:8.45) has a very casual attitude to the upgrading of informal tertiary ways because they do not carry motorised traffic (e.g. it recommends the addition of dust palliative, cutting earth ditches, etc). These paths form a major part of the movement network and should be constructed to the same standard as other movement routes. Because these routes do not need the same structural strength as vehicular access routes there is a lot more flexibility in the type of surfacing chosen; only some of these are described below.

'Blacktop' surfaces

Asphalt can be hand-laid in areas without access for conventional plant (SABITA, 1994). Some form of edging would be required to prevent the pathway from being undermined. The cost of laying asphalt on this type of access way may exclude it as many of the other surfacing options are cheaper. Spray and chip surfaces are not applicable because of the surface texture and plant required.

Concrete surfaces

The benefit of concrete for pedestrian paths is that they can be cast in any layout with very little space requirements for construction. Concrete is widely used in Brazil for pedestrian access ways and narrow lanes (Fig. 5.17). The surface is adequate for multi-functional use, but may be aesthetically undesirable.

Fig. 5.17 A brick-edged, concrete pedestrian pathway being laid in a confined area (Source: M Carrilho Arquitatos, 2000:134)

Block and brick paving

Tayler (pers. comm.) reports many successful cases where brick-on-edge paving was used for narrow access lanes and pedestrian pathways in Pakistan. The same advantages as mentioned for vehicular access ways apply and a much lower-strength brick/block is required. For pedestrian access ways it is less important for pathways that paving blocks all be at the same level and a slightly more uneven surface can be tolerated.

Other surfacing options for pedestrian pathways

Loose coarse aggregate can also be used if a cheap local aggregate can be found. The pathway can serve a dual function as both a pathway and an infiltration trench, provided that it can handle the runoff from the surrounding areas. Edging is required to prevent loss of aggregate.

The cheapest form of surfacing for pedestrian pathways is the stabilization of the in-situ material with either cement, lime or a dust palliative. Dupal® and Labourseal® (COLAS, 2002) are a dust palliative and a single seal respectively that produce cheap, hard 'blacktop' surfaces, but with low strength for very lightly trafficked areas. They require timeous retreatment and maintenance costs increase sharply over time. COLAS (2002) do admit that "there is no cheap, wonder product in the very thin surfacing range".

Alternatively a 75mm layer of soil-cement can be mixed, laid and compacted in a hand operation. This surface has a low strength of 2-3 MPa but will be resistant to pedestrian traffic. The soil-cement pavement will not stand up to the loading of a taxi or a garbage truck and these vehicles have to be prevented from using these pathways. Wright notes that a soil-cement may be acceptable to a community because it is hard enough and channels the water, but may not be acceptable to officials who will be concerned about the durability and maintenance requirements. For the upgrading of the main road through the Thembalethu settlement in George, soil-cement sidewalks were accepted by the PAWC authorities because of the financial savings offered over conventional construction and the opportunity to maximize the use of local labour.

5.8 PAVEMENT STRUCTURE

Design considerations

The structural design of pavements involves the protection of the in-situ material (through the provision, maintenance and possible rehabilitation of pavement layers) to achieve, as cheaply as possible, a chosen level of service over the design period. Factors such as time, traffic, materials, subgrade soils, environmental conditions and economics are taken into consideration (COLTO, 1996). The typical technical, traffic-related considerations for preliminary structural design are: (CSIR, 2000:8.5 edited)

- function of the street;
- level of service of the facility;
- vehicle traffic;
- design bearing capacity;
- street standard (paved/unpaved); and
- expected pedestrian traffic.

For the lower tiers of traditional road classification systems, the low traffic volumes mean that the design considerations are shifted away from loading and capacity concerns. It is acknowledged that, "Non-traffic related factors such as layout planning, stormwater management and drainage, climate, environment, topography and in-situ materials have a major influence on the design of basic access streets" (CSIR, 2000:8.44). The structural design of basic access streets (the Red Book equivalent of main access routes) is aimed at preventing the destructive effects of erosion due to stormwater (Department of National Housing, 1994:7.10).

The two most important on-site factors that affect pavement design are the in-situ soil characteristics and the climatic conditions. South Africa has diverse geology and climatic regions and therefore it is not possible to prescribe a single road structure or surfacing. The soil properties affect the pavement structure and can significantly affect cost if the material can be used for part of the lower pavement. The type of soil will also dictate the behaviour of the material under loading and moisture, as well as the compatibility with stabilizers and other additives. The climatic conditions affect the moisture content of the pavement and the need for protection against the ingress of water. Wet areas are worse affected than dry areas and similarly winter rainfall areas are worse affected than summer rainfall areas. Climates like that of the interior are much easier on road pavements because the rainfall occurs in summer and evaporates after a short period. It is much harsher in the Western and Southern Cape where it stays wet for longer. The lighter the pavement structure (and traffic), the more prone it is to environmental effects (COLTO, 1996). Design standards need to be flexible to accommodate these factors.

Design method for main access routes

The most commonly used structural design method in South Africa is the 'catalogue method' which is derived from the South African Mechanistic Design Method (COLTO, 1996:51). It results in a safe, conservative design for pavements with known high traffic volumes (ibid:96). The TRH 4 catalogue is a set of matrices where each matrix represents a different pavement type. The matrix entries are pavement options that are based on the road category and the anticipated loading on the pavement. These in turn depend on the design strategy (resurfacing and rehabilitation frequency) and design life of the pavement. The road category (A to D) is determined by the road function and its position on the road hierarchy (Table 5.2). The anticipated loading is calculated by relating all the predicted traffic loads for the design life of the road to the equivalent number of single standard 80kN axle loads (E80s). Once the pavement type (granular, bituminous, concrete or waterbound macadam) has been determined, the road class and E80 value are used to obtain a recommended pavement structure. The costs of the different pavement types can then be compared. Some matrix entries give more than one pavement option.

Table 5.2 Road categories for use in the TRH 4 Catalogue (COLTO, 1996:8)

Road Category	Description
A	Major interurban freeways and major rural roads
B	Interurban collectors and rural roads
C	Lightly-trafficked rural roads and strategic roads
D	Rural access roads

This method has been effectively used for roads that have heavy traffic volumes, but may not be appropriate for lightly trafficked access ways. "The functional classification of basic access streets indicates that traffic volumes are so low that the traditional design guidelines are not applicable in most cases" (CUTA, 1987 quoted in CSIR, 2000:8.44). This fact is partially acknowledged by the guidelines in that 'special' categories are made for basic access streets in the Red Book (CSIR, 2000:8.78) and allowances are made for 'innovative designs' in the TRH 4 Handbook (COLTO, 1996:9). From the road categories given in Table 5.2 it is not immediately obvious where low-volume urban access ways (i.e. those in an upgraded settlement) would fit in. The volume anticipated on the main access routes of upgraded informal settlements would suggest that they are Category D roads (< 500 vehicle equivalent units per day), although they are not rural, and there is a higher risk involved in pavement failure. Some of the access ways may be classed as Category C roads because of more frequent use and the higher standards required. In this discussion, main access routes in upgraded settlements will be considered to be Category D roads, but the distinction is marginal because of the unclear definition.

An advantage in informal settlements is that traffic volumes can be counted and the anticipated loading can be fairly accurately calculated. This analysis must be done on a site-by-site basis, but for the purpose of this discussion an estimate for the traffic loading has to be made. As no field data are readily available, an estimate of an ES0.1 traffic class will be used. This is a 'very lightly trafficked' road with the equivalent of a 20-75 vehicles per lane per day. The vehicular traffic in an upgraded settlement may be greater than this, but this bearing capacity will simply serve as an example in order to compare different pavement types.

There are numerous pavement types that could be used in informal settlement upgrading. The limited options discussed here will be based on an examples given in the Red Book (CSIR, 2000:8.78) for a Category UD, Class ES0.03 road, and the options for Category D, ES0.03 roads given in the TRH 4 catalogue (COLTO, 1996:97-101).The pavement profiles all require certain foundation conditions. For Category D roads, the TRH 4 catalogue requires a 150mm layer of G9 material above G10 material, while for Category C roads an additional layer of G7 material quality is required*. In addition to this, if the underlying subgrade has a CBR value of <3, then the pavement layers (including the foundations) have to provide a certain minimum cover: 450mm for very light traffic and 600mm for light traffic. This is significant because informal settlements are often situated on marginal ground and foundation work will increase the overall cost of the pavement.

* For definitions of theses material types, see the Material Classification in the Glossary of Terms

Pavement options for main access routes

Granular bases

The Red Book and the TRH 4 Catalogue (for Category D, Class ES0.03) both propose a low cost granular pavement consisting of a 125mm G7 subbase layer followed by a 100mm G4 base layer and light bituminous surface treatment. This would be laid on top of the G9-equivalent foundation material mentioned earlier. Common practice on the Cape Flats is to place a 150mm layer of crushed base directly onto the sandy in-situ material and cap it with a seal layer (Wright, pers. comm.). The single light seal shown in both design guides has not proved effective in wet regions like the South-west Cape, in which case a thin asphalt is usually used. For main access routes, granular pavements of this type are often likely to be the least cost option, particularly if local materials can be used. Granular pavements, however, are prone to damage by water ingress and drainage of the road surface and subgrade needs to be carefully considered.

Waterbound macadam bases

The second and third options from the Red Book example are waterbound macadam bases placed on either granular (G7) or cemented gravel (C4) bases and capped with a single seal. Waterbound macadam is an expensive material and requires skilled workmanship for construction (Cotton and Tayler, 2000:4.156). Waterbound macadam bases are only recommended for Category C roads in the TRH catalogue. Macadam pavements are less affected by water than granular pavements and should be considered for wet regions. The macadam layer can be used as the travelled way prior to the addition of the bituminous surfacing.

Cemented bases

The TRH 4 cemented base option for the given class road is a 125mm G7 base topped by a 125mm C4 base and a relevant surface material. This can be cheaper than a granular base if a G6 material is used with 2% concrete (Wright, pers. comm.)

Concrete pavements

Portland Cement Concrete (PCC) pavements are usually laid on a 100-150mm hardening layer and are typically 100mm-thick when unreinforced. Perrie (2000) recommends a minimum thickness of 130mm for low-volume access roads, but this is a fairly conservative value. The minimum advisable thickness of the lightest concrete pavements is 75mm (with or without reinforcing). A comprehensive guide to the jointing and construction methods required for concrete pavements is given in

Perrie (2000). The specifications for concrete pavements usually require 25-30MPa, but this strength is not necessary for lightly trafficked roads (Wright, pers. comm.). A great benefit for application in informal settlements is that concrete roads do not require very strong subgrades, as long as the subgrade strength is reasonably uniform (Perrie, 2000). Kerbs can also be cast monolithically with the pavement.

Block and brick pavements

The final option from the Red Book example is concrete block paving laid on 20mm of sand. The Red Book states that this pavement requires a cemented subbase (CSIR, 2000:8.77) but may be able to do without this, depending on the quality of the in-situ material. Adequate foundation conditions would still be required to provide an even platform. A thinner bedding layer of sand produces less deformation and rutting than a thicker layer (CUTA, 1987:31). Thus, there is no reason for providing a bedding layer with a compacted thickness greater than 20mm. An advantage of paving blocks is that if failure of the subgrade occurs, they can be lifted and reused once the subgrade has been repaired. The quality standards for concrete paving blocks stipulate a strength of 25 MPa (CUTA, 1987), which Mr Wright feels may be unnecessarily high for lightly trafficked roads. High standards mean that the blocks are expensive and cannot easily be manufactured locally using labour-based methods. On the other hand the blocks need to be strong enough to resist loads. Locally produced blocks of marginal quality were used in Thembalethu township in George and have performed satisfactorily to date (6 years).

A variation of the concrete block pavement is the brick-on-edge pavement that has been widely used in Pakistan. The bricks provide nearly all of the structural strength of the pavement, but provide a flexible surface. Brick paving was successfully used for the small lanes of the North-east Lahore Upgrading Project:

> *" Brick paving was used for small lanes and this worked well. The design differed from that commonly used in municipality schemes in that the bricks were cement rather than sand grouted and monitoring of their performance suggests that the slight increased cost was more than justified by the increased durability of the paving."* (Tayler, undated:7)

Both concrete block and brick paving require edge restraints for the protection of the pavement edge and to prevent the lateral spread of the blocks (CUTA, 1987; CSIR, 2000). There are other good reasons for providing formal edging, including delineation from the surrounding areas and the prevention of encroachment of houses onto the access route. A brick on edge is a cheap option for doing this.

Pavement options for pedestrian pathways

For pedestrian pathways there is little useful information in design guidelines and a far more practical approach needs to be taken. From a structural perspective the pedestrian pathways only need to be able to carry the loads imposed by pedestrians and two-wheeled vehicles. Their design will therefore be governed by other factors, including the necessities of carrying stormwater and to resisting the erosion caused by runoff. The old Red Book States that "Erosion control should be the main criteria in the design of tertiary ways." (Department of National Housing, 1994:7.14). It is often the case that the chosen surfacing (e.g., asphalt concrete, bricks) will provide the required structural strength. As surfacing options have been described in the previous section, they will not be repeated here. One note on concrete pedestrian pathways is that the minimum advised thickness of 75mm will give more than enough structural strength. It is possible to cast concrete pavements in-situ as thin as 50mm, but they become very brittle at this thickness and require good founding layers.

Alternative construction methods

One of the risks of designing pavements for light vehicles is that the occasional heavy vehicle is required for construction or other purposes and may cause the pavement structure to fail. This situation is very likely in an upgrading project where houses and services are being constructed incrementally over a long period. COLTO (1996:62) warns that if many overloaded vehicles are expected, shallow pavement structures should be avoided. Alternatively the pavement could be designed to cater for these heavy vehicles during the construction phase and then remain 'over-designed' for the light traffic loading during the rest of the design life of the pavement. This may be seen as a waste of resources and an uneconomical solution. A possible solution to this problem has been proposed by Wright (pers. comm.) in the form of a 2-stage cement stabilised road for use in the Western Cape, provided that the houses and services are constructed during or shortly after the road construction.

This pavement construction method involves laying a shaped light gravel layer (75mm) for construction vehicles to use while houses are being built. This gravel layer can be used for approximately a year, and where the road fails, this material can be supplemented and the gravel reinstated. Once the construction is complete, the gravel layer can be salvaged and mixed into the in-situ material. This mix must be able to respond to stabilization (for example a clayey subgrade is unlikely to respond to cement). Stabilizer is then added and the pavement is shaped and compacted to produce a hard soil-cement pavement (150mm). The upper layer(s) as required can then be added to meet the light pavement design. One problem with this method is that of achieving the desired road levels; in order to make sure that the final road level is below the surrounding dwellings, the roadway needs to be box cut and the gravel placed at the bottom. This will channel water and destroy the gravel surface. The level may therefore have to be set when the material is mixed, and some of the in-situ material below the gravel removed. This is quite difficult in amongst surrounding dwellings and with no place to stockpile. This method may also cause problems with the community as they may see the inferior gravel road as a permanent measure and reject it.

A second type of construction method for access roads in informal settlements was proposed for the New Rest Settlement in Cape Town (HHO, 2001). In this settlement there was a problem of highly variable CBR values and unsuitable fill material in certain areas of the site. A cost-effective construction method needed to deal with this problem without having to remove and import large amounts of material. The method proposed involves marking out the access routes and proofrolling the in-situ material with a heavy roller. Where the material fails it will be removed and replaced. The proofrolling will continue until suitable compaction is achieved. This material will then be topped by a conventional granular pavement and an asphalt surface. This method is suited to the area because no clayey material is present. The timing of this type of construction is critical, especially in an area (like the Cape Flats) that has a large water table fluctuation. The in-situ material may be suitable in dry seasons, but fail easily in wet seasons, and the rolling during the dry season will fail to pick up all the weak areas. For this reason the use of a temporary gravel layer for an extended period of time, as proposed by Wright, may be more effective at identifying any weak underlying material.

A final alternative construction method is an innovative, locally-developed pavement system, called the Hyson cell (Figs. 5.18 and 5.19). For light block paving, Hyson cells require a 150mm G7 foundation layer above ripped and compacted subgrade.

"Hyson cells are a hybrid of a concrete pavement and concrete block paving. Concrete is poured into a polyethylene 'net', which provides a temporary formwork and divides the concrete into discreet cells. Through the shrinking action that takes place during drying, small gaps of 0.1-0.2mm appear between the cells. This results in a flexible pavement made up of interlocking concrete blocks. Hyson cells can be laid quickly and can use ready-mixed or hand mixed concrete. Hyson cells are promoted as comparing favourably with conventional concrete or concrete block paving, but a costing analysis in an upgrading context needs to be undertaken. The pavement produced has a 20 year design life with minimal maintenance." (www.hysoncells.co.za)

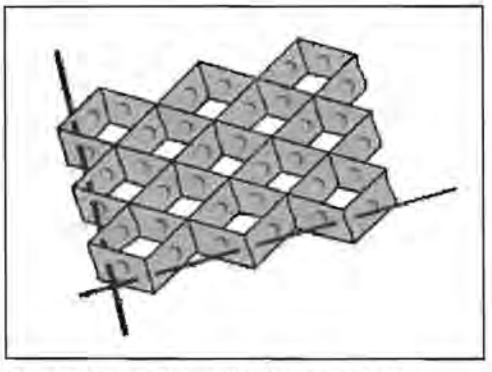

Fig. 5.18 A schematic diagram of the plastic 'formwork' for the cells (Source: www.hysoncells.co.za)

Fig. 5.19 Hyson cells being cast (Source: www.hysoncells.co.za)

The reason that guidelines are so vague on the structure of roads at the lower end of the design spectrum is that they depend so much on the on-site conditions (geology, topography, and climate). Therefore, there is no overarching design guideline or method and a lot of flexibility exists in the choice of pavement and surfacing. In most cases it comes down to a trade off between cost and the risk of pavement failure. It is ultimately the cheapest solution that will last the minimum acceptable design life that is chosen, while still considering community acceptance. The cost savings, however, need not come from a compromise in design standard, but instead from a reduction in access standard and the resistance against over-designing very lightly trafficked access ways.

5.9 ACCESS AND DRAINAGE

In this thesis the different infrastructure services have been separated, including access and drainage, because of the different objectives of each service. There are, however, still some undeniable functional links between access ways and drainage routes. In the previous chapter on drainage, the role of access ways in stormwater management was debated. This section will investigate the means of dealing with water in and around access ways and how this affects the physical form of the road or pathway.

It is vital to control water on and around access ways because the presence of excess water in the pavement layers will usually result in failure irrespective of the quality of materials and construction (Netterberg, 1988 cited in Department of National Housing, 1994:7.3). "Experience has shown that inadequate drainage is probably responsible for more pavement distress in southern Africa than inadequate structural or material design" (COLTO, 1996:43). There are three sources of water that potentially have to be dealt with on access ways: water that falls directly on the surface, stormwater runoff that makes its way onto the surface, and subsurface water. In most cases it is desirable to keep water away from the pavement layers and thus some means of directing or channelling the water is required. This is somewhat contradicted by the method of deliberately using the road as a drain for stormwater drainage. The road-as-drain option has been proposed and motivated in the previous chapter on drainage and this section will therefore include stormwater in the volume that has to be accommodated along the access ways. Another impact of adopting the road-as-drain approach is that it is assumed that access ways will eventually be surfaced.

Subsurface drainage

The control of subsurface water is difficult and often expensive to achieve. Many low-cost pavements do not include subsurface drainage, but some of the options available are:

- raising the access way above ground level;
- constructing side channels deeper than the material depth;
- constructing a cut-off trench;
- placing a permeable layer of material below the subbase; and
- installing subsoil drains.

The TRH 15 Handbook (CSRA, 1994) provides guidelines for investigating subsoil water conditions and for constructing subsoil drains. It is recommended that drains should be provided where traffic exceeds class ES3, where annual average rainfall is > 500mm, and for an infiltration factor of ⅓ and 2-hour drainage period (ibid:51). The traffic class mentioned is far greater than would be expected in an upgraded settlement. However, in settlements with problematic subsoil conditions, premature pavement failure is highly likely if some form of subsoil drainage is not included. The cost of repairing the pavement could be as much or more than the cost of installing the drainage system initially. Another critical aspect is that the collected subsoil water requires an outlet and this can be a major problem in flat areas (Wright, pers. comm.).

Surface drainage

The influence that the layout and grade of a movement network have on drainage has been discussed in the previous section. This section will focus on the cross section of the access way and the impact that this has on drainage.

Camber

Camber directs water to side channels and keeps the travelled way free of water. Conventional camber for surfaced roads is 2-3% to each side of the road. Camber is not advised for the narrower vehicular access ways likely to be constructed in informal settlements because it requires expensive kerbs or channels on both sides. Camber is better suited to wider access routes. Another possible application of camber is where greywater is discharged from the dwellings into the streets, and sullage drains may be required on both sides anyway.

Crossfall

Crossfall serves the same purpose as camber on narrower access ways. Single crossfall of 3% is common on surfaced low-income roads. Kerbs, channels or drains are only required on one side. Crossfall should be cut opposite to the natural ground slope to retard runoff. Where a kerb is used to contain the runoff from the crossfall on a granular pavement it is essential that a channel be provided as well, as experience has shown that where channels are not provided water is likely to seep into the road layers and cause failure (Wright, pers. comm.).

Inverse camber

Inverse camber involves directing water to the centre of the access way. This can be through a constant inward slope with a collector channel in the centre, or simply a dished road surface. The old Red Book discourages the use of inverse camber because the water carrying function of dished roads conflicts with the traffic carrying function, and therefore dished roads were only to be used in sanitary lanes or where traffic is slow moving, of low density and the dished part of a road does not exceed 150m in length (Department of National Housing, 1994:4.12). Where pedestrian traffic exceeds vehicular traffic, this may not be valid and the new Red Book concedes that in the case of very narrow reserves, such as in the case of lanes or alleys where spatial restrictions may preclude the provision of drainage outside the width of the travelled way, a negative or reverse camber can be considered (CSIR, 2000:7.24).It is recommended that where an inverse camber is used, some form of channel should be used to protect the underlying layers.

Inverse camber favours pedestrian movement, but the potential negative effects on vehicular traffic and the road structure must be considered. These include: (Department of National Housing, 1994:4.12)

- the difficulty of locating stormwater inlets that are not a hazard to pedestrians and cyclists;
- the hazard created by splash;
- the nuisance created by continuous flows such as seepage; and
- the failure of the road surface would encourage water penetration into the centre of the road structure and thus accelerate the deterioration of the road.

Level cross section

This is only an option on short pedestrian pathways with sufficient grade to transport runoff. A small edge must be provided to contain the surface flow. This is not appropriate where greywater is discharged onto the pathways.

5.10 ACCESS CONCLUSIONS

The analysis of the function of movement networks in the context of informal settlements raises many new issues that question conventional standards. This could result in a change in the design of 'formal' movement corridors in terms of their layout, size, structure and surfacing. Conventional standards that are applied in greenfield developments have been shown to be unnecessarily high. The first half of this chapter has challenged conventional access standards. Some of the more important conclusions in this regard are:

- Vehicular access to every dwelling is not necessary, often inappropriate, and in some cases not possible. The consequences of high standards are the loss of valuable space in the settlement and a disproportionate amount of the upgrading budget spent on roads.
- Vehicles only need to get within 75m of every dwelling to supply emergency services. This also aids the supply of building materials and commercial goods, as well as access to public transport.
- A three-tier access hierarchy has been proposed, with pedestrian pathways as the lowest level of access.
- The first two levels of the hierarchy cater for vehicles and should be distributed according to the existing layout of tracks in the settlement and the minimum threshold distances to emergency services and public utilities. The width of these access ways is dictated by practical considerations regarding the vehicles that are to use these routes.
- Reticulated services have little impact on the layout and widths of access ways and can be incorporated into the pedestrian pathways.
- The minimum width of the lowest level of access way is dominated by the firebreak function. There are, however, no guidelines on the widths required to prevent or reduce the impacts of fires in dense settlements.

The conclusions that can be drawn from the assessment of design standards for access ways in an informal settlement context are:

- Existing layout of dwellings and tracks in informal settlements do not allow the desired geometric design for the upgraded movement network. Design standards should be relaxed and the resulting lower vehicle speeds accepted. This may even be preferable in a pedestrian-dominated environment.

- The choice of surfacing material is dominated by cost, but is influenced by the need to resist erosion, the need to convey stormwater, and the need to provide a multi-functional hardened space. These factors, as well as the long-term maintenance costs, discount the viability of unsurfaced roads for upgrading.
- For the pavement structure in low-trafficked areas it has been shown that the need to resist the impact of water on the structure dominates over the traditional load bearing function of the pavement layers. A number of alternative construction methods for dealing with problematic ground conditions in informal settlements have been proposed.
- A number of cross sections are available to manage surface drainage. Pathways and narrow lanes can be drained by single crossfall or even a level cross section. For wider routes conventional or inverted camber are more appropriate.

What have previously been regarded as the distinct areas of planning inputs and engineering inputs have deliberately been combined in this chapter to show that both must be manipulated together to find viable solutions. Cost-effective solutions are those that take cognisance of the on-site conditions and cater only for the intended traffic and use of the access way. The access standards and design standards need to be based on realistic traffic measurements and predictions.

This chapter has motivated a revision of access conventions. This, however, poses a number of problems. Access is a highly visual indicator of development in a settlement and communities may have very high expectations regarding the desired level of service. For the authorities, who are responsible for the maintenance of access ways, conservative standards are beneficial because fewer risks are assumed. There are therefore many arguments *for* the retention of high standards in access way design. While these concerns are very important, this chapter has intended to illustrate that high standards cannot be motivated on technical grounds and are not necessary to fulfil the primary function of this service.

Chapter 6

CONCLUSION

Outline of this chapter

This thesis has aimed to explore the role and form of infrastructure in the upgrading of South African informal settlements. Four objectives were identified in the introduction. These were to:

- Investigate the feasibility and potential benefit of treating each of the infrastructure services separately;
- Provide a thorough review of all available technology and current approaches for service provision in informal settlement upgrading;
- Identify the key issues for the design of each of the services in a South African context; and
- Describe the conditions and constraints that are present in the upgrading context.

The review of the service option available for the in-situ upgrading of informal settlements was undertaken to address the lack of integrated knowledge in this field. The main chapters have aimed to present all the available technical options and approaches for each of the four major civil engineering-based services (water supply, sanitation, stormwater drainage and roads/access routes). Within each chapter, the key design issues, as well as the conditions and constraints for the success of that particular service, were identified. Each chapter contains its own conclusions, pertinent to the service in question. As a result, this chapter will limit itself to a brief summary of the central issues. However, where certain relationships between the services emerge from the analysis, the significance of these will be examined in greater detail.

The over-arching objective of this thesis, and the reason the review was undertaken in this particular form, was to question the validity of 'Levels of Service' (LOS) and the conventional associations between packages of services. Whilst this type of 'packaging' may have the benefit of technical simplicity, and perhaps financial optimisation, it imposes it own set of constraints on spatial form and can cause a disruption of existing social and economic networks. This led to the hypothesis, defined in the introduction, that it is beneficial to separate services from one another. This hypothesis was tested by analysing each of the services individually according to their fundamental objectives. Only once this had been done, were their relationships to the other services considered. This chapter will discuss the extent to which the hypothesis has been proven and outline the significant implications that this has for service delivery in upgrading projects in South Africa.

Review of the individual chapters and their conclusions

The conclusions drawn from the analysis of each of the services illustrate clearly that each service is driven by a set of individual concerns that differs significantly from the other services. It was found that the constraints and the conditions for the success of each service in an informal settlement context were different. It is these issues that have shaped each of the chapters and their conclusions. To illustrate this, the focus of each of the chapters is given below:

Sanitation

There are many options for sanitation provision, but no single 'correct' option. The economic and physical conditions in informal settlements have the combined effect of severely limiting the sanitation options that are *actually* feasible. This limited choice has been shown to be dominated by socio-cultural acceptance and maintenance requirements. There is occasionally conflict between the service desired/affordable at a household level and the service that is most appropriate when physical constraints and community benefits are considered.

Water supply

Water supply represents the most mature technology. The central issue here revolves around the value placed upon water by the different parties. Hence the critical elements centre on the consumer/supplier interface. Negotiations over this interface involve securing payment for a level of service that is acceptable to residents. The Free Basic Water policy is very important in this regard. The most simple of supply systems involve community decisions, but higher levels of service and improved technology result in a greater *individual* responsibility.

Drainage

Drainage concerns the elimination of risk to informal settlement residents and is linked to the site rather than to the people living on the site, which is the case for the previous services. There are two levels of risk elimination. The first is the planning issue of whether to upgrade or not. The second is the specific engineering interventions that must be settlement-specific and tailored to cope with the problematic conditions experienced in areas. This involves careful characterisation of settlements and focussed interventions, even managing some of the runoff at household level.

Access

Access again has a very different focus to all of the previous services; sanitation and water needs to be dealt with at the household level, whilst drainage needs are linked to the site. Access is a service that is community oriented. Hence it needs to be looked at in the context of movement patterns and dominant modes of transport as well as considering the social networks and economic livelihoods base of the community. These are the issues that relate to *access* standards. In addition there are an entirely different set of site-specific, physical factors that need to be considered when *design* standards are assessed. However, it is important that these technical design factors do not dominate the social issues when movement networks are planned. A general conclusion, for both access and design standards, is that conventional standards should be re-evaluated according to the (mainly pedestrian) priorities of this new planning context.

From these brief statements it is clear that each service has a completely different underpinning. If only the most basic services are provided in a settlement (e.g. VIPs, communal standpipes, unlined drainage channels and gravel tracks), the services have very little interaction. If, however, one chose the highest level of services, where services are designed primarily for user convenience rather than as suppliers of more basic social and economic needs, then they start to become more interconnected. This makes sense, since it explains why conventional greenfield planning uses integrated service design. What stems from this is the realisation that a set of criteria exists for the design and location of the most basic forms of each service that is not affected by any other engineering service that may be provided. Examples of this are the need for convenience, privacy and prestige in a sanitation system, the need for multi-functional access routes, or the need for drainage interventions to address risk. When higher levels of service are planned and designed, these criteria *still apply*, and have to be considered *before* the relationships with other services. It is these key criteria that have been identified here.

Links between individual services

It is acknowledged that at a practical level of design, costing and construction, it may be useful to consider some of the services together to increase efficiency and avoid conflicts. By separating the services, however, this thesis has challenged the validity of some of the conventional associations between services in the context of informal settlement upgrading. The conclusions that have been drawn in this regard are as follows:

The link between **water supply** and **sanitation** has only played a minor role in the analysis of each of the services. It is recognised that some sanitation technologies require certain levels of water supply and that the two are complementary in terms of achieving health improvements. Sewers are not necessary for the disposal of greywater, but this depends rather on the soil conditions and the volumes produced. Thus the layouts of the two services are independent of each other.

The link between **roads** and **reticulated services** (water, sewer and stormwater pipes) has been shown to be coincidental and does not dictate the layout of either the roads or the pipe networks. In many cases piped sewerage or stormwater may not even be provided. It is noted that there are financial benefits in maintaining this link when full services are provided to a greenfield site. Pedestrian pathways and vehicular access ways are convenient locations for locating reticulated services, but case studies from Brazil have shown that it is possible for them to be completely independent if necessary. This is a likely scenario in the irregular layout of informal settlements.

The link between **sanitation** and **stormwater** is limited to two issues: poor sanitation pollutes urban runoff, and stormwater must be excluded from sanitation systems (particularly on-site sanitation). If sanitation systems are correctly operated and maintained, then pollution of waterways should not be a problem. There are also a number of methods, described in Chapter 2, for preventing stormwater from entering on-site sanitation systems.

The services that have been most problematic to separate are **access** and **drainage**. In both chapters it has been necessary to discuss the other service. There are two important associations between the two services. Firstly, the road-as-drain method has proved to be an efficient drainage solution in low-cost environments. The extent to which this is used obviously depends on the proportion of the site that is serviced by access ways. The dependency on access ways for drainage can be reduced through control of runoff at the source. Secondly, vehicular access ways require their own drains to protect the pavement layers from water ingress. As these drains will feed into the stormwater system anyway, the road drains can easily serve as stormwater drains as well. Again this depends on the level of access provision in a settlement. A consequence of maintaining this connection between access and drainage is that all access ways must be surfaced and shaped to carry runoff.

However, there are also a number of reasons to treat aspects of access and drainage separately. The concept of 'source control' advocated in the Drainage chapter can be planned for irrespective of the road layout. The physical risk associated with external runoff and the location of settlements also has to be dealt with before drainage routes are planned. The standard of access to be provided is also a parameter that can be determined without considering drainage. It is only when design standards (i.e. pavement structure, surfacing and cross-section) are considered that drainage becomes important. There are therefore a number of connections between access and drainage, but also some fundamental features that must be considered separately.

Discussion on the broader objectives of this thesis

The need to make conventional services cheaper for low-income areas was the original motivation for developing a LOS matrix. Standards of service that had become 'acceptable' were not affordable. The means of making things cheaper was to work backwards from the standard high level of services and to reduce existing technologies by using cheaper materials or finding more basic alternatives. This, however, is not the only way of developing more appropriate, low-cost services.

The method that has been used in this thesis works from a different hypothesis. It takes each service in turn and returns to the basic principles underlying the provision of that service by asking the question: "What is the fundamental objective of this service and how can this be achieved?". From this starting point, one may then take this fundamental objective and compare it with (often high) existing standards. In this way it becomes possible to find some compromise that will be both affordable and acceptable to the users. There are two issues that emerge from this approach. The first is that the fundamental objective may be defined by social or economic needs, while the basic level of service fulfils technical requirements (as discussed earlier). This distinction allows a different perspective. The second issue leads from this to some extent, and deals with the additional technical convenience (or engineering efficiency) embodied in a service, which has become something of an *a priori* assumption.

By separating the services and examining the fundamental objectives, one is able to reduce the emphasis that has been so heavily placed on the second issue – technical convenience. Thus, one is able to resist the urge to link services unnecessarily, or make invalid assumptions like, "Services need to be placed along roads, therefore services require roads and roads require services." The engineering wisdom that is embodied in many of the current service conventions, and which may still be appropriate for higher income greenfield site projects, is still acknowledged. It is recognised that many decades of logic, testing and refinement have gone into developing services and standards to optimise efficiency, both in terms of cost and function. It is felt, however, that where circumstances change, these norms should not go unquestioned. For the reality is that this basket of technical solutions was developed for a particular spatial development pattern. Hence it is perfectly logical to assume that if there is a completely new spatial form for settlement development (as is the case with in-situ upgrading), then this may require both a new technical approach and new solutions.

A key finding in each of the chapters is that the unique conditions experienced in informal settlements often require unique solutions. The constraints that exist relate mainly to the obvious fact that dwellings already exist in an irregular layout on the site. Other constraints include the marginal location of many of the settlements, complex social dynamics, and problems with the financing of services. Upgrading therefore cannot be approached like any other residential development with the importation of the same technologies and standards.

The acceptance of in-situ upgraded informal settlements as a new spatial form represents a significant shift in thinking about this type of urban development. This thesis has intended to show that there are two crucial issues that arise under this new development paradigm. The first is that services must be treated individually and not collectively. The benefit of separating out the individual services can be seen in the diverse questions that each chapter in this thesis has raised; four chapters produce four different sets of issues. This is not a triviality that arises from the structure of this thesis, but is rather an imperative that lies at the heart of any successful upgrading project. Indeed, it is argued that the viability of the services will be seriously compromised from the start of a project if services are considered collectively because many of these crucial issues will be overlooked. The second issue is that the key elements dictating affordable and acceptable choice of service are not necessarily those defined by a technical definition of service levels. The technical input into the planning of services varies from one service to the next.

The argument for separating service corresponds well with the current development practice of adopting a Demand Responsive Approach (DRA). This approach aims to address the failures experienced with supply-driven approaches by determining the priorities of a community, what they are willing to pay for and what they are able to pay for, before any intervention is planned. In this way a 'real' demand is ascertained, rather than supplying services that one believes a community 'needs'. If, in a supply-driven development paradigm (like that in operation in South Africa), there is a fundamental problem with the cost and sustainability of what is being supplied, then it is very difficult firstly to correctly identify, and secondly to rectify it. As a result, the current emphasis on delivery of services in South Africa actually threatens the sustainability of the development projects. For, as Cotton and Taylor point out:

> *"Traditional approaches have been "supply driven"...done on an a priori basis without reference to a specific situation...the result is that city-wide 'blue print' solutions are proposed, where everybody in the same category, for example 'slum', gets the same hardware solution regardless of their demand"* (Cotton and Tayler, 2000:1.15)

By considering services individually, services are able to be prioritised and levels can be matched to a personalised need. What emerges from this review is that the preferred method for negotiating services is to gauge the real demand for a single service, rather than for a package of services. In the conventional development model residents can only progress from one level to the other if the economic status of the entire settlement improves. In order to upgrade an individual service in the whole, or even in part of the settlement, it may only be necessary for a single factor to change. Service provision is thus made more flexible and the tendency to provide a 'blueprint' infrastructure solution for all informal settlements is avoided.

Implications of the recommended approach to upgrading services in informal settlements

All the arguments and recommendations that have been put forward in this thesis have been guided by a particular vision of what upgraded informal settlements will look like. This vision is based on the UCT upgrading methodology, as well as examples of successful upgrading projects from Brazil and elsewhere. Common features from these sources are the minimum relocation of dwellings, the retention of much of the existing layout in a settlement, and the acceptance of standards of planning and design that fall below building conventions. As yet, there are no concrete plans or examples that embody this vision, but it is rather based on these guiding principles. There are two fundamental issues that have not yet been addressed:

1) The acceptance of upgraded informal settlements as a permanent form of housing (both by the communities and by the authorities); and

2) The acceptance of standards for some services that are lower than those given to RDP houses or other formal areas.

The first issue is primarily a political one that is currently under much debate in the housing sector. As this debate falls outside of the scope of this thesis, a position has had to be assumed - that informal settlements can be upgraded to a viable form of housing. The contribution that this thesis intends to make to this debate is to show that there are various techniques available to make the infrastructural component of this type of upgrading possible.

The second issue has been dealt with more directly in this thesis. The review of services in the context of informal settlements has recommended the lowering of conventional standards for services on a number of occasions, particularly in the Access chapter. Davidson and Payne (1983:132) have pointed out that:

> *"Standards, in the form of central government laws, local by-laws and regulations and government department ideals can form a considerable constraint to the provision of low priced plots because of their insistence on standards that are unnecessarily high"*

The problem with the lowering of standards is two-fold. The first is that a higher level of risk is assumed by those responsible for the maintenance of services, and the second is that lower standards lead to the impression that residents are being provided with a substandard, temporary services. The question of risk may very likely be superseded by political pressure; the pressure to deliver services and housing to the poor with a small budget may require that increased maintenance risks are taken.

The issue of expectations is more complex, and has been mentioned in every chapter of this thesis. South African history makes this a particularly sensitive issue. It is one that has to be negotiated between communities and authorities in a transparent development process. The reality that emerges from this analysis is that in order to accommodate services in an in-situ upgrading process, while at the same time providing services that are affordable to the urban poor, it will be necessary to lower certain standards. Standards must relate to the location and intended function of facilities (Tayler, 1998:27). Thus, it is argued that lower standards are required in certain circumstances to make these settlements sustainable.

Final remarks

The major issues that face engineers providing services in informal settlements are not technical, but primarily social and economic. It is therefore necessary that engineers (and others) re-evaluate the way they view service provision. This thesis has shown that the 'Levels of Service' paradigm is inappropriate and has aimed to replace it with a demand responsive approach for each service based on community priorities and site specific constraints. As needs are constantly changing, so the nature and method of service provision has to be dynamic. Desegregation of services and the individual assessment of each service, allows this flexibility, and the ability to 'fine-tune' an infrastructure plan for an upgrading project. The field of informal settlement upgrading requires innovative solutions to these highly challenging engineering problems. This process is therefore a necessary one. A paradigm shift is required in order to provide adequate services and improve the quality of live in these settlements that represent an entirely new spatial form on the urban landscape.

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