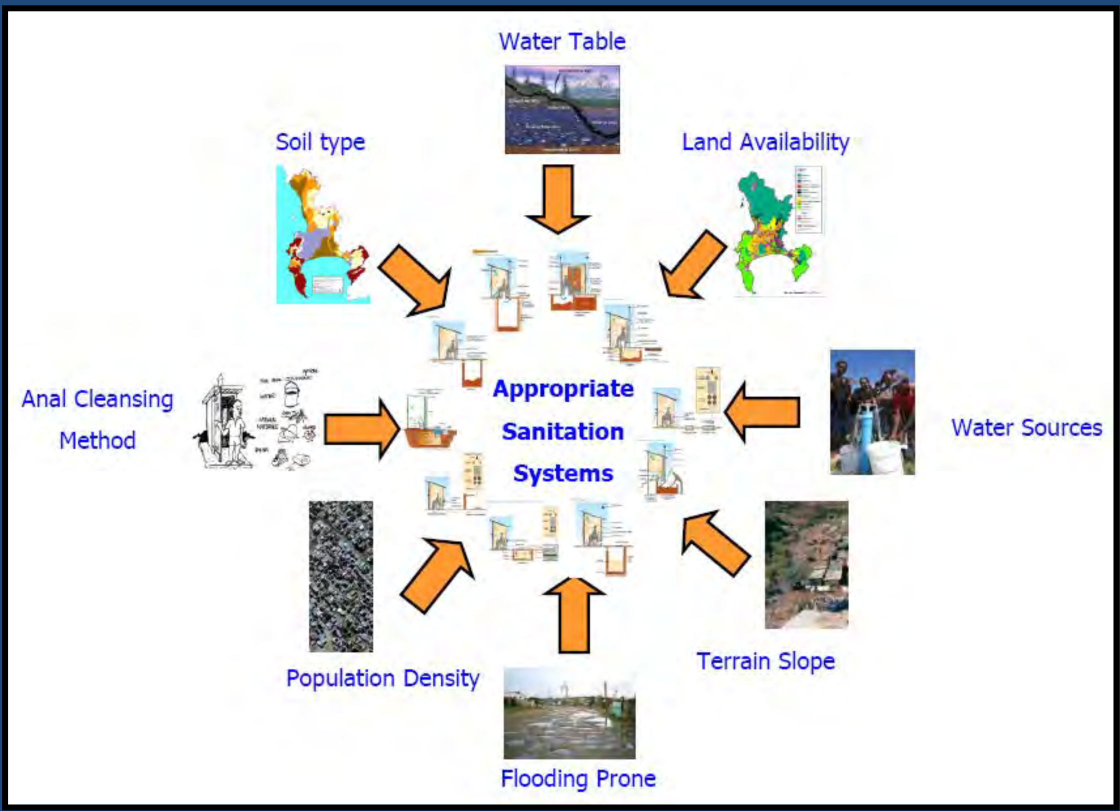
DECISION SUPPORT TOOL FOR THE APPROPRIATE SELECTION OF SANITATION SYSTEMS



Master Thesis

URBAN ENVIRONMENTAL MANAGEMENT

Ir. David Castellano Fabrega

JULY 2007

WAGENINGEN UNIVERSITY WAGENINGEN UR
Vitens
CSIR

Decision Support Tool for the Appropriate Selection of Sanitation Systems

Master Thesis

Submitted in fulfilment of the requirements of the Environmental Sciences Department for the degree of Master in Urban Environmental Management
Wageningen University, The Netherlands

Ir. David Castellano Fabrega

Registration Number: 770124-156-100

July 2007

The fieldwork described in this thesis was carried out in coordination with Vitens International in The Netherlands, the Water Services Department in Cape Town and the Council for Scientific and Industrial Research (CSIR) in Stellenbosch.

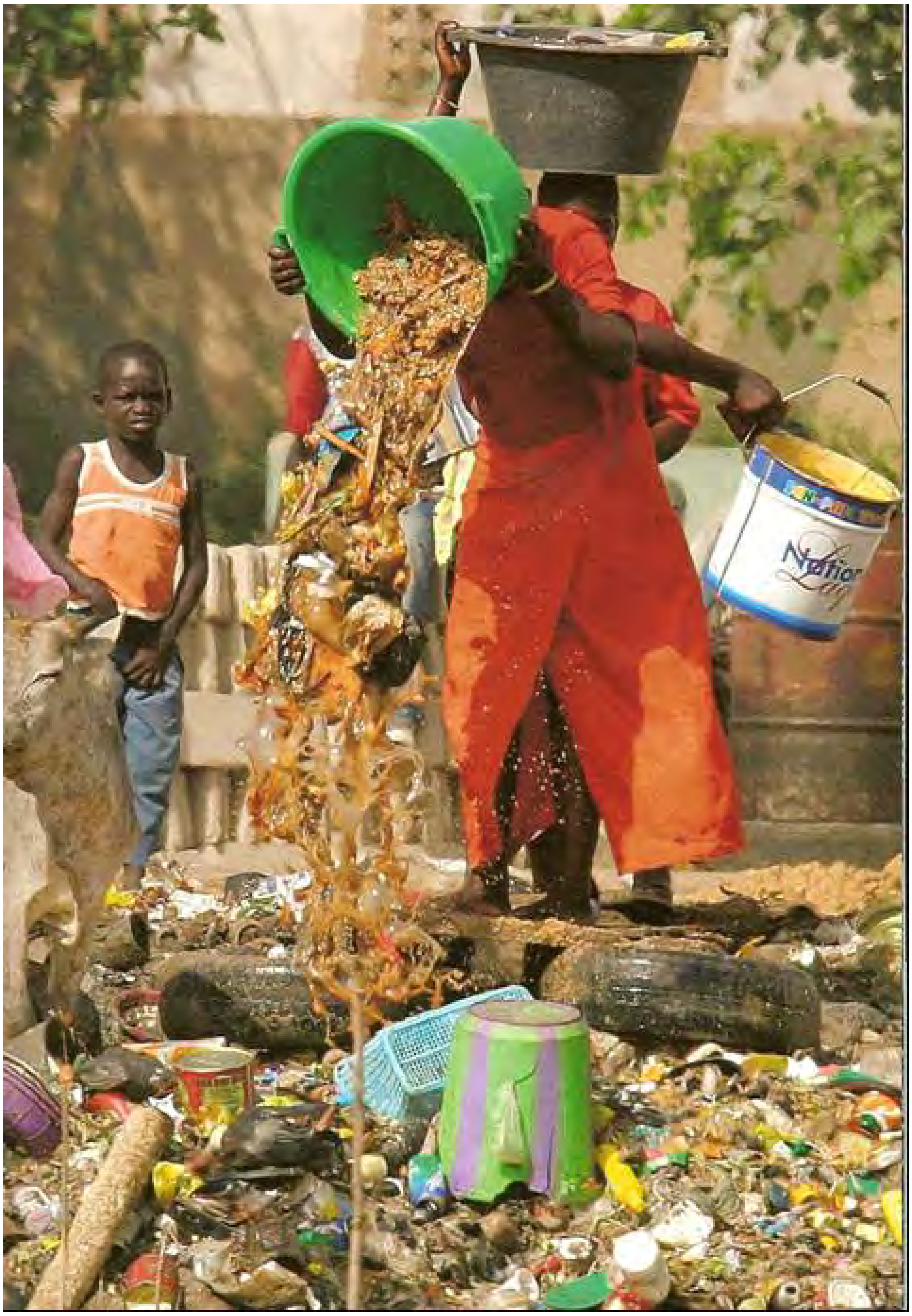
Thesis Supervisors

O. Braadbaart[1], A. Mels[1], S. Veenstra[2], A. Singels[3], J.A. Wilsenach[4]

1. Wageningen University, Department of Environmental Sciences, Urban Environment Group, The Netherlands, 2. Vitens International, The Netherlands, 3. Cape Town Water Services Department, South Africa, 4. The Council for Scientific and Industrial Research (CSIR), Stellenbosch, South Africa.

To

my loving wife Estela, whose enthusiasm and support encourage me to persist.



Dakar, Senegal, 2005. Nic Bothma/EPA

"*Two billion people don't have access to clean toilets or washing facilities. In Africa, it is 40% of the population, and in Asia as much as 52%. The excreta of two billion people pollute backyards and streets every day, seeping into groundwater and contaminating drinking water. Every year over a hundred cubic kilometres of wastewater, filthy with household waste, contaminated by germs, and polluted by detergents and household chemicals, flow untreated into rivers, seas, streams, and ponds… Larger cities and metropolises in developing countries are affected the most…*"

(Who Owns the Water? 2006)

Acknowledgements

I would like to express my most sincere gratitude to my committee chairman, dr. Okke Braadbaart as well as my thesis advisor dr.ir. Adriaan Mels, whose support, assistance and guidance besides their friendship and confidence in my abilities during the whole process have been priceless. I would like also to thank to Siemen Veenstra his support and the opportunity to experience field work in the informal settlements of Cape Town.

A warm thank you to Arne Singels from the Water Services Department in Cape Town and Jac Wilsenach from the CSIR in Stellenbosch, along with their families, for their supervision and assistance, besides their exceptional hospitality to make my stay in Cape Town feel like at home.

I would like to thank all the people in Durbanville's Office for their kindness attention and in general to the Water Services Department of Cape Town for providing me with field data and experiences as well as granting all my necessities. Michael Page, Lawrence Grootboom, Donnavin Wright, Pieta le Roux, Celeste, Tamara, David's and Zola's as well as Farouk Robertson, Charmaine Armstrong, Charmaine Meyer, Letlhogonolo Motlhodi and Sipho Mosai.

I am also very grateful to the Community Water Supply and Sanitation Unit (CWSS) in Bellville and in special to Deborah Cousins, for their friendliness and generous support which enabled me to obtain valuable literature and participate in community workshops within the Disaster Mitigation for Sustainable Livelihoods Programme (DiMP).

My sincere gratitude to Ed and Feddo for providing altruistic assistance in the design of this work as well as for their admirable efforts to make possible the technical programming.

Finally a very special thank you to my parents and sister, along with the rest of my family and friends, for their unconditional love as well as for their surprising enjoyment during my absence.

Abstract

Current trends of population growth and urbanization as well as complex socio-economic environments in most developing cities cause serious difficulties for the selection of appropriate sanitation systems and therefore it demands an increase in the to improve the decision-making process.

In this line a research of existing decision support tools intending to facilitate the selection of suitable sanitation systems is presented. In order to assess the appropriateness of the five decision tools identified they were confronted with six evaluative criteria (user-friendliness, transparency, flexibility, versatility, interactivity and level of detail). The outcome of the evaluation revealed their weakness in flexibility and versatility dimensions. In this way the objective of this study was to develop a transparent, flexible and adaptable sanitation decision support tool while maintaining a high compliance with the other dimensions. This tool aims to assist city officials, planners as well as communities in the decision process to select suitable sanitation solutions for each site specific layout. This decision support tool involves two main lines. The first one is the creation of a secure and easily upgradeable database to keep an improved and updated record of the settlements situation and services delivered. It includes the essential criteria for the assessment of sanitation options and a comprehensive set of relevant aspects with the purpose to maintain an accurate information system of the sites. A Microsoft Access database is organized through a Visual Basic application in order to simplify and clarify the user interface as well as to protect the data entry in the system. On the other hand the database includes the features of a range of sanitation systems as well as their principal characteristics. In the model, based on an Excel screening tool, these characteristics are used as limitations for the later suitability assessment against the specific conditions of the selected settlement. The proposed indicators are founded on the basic physical and environmental aspects of the specific site. Moreover the user is provided with full flexibility and adaptability to decide, modify, add or remove any of the aspects and criteria involved in the sanitation decision support tool.

This tool was tested with data gathered in the informal settlements of Cape Town, South Africa. There are about 220 informal settlements spread all over its territory with an estimated population of about 900.000. Water supply and sanitation services in the informal areas are generally insufficient and poorly maintained. City officials have difficulties to find appropriate sanitation solutions that are consistent with the characteristics of the sites. According to the outcome of the sanitation decision support tool it was concluded that most of the settlements in Cape Town are lacking behind on any feasible sanitation solutions. The main barriers to the appropriateness of sanitation systems are the unsuitable location of the settlements affecting more than 40% of the sites, as well as high and very high housing densities counting about 55% of the investigated settlement.

The final conclusion of the pilot test is that the sanitation decision-support tool designed in this thesis illustrates maximum transparency through its clear interface and traceability of the outcome, demonstrates an improved flexibility by means of unrestricted selection of constraining criteria and values, and provides an enhanced versatility as a result of its easy upgradability and potential use in diverse environments.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

DWAF	Department: Water Affairs and Forestry
EAWAG	Swiss Federal Institute for Environmental Science and Technology
Ecosan	Ecological Sanitation
GIS	Geographical Information System
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
HCES	Household-Centred Environmental Sanitation
IHE	Institute for Water Education
IRC	International Water and Sanitation Centre
IWA	International Water Association
MDG	Millennium Development Goals
NGO	Non-Governmental Organization
NOWAC	No-Water Consumption
SANDEC	Department of Water and Sanitation in Developing Countries
SIS	Servicing Informal Settlements
skat	Swiss Resource Centre and Consultancies for Development
UDT	Urine Diversion Toilet
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
VIP	Ventilated Improved Pit latrine
WASH	Water Sanitation Hygiene
WEDC	Water Engineering and Development Centre
WHO	World Health Organization
WRC	Water Research Commission
WSP	Water and Sanitation Program
WSSCC	Water Supply and Sanitation Collaborative Council
WWTW	Waste Water Treatment Works

CHAPTER ONE
Introduction

The twentieth century has experienced the most astonishing growth of the world's population and its urbanization. The world's population increased from 1 billion at the beginning of the 19th century to more than 2.5 billion in 1950. In the following 55 years the planet gained another 4 billion people and is expected to increase by 1.7 billion people, from 6.5 billion in 2005 to 8.2 billion in 2030. However the projection also considers that population will stabilize around 10 billion by 2100 (Figure 1.1).

Figure 1.1: World Population Projections to 2100

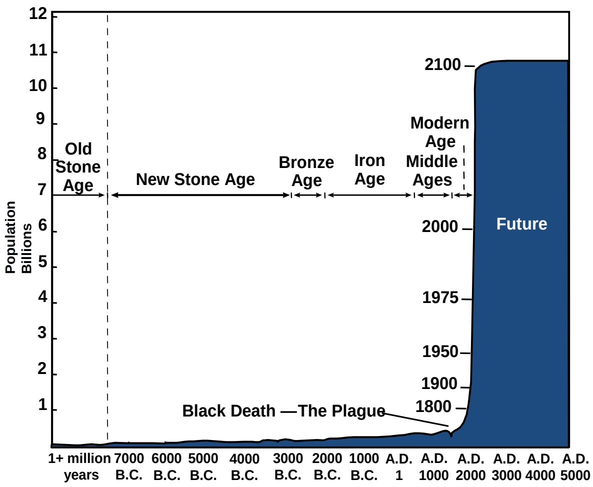
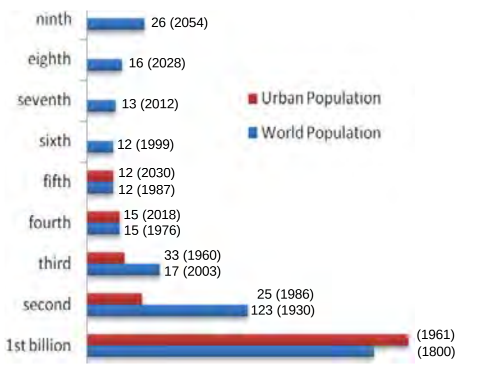


Figure 1.2: Population growth

World Population Growth
Number of years to add each billion (year)



Source1: Population Reference Bureau; United Nations, *World Population Projections to 2100.* (1998).
Sources2: First and second billion: Population Reference Bureau. Third through ninth billion: United Nations, *World Population in 2300* (medium scenario), 2003.

A parallel trend has been experienced by city growth and it is projected to continue to urbanize. In 1900 the proportion of urban population was standing at 13% while in 1950 had increased to 29% of the world's population and, according to the 2005 Revision of World Urbanization Prospects (UN) the total amount of people living in today cities have reached the 49% in 2005. Adding a new billion to the urban population has required a shorter span on every occasion (Figure 1.2). The urban population reached the first billion in 1961, 25 years later another billion was added and it took just 17 years more to join a third billion in 2003. The projections estimate to reach 4 billion in 2018 and around 5 billion by 2030, thus taking 15 and 12 years respectively. There are huge differences in the rapid growth of cities between developed and developing countries. The less developed regions are facing the higher increase in their population and urbanization numbers although industrialized countries keep the most elevated percentage of urban dwellers. It is expected that, by 2030, 56% of the third world population, traditionally rural, will be living in the urban areas while in developed countries will increase very slowly to reach 81% (see Figures 1.3 and 1.4).

Another critical distinction can be pointed to the raise of mega-cities with 10 million residents or more. It is a unique feature of the 20th century. In 2005 the globe accounted 20 mega-cities, increasing from 2 to 20 since 1950, 17 of them are located in developing countries. Therefore it is not strange that in the following decades (UN 2006) the world's population growth is estimated to be absorbed by the urban areas in developing countries. The most noticeable reason for the massive urban population growth in the developing world corresponds to its migration patterns from rural to urban areas and the expansion of towns to urban settlements.

Figure 1.3: Urban and rural population by region

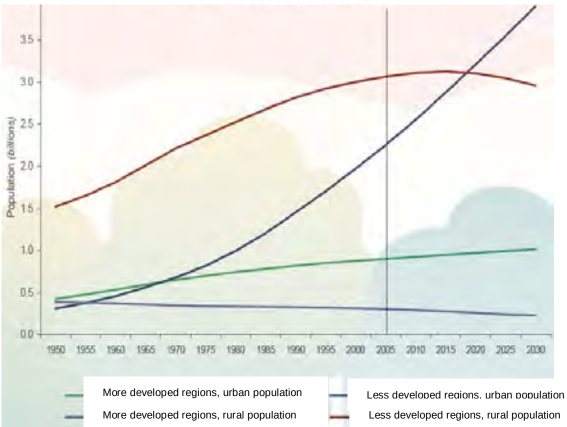
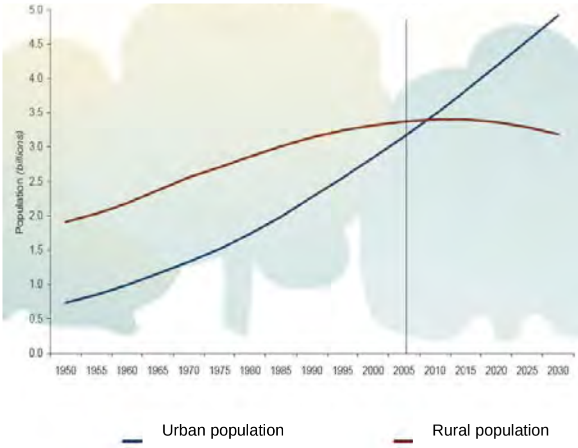


Figure 1.4: World urban and rural population



Source: United Nations, Department of Economic and Social Affairs, Population Division (2006). *World Urbanization Prospects: The 2005 Revision*. Working Paper No. ESA/P/WP/200.

Rapid urbanization is one of the most challenging aspects of the present world and future generations, especially in the less developed regions. Urban planners and governments are unable to cope with the speed of urban population growth, increasing poverty, informal housing escalation such as in peri-urban areas and slums, scarcity of water resources and urban infrastructure.

> "*The growth in many Third world cities is so rapid that present infrastructure is simply unable to handle the growing needs and infrastructure development often cannot keep up with growth rates*."
>
> (Varis, et.al.1997)

Population growth anticipation stresses the conventional approach to water and sanitation services (Scheinberg_et_al, 2006). Urban areas in developing countries face and suffer most from the consequences of rapid urbanization trends. Escalating water demand, ageing infrastructure, increasing poverty and difficult settlement patterns are some of the challenges that urban planners are unable to handle with the traditional western systems.

There is a growing acceptance that the conventional piped approaches to water supply and sanitation are unable to provide solutions for these rapidly growing cities. They are neither capable to catch up with the rapid urbanization nor able to provide a significant improvement in the present services backlog. In the developing countries the conventional paradigm does not match with the development of existing urban, peri-urban and slum areas (Schertenlieb et.al. 2000). Traditional urbanization processes are based on the previous setting up of services and infrastructure, while the current urbanization practices start with the illegal occupation of unplanned and undeveloped land by the poorest and most vulnerable communities (Hogrewe et.al. 1993).

The "Old" sanitation paradigm is founded on centralised systems for the removal of wastewater from dense urban areas. These systems rely on huge amounts of resources and extended areas available in the fringe to treat and dispose the waste. It seemed to be the most appropriate way to service the prosperous sectors of the city, such as industry and the well-off. (Looker 1998) However the current concern on decreasing accessible urban space as well as the explosion of the urban population in the developing world supposes great limitations for the traditional systems. Expensive waste water treatment plants and sewer networks become undersized by the same time they are constructed. Rapid urbanization leads to outgrowing the designed capacity of treatment plants thus tremendously reducing the effluent quality of the disposed water. Sewer networks remain far from the new areas expanded outskirts of the city.

> "*This centralized, highly water-consuming system has, however, shown its limits in some developing and transition countries, especially in fast-growing cities with limited water resources.*"
>
> (Medilanski et.al. 2006)

As a result of the above mentioned constraints the urban poor are the ones who suffer most from the increasing number of underdeveloped urban and peri-urban areas, low water quality, shortages and flood as well as drought situations (Calaguas et al. 2001).

Many centralised treatment systems directly copied from western societies have failed or ended up to be unsustainable in the developing world environment. Most of them abandoned due to high operation costs and maintenance. Moreover as an example, van Lier (1998) exposed the inadequacy of conventional systems in the Middle East caused by differences in the local sewage characteristics. While most local engineers educated under western development programs support the implementation of these systems, their lack of appropriateness is attributed to the disregard for the culture and traditions of the population, the characteristics of the land and the climate of the area where these technologies are intended to be used. Local engineers, based on traditional programs of engineering schools and unable to confront the fact that alternative and affordable systems generally imply an important involvement of the community, ends up over-relaying on conventional service delivery systems (Solo et.al., 1993). They prefer to adopt foreign engineering standards with which they are familiar, although they may turn out unsuitable for the local conditions and costly to construct and maintain.

Moreover deficient data and knowledge available about the conditions of the slums, illegal settlements or highly dense peri-urban areas in developing countries impedes the proper implementation of any sanitation system. In the same line the lack of tools for urban planners to select appropriate sanitation technologies, compliant with every specific characteristic of a given site, reinforce their over-reliance on conventional systems.

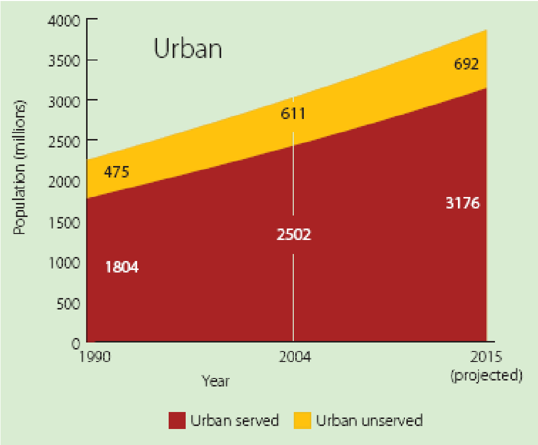
The Millennium Development Goals (MDGs) and specifically number 7 states:

> "*Ensure access to adequate and safe water and improved sanitation services for poor and poorly-serviced communities in rural and urban areas*"

In the same line target 10 of that goal aims to halve the proportion of people without sustainable access to safe drinking water and improved sanitation by 2015. It provides a useful framework to try to apply a paradigm shift (UNESCO 2006). It has been argued that meeting the MDGs will be a hard task if possible. Through their focus on water and sanitation it could provide the basic back- and play-ground to test and probe the suitability of alternative approaches than the conventional one. In this way the water and sanitation targets of the MDGs demands a fundamental change of the conventional structure towards more integrated approaches. Contrary it could be argued that due to the limited time ahead and huge backlog to be covered, expanding action instead of trials would provide at this moment better results. Although the efforts within the MDGs, it is estimated about 700 million urban citizens will still be lacking improved sanitation by 2015 (Figure 1.5). The "improved sanitation facilities" are defined by the MDGs as the following (only facilities which are not shared or are not public are considered improved):

- Flush or pour – flush to: piped sewer system, septic tank or pit latrine
- Ventilated improved pit latrine
- Pit latrine with slab
- Composting toilet

Figure 1.5: Trends in coverage: urban population with and without access to improved sanitation in 1990, 2004 and 2015 (projected)



Source: World Health Organization and UNICEF 2006. *Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade.*

Along these lines the following thesis research intends to develop a framework to support city officials, NGOs, working groups and participation processes in the decision making while trying to implement sanitation systems. An open frame that could match all the specific barriers in different environments in addition to the suitability conditions of any existing or potential sanitation system. Therefore the possibility to provide a valuable tool in order to confront the challenging goals of the MDGs as well as to assist the desperate situation of billions of human beings. During the course of this thesis "sanitation system" is used to describe the path of the different sanitation practices from source to disposal or reuse involving collection, transport and treatment. It is explained in more detail in Chapter 3.

As mentioned in Loetscher (2002) and motivated in the workshop on environmental sanitation "Household-centred environmental sanitation" in Dubendorf there is an:

> "*immediate need for a decision system that is simple, can be easily understood by the users, can be applied with skills that are locally available as much as possible, and which, while not necessarily producing ''correct'' solutions, helps users to avoid taking decisions that are later found to be seriously wrong*"

(SANDEC, 1999)

The demand for a sanitation decision support system is strengthen by the complex socio-economic, urbanization trends and organization of urban areas in developing countries that constrain the ability of city planners to select appropriate sanitation systems. The number of sanitation models aiming to support the selection of sanitation systems is rather limited. There's a need for improving the decision-making process and therefore to expand and improve these instruments as well as to develop a comprehensive set of criteria to evaluate the existing sanitation support tools.

In this line the first objective of this thesis is to find out, collect and evaluate the existing sanitation decision-support tools through literature review (Chapter 2) and in addition to outline their strengths and weaknesses. From this evaluation the methodology (Chapter 3) defines the proposed way to develop an improved sanitation decision support tool in order to overcome and fulfil the weaknesses of the previous models. In the following chapters the design of this decision support tool is described and tested using data from the informal settlements in Cape Town, South Africa (Chapters 4 and 5).

From this interest arise the following general research questions intended to be answered during the course of the Literature Review:

1. *Which decision support tools exist in the present intending to assist in the selection of appropriate sanitation systems?*

Once the decision support tools are identified the following research question applies:

2. *How appropriate are these sanitation decision support tools?*

(Refers to the fulfilment of a set of six evaluative criteria: user-friendliness, transparency, flexibility, versatility, interactivity and level of detail; defined in Chapter 2)

Based on the possible outcome of the evaluation process the scope of the question is narrowed to:

3. *How can the existing sanitation decision support tools be improved to comply with the evaluative criteria?*

(The answer to this question, in Chapter 3, is used as ground foundations for the following design of a new sanitation decision support tool).

Finally in order to assess the new decision support tool using field data, the last research question comes out:

4. *How does it perform using data from the informal settlements in Cape Town, South Africa?*

(The evaluation of the pilot testing in Chapter 5 provides the response).

CHAPTER TWO
Appropriate Sanitation Decision Support Tools

For the purpose of this thesis research two major literature lines were identified in order to draw a suitable framework for the selection of appropriate sanitation systems. First of all the theoretical approach based on the classification of different sanitation systems with the aim to define their main characteristics and limitations. On the other hand existing support tools on the selection of suitable sanitation systems were considered to plan and design the settlements database and sanitation decision support tool in Chapter 3 and 4.

Furthermore at the end of this Chapter (section 2.3) a third literature line based on the evaluation criteria for decision support systems is examined with the aim to assess the identified sanitation support tools and in order to highlight and overcome the weaknesses of each one of the reviewed models.

In front of the world-wide current sanitation crisis and since the old paradigm has probed inadequate to implement in most rapid-growing urban environments, new approaches have been developed. The 1977 United Nations 'Water Conference' at Mar del Plata set up an International Water and Sanitation Decade (1981-1990) with the aim to improve the existing situation on water supply and sanitation. Despite its failure to meet the goals, there was a fundamental conclusion, the importance of country-specific characteristics and the need to focus in demand-based approaches to achieve sustainable development. 10 years later, on September 2000, 192 United Nations member states, in their eagerness to meet the needs of the world's poorest agreed on 8 fundamental Millennium Development Goals (MDGs), within them, the target of halving the number of people without basic water supply and sanitation by 2015. Rapid urbanization, increasing poverty and limited resources make these goals difficult to attain and challenging. Nevertheless in order to accomplish the MDGs and as a result of the conventional models' inability to tackle the enormous backlog in water supply and sanitation services, it is necessary to develop new approaches compliant with the current and future needs and circumstances.

In this line in February 2000 the Environmental Sanitation Working Group (ESWG) created by the Water Supply and Sanitation Collaborative Council (WSSCC) in a meeting in Bellagio identified the need for more effective sanitation solutions in a holistic and integrated approach leading to the so called Bellagio Principals and the Household Centred Environmental Sanitation (HCES) approach (WASH 2004). In this way they support a shift from the conventional linear model to a resource recovery circular model founded on people-centred solutions, on-site conditions, and economic and environmental balances.

Some relevant literature used for the development of this Thesis work can be found, among others, on the publications under 'the appropriate technology phase' from the World Bank International Drinking Water Supply and Sanitation Decade Program as well as the following studies of Kalbermatten and Mara.

Additionally several research papers and guidelines from international institutions and organizations such as United Nations (UNDP, UNESCO), the World Health Organization (WHO), the World Bank, the Swiss Resource Centre and Consultancies for Development (skat), the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), the Swiss Federal Institute for Environmental Science and Technology (EAWAG), the International Water and Sanitation Center (IRC), the International Water Association (IWA), the Water and Sanitation Program (WSP) and the Sanitation Connection Network are gratefully acknowledged.

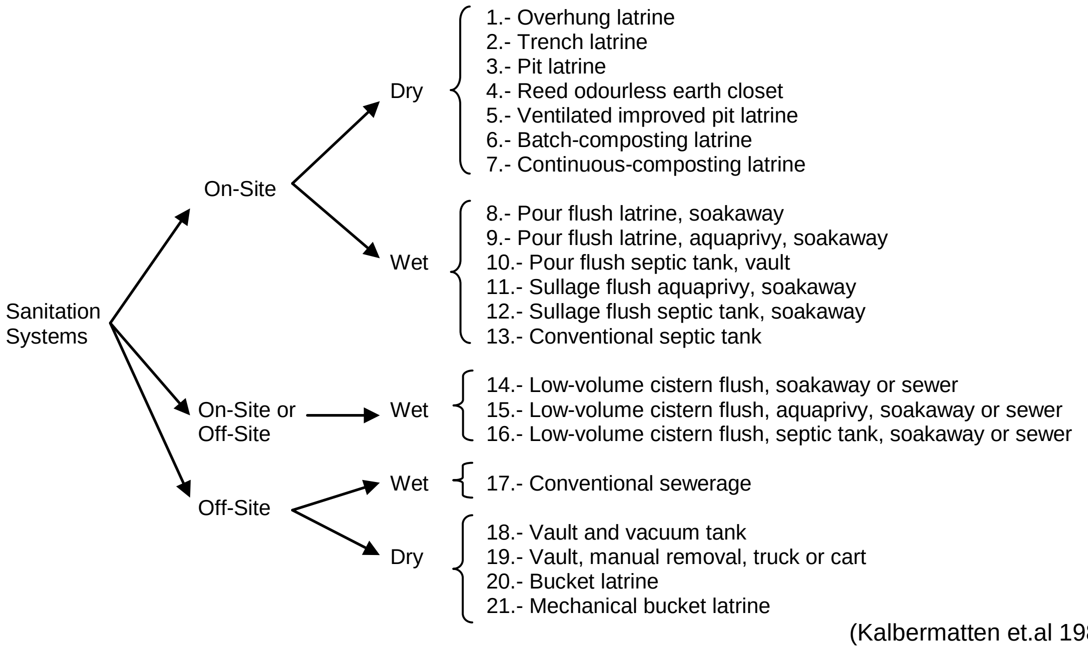
2.1. Classification of Sanitation Systems

Each sanitation system involves different levels of environmental and health protection, water consumption, user convenience, treatment and transport. Classification of sanitation systems can be organised in several ways depending on disposal and/or treatment location, water use, community application, hygienic practices, costs, reuse potential, or even public-private responsibility.

One of the most common classifications of sanitation technologies is associated to the disposal location of human waste; either on- or off-site sanitation systems. On-site systems imply the disposal of excreta and related wastes such as toilet paper and wastewater on the same ground or nearby to the sanitation facility. Systems included in this category are: ventilated improved pit latrines (VIP), urine diversion composting latrines (UDT), pour-flush latrines, no water consumption latrines (NOWAC), aquaprivies and septic tanks. On the other hand off-site systems involve the removal of human waste from the plot by transferring it to an external disposal site or treatment facility.

The transport can be organised in several ways such as sewers or vacuum tankers as well as depending on the emptying frequency for systems involving temporary storage. Systems included in this classification are: chemical and container latrines, conservancy tanks, latrines connected to conventional, small bore and shallow/simplified sewer networks.

Another widespread classification is based on the water use, dividing the different sanitation technologies in wet systems such as septic tanks and dry systems for instance composting latrines. As a basic classification see the following example related to figure 2.1 and the more recent and detailed classification in Table 2.1.



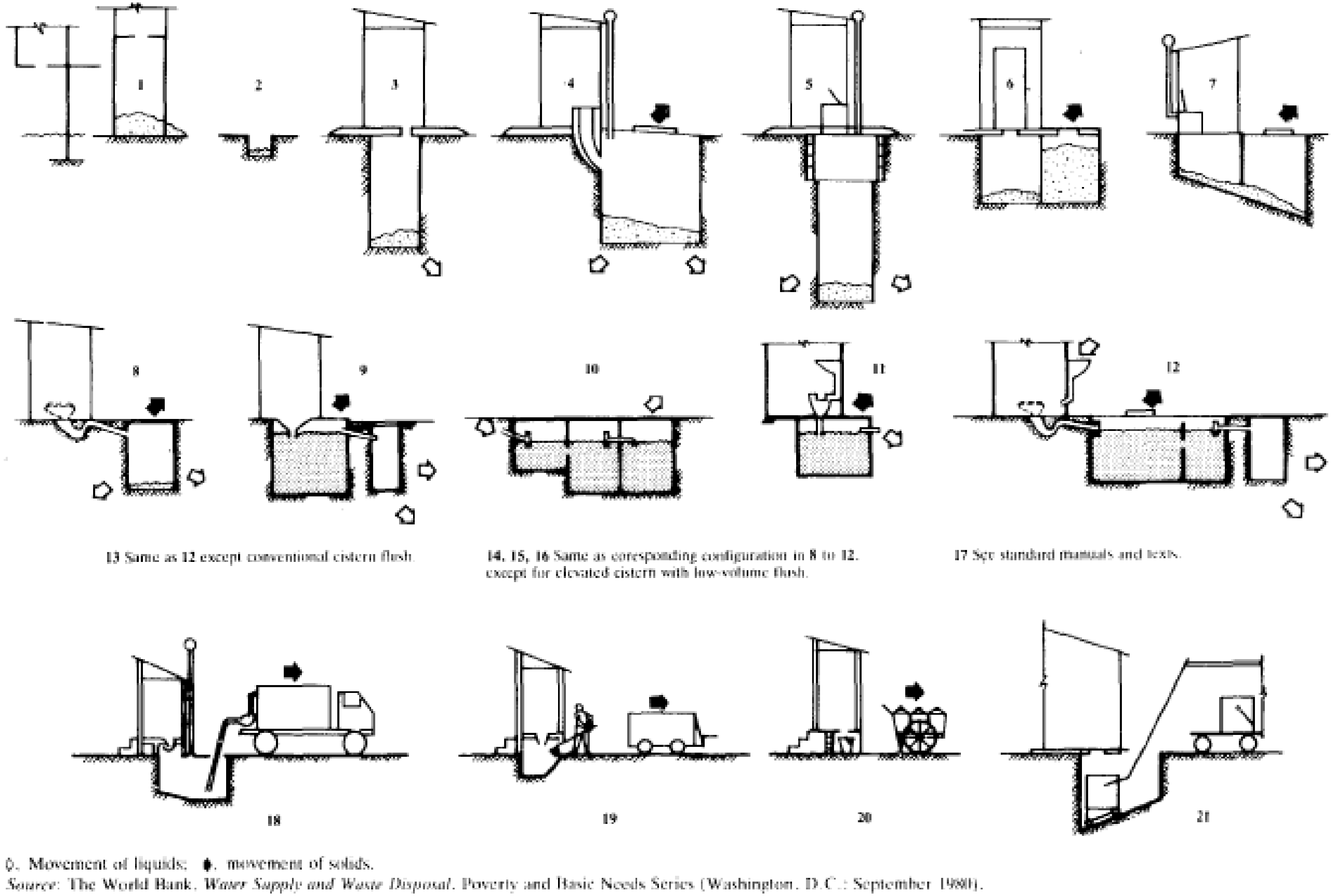
(Kalbermatten et.al 1980)

While the general classification of sanitation systems benefits from its wide agreement within the sanitary specialists, the limiting criteria as well as its values differs greatly depending on the social, economic, institutional, environmental and technological perspective. The number of constraints increases proportionally to the scope of view thus a broad range of stakeholders' involvement is essential in order to overcome the numerous limitations that each sanitation system offers in front of the specific service delivery conditions and circumstances.

Therefore in this thesis research I propose a sanitation support tool, focussing specifically on the technical selection of sanitation systems based on physical data, thus intending to provide a useful instrument to enable a more comprehensible view of the settlements pattern and available sanitation options in the decision-making and participation process. It could be used by city officials, working groups as well as non-governmental organizations trying to facilitate the discussion on available sanitation options and the collectively definition of site-specific constraining criteria.

Since the 80's, comparative criteria on the appropriateness of sanitation systems have been developed in order to assess its suitability on diverse environments. Such criteria include land and water availability, groundwater table, terrain conditions, housing density, operating costs, institutional requirements, reuse potential, etc. As it is shown in table 2.2 each sanitation system is limited by different factors and values. However several authors such as 'A Guide to the Development of on-Site Sanitation' from the WHO in 1992 or Kalbermatten, et.al., 1980 refer to the same common limitations, mainly the physical conditions corresponding to the lay-out of the settlement. In this way among others the topography, water table, type of soil, water availability, flooding prone risk, population number and density.

Figure 2.1: Generic Classification of Sanitation Systems



Source: The World Bank, Water Supply and Waste Disposal, Poverty and Basic Needs Series (Washington, D.C, September 1980).

Table 2.1: Sanitation Systems Typology

Sanitation Systems Typology				
SYSTEM	General Description	Technical options		
		Toilet	Grey water	Stormwater
1A On-site dry	Dry latrines hygienisation and re-use of excreta in gardens.	Twin pits or , composting toilet	Infiltration, onsite reuse or discharge into drains	Onsite reuse, infiltration or discharge into drains
1B On site dry with (semi-) centralised treatment	Dry latrines, collection & treatment of faecal sludge at neighbourhood or city level before reuse in agriculture	Simple pit latrines	Infiltration or discharge into drains	Infiltration or discharge into drains
1C On site dry with urine diversion	HH latrine with urine separation. On-site reuse of urine in garden. Faeces dehydrated on-site. Possible reuse onsite or further downstream	Urine separating latrines, co-composting toilets, twin pits	Treatment and reuse at household level (eg constructed wetland)	Infiltration or discharge into drains
2A On site semi wet (pour-flush)	Latrine system at hh level with infiltration of liquid wastes, emptying of faecal sludge when full (additional hygienisation?) and reuse in garden or disposal	Twin pit pour flush or similar	Infiltration, onsite reuse or discharge into drains	Infiltration, onsite reuse or discharge into drains
2B On site wet with (semi) centralised treatment	As 2A with faecal sludge evacuation system, transport and treatment on neighbourhood or centralised level before reuse in agriculture	Twin pit pour flush or similar may have septic tank or ABR	Mixed with blackwater and treated on hh or neighbourhood level, infiltrated or reused in garden and agriculture	On-site use or infiltration as in 1A; discharge into drains, possible reuse in agriculture
3A Waterborne with (pre) treatment and (semi) centralized treatment	Toilet with on-site pre-treatment linked to small bore sewerage system.	Pour flush or flush toilet with septic tank/ vault or similar	Mixed with blackwater and transported for treatment	Discharge into drainage.
3B Waterborne with (semi) centralized treatment	Same as 3A however without pretreatment on hh level and uses simplified sewers	Pour flush or flush toilet	On-site use or infiltration as in 1A; or else discharge into drains for evacuation and discharge in surface water or reuse in agriculture	On-site use or infiltration as in 1A; or else discharge into drains for evacuation and discharge in surface water or reuse in agriculture
3C Waterborne with centralized treatment	Flush toilets and conventional combined sewers	Flush toilet	Mixed with black water in the sewer	Mixed with blackwater – possibility of storm-overflow and discharge to water bodies.

Source: Sanitation 21. Simple Approaches to Complex Sanitation. A draft Framework for Analysis. IWA 2006.

Table 2.2: Descriptive Comparison of Sanitation Technologies (Kalbermatten, et.al., 1980).

Sanitation technology	*Rural application*	*Urban application*	*Construction cost*	*Operating cost*	*Ease of construction*	*Self-help potential*	*Water requirement*	*Required soil conditions*	*Complementary off-site investment*[a]	*Reuse potential*	*Health benefits*	*Institutional requirements*
Ventilated improved pit (VIP) latrines and Reed Odorless Earth Closets (ROEC's)	Suitable	Suitable in L/ M-density areas	L	L	Very easy except in wet or rocky ground	H	None	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Good	L
Pour-flush (PF) toilets	Suitable	Suitable in L/ M-density areas	L	L	Easy	H	Water near toilet	Stable permeable soil; groundwater at least 1 meter below surface[b]	None	L	Very good	L
Double vault composting (DVC) toilets	Suitable	Suitable in L/ M density areas	M	L	Very easy except in wet or rocky ground	H	None	None (can be built above ground)	None	H	Good	L
Self-topping aquaprivy	Suitable	Suitable in L/ M-density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil; groundwater at least 1 meter below surface[b]	Treatment facilities for sludge	M	Very good	L
Septic tank	Suitable for rural institutions	Suitable in L/ M-density areas	H	H	Requires some skilled labor	L	Water piped to house and toilet	Permeable soil; groundwater at least 1 meter below surface[b]	Off-site treatment facilities for sludge	M	Very good	L
Three-stage septic tanks	Suitable	Suitable in L/ M-density areas	M	L	Requires some skilled labor	H	Water near toilet	Permeable soil; groundwater at least 1 meter below surface[b]	Treatment facilities for sludge	M	Very good	L
Vault toilets and cartage	Not suitable	Suitable	M	H	Requires some skilled labor	H (for vault construction)	Water near toilet	None (can be built above ground)	Treatment facilities for night soil	H	Very good	VH
Sewered PF toilets, septic tanks, aquaprivies	Not suitable	Suitable	H	M	Requires skilled engineer/ builder	L	Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H
Sewerage	Not suitable	Suitable	VH	H	Requires skilled engineer/ builder	L	Water piped to house and toilet	None	Sewers and treatment facilities	H	Very good	H

Note: L, low; M, medium; H, high; VH, very high.

a. On- or off-site sullage disposal facilities are required for nonsewered technologies with water service levels in excess of 50 to 100 lcd, depending on population density.

b. If groundwater is less than 1 meter below the surface, a plinth can be built.

Physical site conditions are regarded as relatively fixed and consistent information giving the basic frame were to operate. On the other hand although the population size, density as well as the availability of water supply and distance to the formal services is variable and unpredictable they play an extremely important role for the appropriate implementation of any sanitation system.

Table 2.3: Critical Information Needed for Selection and Design of Sanitation Systems

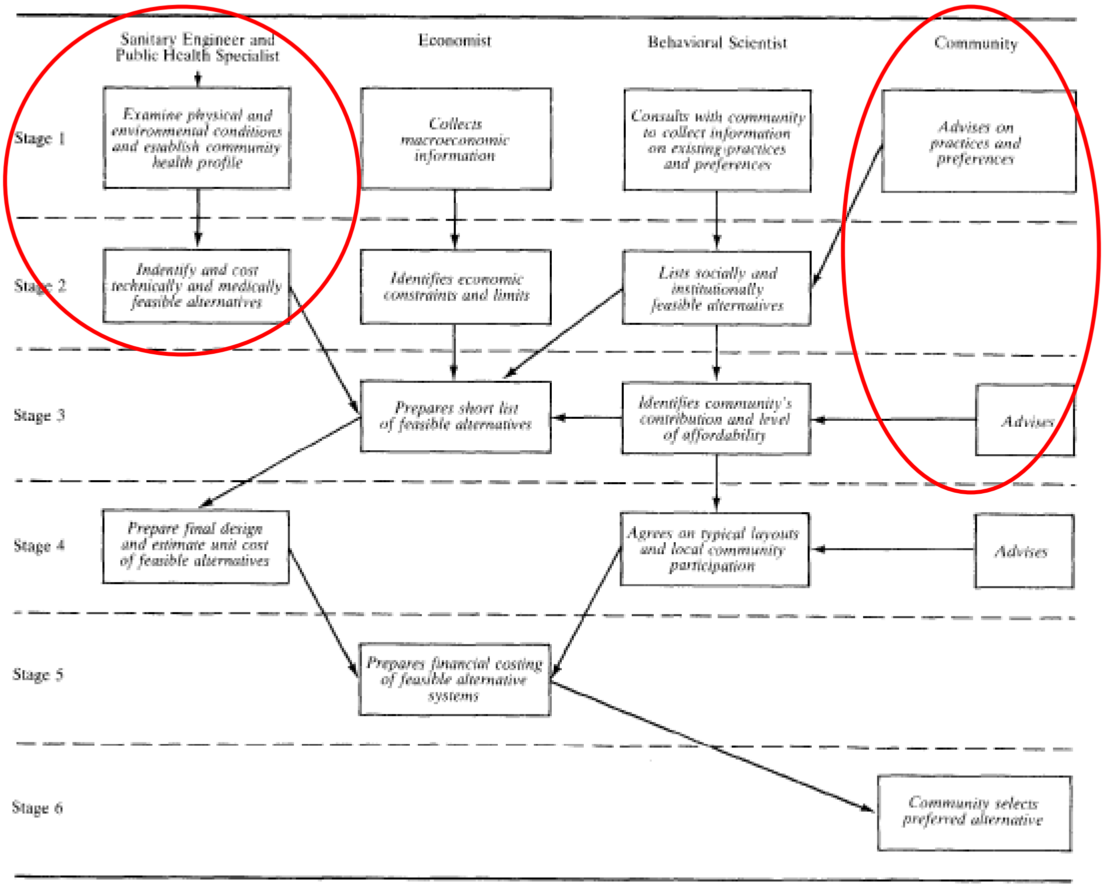
Item	*Description*
Climatic conditions	Temperature ranges Precipitation (including drought or flood periods)
Site conditions	Topography Geology (including soil stability) Hydrogeology (including seasonal water table fluctuations) Vulnerability to flooding
Population	Number (present and projected) Density (including growth patterns) Housing types (including occupancy rates and tenure patterns) Health status (of all age groups) Income levels Locally available skills (managerial and technical) Locally available materials and components Municipal services available (including roads, power)
Environmental sanitation	Existing water supply service levels (including accessibility, reliability, and costs) Marginal costs of water supply improvements Existing facilities for excreta disposal, sullage removal, and storm drainage Other environmental problems (such as garbage or animal wastes)
Sociocultural factors	People's perceptions of present situation, interest in or susceptibility to change Reasons for acceptance or rejection of any previous upgrading attempts Level of hygiene education Religious or cultural factors affecting hygiene practices and technology choice Location or use of facilities by both sexes and all age groups Attitudes toward resource reclamation Attitudes toward communal or shared facilities
Institutional framework	Allocation of responsibility: effectiveness of state, local, or municipal institutions in providing water, sewerage, sanitation, street cleaning, drainage, health and education services, housing and urban upgrading

Note: The priority given various items will vary with the sanitation options being considered; the list above indicates typical areas to be investigated by planners and designers.

Source: The World Bank, Water Supply and Waste Disposal, Poverty and Basic Needs Series (Washington, D.C, September 1980).

In addition as it has been previously mentioned it is particularly important to locate the tool in the correct arrangement within the decision making process. As it shows figure 2.2 a database interface would be a great support mechanism, in stage 1 of the sanitary engineers column, to collect and maintain the physical and environmental conditions of the specific site while the actual sanitation decision screening tool would be relevant for the identification of technically feasible alternatives in stage 2. In the same way it could be used in order to provide advice on community preferences.

Figure 2.2: Recommended Structure of Feasibility Studies for Sanitation Program Planning



Source: Appropriate Sanitation Alternatives. *A Planning and Design Manual*. World Bank Studies in Water Supply and Sanitation 2, 1982.

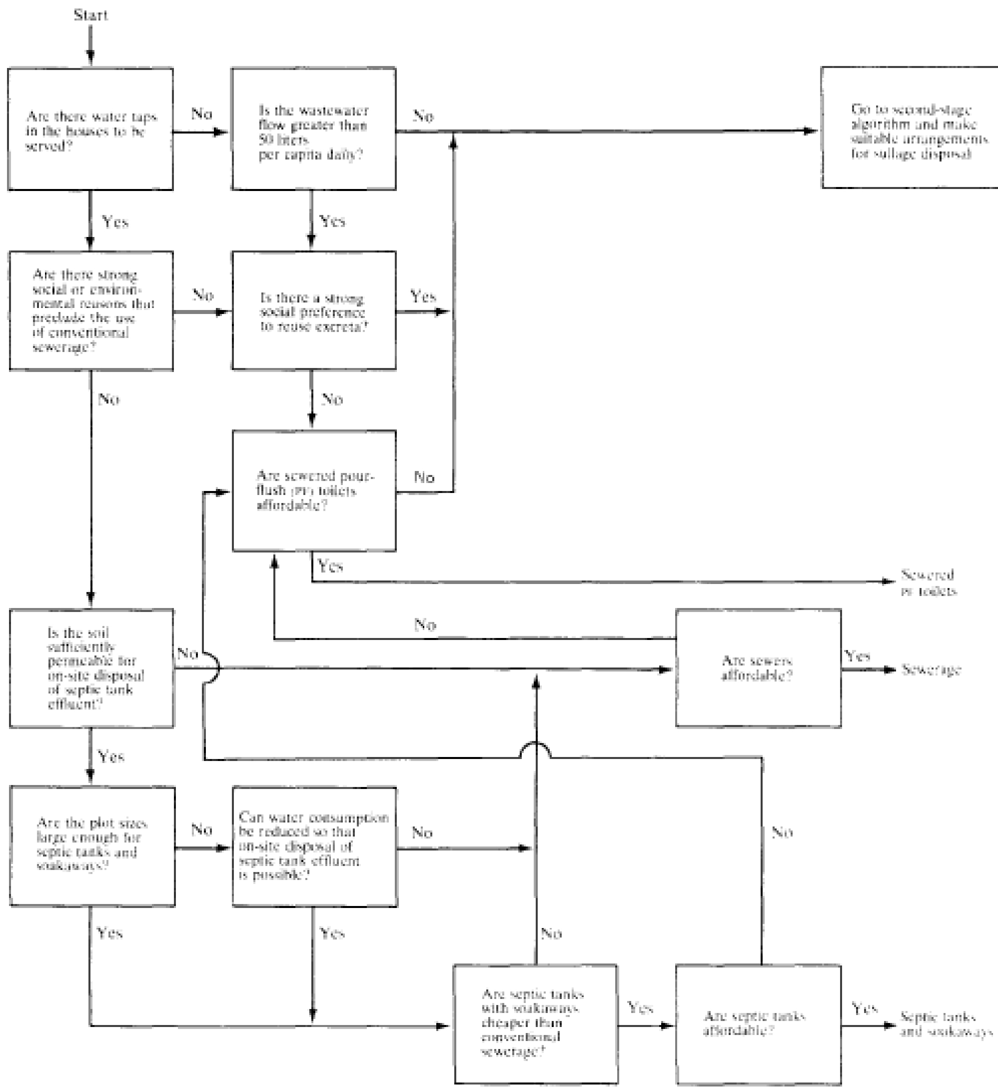
2.2. Existing Sanitation Decision Support Tools

Sanitation decision support tools are not common in the present implementation process. Although several guidelines and models have been elaborated by institutions such as WEDC (Cotton et.al 1988) or WHO (Franceys et.al 1992) in the last decades, few of them challenges a detailed insight on specific outcomes associated to those standards.

The first decision support tool I was able to identify through the literature review was made available by Kalbermatten and Mara around 1980 and during the

International Water and Sanitation Decade. They designed an algorithm (see figure 2.3) based on low-cost sanitation systems intended to match the main characteristics of a settlement. The feasible option is reached by a set of questions about the specific conditions of the site leading to close answers (Yes or No). The algorithm involves three stages of progression and gets narrow in order to offer one single solution.

Figure 2.3: First-stage Algorithm for Selection of Sanitation Technology

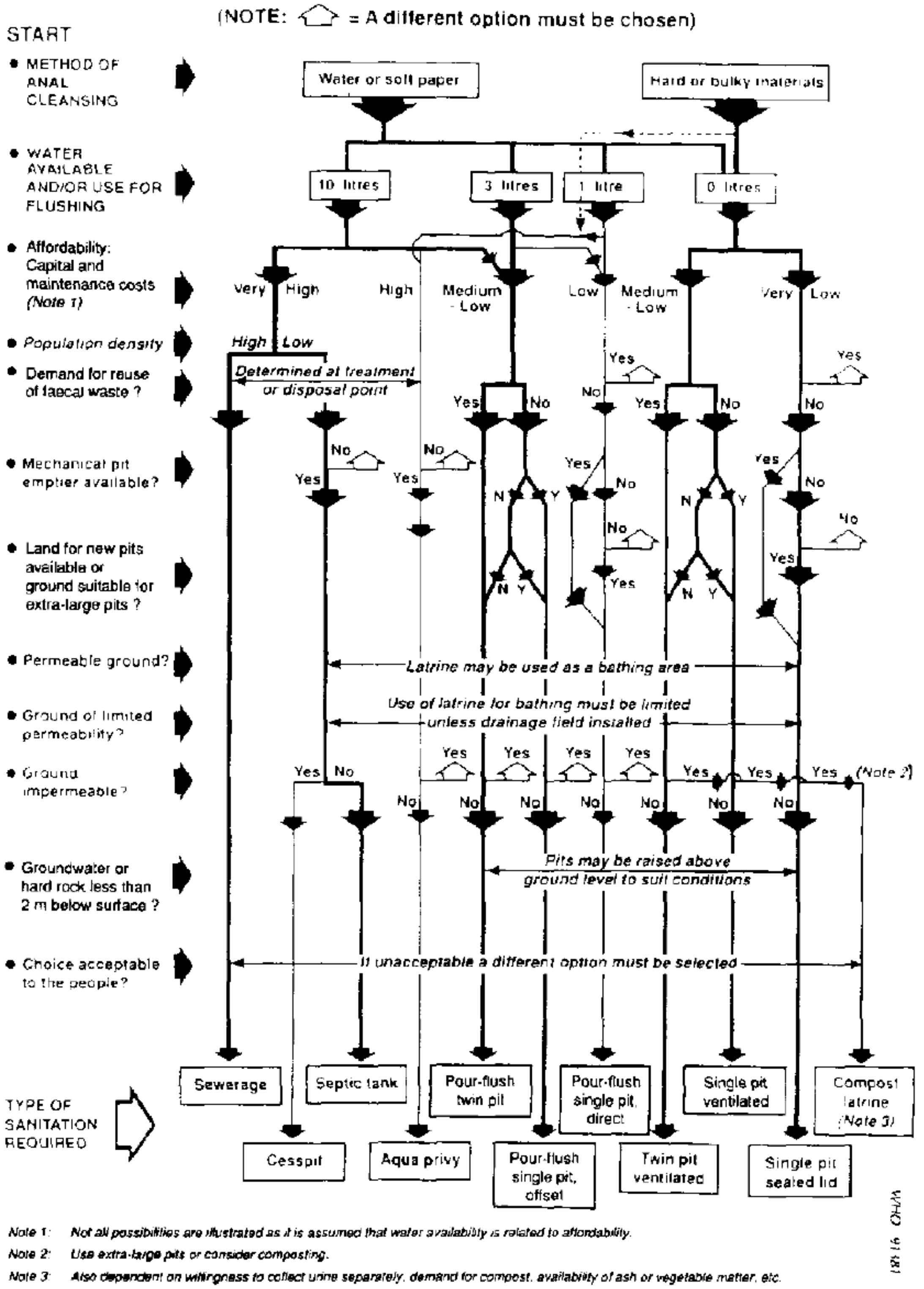


Source: Kalbermatten, Mara, et. al., 1982.

It is a fabulous, fascinating and inspiring design, the model besides its simplicity and despite its few limitations is a complete, elaborated and straightforwardly comprehensive tool.

In the same line in 1992 WHO presented a 'Decision Tree for Selection of Sanitation' (R Franceys, J Pickford & R Reed). It is a little bit more complex and detailed than the previous one and including for first time the issue of community acceptability besides affordability. It is also a revealing work although based on the same grounds of the preceding. It intends to offer again a sole option as an outcome of the decision tree (see figure 2.4).

Figure 2.4: Decision Tree for Selection of Sanitation.



Source: *A guide to the development of On-Site sanitation*, WHO, 1992

In the paper from Rachelle G. Navarro (1994) it can be found a basic and extremely simple screening instrument combining different sanitation systems with its own limitations in diverse environments. Although its lack of detail I find it a good example of simplicity and clearness.

Figure 2.5: Preliminary Comparative Analysis of Low-Cost Sanitation Systems.

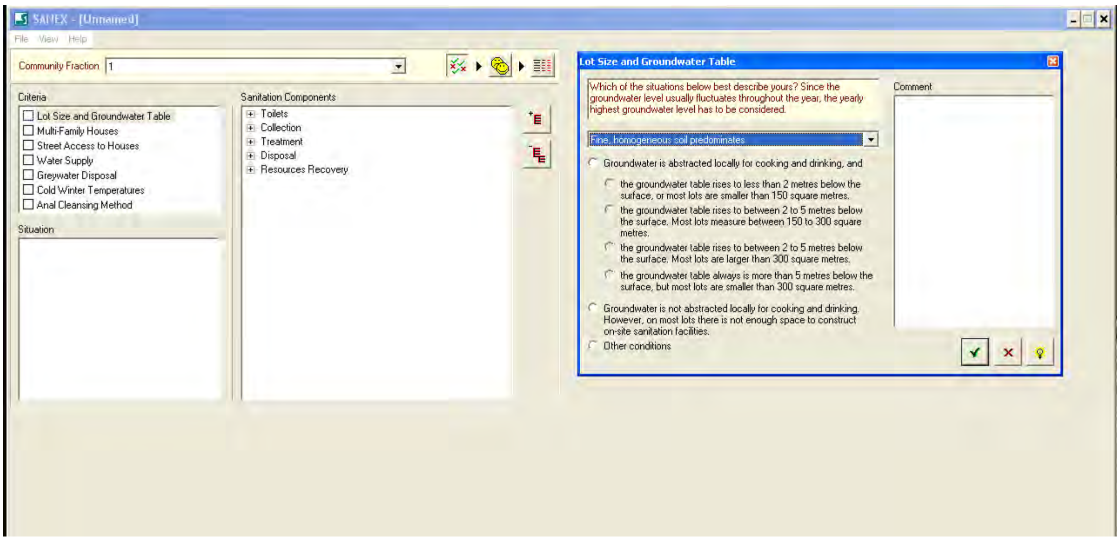
Key Considerations	Sanitation Systems: Pit Latrines	Raised Pit Latrine	Double Pit Latrine	Septic Tank	Aqua Privy	Composting Toilets	Bucket Latrine	Vault and Cartage	Shallow Sewer System	Small Bore Sewer System
Feasible in adverse ground condition	○	⊖	⊖	○	○	●	●	●	●	●
Feasible in high density settlements	○	○	○	○	○	⊖	●	●	●	●
Minimum water requirement	●	●	●	⊖	⊖	●	●	⊖	●	●
No large equipment for waste collection	●	●	●	⊖	○	●	●	⊖	●	●
No wastehandling requirement	●	●	●	●	●	○	○	●	●	●
Allows use of water for toilet hygiene	○	○	○	●	●	○	○	●	●	●

Legend:
● Feasible
⊖ Feasible but conditional
○ Not feasible
(shaded) Possible Options

Source**:** Rachelle G. Navarro. *Improving Sanitation in Coastal Communities with Special Reference to Puerto Princesa, Palawan Province, Philippines*. McGill University, Montreal, July, 1994.

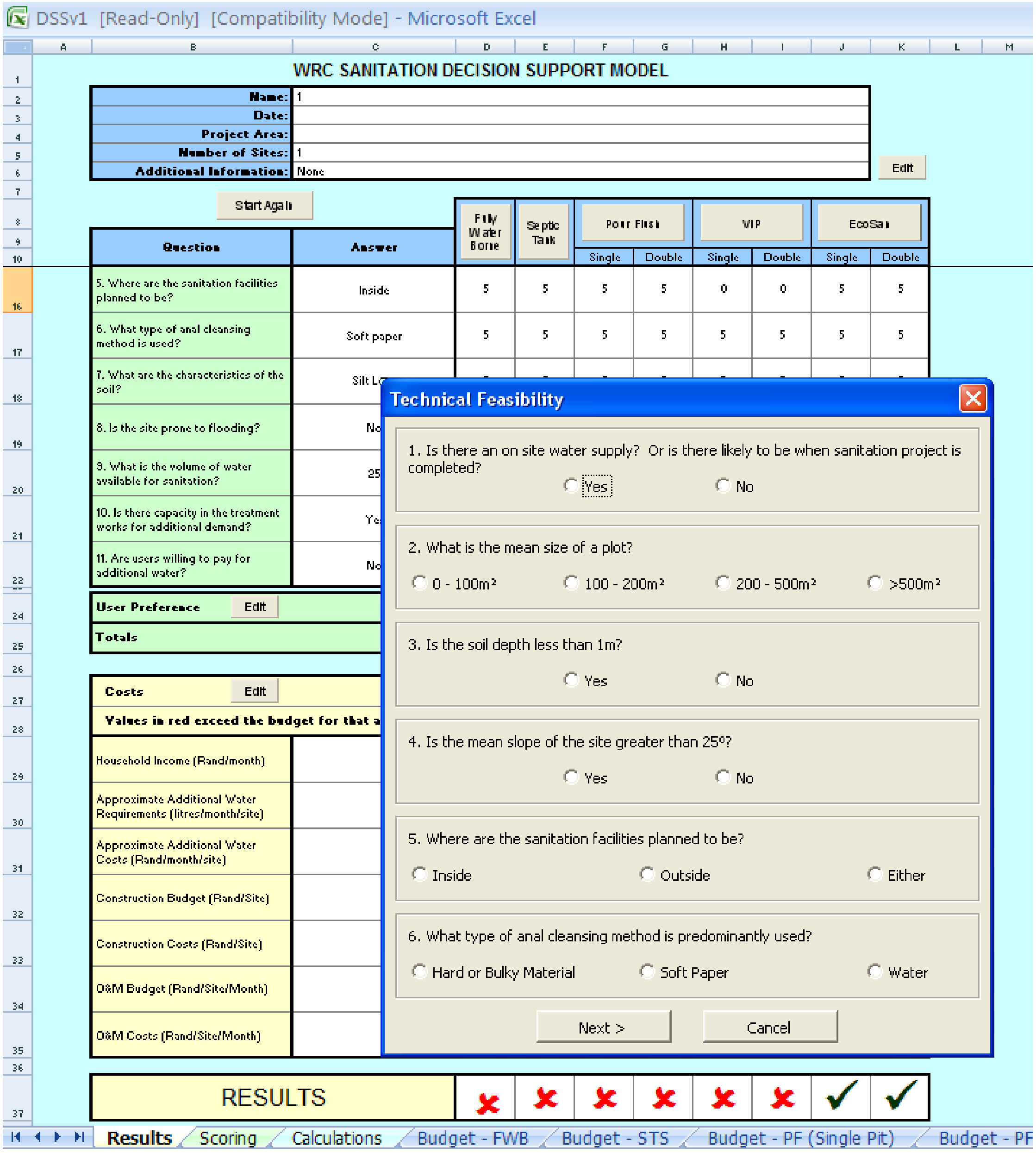
However it is not since 2002 that appears 'A decision support system for selecting sanitation systems in developing countries' (SANEX) from Thomas Loetscher, the first software algorithm developed to assess the suitability of different sanitation options. It is a brilliant work conceived in 2 separate steps. The first one is based on the screening process of diverse sanitation systems to assess its feasibility while the second step comprises a set of elaborated techniques and criteria to rate the remaining feasible options derived from its implementability and sustainability. SANEX provides a relatively user-friendly interface (see example below) in a complex mathematical frame.

Figure 2.6: SANEX screenshots



Finally the beginning of 2007 brought the 'WRC Sanitation Support Model' developed by the Water Research Commission of South Africa. It is based on the technical feasibility of few sanitation options such as fully water borne, septic tank, pour-flush, VIP and Ecosan. The Excel screening process is founded in the pre-estimated ratings related to the technical limitations of each sanitation system. The data introduced in the model is later used to approximate the costs related to the implementation of the feasible systems.

Figure 2.7: WRC Decision Support Model screenshots



Decision support models and screening tools are commonly and increasingly used in the present. Much literature can be found on this topic however few of them focus on sanitation issues and specifically on the selection of suitable sanitation systems. Nevertheless I have been able to report the existence of some of them and in consequence to answer positively the first research question introduced in Chapter 1.

2.3. Assessment of Sanitation Decision Support Tools

One of the main aspects for success of a decision support model is the approach to produce knowledge from the data acquired in its frame such as a database and mathematical techniques and the way is presented to the end users (Engelen 2000). The selection of a proper structural design is of utmost importance. In order to achieve the most favourable application, decision support tools should fulfil a set of evaluative criteria.

> "*The ideal would be to develop a single, integrated toolkit that can be used for different purposes in different stages of the process*."
>
> (Cloete F. 2001)

Experience in the design of decision support tools identifies the significance of the assessment dimensions flexibility, user-friendliness and adaptability (Henderson 1985). Although the previously mentioned references define a variable number of evaluative criteria as well as slightly different extension of its characterization I have tried to develop a homogeneous list of 6 criteria (combining the ones provided in the references) in order to establish the weaknesses and strengths of the decision support tools involved in section 2.2.

A different list of criteria as well as alternative interpretations could have been reasonable. However taking into account that they are not all elaborated in the same format (flow diagrams, decision tables or computer-based) I consider the selected criteria adequate enough to illustrate the distinctive features of each structural design and their implications for its operation and end-users.

Evaluative Criteria

User-friendliness: User friendliness of the system refers very much to the ease with which the system can be used by its intended end-user (simplicity). As little as possible time should be lost in executing tasks that are not immediately relevant to the problems for which it is developed. User friendliness is among others obtained if the system has a well designed, intuitive and uniform user interface. Also, a system is most user-friendly if it is equipped with an appropriate and easy to manipulate set of tools required for carrying out the analytical tasks (Engelen 2000). Because of the frequent low levels of literacy (technical and/or electronic) among public officials and communities, especially in developing countries, the simpler the user-interface, the better. This means that the use of simple concepts and clear commands (fixed or prompting) guiding users step by step through the model improves its value (Cloete F. 2001).

Transparency: Transparency refers to the tractability of the results generated by the system as well as the documentation of the different tasks carried out by the system. The more the system will carry out its tasks in a manner that makes intuitive sense to the end-user, the more transparent it will be. The more models and tools of the system are opened up and documented, the more transparent it will be (Engelen 2000). Is there a clear visualization of the result, outputs and the path to reach them? How were the data, information and results ensured? How could the input data and the final output be archived for later use? (RBA Centre 2003).

Flexibility: was the tool capable of incorporating user remarks, local knowledge, new information and new issues? Was it sensitive to local context (in term of local culture, local data, local models)? Could the data choices, assumptions and constraints be manipulated, added or diverted? (RBA Centre 2003).

Versatility/Adaptability: it refers to the ability to address more than one problem or situation and to be applied in different settings for different purposes (Cloete F. 2001). Could it be adapted to address universal issues? At which pace could it be adapted? (RBA Centre 2003). Is it easy to upgrade?

Interactivity: it refers to the ease with which the end-user can interact with the system. What proportion of the tasks can the user carry out directly and via the user-interface of the system without having to fall back on other analytical instruments? What tools are available in the system to support the user in carrying out these analytical tasks during a session with the system? How much effort then is involved in carrying out the tasks, and what kind of manoeuvres are required on behalf of the user? (Engelen 2000).

Level of Detail: it refers to the proportion of relevant domain processes that are generally represented by the models and the tools of the system at a sufficient level of completeness (Engelen 2000).

Table 2.4 presents an evaluation matrix showing the weaknesses and strengths of the five sanitation decision support tools relative to these criteria.

		SANITATION DECISION SUPPORT TOOLS				
		Kalbermatten 1982	WHO 1992	Navarro 1994	SANEX 2002	WRC 2007
CRITERIA	User-friendliness	++	+	++	+	++
	Transparency	++	++	+	-	+
	Flexibility	-	-	- -	- +	- +
	Versatility/Adaptability	- -	- -	- -	-	-
	Interactivity	- +	- +	- -	++	+
	Level of detail	-	-	- -	++	+

Table 2.4: Assessment of sanitation support tools. 5 points scale (--worst to best ++)

The sanitation algorithms developed by Kalbermatten (1982) and WHO (1992) although they present a lucid and transparent process framework they are accounted with an excessively rigid structure. The user is unable to decide on or modify any pre-established routine. Since their condition of flow diagrams they are unable to deliver enhanced versatility and interactivity to the process. Moreover the model lacks in the provision of actual values to support the decision that leads to the feasible systems in one way or another leading to a low level of detail.

In the case of the decision table from Navarro (1994) while it displays the results in a nice and comprehensive frame its simplicity fails to provide any footprint in the rest of evaluative dimensions.

Contrary, the big improvement of SANEX-software is the level of detail providing definite limiting values specific for each sanitation system and dependent from the site lay out. Furthermore as a computer-based model it allows a higher interactivity with the user. However these values are fixed by the author and concealed into the program thus making it impossible to follow the routine and realise the explicit constraints leading to the feasibility of the systems. The lack of transparency and flexibility to decide on the values limiting the suitability of the sanitation options weakens the universal adaptability of the model.

In the same line the WRC tool has a clear and simple framework with high interactivity in addition to improved transparency. Besides that the user is able to consult at any time the screening values defined in the model, its outcome describes the main constraints affecting the unfeasible sanitation systems. On the other hand and similarly to SANEX the ranking values deciding on the appropriateness of the sanitation options are predetermined in advance and limiting its flexibility. Within the few sanitation systems included in the model, Ecosan is slightly biased while the other systems are strongly constrained. Based on the screening values of the model Ecosan would be just limited in the case of water use as anal cleansing method. Aside its isolated limitation what surprised me is the inexistent consideration of housing-population density as a barrier for the selection of sanitation systems in the whole model.

Nevertheless while the first algorithms are founded in permanent structures and open uncertainties the modern computer-based models stand for fixed limiting values in variable environments. A common feature in all of them is that whatever site specific conditions are present, almost all tools provide if not always a feasible sanitation option in the outcome of the model. This is something hard to believe taking into account the existing situation in most developing countries.

While computer-based models are able to maintain a friendly user interface and improve considerably the interactivity and level of detail they seem to partly weaken its transparency. In any case a common characteristic in the five models presented is that none of them have the capacity to offer enough if any flexibility and versatility to the decision process.

In order to conclude this chapter I come back to the second research question posed in the introduction of this thesis. Based on the outcome of the assessment in table 2.4 it can be affirmed that there are no decision support tools that fit for its purpose, by means of lacking some of the requirements for its certain application. In this way besides transparency, the dimensions flexibility and versatility will play an important role in the design and outcome of the proposed screening tool in the following chapters.

CHAPTER THREE
Methodology

Based on the outcome of the sanitation decision support tools assessment (Table 2.4) this chapter aims to provide the grounds for the design of a new decision-support tool. In this line the weaknesses of the previous models are used as guiding principles for the improvement of the new design. In addition at the end of this chapter the steps followed during the planning and execution of the sanitation decision support tool are outlined.

While computer-based decision support systems provide inherent interactivity, the tool described in this thesis intends to maintain a high degree of user-friendliness at the same time that aims to improve the below mentioned dimensions. Therefore in order to overcome some of the mentioned bottlenecks in the previous chapter the design of a transparent, flexible and adaptable database and sanitation decision support screening tool is proposed by the means of:

- **Transparent**: to provide an interface where the limiting criteria and values for the selection of appropriate sanitation systems can be consulted at any stage. In addition a simple, clear and visual outcome must allow acknowledging the routine and constraints for the feasibility evaluation of each sanitation system.

- **Flexible**: to provide a frame where any criteria or value as well as explicit limitations for each sanitation system can be easily modified by the user depending on site specific needs.

- **Versatile/Adaptable**: to provide a structure design that allows to be used in diverse settings such as community participation or decision-making as well as for different purposes for instance technical feasibility, performance suitability or sustainability assessment. The tool must be easily upgradable and simple to accommodate.

Although each one of the different aspects influencing the appropriate selection of sanitation systems is important, due to the limited time and length, the level of detail attained in the tool is questionable. This thesis just focuses on the computer-based user interface and database of the settlements' physical and demographical situation as well as the existing services and restrictive technical features for the selection of suitable sanitation options. In this sense it concentrates on the technical adequacy while other aspects such as community acceptability and economic affordability are left out of the scope of this thesis as a further second stage in the decision-making process. In any case the proposed tool would allow including criteria for their suitability assessment.

In the routine of the decision support tool the characteristics of sanitation systems are defined and used in the model as limitations for the later suitability assessment against the specific conditions of the selected settlement. Therefore the key subject in this model is the definition of the constraining criteria where each one of the sanitation systems is related to. However these aspects must be provided with certain amount of flexibility in order to be modified, added or withdrawn depending on the particular features of the settlements and environmental needs. In this way although in the next chapter some critical criteria for the appropriateness of sanitation systems is suggested based on scientific grounds, this model pretends to deliver a simple and adaptable frame where any assessing criteria could be introduced.

Therefore this Thesis research applies a modelling or design approach methodology comprehensively described and organised in the following steps:

1. Founded in the assessment of existing decision support tools the main design line of the proposed model was defined. The creation of a database to store the information and development of the settlements as well as a screening tool for the selection of appropriate sanitation systems.

2. Based on literature and with the purpose to test the tool with the informal settlements in Cape Town a list with the technical specifications of the accepted sanitation systems suitable for South Africa (DWAF, 2002) as well as their main characteristics and limitations was developed.

3. The database for the collection of relevant information as well as to introduce the above mentioned limitations was designed jointly with the assistance of two information systems management experts. The model is founded in Microsoft Office Access databases in a Visual Basic user interface.

4. The sanitation decision support screening tool was developed in a three stage process with Microsoft Office Excel. First of all the criteria and values related to the site layout conditions considered to be potentially detrimental for the implementation of sanitation systems was defined. Afterwards the characterization of sanitation systems and their limitations and finally the introduction of the specific conditions of the settlement in order to assess their feasibility by comparing them with the constraining values.

5. In the same line as SANEX and WRC the conjunctive elimination rule was utilised in order to solve the multi-attribute screening problem thus facilitating the technical feasibility of sanitation systems. It is based in the fulfilment of all the criteria in order to be regarded as a feasible option; failing one single aspect limits its suitability.

6. The sanitation decision support screening tool, temporally named 'Settlers', was tested through the data collected from the Water Services Department and the Geographic Information System (GIS) in the city council of Cape Town, South Africa. Additionally the information gathered was supported by interviews with city officials, working groups and community leaders as well as by field observation work.

CHAPTER FOUR
Sanitation Model Design

The purpose of this chapter is to describe the framework where the decision support tool lays. In the first section the definition of appropriate sanitation system and its elements as well as the list of the sanitation options considered acceptable by DWAF (2002) is presented. Sections 2 and 3 aim to suggest the importance of criteria, values and general aspects relevant for the selection of sanitation systems included in the database and screening tool. Finally the following two sections concentrate in the illustration of the user-interface design aspects as well as in the main functions for the proper operation of the tool.

4.1. Sanitation Systems

Sanitation conditions in the slums and peri-urban areas indicate that inappropriate disposal of human waste has a negative impact to the health of the community and to the environment (Baghri et.al. 2004). In most of the communities world-wide, interventions have been done to improve sanitation conditions. Such interventions were either provision of sanitation facilities to the community by the local government, isolated initiatives with external funding or improvised systems constructed by communities themselves. This chapter provides a brief introduction to the currently applied sanitation systems as well as available low-cost sanitation alternatives.

Technological, environmental and economical criteria are strong aspects to be aware of, thus the chance of success of a sanitation system, selected without paying attention to the previous principals, is really small. However sanitation does not just depends on these aspects; a major failure cause of sanitation systems is the disregarding of the settlements' socio-economic characteristics. Increasing the acceptability and suitability of the implementation of a sanitation system, requires the involvement of the community (Tandia C.T. 2006). Participation is a compulsory step in order to stress the behaviour, customs, hygienic practices and organization of the community as well as to provide the appropriate maintenance schemes and educational programmes. In this way providing adequate sanitation facilities implies much more than merely technical or economical points of view, it is a matter of human beings behaviour and community needs, values and culture. In this sense applies the following definition:

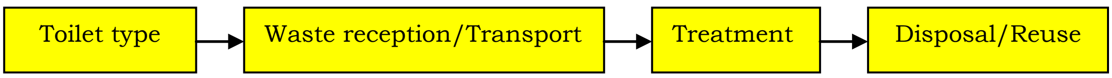
"An appropriate sanitation system is one that has been chosen within the full context of the environment in which it is to be placed"

(Wall and Jackson, 1992)

Nevertheless this thesis as well as the outcome of the sanitation model just takes into consideration the technological feasibility of the systems to a given environment. Linked to the feasibility assessment an estimation of the related costs could be also provided in a further stage. The purpose of this approach relies on the prioritisation of the different stages on the delivery of sanitation services. This support model intends to assist city officials or sanitary responsible in the consideration of the various sanitation systems available for a certain plot. Once they are aware of the different solutions and costs involved, then a communication and discussion phase with the community must be considered.

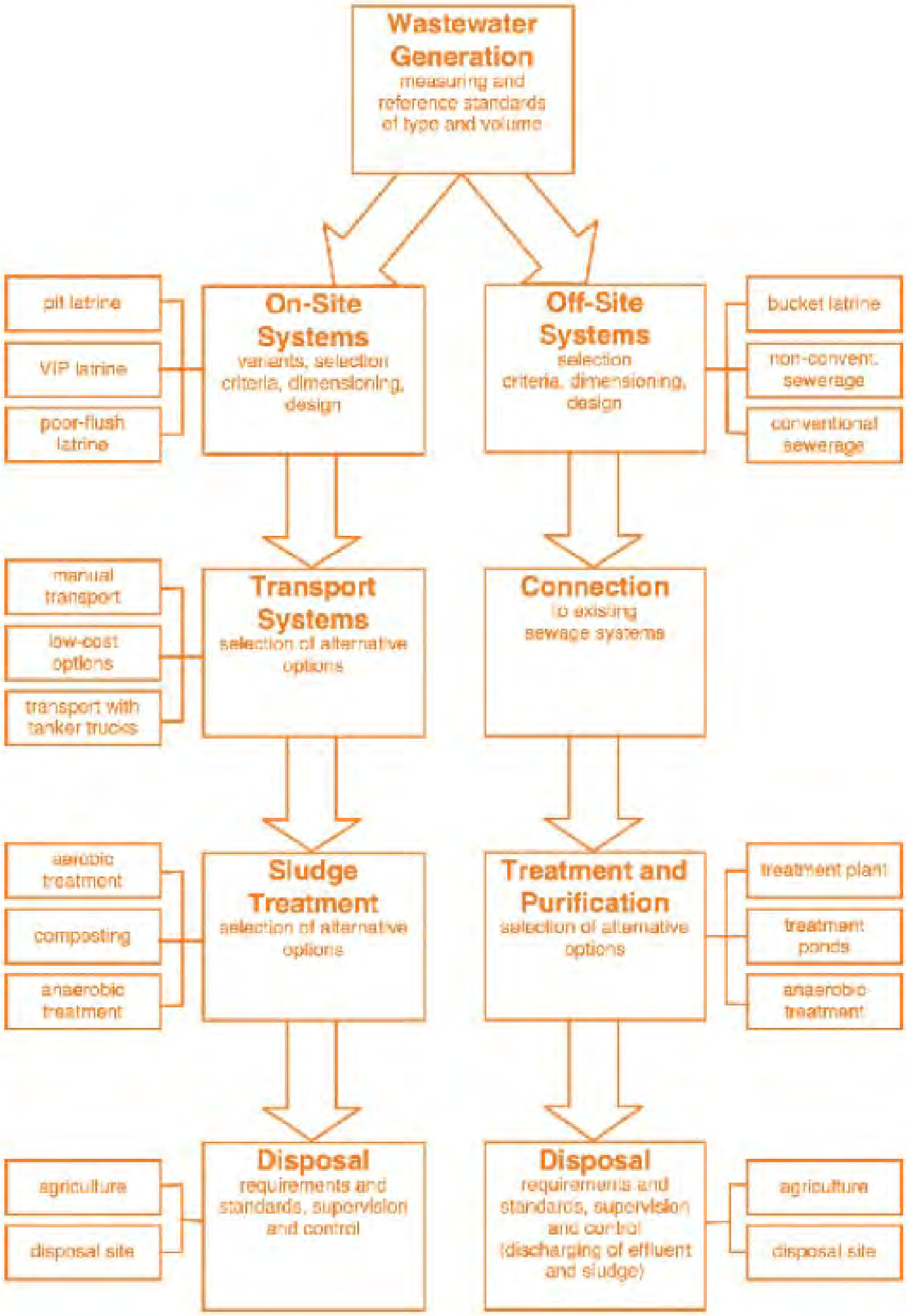
A sanitation system implies much more than a single element such as a toilet or sewer network. During this thesis the term 'sanitation system' is used to describe all the technical elements involved in the sanitation process. That means from toilet to disposal or reuse going through collection, transport and treatment. In this way the split of the system in different functions allows an enhanced flexibility in the selection of suitable sanitation systems for specific layouts (de Bruijne 2007). On the other hand some combinations are incompatible such as public standpipes with household waterborne toilets (Mara D.D., 1996) thus a pre-stage matching the complementary process elements would provide an improved starting phase.

The selection of suitable sanitation systems is a complex issue. There are many factors that influence the performance of each system. The listed sanitation options in this chapter are based on its functions and described as fixed sanitation process block-trains. Any sanitation system is composed of a toilet type (flush, dry, etc.), waste reception (including human excreta, urine, water and cleansing material) and/or transport (such as vacuum tanker or sewers), treatment (on-, off-site) and finally disposal or reuse.



Each one of these functions is affected by different external factors (Figure 4.1) that could constrain its use. Depending on the system some functions take place in the same location, for instance septic tanks receive the human waste, toilet flush and cleansing material in the same reactor where the treatment occurs; the same happens with composting toilets but in a dry manner. On the other hand container and chemical toilets receive the waste into the same structure frame of the toilet. Other sanitation facilities, such as sewer based systems, involve transport in the reception of the waste. In addition there are also systems, for example container toilets and conservancy tanks, that require waste storage for a relative period of time before emptying or/and transport. Emptying frequency also vary within the different systems and depending on the number of users. Even more septic tanks, aquaprivies and pit latrines, typically on-site systems, need to be desludged for further treatment and disposal off-site. In each system, the waste treatment can be as simple as infiltration to the soil or much complex as activated sludge processes in WWTW; and some systems even require both.

Figure 4.1: Sanitation options and processes diagram



Source: GTZ Deutsche Gesellschaft für Technische Zusammenarbeit (2005), *Improvement of Sanitation and Solid Waste Management in Urban Poor Settlements*. Eschborn, Germany.

The proposed indicators in this thesis are based on the basic physical and environmental aspects of the settlement where the sanitation systems are intended to be used. Moreover the proposed indicators are also considered as limitations for the sanitation options and used as comparative criteria. Beside these indicators other general aspects such as location, area or age of the settlement are included in a database in order to keep control and updated information over the sites. The database contains all the aspects and indicators of the settlements and is connected to a sanitation assessment support tool or screening tool that automatically outlines the appropriate sanitation systems. The model aims to help assessing technically feasible solutions for a concrete settlement. Moreover this model has been developed specifically to assess the sanitation systems that could match the characteristics of illegal settlements in urban developing areas.

The sanitation systems included in the decision support model are listed below and classified by waste reception location and water use:

On-site systems

Dry

1. **VIP + Mechanical emptying + WWTW**
2. **VIDP + Manual emptying + Composting + Reuse (fertiliser)**
3. **Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse**
4. **Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse**

Wet

5. **Pour-flush + Lined Pit + Mechanical emptying + WWTW**
6. **Pour/Low-flush + Aqua-privy + Soak-away + Mechanical emptying + WWTW (sludge)**
7. **Full-flush + Septic Tank + Soak-away + Mechanical emptying + WWTW (sludge)**
8. **NOWAC + Anaerobic up-flow filter + Soak-away + Mechanical emptying (sand)**

Off-site systems

Dry

9. **Container + Manual replacing + WWTW**
10. **Chemical + Mechanical emptying + WWTW**

Wet

11. **Pour/Low-flush + Conservancy Tank + Mechanical emptying + WWTW**
12. **Full flush + Conventional sewer + WWTW**
13. **Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying (sludge)**
14. **Low-flush + Shallow sewer + (Conventional sewer) + WWTW**

All the aspects and assumptions described below aim to define the most appropriate sanitation system for each specific site. Nevertheless it is known that many exceptions and modifications in the sanitation systems could allow one technology to fit in a constraining situation. Therefore the sanitation model enables the user to enforce the selection of a sanitation option classified as unfeasible as well as to modify any limiting value. The sanitation systems included into the support model correspond to the sanitation options defined by DWAF (2002) that meet the requirements for basic sanitation in South Africa. Container and chemical toilets are also added due to the common use of these systems as an emergency solution in the informal settlements and in order to have a comparative idea of the related limitations. Furthermore any other sanitation system can be added easily later to the model and in this way upgrade the support tool.

The criteria considered to be critical for the implementation of sanitation systems, as well as the general characteristics of the informal settlements is described below. Next to each criterion the possible options and values are also attached.

4.2. Critical Sanitation Criteria

Each characteristic is used for the decision support model to assess the suitability of the different sanitation systems. All these aspects must be introduced in the database in order to run the sanitation assessment.

- ***Access tracks*:**

  1. *No Access:* inaccessible area
  2. *Peripheral Access:* access to the periphery of the area
  3. *Partial Access:* access to several households inside the area
  4. *Full Access:* access to all the households inside the area

  Based on the availability of access roads in the settlement and the common use of vacuum tankers, any system based on emptying services where no tracks are available is constrained. All the systems, associated to mechanical emptying or manual replacement in the process train, are affected by this criterion. It's acknowledged that the emptying frequency differs from the type of sanitation system applied (i.e. once a year for VIPs or once a week for chemical toilets, depending on the number of users and size of the storage compartment). These differences could appear in the cost estimates of each sanitation system but not in the model. However soon or later in all these systems an emptying service is required and therefore access tracks become a major constraint. On the other hand, peripheral access and partial access do not constrain any system in itself although it restricts their application. Consequently individual household facilities with emptying required systems are considered unfeasible. Nevertheless peripheral access implies the installation and service delivery of communal or shared facilities in the surroundings of the settlement while partial access allows the location of facilities inside the area. Full access does not constrain any sanitation system.

- ***Population density:*** Calculated by dividing the number of dwellings in the settlement by the total area, without subtracting roads, etc. (Muller 1989)

  1. *< 50 households/hectare: Low*
  2. *50 - 150 households/hectare: Medium*
  3. *150 – 300 households/hectare: High*
  4. *> 300 households/hectare: Very High*

  Based on the "Protocol to manage the potential of groundwater contamination from on-site sanitation" published by DWAF 1997, the groundwater pollution risk increases proportionally to the size and density of the settlement. A minimum population density of 50 households/hectare coupled with a settlement size bigger than 100 households supposes a likely potential of groundwater pollution through leached nutrients mainly nitrogen and bacteria. Therefore on-site sanitation systems relying flushed water along with on soil percolation (i.e. soak-away disposal) are constrained in *Medium - High - Very High* densities. However in the case of sizes smaller than 100 households, the restriction is reduced to *High* and *Very High* densities for the same systems together with VIPs. In addition it is assumed that composting systems in dense settlements experience a lack of additional organic matter for the proper operation of the process as well as potential low demand or opportunity for reuse; thus composting toilets are also considered inappropriate in *High* and *Very High* densities.

- ***Water availability:*** it takes into account the type of water supply connection and the amount installed in the settlement. Automatically the ratio households/connection is calculated.

1. *No connection:* No water available or fetched far away from the settlement
2. *On-site groundwater extraction:* water extracted from wells or bore-holes
3. *Water tanker:* water supplied by truck transport
4. *Communal standpipe:* Piped water connection for public use
5. *Yard Tap:* Single tap provided in each plot, either as a private standpipe or mounted on the wall of a toilet, if a water-borne sanitation system is used
6. *Yard Tank:* Water tank installed in the household yard that can be filled either by a tanker truck or by a trickle feed arrangement. In most of the cases the volume of the yard tank is limited to 200 litres
7. *Roof Tank:* Water tank installed on the roof of the house and supplied via a trickle feed arrangement
8. *Household connection:* Metered connection into the house. It requires a waste water system, such as septic tanks or sewerage

Any sanitation option requiring water for the correct performance of the system is constrained where the availability of a reliable water connection or on-site source is not present. Therefore sanitation options classified as wet systems are limited by the lack of water sources (i.e. Pour-, low- and full-flush toilets). When the involved water supply consists of a well, water tankers or a tank in the yard, then the feasible water-borne sanitation solutions just include pour and low-flush systems. Alternatively public standpipes allow any water-borne system as long as it is provided as a shared or communal facility.

Furthermore the database provides the opportunity to include the current water supply system in the settlement, its amount, household ratio, distance from households and grey water disposal availability, in order to identify the water supply service level.

- ***Water table depth:*** Distance from groundwater table to ground surface.

1. *< 2 meter*
2. *2 – 5 meters*
3. *5 – 10 meters*
4. *> 10 meters*

Based on the risk of groundwater pollution as well as the potential health risk associated to the contamination of stagnated water on the ground, any draining system is constrained when water table depth is less than 5 meter. This value includes the possibility to elevate the structure between 0.5 and 1 meter above the ground. In the case of on-site groundwater extraction a minimum of 5 meters is required (Loetscher, 2002). The sanitation systems affected by water table depth includes pit latrines and soak-away disposal. When the draining system implies flushing water it requires 10 meters above groundwater level. In any case it should be guaranteed a minimum distance of 3 meters between the bottom of the pit or soak-away system and the groundwater table.

- ***Type of soil:*** (Brown RB, 1998)

  1. *Sandy*
  2. *Loamy sand and Sandy loam*
  3. *Loam*
  4. *Silt*
  5. *Silty loam*
  6. *Clay loam*
  7. *Sandy clay loam*
  8. *Silty clay loam*
  9. *Clayey*
  10. *Bare rock*

Based on the soil absorption any on-site drainage system is limited by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay). In contrast the same systems are inadequate on sand and fractured rock soils due to high percolation rates thus likely groundwater pollution. Along these lines loamy sand and sandy loam restricts the proper use of wet on-site draining systems such as pour-flush pit latrines and soak-away disposal. Moreover based on costs grounds, conventional sewerage is also constrained by the presence of bare rock.

- ***Flooding prone areas:***

  1. *Below 1:50 year flood line:* The level reached by the water body, river, stream or watercourse during a 1:50 year flood event (the most severe flood which could be expected to occur within a 50 year period)
  2. *Low lying area:* The flat, floodplain land between the water body and its 1:50 year flood line
  3. *Other:* Any other situation besides the previous ones

Seasonally high water table cause to exceed the absorptive capacity of the soil and consequent failure of the on-site disposal function. In the areas defined as flooding prone soil absorption will be jeopardized and thus any on-site drainage system. These systems include pit latrines and soak-away disposal (i.e. VIPs and septic tanks). In low lying areas wet-draining systems are also constrained. Composting systems are not recommended in flooding prone areas due to potential endangerment of required dryness condition of the waste. Furthermore sanitation systems, such as conservancy tanks, are also constrained because of possible overflow risk as a result of surface infiltration.

- ***Slope:*** Terrain inclination

  1. < 25°
  2. > 25°: Very steep slope, more than 1:4 ratio

Systems based on on-site drainage are less suitable for use in steep topography as the flow my seep back to surface level further down the slope. Moreover excavation on very steep slopes is prone to terrain slipping. In this way a slope higher than 25º will constrain the use of pit latrines and soak-away disposal systems (WRC 2006).

- ***Land availability:*** Land type and ownership is directly related to the potential level of sanitation services delivered to the settlements. Generally systems are just able to upgrade and benefit from its development when the land is considered suitable and servicing consent is granted.

  1. *City Council land*
  2. *State/Provincial land*
  3. *Private land*
  4. *Road reserves*
  5. *Nature reserves*
  6. *Servitudes*
  7. *Old refuse tip site*
  8. *Under legal process*
  9. *Hazardous site*

- ***Sewer availability:*** Two major criteria are considered to control the suitability of sewer based systems

  - ***Distance to main sewer:*** Distance from the settlement to the closer main sewer line considering gravity flow

    1. > 1000 meter
    2. < 1000 meter

  Based on economic grounds any sanitation system relying on sewer availability where gravity distance from the settlement to the main sewer is higher than 1000 meters are considered unsuitable, unless the "City priority" option in the model is selected.

  - ***Wastewater Treatment Plant Capacity:*** Operation percentage of the WWTW design capacity. Each settlement is associated to a wastewater catchment's area and therefore to a specific treatment plant. Up to date information of the WWTW operation capacity is available in the model database. An estimated sewage value of 10litres/person/day (low-flush toilets) or 30litres/p/d (full-flush toilets) as well as the population size and growth are used to calculate the extra flow load to WWTW in a 10 years life time. In this way an operation percentage of its design capacity higher than 95% at the end of the 10 years span is a major restriction for sewer based systems. At this moment population growth is not yet implemented in the model.

- ***Anal cleansing method:***

  1. *Water*

2. *Hard or bulky*
3. *Soft paper*

Normally in the majority of developing areas the desired anal cleansing method is soft paper, however informal settlements are characterised by low-income profiles and consequently lacking the financial means to afford toilet paper. In this way most of its settlers rely on hard or bulky materials such as vegetable leafs and hard paper, that generally cause the failure and blockage of flush toilet siphons. For that reason flush sanitation systems are constrained when hard or bulky materials are used as anal cleansing method.

Moreover in most Asian countries water is the standard anal cleansing method option thus it has been also included in the database. Water anal cleansing limits the use of the urine diversion composting toilet included in this support model although other composting toilet designs can be added to the model allowing its use.

4.3. General Aspects

The following criteria aim to maintain an improved database of the informal settlements situation and development as well as to facilitate the measurement of some critical criteria previously described.

- ***Name of the settlement:*** used to identify and search the settlement in the database

- ***Location:*** in this case the metropolitan area of the city of Cape Town is divided in 21 sub-councils and 105 wards. The user introduces the ward and the sub-council is automatically identified. However the values of the database can be easily changed to town/city/province/country

- ***Age (years):*** the period of time since the settlement was identified. It is automatically updated and it could be used as a main aspect to define the service priority

- ***Area (hectares):*** surface of land occupied by the settlement including roads, parks, etc

- ***Number of dwellings:*** the number of households and the year of the counting is introduced in the database. It is used to calculate the population growth while subsequent counts are added

- ***Health risk:*** it is defined in three levels, low, medium and high risk

- ***Fire risk:*** based on the settlement density and defined in three levels, low, medium and high fire risk.

    - Low: < 50 households/hectare
    - Medium: 50-100 households/hectare
    - High: > 100 households/hectare

- ***Sanitation availability:*** the type of sanitation systems and number of facilities currently used in the settlement. Automatically the ratio households/toilet is calculated.

- ***Priority:*** based on the guidelines for servicing the informal settlements in Cape Town a prioritization ranking is included in the database. The ranking involves several aspects from the database

Value	Age (years)	Health Risk	Fire Risk	Flooding Prone	Water Availability (Ratio of dwelling units per standpipe)	Sanitation Availability (Ratio of dwelling units per toilet)	TOTAL SCORE	PRIORITY
5	>10 years	high	>100	1:50 year	>400	>16	6-15	High
4	5-10 years				301-400	12-16		
3	3-5 years	medium	50-100	low lying	201-300	8-12	16-21	Medium
2	1-3 years				101-200	4-8		
1	<1 year	low	<50	other	0-100	0-4	22-30	Low

In this way the sum of the previous values defines the priority level for services delivery

- ***Electricity:*** two major aspects are identified to the delivery of electricity services:
  - Public lightning
  - Electrification of the site

- ***Solid waste:*** stands for the type of collection system in the settlement
  - None
  - Off-site collection
  - Kerbside collection
  - Door to door

- ***Comments:*** at the end there is a space available to add any relevant comment about the settlement.

4.4. Database Interface

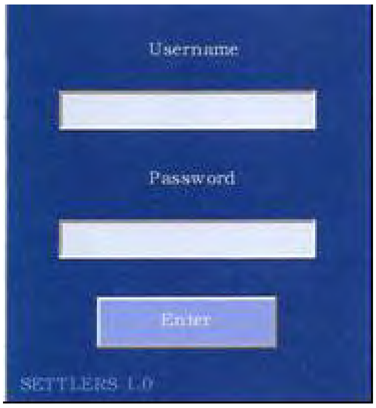
A database provides an input framework for the data used in the model operation. Decision support tools are intended to assist in the problem solving process (Engelen 2000). However users may not be familiar with the technical computer-based systems, therefore the user-interface offers the frame to interact with the computer. Nowadays in order to maximise its user-friendliness interactive function buttons and window prompts are commonly used.

In order to maintain a reliable and upgradable database with all the information described above as well as to oversee the development of the sites assessed through the model a Visual Basic interface has been designed. It offers an easy to use framework at the same time that protects the data introduced and the maintenance of its aspects and values. In this section the main characteristics of the database are introduced while following an specific procedure:

1. Log in
2. Introduction of a new settlement
3. Search, edit and deletion of settlements
4. Maintenance of the database
5. Log off

Log In

When starting the program you are asked to fill in your username and password. Its main function is to define the level of user access thus limiting the risk to modify or lose data. Once the information is introduced and processed an emerging window welcomes you and states your username and access level.



The first screen to appear after logging in is the main menu window. It allows you to choose within different options such as new entry, edit, delete entry, search and maintenance as well as the possibility to consult the help tutorial or close the software.

New Entry

When the new entry button is selected an emerging window pops up into the screen. It gives to the user the possibility to introduce the characteristics, values and relevant information about the settlements' current situation. These aspects include all the critical and general criteria described in the previous sections.

The new entry window is composed of four tabs:

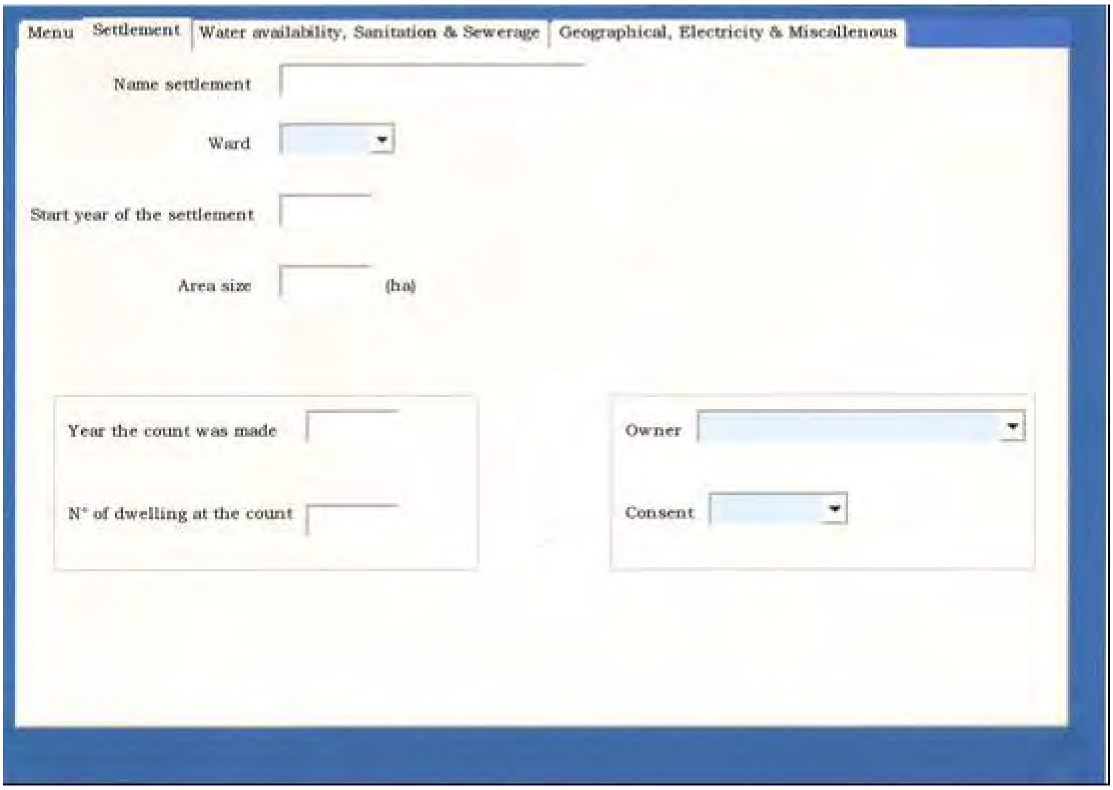
- Menu: a button in the bottom of the tab allows to go back to the main menu

- Settlement: allows the user to introduce the name of the settlement, location, area of the site, year and number of dwelling's counting, land ownership and consent for servicing. See the following screenshot.

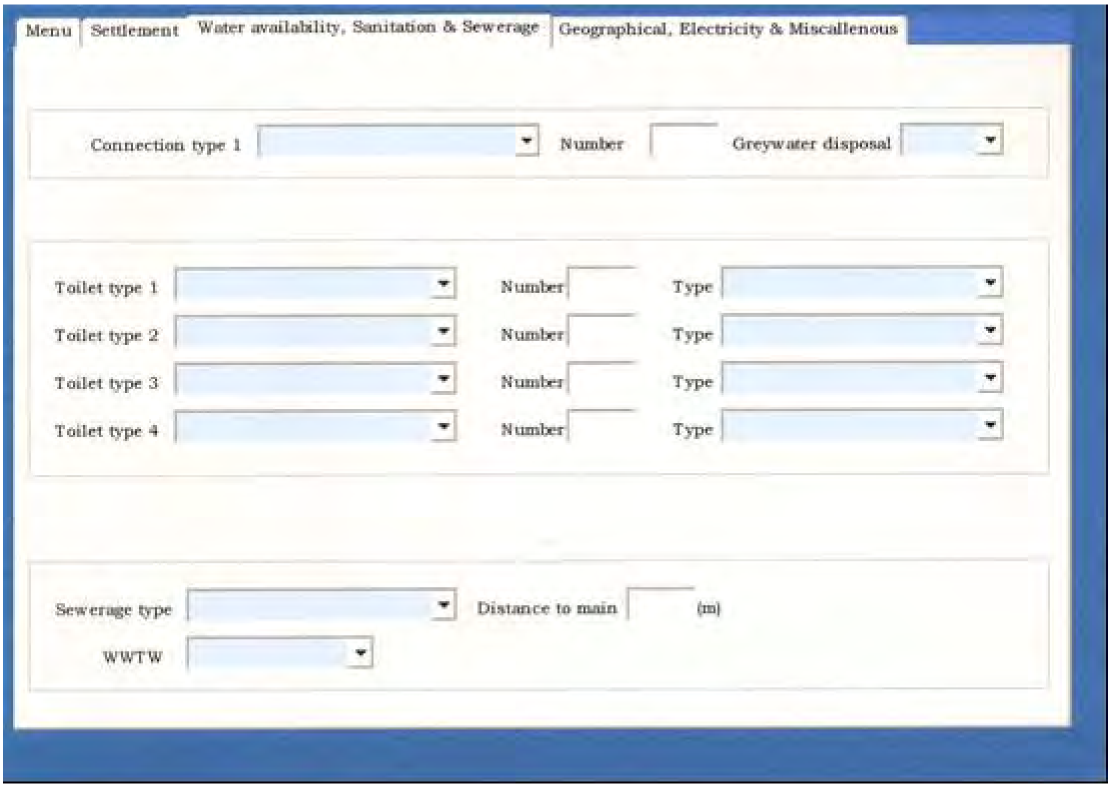
- Water availability, sanitation & sewerage: this tab includes the type and number of water supply connections, the availability of grey water disposal systems, the toilet types as well as the amount and provision options, distance to main sewer, type of sewerage and name of the WWTW.

- Geographical, electricity & miscellaneous: in the last tab the user can find the type of soil, water table depth, flooding prone options, availability of public light and electrification, accessibility, terrain slope, type of solid waste collection and open space for comments. At the bottom of the tab a button permits to save the data.

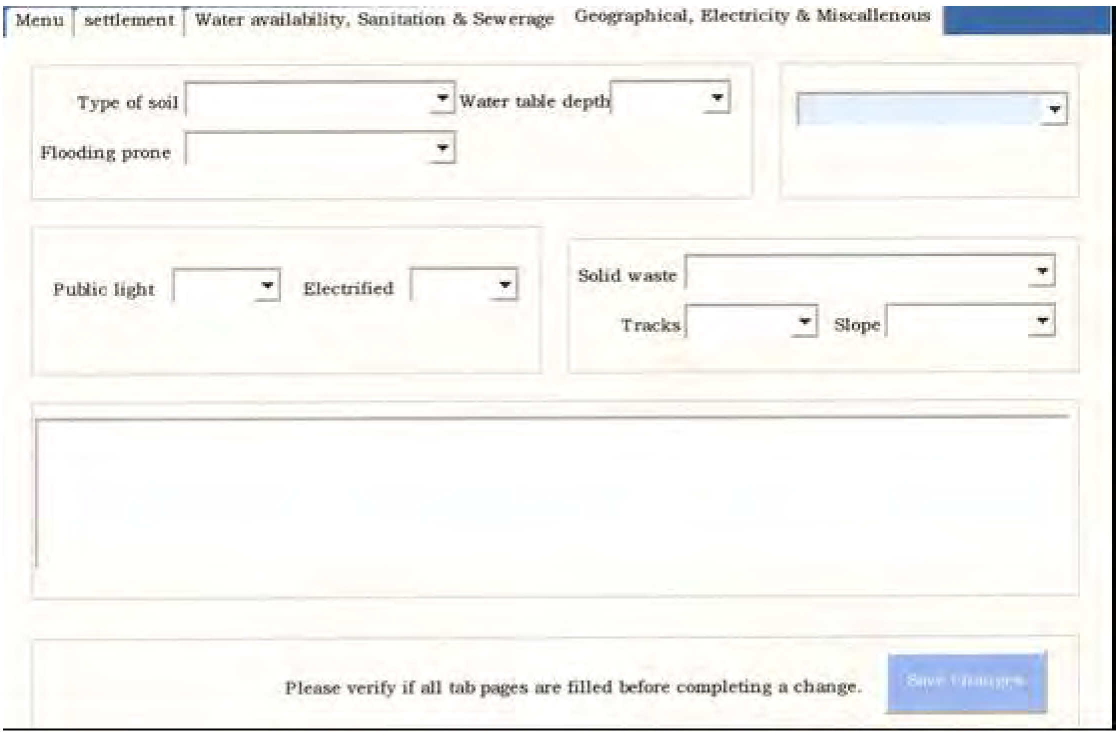
Settlement



Water availability, sanitation & sewerage



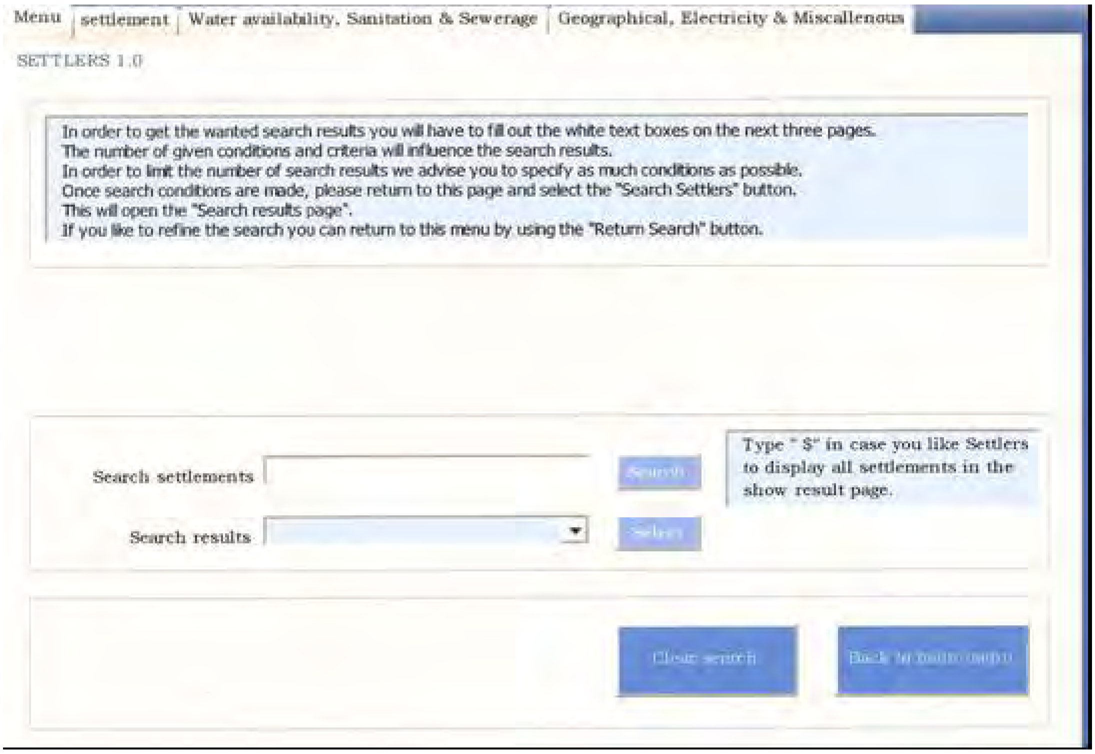
Geographical, electricity & miscellaneous

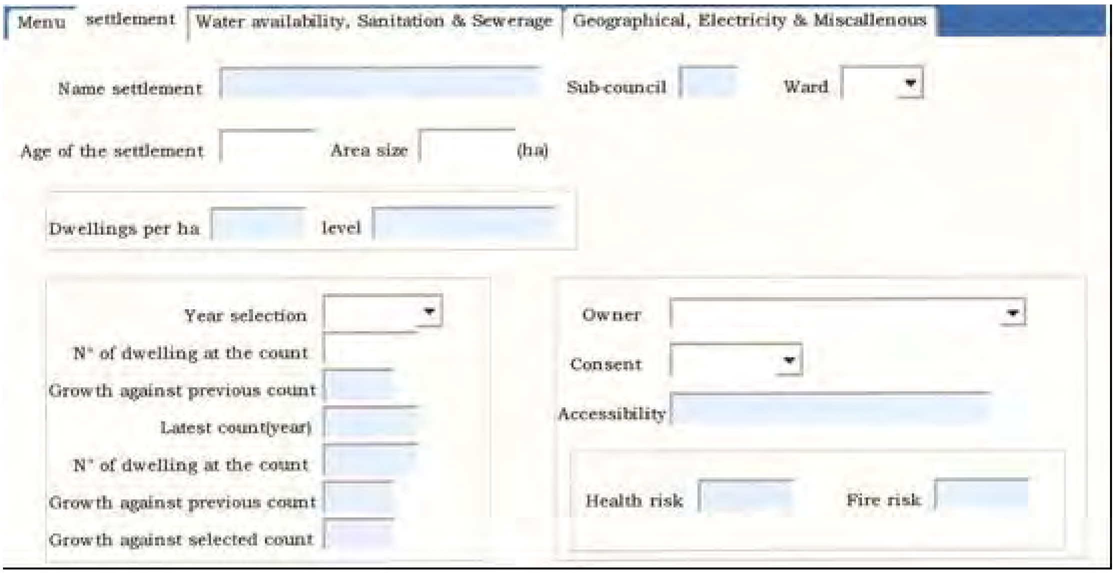


Once the data is completely filled in and saved another window appears to confirm the successfulness of the entry as well as to give the chance for additional entries or going back to the main menu.

Search, Edit and Deletion of settlements

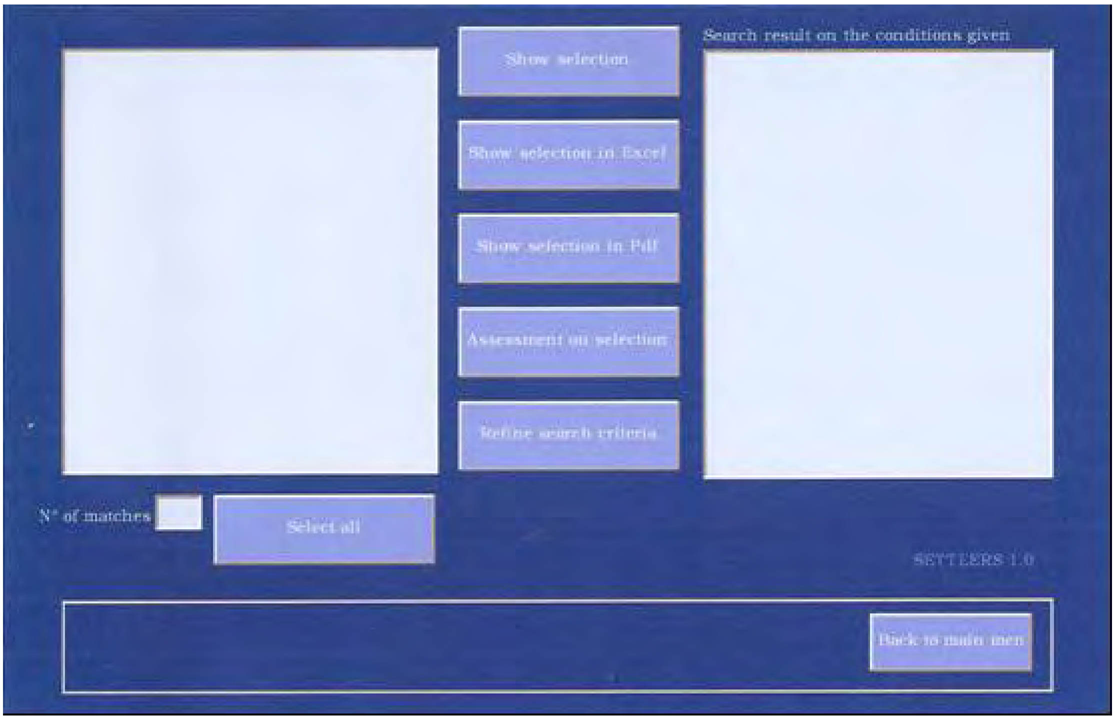
When the user wants to search, edit or delete a previous entry then a slightly different window than the one for new entry emerges. The main variation is that in the Menu tab a search engine is presented in order to find the settlement by its name into the database. The settlements can be also explored by any value in the tabs such as land ownership, number of dwellings, type of soil or comments. If the search does not return any result then a window pops up advising for a new one (see the following screenshots). For the Edit and Delete options once the settlement is selected all the information available is automatically upgraded in the already mentioned tabs (New Entry) including the automatic calculations of the system, for instance densities and growth. When editing after the changes have been made and in the same way as in the New Entry the last tab provides a button for saving the data.





In the case of deletion the last tab, through a button in the bottom of the screen allows the user to delete the entry. In any case once pushed the button it emerges another window asking for confirmation

When using the search option of the Main Menu the results are shown in a completely different manner. A window with several button options and stating the number of settlements matching your search entry pops up. The window provides two big boxes around the button options. In the left side box all the settlements matched are listed for the selection of the desired site. More than one settlement can be selected and in case of need a push button allows for the selection of all the listed sites. Once the settlements are selected they will appear in the right side of the main buttons.



The main options include:

- *Show selection*: all the information available about the selected settlements is shown in the format of windows and tabs such as in the Edit option.

- *Show selection in Excel*: all the information available about the selected settlements is shown in Excel format.

- *Show selection in PDF*: all the information available about the selected settlements is shown in PDF format.

- *Assessment on selection*: this button is linked to the sanitation assessment related to the values entered in the database's critical aspects. The screening tool is explained in the following section of this chapter.

- *Refine search criteria*: in order to reintroduce the search values and repeat the search.

PDF

Doornbach

Acrobat Document

Location

Sub-council	Ward
1	1

Age/Size

Age (years)	Area (ha)
1	72

N° of dwellings / Density

Year	Count	Growth	Dwell/ha	Level
2001	100	0.0%	0	acceptable
2002	200	100.0%	2.8 p/ha	[illegible]
2003	300	50.0%	4.2 p/ha	de-densify
2004	400	33.3%	5.6 p/ha	acceptable
2005	500	25.0%	6.9 p/ha	[illegible]
2006	600	20.0%	8.3 p/ha	de-densify
2007	700	16.7%	9.7 p/ha	acceptable
2008	800	14.3%	11.1 p/ha	[illegible]
2009	900	12.5%	12.5 p/ha	de-densify
0	0	0.0%	0.0 p/ha	0
0	0	0.0%	0.0 p/ha	0

Land availability / General risk

Owner	Consent	Accessibility	Health risk	Fire risk
Private land	yes	0	low	low
[illegible]	no	0	medium	medium
[illegible]	yes	0	high	high
[illegible]	no	0	0	0
[illegible]	yes	0	0	0
[illegible]	no	0	0	0
[illegible]	yes	0	0	0
[illegible]	no	0	0	0
[illegible]	yes	0	0	0
0	0	0	0	0
0	0	0	0	0

Water availability

Connection type	Number	Ratio Households/ Connections	Distance	Grey water disposal	Service level
No connection	1	20	<200 meter	yes	see note
Water Tank	2	0	>200 meter	no	T21
[illegible]	3	0	0	0	0
[illegible]	4	0	0	0	0
Yard Tap	5	0	0	0	0
0	6	0	0	0	0
0	7	0	0	0	0
0	8	0	0	0	0
0	9	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0
0	0	0	0	0	0

Sanitation availability

Toilet	Number	Type	Ratio	Service level
Bucket	1	individual	14 per toilet	0
Chemical	2	shared	0 per toilet	0
Container	3	communal	0 per toilet	0
VIP	4	0	0 per toilet	0
VIDP	5	0	0 per toilet	0
Pit Liner	6	0	0 per toilet	0
Flush	7	0	0 per toilet	0
Pour-flush	8	0	0 per toilet	0
ECOSAN	9	0	0 per toilet	0
Porta-Pottie	10	0	0 per toilet	0
NOWAC	11	0	0 per toilet	0
0	0	0	0 per toilet	0

Sewerage availability

Type	Distance to main (m)	WWTW & Capacity	Capacity
Conventional	1	Athlone	85.3%
Small Bore	2	Bellville	97.2%
Shallow	3	Borchards	88.6%
Vacuum	4	Cape Flats	64.6%
0	5	[illegible]	87.1%
0	6	Klipheuvel	100.0%
0	7	[illegible]	45.8%
0	8	Llandudno	70.0%
0	9	Macassar	65.4%
0	10	Melkbos	42.2%
0	11	[illegible]	100.0%
0	0	[illegible]	64.3%

Soil description

Type of soil	Water table depth	Flooding prone	Priority
Sand	< 1,5m	[illegible]	0
Loamy sand	> 1,5m	[illegible]	0
Sandy loam	0	Other	0
Loamy sand	0	0	0
Silt loam	0	0	0
[illegible]	0	0	0
[illegible]	0	0	0
Clay	0	0	0
[illegible]	0	0	0
Clay loam	0	0	0
[illegible]	0	0	0
Silt	0	0	0

Electricity

Public light	Electrified
yes	yes
no	no
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0

Miscellaneous

Solid waste	Tracks	Slope
door to door	full access	<10
[illegible]	[illegible]	<25
none	no access	>25
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0

Comments

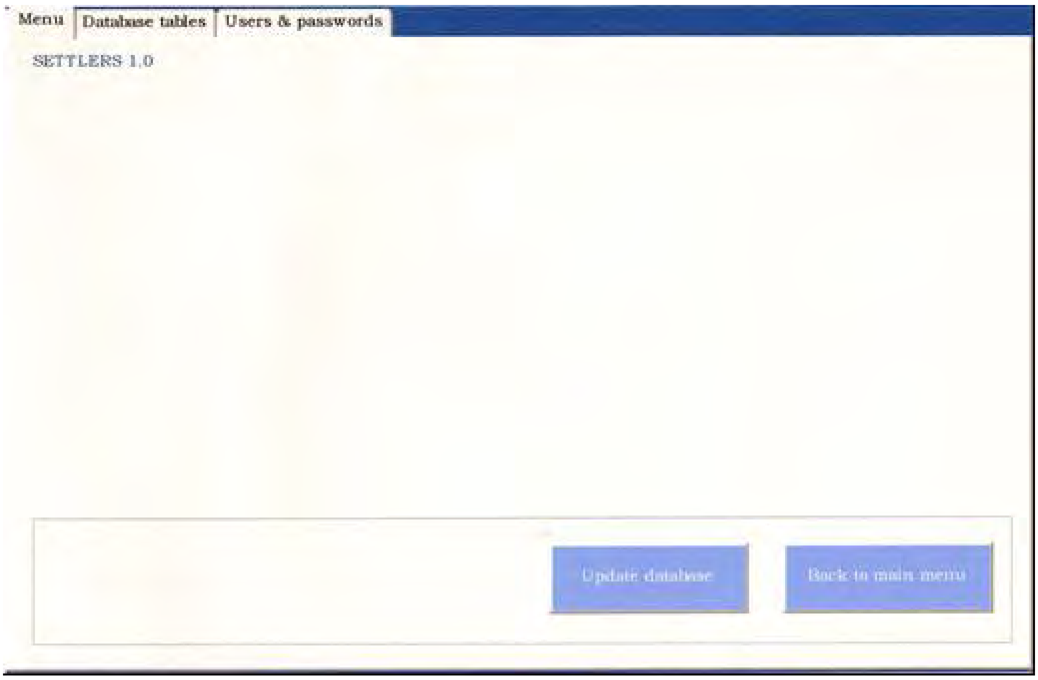
hoe gaat het ermee. Met mij gaat het goed. Ja heel goed. Hoe heel goed. Heel heel goed en dan overdrijf ik niet eens. J e weet hoe ik erover denk. Als ik zeg dat het goed met me gaat, dan gaat het ook goed slecht met mijn

Excel.

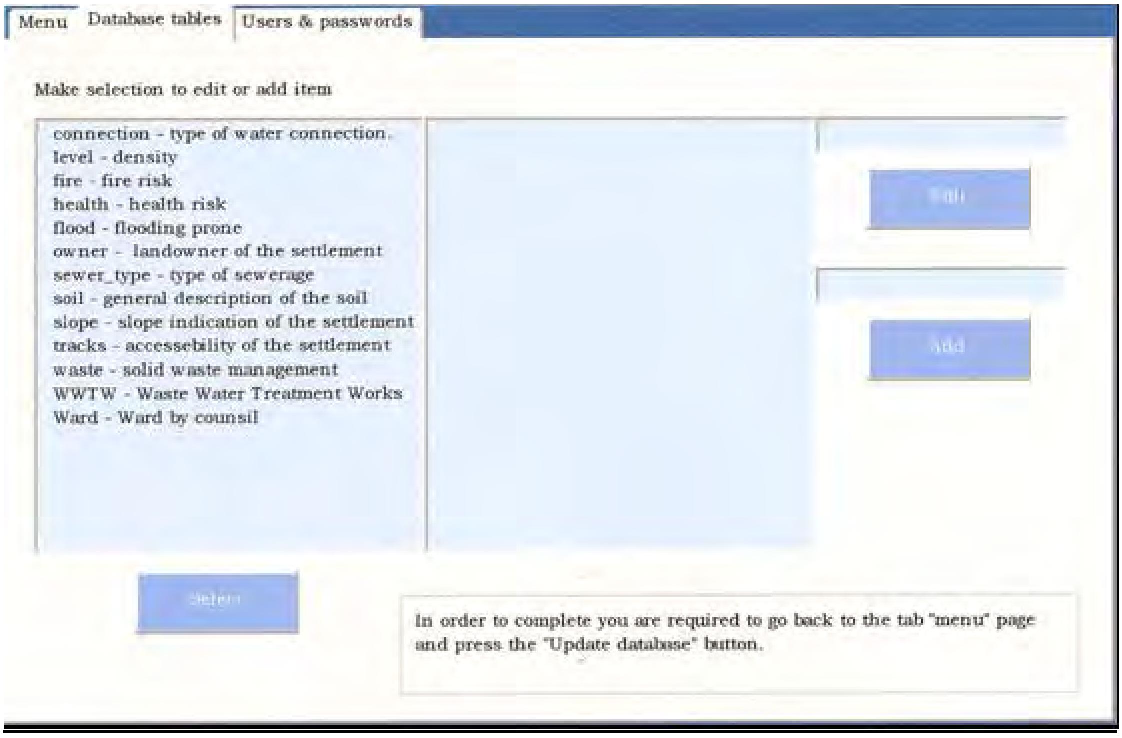
	Location		Age/Size		N° of dwellings			Density		Land availability	
Settlement	Sub-council	Ward	Age (years)	Area (ha)	Year	Count	Growth	Dwell/ha	Level	Owner	Consen:
Doornbach	1	1	1	72	2001	100	0.00%		acceptable	Private land	yes
	2	2	2	72	2002	200	100.00%	2.8 p/ha	partial acceptable		
	3	3	3	72	2003	300	50.00%	4.2 p/ha	de-densify		
	4	4	4	72	2004	400	33.33%	5.6 p/ha	acceptable		
	5	5	5	72	2005	500	25.00%	6.9 p/ha	partial acceptable		
	6	6	6	72	2006	600	20.00%	8.3 p/ha	de-densify		
	7	7	7	72	2007	700	16.67%	9.7 p/ha	acceptable		
	8	8	8	72	2008	800	14.29%	11.1 p/ha	partial acceptable		
Imizamu Yetu	1	1	1	60	2001	100	0.00%		acceptable		
	2	2	2	60	2002	200	100.00%	3.3 p/ha	partial acceptable		
	3	3	3	60	2003	300	50.00%	5.0 p/ha	de-densify		
	4	4	4	60	2004	400	33.33%	6.7 p/ha	acceptable	In road reserves	no
	5	5	5	60	2005	500	25.00%	8.3 p/ha	partial acceptable		
	6	6	6	60	2006	600	20.00%	10.0 p/ha	de-densify		
	7	7	7	60	2007	700	16.67%	11.7 p/ha	acceptable		
	8	8	8	60	2008	800	14.29%	13.3 p/ha	partial acceptable		
Barcelona	1	1	1	15	2001	100	0.00%		acceptable		
	2	2	2	15	2002	200	100.00%	13.3 p/ha	partial acceptable		
	3	3	3	15	2003	300	50.00%	20.0 p/ha	de-densify		
	4	4	4	15	2004	400	33.33%	26.7 p/ha	acceptable		
	5	5	5	15	2005	500	25.00%	33.3 p/ha	partial acceptable	In servitudes	yes
	6	6	6	15	2006	600	20.00%	40.0 p/ha	de-densify		
	7	7	7	15	2007	700	16.67%	46.7 p/ha	acceptable		
	8	8	8	15	2008	800	14.29%	53.3 p/ha	partial acceptable		
Kosovo	1	1	1	23	2001	100	0.00%		acceptable		
	2	2	2	23	2002	200	100.00%	8.7 p/ha	partial acceptable		
	3	3	3	23	2003	300	50.00%	13.0 p/ha	de-densify		
	4	4	4	23	2004	400	33.33%	17.4 p/ha	acceptable		
	5	5	5	23	2005	500	25.00%	21.7 p/ha	partial acceptable		
	6	6	6	23	2006	600	20.00%	26.1 p/ha	de-densify	Below 50-year flood	no
	7	7	7	23	2007	700	16.67%	30.4 p/ha	acceptable		

<u>Maintenance of the database</u>

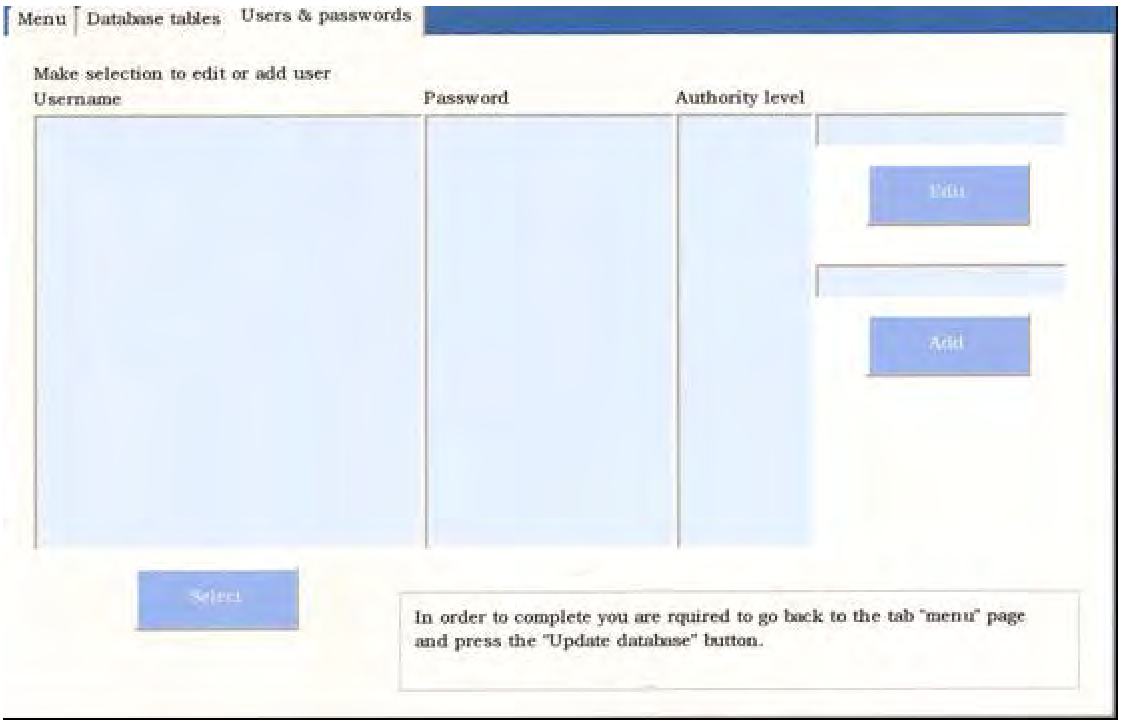
This option is restricted to most of the users as it includes the main security features as well as the possibility to modify, add and remove the aspects and values of the database. It consists of an emerging window with three different tabs. In the first one ‘Menu’ it has the ability to save the modifications introduced as well as to return to the main menu.



The second tab 'Database tables' includes all the aspects and tables with its values where the information is stored. These values and aspects can be modified by clicking in the edit button. Using the 'Add' button new aspects and values can be entered in the database. In any case it will be necessary to return to the Menu tab in order to save the changes.



Finally in the third tab 'Users & passwords the new users can be entered as well as their authority level that restricts the access to some features.



Log off

In order to exit the software the user has to move to the Main Menu where the 'Close settlers' button is present. Once the button is pushed an emerging window appears with the following three options: 'Save and Close', 'Close' and the possibility to return to the Main Menu. Before the complete exit another pop up screen thanks the current user for using the software.

4.5. Sanitation Screening Tool

> "*Decision making is the study of identifying and choosing alternatives based on the values and preferences of the decision maker. Making a decision implies that there are alternative choices to be considered, and in such a case we want not only to identify as many of these alternatives as possible but to choose the one that best fits with our goals, objectives, desires, values, and so on.*"
>
> (Harris 1998)

According to János Fülöp (2005) decision making process can be divided into the following 8 steps:

- ***Define the problem***: difficulties to find suitable sanitation systems
- ***Determine requirements***: design of decision support model
- ***Establish goals***: selection of appropriate sanitation systems
- ***Identify alternatives***: list of sanitation systems (section 4.1)
- ***Define criteria***: list of critical criteria (section 4.2)
- ***Select a decision making tool***: screening model (section 4.5)
- ***Evaluate alternatives against criteria***: pilot testing (Chapter 5)
- ***Validate solutions against problem statement***: evaluation (section 5.3)

When the number of criteria is finite and the alternatives are explicitly specified then the Multi-attribute decision making method applies. In order to screen the feasibility of sanitation options the conjunctive rule or method was used. It requires that every alternative must meet the minimum conditions of each criteria in order to evaluate positively (Linkov et al. 2004).

Translating it to the Excel framework, in which the tool was designed, it implies the following function arguments:

- Conditional '**IF'**: *Returns one value if a condition you specify evaluates to TRUE and another value if it evaluates to FALSE.*

  IF(**logical_test**,**value_if_true**,value_if_false)

- Logical function '**AND'**: *Returns TRUE if all its arguments are TRUE; returns FALSE if one or more argument is FALSE.*

  AND(**logical1**,logical2, ...)

- Logical function '**OR'**: *Returns TRUE if any argument is TRUE; returns FALSE if all arguments are FALSE.*

  OR(**logical1**,logical2,...)

In order to get an idea of how the data is screened in each cell of the tool the following example applies:

Cells formula:

f_x =

IF(OR(Ci=Constraints!Ci,…,Ci=Constraints!Cj),"Red",IF(AND(Constraints!Ci=0,...,Constraints!Cj=0),"",
IF(AND(OR(Constraints!Ci<>0,…,Constraints!Cj<>0),Ci="Not Available"),"Not Available","Green")))

If any of the constraining values (Constraints!Ci) introduced in stage 1 (see point 3) is equal to the condition value of the site (Ci) then returns a Red cell.

=IF(OR(Ci=Constraints!Ci,…,Ci=Constraints!Cj),"Red",

If there are no constraining values (Constraints!Ci=0) introduced in stage 1 (none of them) then return "_" (nothing), a white cell.

IF(AND(Constraints!Ci=0,…,Constraints!Cj=0),"_",

If any of the constraining values (Constraints!Ci) is different than zero (<>0), in other words, if there is any constraining values introduced in stage 1 and the condition value of the site (Ci) is not available then returns "Not Available".

IF(AND(OR(Constraints!Ci<>0,…,Constraints!Cj<>0),Ci="Not Available"),"Not Available",

Otherwise returns a Green cell.

"Green")))

At the present stage the screening tool is still an Excel-based decision support table. The idea is to convert it to Visual Basic and include it into the database instead of being used as a link. The decision support tool can be used in direct conjunction with the database or as a single mechanism. Nevertheless this tool is founded in three main steps:

- Step 1: definition of the constraining criteria and values for the proper operation of sanitation systems. In the case of using the ones included in the database and described in the previous sections this step would not be necessary. However it gives complete decision freedom to the user.

- Step 2: define the sanitation systems to be considered. As stated in the beginning of this chapter they must be assembled in different blocks. In any case the screening tool already supplies some sanitation systems (see Appendix A). Moreover it can be easily updated with new systems whenever the user believes necessary. Following the definition of the different sanitation systems the user must select the limitations for each one of the systems by selecting the value from a closed list linked to step1.

- Step 3: select the conditions of the settlement to be considered by choosing the various options also linked to step 1. In case of using the settlement directly from the database this values will be instantly shown into the appropriate cells. The result is shown immediately.

The outcome of the decision support screening tool is based on the comparison between the values of the limiting criteria defined by the user and the existing conditions of the settlement intended to be assessed. The freedom of choice as well as the possibility to decide on and modify any value or criteria provides the tool with huge flexibility and transparency.

In step 3 the results are shown directly in a colourful frame. Excel cells where each site specific aspect such as housing density, water table depth, type of soil and so on is compared with the previously defined constraining values of the sanitation system, become green or red depending on the compliance with the values. Green cells stand for the overcome of limiting criteria while red ones highlight the actual barriers related to the characteristics of the settlement and the specific sanitation system. The empty cells appear when sanitation options have no limitation in respect to the specific constraining criteria. Any red cell present in the row of a sanitation system supposes a barrier for its feasibility.

In order to be classified as a feasible option the system must fulfil all the cells in green or white colour. Finally if any data about the current condition of the selected settlement is missing then the cell stays with the statement 'Not Available' in a yellow background. It is compulsory to introduce all the required information otherwise the screening tool will not assess its feasibility classifying the system as 'Not Available'.

STEP 1. Definition of constraining criteria and values

	CRITERIA								
	Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method
VALUES	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available
	No access	Low	No connection	< 2m	Sandy	Below 1:50 year	< 25	> 95	soft paper
	Peripheral	Medium	On-site groundwater extraction	2 - 5m	Loam/Sand	Low laying areas	> 25	< 95	hard or bulky materials
	Partial	High	Water Tanker	5 - 10m	Loam	Other			water
	Full	Very High	Communal standpipe	> 10m	Silt				
			Yard Tap		Silt/Loam				
			Yard Tank		Clay loam				
			Roof Tank		Sand/Clay/Loam				
			Household connection		Silt/Clay/Loam				
					Clayey				

STEP 2. Definition of sanitation systems and limitations

	Sanitation Systems	Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method
1	Container + Manual emptying + WWTW	No access								
2	Chemical + Mechanical emptying + WWTW	No access								
3	VIP + Mechanical emptying + WWTW	No access	High Very High		< 2m 2 - 5m	Sandy Clayey	Below 1:50 year	> 25		
4	VIDP + Manual emptying + Reuse		High Very High		< 2m 2 - 5m	Sandy Clayey	Below 1:50 year	> 25		
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		High Very High				Below 1:50 year			water
6	Double Composting/Urine diversion + Manual emptying + Faecal matter		High Very High				Below 1:50 year			water
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	No access	Medium High Very High	No connection	< 2m 2 - 5m 5 - 10m	Sandy Loam/Sand Clayey	Below 1:50 year Low laying areas	> 25		
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	No access	Medium High Very High	No connection	< 2m 2 - 5m 5 - 10m	Sandy Loam/Sand Clayey	Below 1:50 year Low laying areas	> 25		
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	No access	High Very High	No connection			Below 1:50 year			
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		High Very High			Clayey	Below 1:50 year			
11	Full flush + Conventional sewer + WWTW			No connection On-site groundwater extraction Water Tanker Yard Tank		Bare rock			> 95	hard or bulky materials
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying (sludge)	No access	High Very High	No connection On-site groundwater extraction Water Tanker Yard Tank			Below 1:50 year		> 95	hard or bulky materials
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	No access	Medium High Very High	No connection On-site groundwater extraction Water Tanker Yard Tank	< 2m 2 - 5m 5 - 10m	Sandy Loam/Sand Clayey	Below 1:50 year Low laying areas	> 25	> 95	hard or bulky materials
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			No connection					> 95	hard or bulky materials

STEP 3. Selection of the settlement's conditions. Direct outcome.

		Settlement Aspects from Database									
		Partial	Medium	Communal standpipe	5 - 10m	Clayey	Low laying areas	< 25	< 95	soft paper	
	SANITATION SYSTEMS	Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW										**Feasible**
2	Chemical + Mechanical emptying + WWTW										**Feasible**
3	VIP + Mechanical emptying + WWTW										**Unfeasible**
4	VIDP + Manual emptying + Reuse										**Unfeasible**
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse										**Feasible**
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse										**Feasible**
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW										**Unfeasible**
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)										**Unfeasible**
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW										**Feasible**
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)										**Unfeasible**
11	Full flush + Conventional sewer + WWTW										**Feasible**
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying										**Feasible**
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)										**Unfeasible**
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW										**Feasible**

CHAPTER FIVE
Cape Town's Informal Settlements: Pilot Testing

In order to outline the current situation of the informal settlements in Cape Town as well as to describe the main limitations and barriers to the sanitation service delivery this chapter includes an overview of the case followed by the results based on the sanitation decision-support tool and finally an evaluation of the outcome.

In order to analyse the data gathered in Cape Town I used the limitations already included in the database and the sanitation systems considered in the previous chapter and Appendix A. These aspects take into account land availability and accessibility, housing density, water supply system, water table depth, type of soil, flooding prone areas, terrain slope, WWTW capacity and anal cleansing method. Nevertheless I have been just able to report accurately on the name, location, number of dwellings and area of all these settlements while the other aspects are estimated from my own field observations and city documents. Due to the limited data available I centre my attention in the housing density aspect. However a general description and potential threats of the other aspects are also incorporated.

5.1. Case Background

From July to September 2006 I stayed in Cape Town collecting information about sanitation services delivery in the informal settlements. One of the main obstacles for this pilot testing was the outdated, unreliable and heterogeneous information available. The data differs greatly depending on the source, among others relevant information is missing, names of the settlements don't concord or population counting is old. This is a common problem in developing countries and even more when involves informal, squatter, slums, peri-urban or illegal settlements. This was the main reason for designing a database interface prior to the sanitation screening tool. Finally I was able to develop a list of 265 informal sites (Appendix C) combining the Water Services Department database 'Servicing informal settlements (SIS): draft situation report on the provision of services as at 31 March 2006' (Appendix B) and the GIS database available in the city council. The Water Services Department defines 194 informal settlements; such a difference is caused by the inclusion of several informal sites from the same area in a single settlement.

The history of water and sanitation in South Africa has been extremely influenced by the history of the country as a whole. The transcript on history background information (Box 1) has been extracted from the Department of Water Affairs and Forestry (*Water Supply and Sanitation Policy. White Paper*, Cape Town, 1994).

BOX 1. THE HISTORY OF WATER DEVELOPMENT IN SOUTH AFRICA

The history of water is a mirror of the history of housing, migration, land, social engineering and development. One sector of the economy of South Africa has developed from a rudimentary settler level into that of a sophisticated and industrialised economy using modern techniques in keeping with those of the western world. The other sector of the economy is poverty-bound. This sector enjoys little of the services and advantages of the wealthy sector which was developed largely at the cost of the poor. The development of South Africa's water resources has been linked more with supporting the progress of the country's wealthy sector than with alleviating the position of the poor.

By the end of the 19th century most of the water used in South Africa was for white commercial agriculture. Legislation enacted in the early years of this century concentrated on the construction of works to benefit irrigation. In the mid-1930's subsidies were introduced to accelerate the development of private irrigation schemes. Later, the emphasis on irrigation in the legislation proved to be inadequate for the water requirements of an expanding industrial base. Accordingly, in 1956 a new Water Act (Act 54 of 1956) intended to ensure an equitable distribution of water as well as to authorise strict control over the abstraction, use, supply, distribution and pollution of water, and the treatment and discharge of effluent.

With the introduction of Grand Apartheid it became very clear that virtually all of the vast investments mentioned above served the white sector of South Africa and the rest were left to fare for themselves. The government engaged in some development of water but the investments were very unevenly distributed and totally inadequate.
The history of the development of sanitation services closely parallels the history of water service development in South Africa. In the wealthy areas from municipalities and towns the development of water supplies generally made provision for the greater quantities of water required for water borne sewage services while the poor population, the vast majority of the country, was lacking behind in any urban infrastructure.

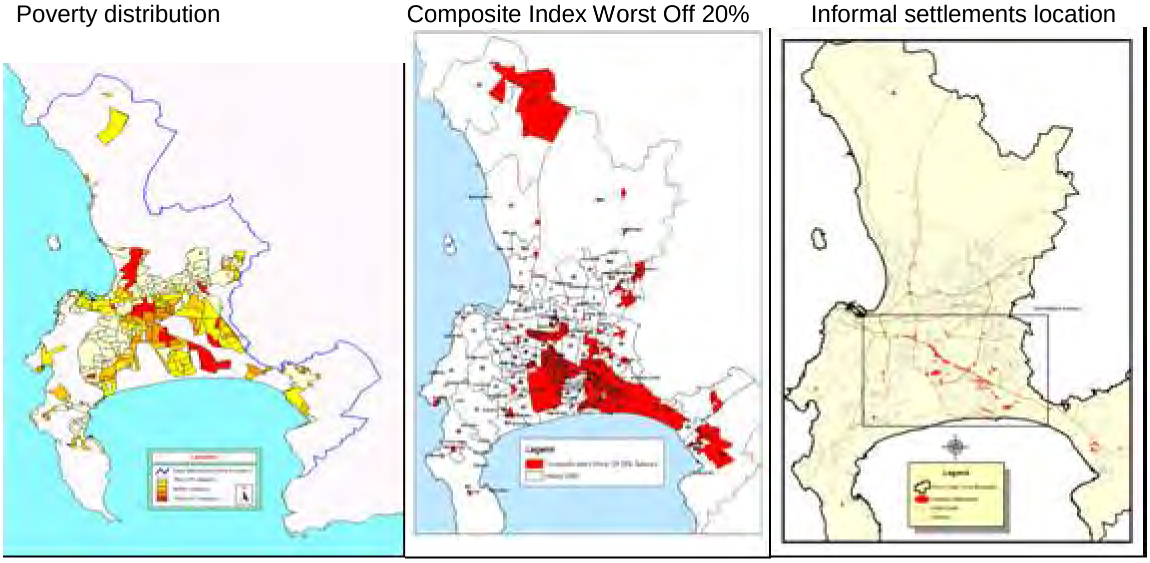
The constitution of South Africa assigns the management of water resources to National Government. On the other hand the management of water and sanitation services is allocated to Local Government, in this case the city Council and specifically the Water Service Department of Cape Town. Cape Town is one of the five metropolitan areas in South Africa. It has a racially-mixed population of 3.3 million people, composed of Coloured[1] (46%), Black (35%), White (18%) and Indian. The distribution of income across racial groups is alarmingly unequal. Unemployment (23.4%) and poverty (35%) as well as housing and infrastructure backlog are especially stressed in the black community. 90% of Black Africans

[1] **Coloured:** Also referred as Cape Coloureds. Originally from the Cape, descendants of the imported slaves as well as used for other groups of mixed ancestry. Promoted during Apartheid segregation policies in the classification of the different ethnic groups (White, Coloured, Indian and Black). Nevertheless it is still officially used nowadays.

lives in informal dwellings and are mainly engaged in the under-valuated second economy market.

During the last decade Cape Town as well as other metropolitan areas and big cities in South Africa have experienced a huge increase in the number of informal settlements[2]. Urban areas are growing rapidly as they are perceived as a potential source of income and the only way to get advantage of the limited developments in the country. There are more than 220 informal settlements spread all over its territory with an estimated population of about 900.000. In most of the cases the inhabitants of these townships are characterized by low income profiles, living under extreme conditions, lacking the proper financial means and urban infrastructure to cover their basic needs.

Poverty distribution | Composite Index Worst Off 20% | Informal settlements location



Source: *Water Services Development Plan*, city of Cape Town, 2006.

The Water Services Department defined two main goals in respect to the informal settlements in the city of Cape Town:

- To ensure access to a basic water supply to all informal settlements by 2008.
- To ensure access to a basic sanitation service to at least 70% of all the informal settlements by 2010.

Both targets are extremely difficult to achieve due to the already existing gap in the service delivery. These optimistic goals will be challenged because of the constant flow of people immigrating from rural areas, poorer provinces and

[2] **Informal settlements:** based on the UN Habitat Programme definition, these are defined as:

i) Residential areas where a group of housing units has been constructed on land to which the occupants have no legal claim, or which they occupy illegally;

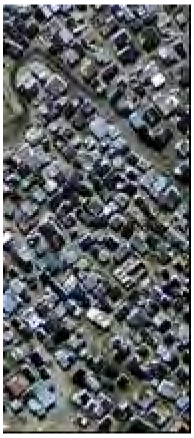
ii) Unplanned settlements and areas where housing is not in compliance with current planning and building regulations (unauthorized housing).

Many other terms and definitions have also been devised for informal human settlements, for example: unplanned settlements, squatter settlements, marginal settlements, unconventional dwellings, non-permanent structures, inadequate housing, slums, townships, etc.

neighbouring countries. They are also dealing with irregular settlements as well as ambiguous socio-economic, cultural and environmental circumstances.

In the case of dense urban low-income settlements, as it commonly occurs in the City of Cape Town, waterborne or equivalent sanitation services such as flush systems become much more limited, even though they are still recommended as appropriate basic sanitation. It is understandable since city officials have enormous difficulties to find appropriate sanitation solutions consistent with the capital and operational budget of the city, as well as with the characteristics and rapid growth of the informal settlements.

Furthermore the city of Cape Town has agreed upon the provision of basic services free of charge. The guidelines for water services in Cape Town describe a water supply of 6000 litres and 4200 litres of sewerage service per household monthly at no cost for all its citizens. Public standpipes in the informal settlements are not accounted for revenue, however these areas face a wide range of water and sanitation related problems. In most of the communities reviewed, sanitation facilities were insufficient or poorly maintained. The main cause is the lack of capital and operational budget for essential sanitation services to deal with the increasing number of informal settlements and its growth, in addition to the insufficient number of technical staff.



Another common problem is the high densities and informal organization of the settlements that limit the space and access availability thus the delivery of proper infrastructure. Frequently most of these settlements are located far from formal services and in unsuitable land such as wetlands, servitudes, steep slopes, flooding prone areas and private land, turning the services even more difficult and complex. Servicing these areas is difficult due to the nature of the terrain and the density and layout of the settlements. In addition there are some social factors hindering the implementation and acceptability of alternative sanitation solutions other than water borne flush toilets; inhabitants of these areas perceive full-flush toilets as an equity concept towards the better standing and developed areas of the city. The social dynamics and community organization differs significantly from site to site mainly because of the high and increasing immigration. The major part of the immigrants come from the Eastern Cape Province, however there's a growing number of rural-urban migration and people from neighbouring countries; most of them unskilled and with a low income profile, looking for job opportunities an improvement of their wealth being. In this way most of the communities are composed of a great variety of cultural backgrounds with different languages, customs and traditions that hardly mix up together. As a result most informal settlements lack the necessary social cohesion as well as financial means of its community to get-up-and-go forwards.

Sanitation is one of the most widespread concerning topics in South Africa and sometimes is prone to be used as a political tool hindering every so often the appropriate service delivery. Political and institutional biases are the result of the constant structural and political modifications in the city Council. Therefore some of the top levels and key elements in the city departments have been replaced or have deserted without any transition or data transfer; with the consequent loss of knowledge and skilled workers. In the same way the service delivery in the informal settlements is lacking the indispensable amount of manpower as well as the coordination of the different city departments involved in the provision of services such as Water Services, Human Settlements, Health, Cleansing, Electricity and Roads. The result of this situation is the lack of updated and reliable data. Therefore the statistics and rates remain promising but the reality is revealing and the data are unreliable.

Most informal settlements are located in unsuitable ground and the land is generally occupied illegally. When this land comprises a private owner, the Water Services Department needs to obtain the consent in order to deliver services on-site. On the other hand from the legal point of view if the owner's consent is not granted as well as if the land involves other type of restrictions such as servitudes, located in an old refuse tip or is under legal process, then the provision of sanitation services would not be possible. A common practice is to relocate the inhabitants settled in the restricted areas to city owned land available, it is also applied with the aim to de-densify overcrowded settlements. However this is a really complex issue as long as, first, the affected community will offer massive resistance to be moved; unless the relocation provides more suitable land, better conditions and closer to the economic activity of the city, and secondly there's a current great concern about the land availability in the city, the accessible space is rapidly decreasing and thus the options for proper relocation.

Water borne systems such as pour and full flush toilets connected to the sewerage network in the informal areas cause many operational problems to the city council since they are responsible for the operation, maintenance, repair and replacement of these facilities. The main weakness of the system is related to the cleansing material used by the settlers other than toilet paper. The informal settlements are linked to low-income communities lacking the financial resources to afford the monthly basic needs required. Therefore materials such as vegetable leafs, stones or hard paper are commonly used, leading to constant blockages and failures of the system.

Grey water problem. Existing standpipe in the foreground

Drinking water is normally supplied by the use of public or communal standpipes connected to the reticulation system. Cape Town drinking water resources is essentially dependent on surface water thus relying completely on winter rainfalls. Water is stored in a number of Dams from where is treated and distributed. Short rainfall during winter represents scarcity during summer. Global warming and population growth is already placing a burden on water resources. Further investment will be required in order to ensure sufficient water resources, sustain water and sewerage infrastructure and economic growth. It's clear that water borne sanitation systems could imply an excessive burden to the currently stressed water supply system and thus become a key constraint in the near future. The situation related to drinking water availability in the informal settlements has improved enormously and rapidly in the last years. Consequently water consumption in the informal areas has increased considerably although it remains below the developed areas. As a result of the higher water consumption due to the installation of a large number of public standpipes, is increasing the current huge concerning problem of grey water. Standpipes are not only used for collection of drinking water but also washing hands, clothes, dishes and utensils. This results in excessive grey water accumulation. Where no formal sewer or storm water is nearby, or the ground water table is high, the grey water eventually stagnates and becomes a serious hygienic problem. The more standpipes, the greater is the problem.

Grey water being disposed of by resident. Unhygienic situation on doorstep

Finally, slow capital expenditure in water infrastructure has dreadful implications for the service delivery to the community. Insufficient budget leads to restrain the currently ageing infrastructure and slows or constrains the construction of any new infrastructure. Consequences of the ageing bulk infrastructure are the current water losses in the distribution systems. Unaccounted water caused among others by illegal connections and leaks in the network stands for 25% of the total amount of drinking water supplied to the reticulation system. Sewer pipes are ageing as well, in that sense trenches appear all of the sudden in the middle of some streets. Consequently sewage drains to the soil and groundwater, increasing pollution of alternative water sources. On the other hand water infiltrates into the sewerage and moves to the waste water treatment plants. The excess of flow strain the currently overloaded treatment works and the effluent quality. Nowadays almost 40% of the waste water treatment plants are working near or over their designed capacity and most of them do not comply with some of the effluent disposal standards.

Therefore the factors affecting the effective and proper sanitation service delivery in the informal settlements can be summarised as follows:

- Rapid urbanization, population growth, strong migration patterns and increasing water demand
- Increasing shortage of water resources
- Settlements' ambiguous socio-economic conditions
- Irregular, unplanned and complex site lay-outs
- Unsuitable grounds, uncertain situation of the settlements and lack of land tenure
- Ageing, corroding and leaking water and wastewater infrastructure
- Overloaded wastewater treatment works and poor effluent quality
- Insufficient Capital and Operational budget
- Deficient revenue collection
- Lack of Institutional capacity

- Lack of reliable and updated data on the informal settlements conditions and services
- Difficulty to find appropriate sanitation solutions

Although the focus of this thesis is concentrated on the appropriate selection of suitable sanitation technologies, sanitation is a much broadened subject that could be defined as any system that promotes sanitary or healthy living conditions. It includes systems to manage waste water, storm water, solid waste, and household refuse and it also includes ensuring that people have safe drinking water and enough water for washing.

Some of these problems are out of the scope of this research; however by making available a proper database framework and assessing on the appropriate sanitation systems, this tool aims to highlight the main limitations of the sanitation systems based on the current situation of the informal settlements. It has the final aspiration to help increasing services flexibility, reduce servicing costs, improve the delivery of emergency services, enhance user satisfaction and release some pressure from water resources and waste water treatment works.

Finally I attach a few pictures of the above described situation on sanitation and water supply services.


Kosovo,2005. Greywater problem around standpipe


Kosovo,2005. Dumping of refuse. Unhygienic situation


Green Park, 2005. Poor maintained toilet


S West, 2005. Clogging problems


Burundi, 2005. Standpipe vandalised. Stagnant water problem


Shuku, 2005. Failure of greywater drainage rings


Greywater flows around standpipe


Defecation in the bushes or alongside open channels common, due to insufficient sanitation available


Poor toilet maintenance

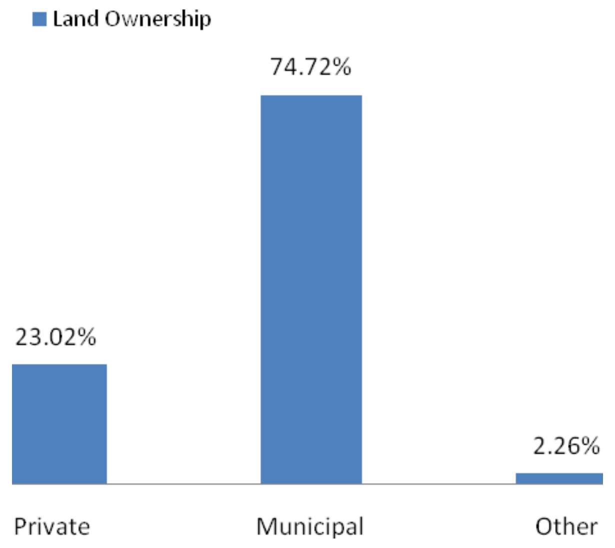
5.2. Results

Land Availability

Although the land availability is not included in the sanitation screening tool it gives a general view and some insight in the current situation of the informal settlements.

From the data available on the 265 informal settlements appears the first limitation for the proper implementation of sanitation services. More than 22% of the settlements are located in private land therefore consent from the owner is required. If this consent is granted then temporary services based on non-permanent infrastructure such as chemical and container toilets, delivered in a 5 households/toilet rate if possible, is applied. Otherwise there is no chance for on-site services leading to peripheral facilities when the conditions allow it.

Figure 5.1: Settlements Land Distribution



Municipal land accounts for the major part of the settlements with 58.5% of its total amount. In principle these areas can be serviced without many limitations. However it has to be considered that some of this land is also not suitable for settling, for instance flooding prone or planned areas for city development or services.

Servitudes as well as road and rail reserves comprise different ownerships from private companies to municipality and province. What matches in all of them is its unsuitability for the population settlement due to private ownership, planning and dangerous circumstances such as being located under power lines (fire risk) or next to main highways. They reach 8% and 6% respectively. In the same way under the title of “Other” with more than 5% includes land under legal process, nature reserves, old refuse tip sites and landfills. Again they are constrained by the same barriers thus becoming impractical the delivery of any type of permanent or upgradable sanitation system.

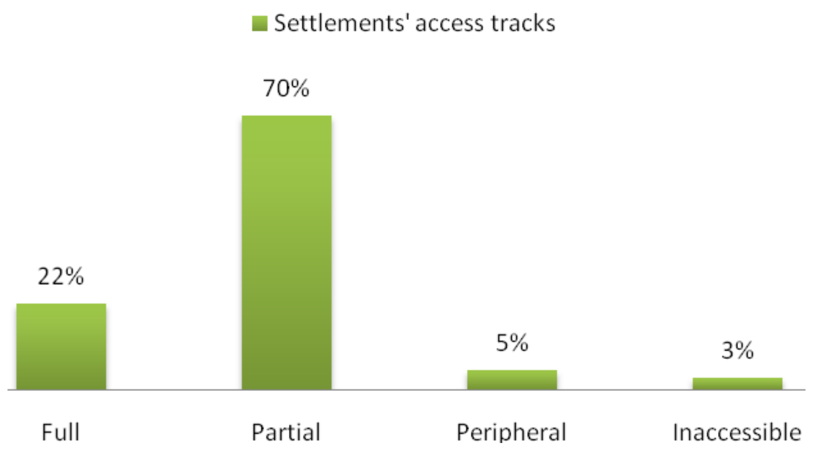
Finally adding the values of the constrained land such as private, servitudes, road/rail reserves and other to the amount of settlements located in unsuitable municipal land it can be argued that more than 50% of the informal settlements in Cape Town are directly limited by the mere fact of land ownership.

Land Accessibility

Access to the informal settlements comprises different values such as peripheral, partial, full or none access. Peripheral access comes along with the inability to service inside the settlements due to none existing inner streets or lacking ownership consent. In the case of "no access" it refers to the inability of reaching the interior of the settlement as well as the peripheral area. By partial access is understood the ability to service the interior of the settlement where just the main streets are accessible. On the other hand full access involves the availability to reach all the dwellings in the settlement.

This aspect is normally correlated with the density of the settlement where higher densities correspond to less accessibility. I was unable to gather the data for all the settlements but I visited most of them during my stage in Cape Town. I cannot give exact and accurate values of the current situation however in the vast majority of the informal settlements partial access was available. Where partial access or owners' consent was not granted peripheral services were generally possible. While full access is rare its percentage is significant due to the low-density or small settlement where one accessible point leads to all the dwellings. Less than 5% of the settlements included in this thesis were located in completely inaccessible sites. The following figure 5.2 provides an estimate based on my visits to the informal areas.

Figure 5.2: Land Accessibility



Given the pre-condition that all the rest of limiting criteria would allow it or just considering land accessibility as the standing-alone constraint, then either fully, partially or peripherally accessible settlements could benefit from any sanitation system. In the case of inaccessible settlements all the systems involving mechanical emptying would be constrained (see Table 5.1 and 5.2 below).

	Settlement Aspects from Database									
	No access	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
	Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
Container + Manual emptying + WWTW										Unfeasible
Chemical + Mechanical emptying + WWTW										Unfeasible
VIP + Mechanical emptying + WWTW		Not Available		Not Available	Not Available	Not Available	Not Available			Unfeasible
VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
Pour-flush + Lined Pit + Mechanical emptying + WWTW		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Unfeasible
Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Unfeasible
Pour-flush + Conservancy Tank + Mechanical emptying + WWTW		Not Available	Not Available			Not Available				Unfeasible
NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying		Not Available	Not Available			Not Available		Not Available	Not Available	Unfeasible
Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.1: Feasibility of sanitation systems in inaccessible settlements

		Peripheral	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW										Feasible
2	Chemical + Mechanical emptying + WWTW										Feasible
3	VIP + Mechanical emptying + WWTW		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW		Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying		Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

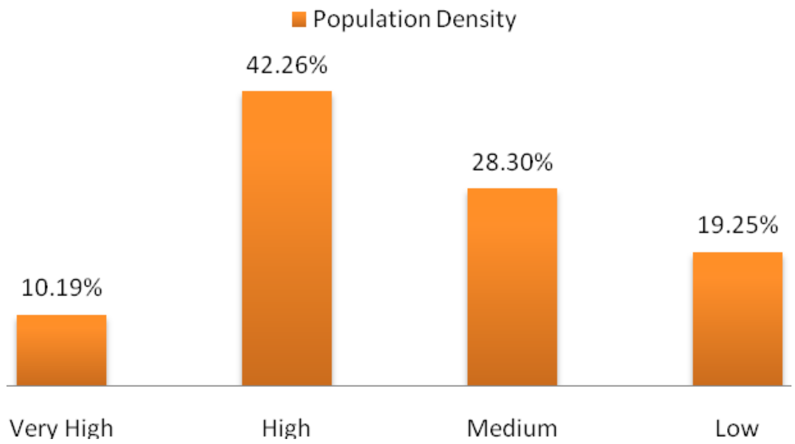
Table 5.2: Feasibility of sanitation systems for full, partial and peripheral accessibility

Moreover systems requiring emptying services in partially or peripheral accessible settlements would allow only for shared or communal facilities while full access could facilitate the implementation of individual or household sanitation services.

Housing density

Density is measured by the number of households in one hectare of land including roads, services and public facilities. As it shows figure 5.3 and in compliance with most of the slum and peri-urban areas in the developing world Cape Town's informal settlements are characterised by high densities. This is one of the most challenging limitations if not the most important. Around 42% of the sites have densities between 150 and 300 households per hectare while more than 10% even rise above the 300 households/ha.

Figure 5.3: Housing density distribution



Medium density settlements, including 28.3% are distributed quite evenly between 50 to 150 households/ha. Most of the low density sites comprise very small settlements with a few 1-50 households and normally located in the outskirts of the city.

		Settlement Aspects from Database									
		Not Available	High	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available			Not Available	Not Available	Not Available	Not Available			Unfeasible
4	VIDP + Manual emptying + Reuse				Not Available	Not Available	Not Available	Not Available			Unfeasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse						Not Available				Unfeasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse						Not Available				Unfeasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available		Not Available			Not Available				Unfeasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)				Not Available	Not Available	Not Available	Not Available			Unfeasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available		Not Available			Not Available		Not Available	Not Available	Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.3: Feasibility of sanitation systems for High-Very high density

When considering housing density as a single limitation for the proper implementation of the sanitation systems described in Appendix A then those ones needing certain amount of space availability such as septic tanks, VIPs and conservancy tanks become restrained by high and very high densities. In the same way composting systems introduced in the model are limited by the low reuse potential in urban highly dense settlements and the lack of space availability for the proper function of the process. In addition medium densities suppose a barrier for the systems based on flushing water with on-site drainage, for instance aquaprivy.

		Settlement Aspects from Database									
		Not Available	Medium	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available			Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse				Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse						Not Available			Not Available	Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse						Not Available			Not Available	Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available		Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)					Not Available	Not Available				Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available		Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.4: Feasibility of sanitation systems for Medium density

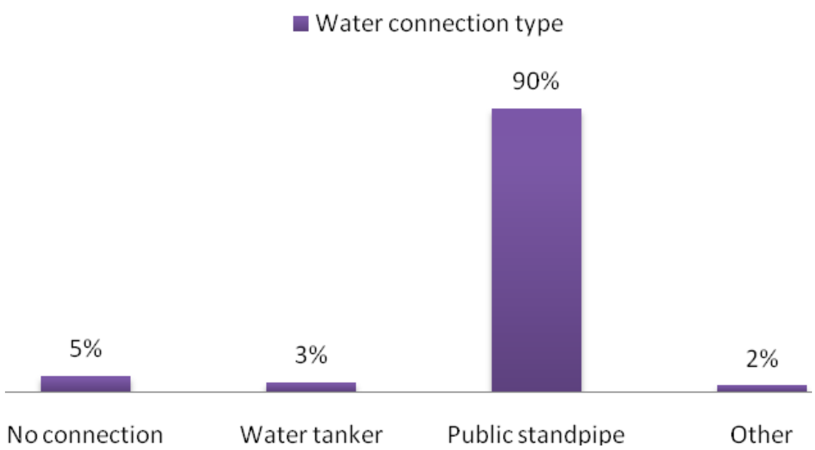
On the other hand when housing density appears below 50 households/hectare then all the systems introduced in the model turn out to be feasible. Nevertheless this would take place in the ideal situation of no other major constraint.

Water supply availability

As it was already stated in the introduction of the case water supply connections have improved a lot in the last years. Even though basic water supply services defined as public standpipes in a range of 200 meters shared within 25 households still remain below 75% of the total informal population (WSDP 2006). Additionally the huge increment on standpipes has led to grey water accumulation and consequent hazards. Although grey water is included into the database it does not play a part into the sanitation screening tool. Despite the fact that some sanitation systems are able to handle grey water the reason lays on the existence of grey water systems independent from the sanitation option. In any case depending on the specific necessities of a settlement it could be included easily as a limitation.

Based on the data available in 'Servicing informal settlements (SIS): draft situation report on the provision of services as at 31 March 2006' about 90% of the informal settlements are currently supplied via communal standpipes while none of them possess household water connection; with the exception of some self-made illegal connections. The remaining 10 % compiles the settlements without any type of water supply connection 5% due to inaccessibility or lack of consent, the ones supplied through water tankers as a result of being distant from formal services and finally "Other" including on-site groundwater extraction and the use of neighbouring facilities.

Figure 5.4: Water supply availability



Once introduced the type of water supply connection to the model all systems involving any use of water such as pour-low-full flush systems are considered unfeasible options where no water connection is available.

		Settlement Aspects from Database									
		Not Available	Not Available	No connection	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available				Not Available				Unfeasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW					Not Available			Not Available	Not Available	Unfeasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available				Not Available		Not Available	Not Available	Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW								Not Available	Not Available	Unfeasible

Table 5.5: Feasibility of sanitation systems in the cases without water supply connection

In addition when water is supplied by means of water tankers, groundwater extraction or yard tanks full-flush systems are limited due to the need for a reliable and constant flow of water. In this case low-flush systems are considered feasible as long as their water tank can be filled by hand.

		Settlement Aspects from Database									
		Not Available	Not Available	Water Tanker	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available				Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW					Not Available			Not Available	Not Available	Unfeasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available				Not Available		Not Available	Not Available	Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW								Not Available	Not Available	Feasible

Table 5.6: Feasibility of sanitation systems in areas supplied by water tankers and groundwater

In contrast when a reliable source of water supply is present such as communal standpipes or yard taps all the systems become technically feasible options. However since almost all the settlements are serviced with public standpipes any system related to flushed water would only be possible if serviced as communal or shared facilities.

		Settlement Aspects from Database									
		Not Available	Not Available	Communal standpipe	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available				Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW					Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available				Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW								Not Available	Not Available	Feasible

Table 5.7: Feasibility of sanitation systems in areas with water supply connection

Water table depth

I was unable to collect all the data related to water table depth in the informal settlements. Therefore with the help of '*A protocol to manage the potential of groundwater contamination from on site sanitation*' from the National Sanitation Co-ordination Office, Directorate of Geohydrology, Water Affairs and Forestry (DWAF, 1997) added to the article of John Yeld in 2005 '*Tapping the hidden reserves of the land for our thirsty* city' from the South African Groundwater Division – Western Cape Branch I have been able to generalise the situation in respect to the Cape Flats area.

The majority of informal settlements, around 75% are located in the low laying areas of the Cape Flats. This area accommodates shallow water table in dune fields with clay lenses and it is considered a valuable resource that could yield sustainably about 18 million m^3. Water shortages in Cape Town are pushing research to assess the potential use of groundwater such as the Cape Flats Aquifers and the Table Mountain Group Aquifer. In this sense these water resources must be protected.

Taking this into account and that the minimum height of unsaturated soil below the disposal point should be at least 3 meters (DWAF 1997), for the purpose of this pilot testing any sanitation system related to effluent drainage or direct disposal would be limited where water table depth is below 5 meters.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	2 - 5m	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available			Not Available	Not Available	Not Available			Unfeasible
4	VIDP + Manual emptying + Reuse		Not Available			Not Available	Not Available	Not Available			Unfeasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.8: Feasibility of sanitation systems in areas with water table higher than 5 meters

The only exception within the systems involving drainage is NOWAC thus it supposes to dispose small amounts of already treated wastewater. In this way although the assessment on the potential use of the Cape Flats Aquifers has not yet been published it seems a beneficial option to discharge treated effluent in order to recharge the aquifers.

Moreover in the case of draining systems using flushed water the water table depth condition is rigorously increased to 10 meters. Its aim is to protect the quality of the groundwater aquifer due to the greater amount of water usage leading to higher infiltration rates. Table 5.9 draws attention to the unfeasible sanitation options when considering water tables between 5 and 10 meters while Table 5.10 represents the ideal situation where all systems are considered to be feasible in the absents of other limitations.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	5 - 10m	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available			Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available			Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.9: Feasibility of sanitation systems in areas with a water table lower than 10 meters

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	> 10m	Not Available	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available			Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available			Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available	Not Available			Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Not Available	Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.10: Feasibility of sanitation systems in areas with a water table higher than 10 meters

Soil type

Although most of the informal settlements are located in the Cape Flats in sand/loam soils, I faced the same limitation as in the water table depth. Each site should be assessed independently in order to decide if the soil is suitable for the proper implementation of different sanitation systems. Consequently I will just provide a general example of how the model works depending on the values entered in the database and the ones defined as limitations.

The first exemplar shows the unfeasible sanitation systems when the ground comprises sandy or clayey soils. Sandy soils do not offer enough retention time to wastewater so its high percolation rates could easily pollute groundwater aquifers. Contrary clayey soils do not allow enough infiltration thus waste accumulates, VIPs fill up rapidly and wastewater stagnates in the surface. In this way any sanitation system requiring on-site drainage would be constrained. NOWAC here again is considered an exception but just in the case of sandy soils where it becomes feasible thus its hypothetical clean effluent does not hold any danger for the groundwater reserves.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Clayey	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available		Not Available	Not Available			Unfeasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available		Not Available	Not Available			Unfeasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available								Unfeasible
11	Full flush + Conventional sewer + WWTW			Not Available					Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.11: Feasibility of sanitation systems in areas with Sandy and Clayey soil

Soils composed of a mix of sand and loam commonly expressed as sandy loams and loamy sands would be also considered a barrier for the sustainable function of systems using flushed water and relying on soil drainage. Sand and loam blends grant slightly higher retention times than sandy soils however when water is flushed they are not capable to provide sufficient resistance to prevent the infiltration of polluted wastewater to groundwater levels. As follows Table 5.12 illustrates the unfeasible sanitation options in case of the willingness or necessity to protect groundwater in sand/loam soils.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Loam/Sand	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available		Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available		Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available								Feasible
11	Full flush + Conventional sewer + WWTW			Not Available					Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.12: Feasibility of sanitation systems in areas with Sandy loam and loamy sand soil

Finally by the purpose of this example bare rock surfaces could be considered a strong constraint when considering excavation works for the construction of a sanitation system. In this case the only system affected by this barrier is conventional sewerage. It could be also extended to other systems such as VIPs and septic tanks but I regarded them as being able to lay on surface ground. Nevertheless the user of the model has complete freedom to define the obstacles for each sanitation option. Whatever other type of soil does not influence in the correct performance of any sanitation systems.

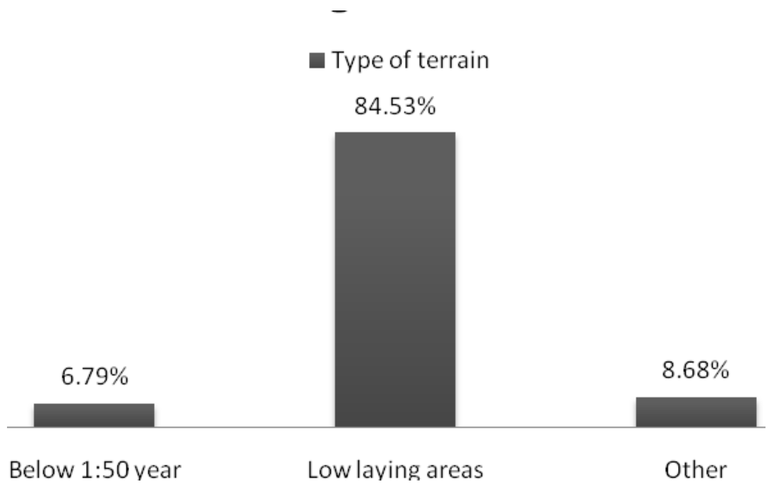
		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Clay loam	Not Available	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available		Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available		Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available								Feasible
11	Full flush + Conventional sewer + WWTW			Not Available					Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available	Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.13: Feasibility of sanitation systems in areas with other soil type

Flooding prone areas

Winter rainfalls normally lead to floods in the low laying areas of the Cape plain. In this sense the GIS Department of the city council in Cape Town has developed a map of the flooding prone areas (below 1:50 year) through the whole territory. From the same data source I analysed and compared it with the location of the informal settlements and the topographical contours (20 meters variation level). In this way the settlements within a defined flooding prone area in the map or in direct contact were considered into the below 1:50 year flood line group accounting 6.79% of the informal settlements. The sites located into the same contour line of the flooding prone areas (less than 20 meters difference) such as the Cape Flats and some settlements in the south-east and north-west of Cape Town were classified as low laying areas. This group turns out to embrace the vast majority of the settlements with an estimated value of 84.53%. The rest 8.68% of the 265 informal sites included into the 'Other' section are located above 20 meters of any flooding prone area.

Figure 5.5: Flooding prone areas



With this information in mind, once introduced the data in the screening tool and in compliance with the previous definition of the limiting criteria and values for each one of the sanitation options involved in the model, sanitation systems located in settlements below 1:50 year flood line become strongly constrained. Therefore all the systems relying on soil drainage as well as the ones storing considerable amounts of wastewater such as septic and conservancy tanks are thus considered unfeasible. In addition the composting options from the model are also limited due to the potential hazard and improvable capability to maintain dry conditions compulsory for its appropriate operation.

Table 5.14 indicates that the only feasible sanitation options in flooding prone informal settlements are reduced to emergency facilities such as chemical and container toilets as well as the systems involving complete and sealed sewerage networks, in this case conventional and shallow/simplified sewerage systems. In any case is doubtful that flooding prone sites are suitable or able to accommodate any human settlement. However this is the case and present reality.

		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
	Settlement Aspects from Database	Not Available	Not Available	Not Available	Not Available	Not Available	Below 1:50 year	Not Available	Not Available	Not Available	
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available		Not Available			Unfeasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available		Not Available			Unfeasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available								Unfeasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available								Unfeasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available							Unfeasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available					Unfeasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available					Not Available	Not Available	Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.14: Feasibility of sanitation systems in Flooding prone areas (below 1:50 year)

When the conditions are a little bit softened by means of low laying areas then the sanitation options founded on flushing water and effluent drainage with the previously already mentioned exclusion of NOWAC systems are constrained again. VIPs and composting options could be raised above the ground to overcome eventual risky situations.

		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
	Settlement Aspects from Database	Not Available	Not Available	Not Available	Not Available	Not Available	Low laying areas	Not Available	Not Available	Not Available	
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available		Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available		Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available								Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available								Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available			Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available			Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available							Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available					Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available					Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.15: Feasibility of sanitation systems in Low laying areas

In principle all the settlements located 20 meters above the flood line could benefit from any sanitation option.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Not Available	Other	Not Available	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available		Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available		Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available								Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available								Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available							Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available					Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available					Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Not Available	Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.16: Feasibility of sanitation systems in Other than flooding

Terrain slope

As it has been explained in the previous chapter systems based on on-site percolation are less suitable for use in steep topography as the flow my seep back to surface level further down the slope as well as excavation on very steep slopes is prone to terrain slipping. In the case of the informal settlements in Cape Town this is not a common problem.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	> 25	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available				Unfeasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available				Unfeasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available				Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available				Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available				Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

Table 5.17: Feasibility of sanitation systems in Terrain slope > 25^{o}

From the 265 sites included in the model I was just able to locate a single settlement (Hangberg) with this feature and maybe 2 more of them were close to the constraining value of 25 degrees (1:4 ratio). In this way I would argue that terrain slope is not a key limitation in Cape Town informal settlements. Yet in order to demonstrate the outcome of the model when terrain slope turns out to be limiting the suitability of sanitation systems Table 5.17 and 5.18 are represented.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	< 25	Not Available	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available				Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available				Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available				Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available				Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available				Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available	Not Available	Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available	Not Available	Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available	Not Available	Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available	Not Available	Feasible

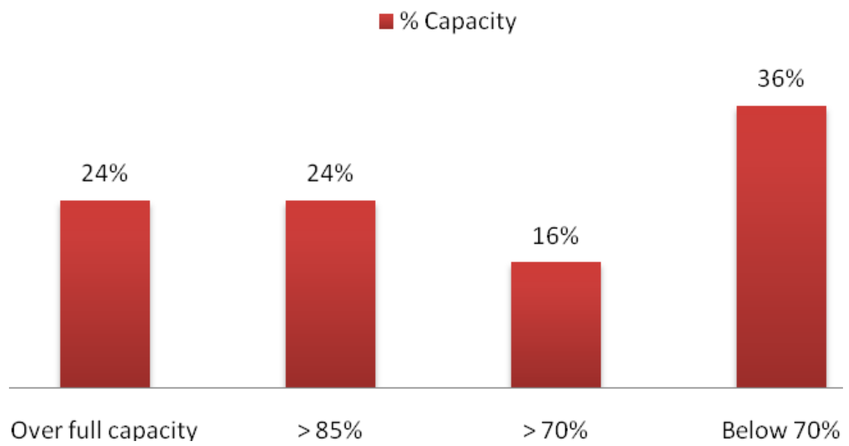
Table 5.18: Feasibility of sanitation systems in Terrain slope <25^{o}

Wastewater treatment works capacity

The database collects the information about the distance from the settlement to the main sewer line and the WWTW capacity. Based on cost grounds the distance could be used as a limiting aspect. In this example it is considered that a distance of more than 1000 meters to the main sewer line would not allow the suitability of any sewer-founded system. Just 11 sites were not compliant with this criteria thus I only use as example the WWTW capacity. The model's database incorporates the current capacity of the WWTW where the nearest sewer network leads. Calculations for the future capacity of the WWTW are explained in chapter 4.

When future capacity overflows 95% any sanitation option based on sewerage network is asserted as unfeasible. This value % should be assessed in compliance with the size and characteristics of the specific WWTW. From the data evaluated in Cape Town's '*Water Services Development Plan (WSDP 2006)*' 24% of the WWTW are already being overloaded and the same amount is currently operating at more than 85% of its capacity. The information required to link each settlement with its corresponding WWTW is not yet available and based on the first analysis, just one particular WWTW is located in the middle of several highly dense settlements. For that reason and in this case the screening tool is only used to outline which consequences would enclose the WWTW capacity in relation to the suitability of the different sanitation options.

Figure 5.6: Distribution of WWTW by capacity



Systems such as conventional, small bore and shallow sewerage networks leading to Wastewater treatment works are limited when capacity exceeds 95%. On the other way around no barriers are encountered for the implementation and operation of the above mentioned systems.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	> 95	Not Available	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available				Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available				Not Available	Unfeasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available			Not Available	Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available		Not Available	Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available						Not Available	Unfeasible

Table 5.19: Feasibility of sanitation systems when WWTW capacity > 95%

Anal cleansing method

As explained in the introduction to this chapter the informal settlements in Cape Town where sewer-based systems are delivered suffer from constant blockages and malfunction of the system. The main cause is related to the cleansing material used by the settlers. As they do not have sufficient financial means they endlessly rely in hard or bulky materials such as leafs, plastics and hard paper. The team responsible, within the WS Department, for the maintenance of these facilities are unable to handle the constant demands for repair.

Therefore although it is not possible to define specifically for each settlement the type of material used I would affirm that soft paper is the most desired cleansing option but not the commonly employed. Water has been included in the different choices due to the huge immigration rates and the potential for diverse cultural backgrounds. In the same line with the previous aspect none of the sewerage options are suitable when using hard or bulky material.

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	hard or bulky materials	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available				Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available		Unfeasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available		Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available		Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available		Unfeasible

Table 5.20: Feasibility of sanitation systems when using hard or bulky cleansing material

		Settlement Aspects from Database									
		Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	water	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW	Not Available									Feasible
2	Chemical + Mechanical emptying + WWTW	Not Available									Feasible
3	VIP + Mechanical emptying + WWTW	Not Available	Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
4	VIDP + Manual emptying + Reuse		Not Available		Not Available	Not Available	Not Available	Not Available			Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse		Not Available				Not Available				Unfeasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse		Not Available				Not Available				Unfeasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available			Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW	Not Available	Not Available	Not Available			Not Available				Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)		Not Available			Not Available	Not Available				Feasible
11	Full flush + Conventional sewer + WWTW			Not Available		Not Available			Not Available		Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying	Not Available	Not Available	Not Available			Not Available		Not Available		Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available	Not Available		Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW			Not Available					Not Available		Feasible

Table 5.21: Feasibility of sanitation systems when using water as cleansing material

In addition although a special washing area could be provided, water as cleansing material constrains the operation of the composting options included.

5.3. Evaluation

Although the data used to test the sanitation decision support screening tool was quite vague and superficial in some of the aspects required for the proper evaluation of the outcomes I believe of relevance to summarize some of the findings.

The limitations included into the screening model are weighted using the same pattern. As soon as a single constraining aspect fails, the whole sanitation system becomes unfeasible. However there are criteria that appear in more systems than others and thus limiting more options. In this way housing density and flooding prone areas are found in 10 of the 14 systems incorporated in the model where the average of limitations per system lays around 6. While some of the systems affected by flooding prone areas such as composting, conservancy and septic tanks could solve their limitations by complete sealing or exceptionally lifting the facilities above the ground, housing density gives the impression to harvest much more complex answers. Moreover when taking into account the astonishing rates presented in the introduction of this thesis. Therefore despite the particular weaknesses of the designed sanitation tool as well as the accessible data available and supported by the literature review it could be, if not confirmed, at least established a strong correlation between housing density and the appropriateness of sanitation systems. In any case there is another aspect which is relatively linked to housing density that restrictively limits the proper implementation of sanitation systems in the majority of urban settlements in developing countries. Land availability is a worldwide growing concern however in the Third world cities it is magnified by migration patterns and low income profiles. As Figure 5.1 shows and in line with most developing cities, more than 40% of the informal settlements in Cape Town are located in unsuitable land. Regardless the characteristics of the land, including density; land availability comprises an enormous barrier thus able to jeopardise the delivery of any sanitation service. Although it was intended to be included into the screening tool, and I believe that in a future stage it should, at the end it was set apart due to the small dependence with the technical suitability of sanitation systems.

The results expose in general terms that few sanitation options are able to handle the extreme situation of most of the informal settlements. In order to outline and emphasize this statement a compilation of the most common scenario based on the data analysis described in the previous paragraphs is presented. In this way a typical informal settlement in the city of Cape Town comprises the following characteristics:

- Access availability: **Partial**
- Housing density: **High**
- Water supply connection: **Public standpipe**
- Water table depth: **2 – 5 meters**
- Soil type: **sand/loam**
- Flooding prone: **Low laying area**
- Slope: **$< 25^o$**
- WWTW capacity: **$< 95^o$**
- Anal cleansing method: **Hard or bulky material**

Once introduced the data into the sanitation screening tool the following outcome is revealing.

		Settlement Aspects from Database									
		Partial	High	Communal standpipe	2 - 5m	Loam/Sand	Low laying areas	< 25	< 95	hard or bulky materials	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW										Feasible
2	Chemical + Mechanical emptying + WWTW										Feasible
3	VIP + Mechanical emptying + WWTW										Unfeasible
4	VIDP + Manual emptying + Reuse										Unfeasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse										Unfeasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse										Unfeasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW										Unfeasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)										Unfeasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW										Unfeasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)										Unfeasible
11	Full flush + Conventional sewer + WWTW										Unfeasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying										Unfeasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)										Unfeasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW										Unfeasible

Table 5.22: Summary feasible/unfeasible systems

The main conclusion of the test is that housing density is a major limitation for the suitable performance of most of the sanitation options included in the system. As I mentioned before water table depth and soil type could differ a lot between and within the informal settlements. The values constraining the sanitation systems in low laying areas might be controversial thus argued its correctness. In any case water table, type of soil and flooding prone aspects constrain the same sanitation options as housing density does, therefore making no difference in front of the final result. On the other hand cleansing methods play a strong role in this example, being the only aspect limiting the suitability of conventional and shallow sewerage. Technically it seems that this constraint could allow for easier problem-solving solution than the rest of the limitations thus making available two more options to the outcome. The feasible options regarded as appropriate by the model include container and chemical toilets. They are just constrained through land accessibility by means of lacking access tracks to the settlement. Although they are not considered appropriate sanitation systems by the MDGs (WHO/UNICEF 2006) and DWAF (2002) they are commonly used as emergency services in the informal settlements of Cape Town. They turn out to be more robust in the practical evaluation and one of the few feasible options yet usually expensive to operate and involving lower sense of community acceptance and satisfaction.

Accessibility (Figure 5.2) also brings along uncertainty on the type of sanitation service delivery. That means where space availability is limited or access tracks are not available sanitation systems relying on emptying services will not allow for individual household facilities. Therefore they would be just possible as shared or public amenities. Even if they are the most desired option and ensured with proper and well organised maintenance they will still be considered inappropriate by the MDG definition. In the same way in highly dense settlements as well as where land comprises some type of restriction public facilities could allow better sanitation services and contribute to the MDGs. I cannot support the withdrawal of public facilities based on bad experiences of the past while they could offer a huge improvement in the sanitation service delivery in most urban areas of developing countries. Moreover when considering that some cultures have been successfully relying on them for centuries besides the fact that human beings have the quality to learn from past mistakes.

As an ending I would like to point out the minimum requirements that should be accomplished in order to deliver any sanitation facility included into the support tool. To be able to reach the 100% of the systems a site should be located in suitable land, with at least partial access, low housing density, public standpipes as a minimum level of water supply, with water tables higher than 10 meters, in any type of soil but sandy, sand/loam, clayey or bare rock surfaces, located out of flooding prone or low laying areas, with a terrain slope lower than 25^{o}, in a range of less than 1000 meters from sewer lines leading to WWTW with less than 95% of its capacity in use and employing soft paper as cleansing method.

		Settlement Aspects from Database									
		Partial	Low	Communal standpipe	> 10m	Silt/Loam	Other	< 25	< 95	soft paper	
		Access Tracks	Density	Water supply	Water table depth	Soil type	Flooding prone	Slope	WWTW Capacity (%)	Anal cleansing method	Technical Feasibility
1	Container + Manual emptying + WWTW										Feasible
2	Chemical + Mechanical emptying + WWTW										Feasible
3	VIP + Mechanical emptying + WWTW										Feasible
4	VIDP + Manual emptying + Reuse										Feasible
5	Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine drainage/reuse										Feasible
6	Double Composting/Urine diversion + Manual emptying + Faecal matter composting + Urine reuse/reuse										Feasible
7	Pour-flush + Lined Pit + Mechanical emptying + WWTW										Feasible
8	Pour-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)										Feasible
9	Pour-flush + Conservancy Tank + Mechanical emptying + WWTW										Feasible
10	NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)										Feasible
11	Full flush + Conventional sewer + WWTW										Feasible
12	Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying										Feasible
13	Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)										Feasible
14	Low-flush + Shallow sewer + (Conventional sewer) + WWTW										Feasible

Table 5.23: Summary aspects feasible systems

It is also acknowledged that different criteria and values as well as the inclusion of more sanitation alternatives would result in a completely different assessment. However most of the aspects and its values were defined in compliance with the available literature.

CHAPTER SIX
Conclusions & Recommendations

Conclusions:

This thesis research intended to develop a framework to support participatory decision making for the selection of sanitation systems through an open frame that could match all the specific limitations in different settings. By that it aims to contribute to the challenging goals of the MDG_7. Although this thesis just focused on the technical and environmental appropriateness (i.e. water table, soil type, water supply connection) of sanitation systems related to the site layout conditions (for instance housing density and settlement accessibility), it could be employed to cover broader aspects such as community acceptability and economic affordability. Current urbanization trends as well as population growth and complex socio-economic conditions in urban areas of developing countries exceed the capacity of city planners to select appropriate sanitation systems thus stressing the necessity to improve the decision-making process.

In this line and in compliance with the research questions, the first objective of this thesis was to identify the existing sanitation decision-support tools and to assess them using a set of evaluative criteria (user-friendliness, transparency, flexibility, versatility, interactivity and level of detail) in order to summarize their strengths and weaknesses. The reviewed literature revealed that a limited number of decision support tools intending to assist in the selection of appropriate sanitation systems were available. Five major sanitation decision support tools were located comprising different formats such as flow diagrams (Kalbermatten 1982 and WHO 1992), decision table (Navarro 1994) and computer-based systems (SANEX 2002 and WRC 2007). As Table 2.4 shows, the non-electronic decision-support tools although they offer admirable user-friendliness and transparency, they are provided with low interactivity and level of detail. On the other hand computer-based models are equipped as well with a friendly user interface and are able to increase significantly their interactivity and level of detail. However it seems that while greater is the complexity and detail of the tools, the weaker is their transparency. Furthermore none of the five models evaluated provides sufficient flexibility and versatility to the decision process. Too rigid algorithm structures in the non-electronic sanitation decision-support tools as well as the predetermined in advance, fixed limiting values and assumptions in SANEX and WRC were the main reasons.

From this concern and in order to fulfil the weaknesses of the previous models an improved sanitation decision support tool was developed. Transparency, flexibility and versatility were used as guidelines for the design of the database and sanitation decision support screening tool. For the purpose of this thesis 9 limiting criteria and its values were selected (section 4.2) for the feasibility assessment of 14 sanitation systems (Appendix A). Although the results could differ greatly depending on the selected criteria it provides maximum user flexibility to decide on them as well as adaptability to the scenario where is intended to be employed.

The pilot test of Cape Town concluded that none of the included sanitation options considered “appropriate” (by means of the MDGs) was suitable for the general site layouts of the informal settlements. Despite the vagueness and ambiguity of some data and regardless of its arguable results the screening tool illustrates a clear conclusion. The user is able to recognise in a logical and transparent way the technical limitations for the feasibility of each one of the sanitation systems involved in the assessment. In this way besides the feasible options and as an added value, the outcome presents a set of constraints that must be surpassed in order to implement the sanitation systems considered unfeasible. Housing density is the major urban obstacle for the proper performance of most of the sanitation options included in the decision support tool. Moreover access tracks and anal cleansing method become key limitations in highly dense settlements since they could jeopardise the suitability of the few sanitation options available such as container toilets and sewerage systems.

<u>Recommendations and Further research:</u>

The most urgent issue is to test the tool in several and diverse environments in order to validate, discuss and improve the design and operation of the sanitation decision support tool.

It is also strongly recommended to create a pre-stage where the sanitation systems could be assembled. In this sense an upgradable library with a list of the different possible elements for each sanitation block (toilets, collection, transport, treatment, disposal/reuse) should be supplied. It would be positive to modify the current lexical format (name + name +…..+ name) to a more graphical format with drawings or pictures. In this way it would gain in simplicity thus comprehensiveness in communities participatory planning. In the same line the addition of a post-screening stage would enhance a more complete and detailed approach to the feasible options. For instance a sustainability or performance assessment as well as related cost estimates could be included.

Finally in order to conclude, a list of potential aspects for further research needed to improve the presented sanitation decision support model is outlined.

- Develop accurate time-line calculations such as flows vs population growth
- Integrate flexible statistics in the database
- Facilitate and qualify the database to be integrated in intranet networks and GIS systems.

References

Baghri S. and Wilson T. (2004). *Plan's approach to water and environmental sanitation.* Working Paper Series. Plan International Headquarters, United Kingdom.

Brown R.B. (1998), *Factsheet SL-29: Soil Texture.* Institute of Food and Agricultural Sciences, University of Florida: USA.

Calaguas B. and Roaf V. (2001), *Access to water and sanitation by the urban poor*. WaterAid, Paper presented to the Development Studies Association Conference, Manchester.

Central Witwatersrand Regional Services Council (1994), *Assessment of the various options available for providing sanitation services to the Central Witwatersrand Regional Services Council area.* Draft final report, Johannesburg, South Africa.

City of Cape Town (2006), *Draft Water Services Development Plan (WSDP) 2006/07*. Revision: 8 February 2006.

Cloete F. (2001), *Improving Effective Governance Performance in Developing Countries with Electronic Decision Support Tools.* PUBLICFUTURES 2ND ANNUAL CONFERENCE, London.

Cotton A. and Saywell D. (1988), *On-Plot Sanitation in Low-Income Urban Communities: Guidelines for Selection.* WEDC Water Engineering and Development Centre, Loughborough University.

de Bruijne G., Geurts M. and Appleton B. (2007), *Sanitation for All?* Thematic Overview Paper 20. IRC International Water and Sanitation Centre, Delft, The Netherlands.

DWAF Department: Water Affairs and Forestry (1994), *Water Supply and Sanitation Policy. White Paper*, Cape Town, South Africa.

DWAF Department: Water Affairs and Forestry (1997), *A protocol to manage the potential of groundwater contamination from on site sanitation*. National Sanitation Co-ordination Office, Directorate of Geohydrology, South Africa.

DWAF Department: Water Affairs and Forestry (2002). *Sanitation for a Healthy Nation. Sanitation Technology Options.* South Africa.

EAWAG/SANDEC and WSSCC (2000), *Working Group on Environmental Sanitation Report*. Swiss Federal Institute for Environmental Science and Technology, Duebendorf, Switzerland.

Engelen G. (2000), *The development of the WADBOS decision support system*. Technical paper prepared for the National Institute for Coastal and Marine Management (RIKZ), Directorate-General of Public Works and Water Management, Ministry of Transport, Public Works and Water Management. The Hague, The Netherlands.

Franceys R., Pickford J. & Reed R. (1992), *A guide to the development of on-site sanitation.* World Health Organisation, Geneva.

Fülöp J. (2005), *Introduction to Decision Making Methods*. Laboratory of Operations Research and Decision Systems, Computer and Automation Institute, Hungarian Academy of Sciences.

GTZ Deutsche Gesellschaft für Technische Zusammenarbeit (2005), *Improvement of Sanitation and Solid Waste Management in Urban Poor Settlements*. Eschborn, Germany.

Harris R. (1998), *Introduction to Decision Making.* VirtualSalt. http://www.virtualsalt.com/crebook5.htm

Henderson J.C. and Schilling D.A. (1985), *Design and Implementation of Decision Support Systems in the Public Sector.* Sloan School of Management, Massachusetts Institute of Technology. Faculty of Management Sciences, Ohio State University.

Hogrewe W., Joyce S.D. and Perez E.A. (1993), *The Unique Challenges of Improving Peri-Urban Sanitation*. Technical Report No. 86.

Kalbermatten JM, Julius DS, Gunnerson CG (1980), *Appropriate technology for water supply and sanitation. Technical and economic options.* Research Project RPO 671-46. Washington, D.C: World Bank.

Linkov I., Varghese A., Jamil S., Seager T.P., Kiker, G. and Bridges, T. (2004) .*Multi-criteria decision analysis: A framework for structuring remedial decisions at the contaminated sites*., In: Linkov I. and Ramadan A.B. (Eds.), *Comparative Risk Assessment and Environmental Decision Making*. Springer, New York.

Loetscher T., Keller J. (2002), *A decision support system for selecting sanitation systems in developing countries.* Advanced Wastewater Management Centre, The University of Queensland, Brisbane, Australia. Socio-Economic Planning Sciences 36 267–290.

Looker N. (1998), *Municipal wastewater management in Latin America and the Caribbean: a discussion paper on trends, challenges and the market*. Prepared for: The Round Table on Municipal Water, Vancouver, Canada.

Mara D.D. (1996), *Low-Cost Urban Sanitation*. John Wiley & Sons, Ltd.

Medilanski E., Chuan L., Mosler HJ, Schertenleib R. and Larsen T.A. (2006), *Environment and Urbanization.*

Muller P. and Truman H. (1989), *Suburban downtowns and the transformation of metropolitan Atlanta's business landscape*. Urban Geography.

Navarro R.G. (1994), *Improving Sanitation in Coastal Communities with Special Reference to Puerto Princesa, Palawan Province, Philippines*. School of Architecture, McGill University, Montreal.

RBA Centre, Delft University of Technology (2003), *Public Participation and the European Water Framework Directive. The role of information and ICT tools.*

SANDEC (1999). Household-centred environmental sanitation. Dubendorf, Switzerland.

Sanitation 21, IWA (2006). *Simple Approaches to Complex Sanitation. A draft Framework for Analysis*.

Scheinberg (2006), *The ISSUE Programme: Pushing the Paradigm Shift in the Urban Environment.*

Schertenlieb and Heinss (2002), *Keeping Wastewater in Sight and in Mind-A New Approach to Environmental Sanitation*. Department of Water and Sanitation in Developing Countries, Swiss Federal Institute for Environmental Science and Technology, City Development Strategies Initiative: Journal 6.

Solo T.M., Perez E. and Joyce S. (1993), *Constraints in Providing Water and Sanitation Services to the Poor*. Technical Report No. 85.

Tandia C.T. (2006), *Involvement / community participation in hygiene and water in Central and Western Africa.* Presentation at the International Conference Community Health in African Region. Addis Ababa, Ethiopia.

UNESCO United Nations Educational, Scientific and Cultural Organisation (2006), *Capacity building for ecological sanitation*. *Concepts for ecologically sustainable sanitation in formal and continuing education.* International Hydrological Programme (IHP).

United Nations, Department of Economic and Social Affairs, Population Division (2003), *World Population in 2300* (medium scenario).

United Nations, Department of Economic and Social Affairs, Population Division (2006), *World Urbanization Prospects: The 2005 Revision*. Working Paper No. ESA/P/WP/200.

United Nations, Population Reference Bureau (1998), *World Population Projections to 2100.*

van Lier, Pol, Seeman, and Lettinga (1998), *Decentralized Urban Sanitation Concepts: Perspectives for Reduced Water Consumption and Wastewater Reclamation for Reuse*. EP&RC Foundation, Wageningen (The Netherlands), Sub-Department of Environmental Technology, Agricultural University.

Varis O. and Somlyódi L. (1997), *Global urbanization and urban water: Can sustainability be afforded?* IAWQ, Elsevier Science Ltd.

Wall K. and Jackson B. (1992), *Lower standards can ease backlogs*. Business day.

WASH (2004), EAWAG/SANDEC and WSSCC, *HCES: Implementing the Bellagio Principles in Urban Environmental Sanitation Services: Provisional Guidelines for Decision-Makers.* In Press.

Who Owns the Water? (2006). Lars Muller publishers. With the support of EAWAG, the Swiss Federal Institute of Aquatic Science and Technology.

WHO World Health Organization and UNICEF (2006). *Meeting the MDG drinking water and sanitation target: the urban and rural challenge of the decade*.

World Bank (1980), *Water Supply and Waste Disposal, Poverty and Basic Needs Series*. Washington, D.C.

World Bank (1982), *Appropriate Sanitation Alternatives*. *A Planning and Design Manual*. Studies in Water Supply and Sanitation 2.

WRC Water Research Commission (2007). *Sanitation Decision Support Model*. South Africa.

Yeld J. (2005), *Tapping the hidden reserves of the land for our thirsty* city. South African Groundwater Division – Western Cape Branch.

Abstract

Current trends of population growth and urbanization as well as complex socio-economic environments in most developing cities cause serious difficulties for the selection of appropriate sanitation systems.

Evaluation of the existing decision support tools for the selection of appropriate sanitation systems revealed their weakness in flexibility and versatility. Although transparency was variable within the different models it is considered a key element in the participatory process. In this way the objective of this study was to develop a transparent and flexible decision support tool intended to help city officials, planners as well as any community sanitary decision process to select suitable sanitation solutions for each site specific layout. The decision support model involves two main lines. The first one is the creation of a secure and easily upgradeable database to keep an improved and updated record of the settlements situation and services delivered. It includes the essential criteria for the sanitation options assessment and a comprehensive set of relevant aspects with the purpose to maintain an accurate information system about the inserted settlements. A Microsoft Access database is organized through a Visual Basic application in order to simplify and clarify the user interface as well as to protect the data entry in the system. The data can be examined, presented and listed using selected parameters either in Excel or PDF format. On the other hand the database includes the features of a range of sanitation technologies as well as their principal characteristics. In the model, based on an Excel screening tool, these characteristics are used as limitations for the later suitability assessment against the specific conditions of the selected settlement. The proposed indicators are founded on the basic physical and environmental aspects of the specific site. Moreover the user is provided with full flexibility and adaptability to decide, modify, add or remove any of the aspects and criteria involved in the decision support model.

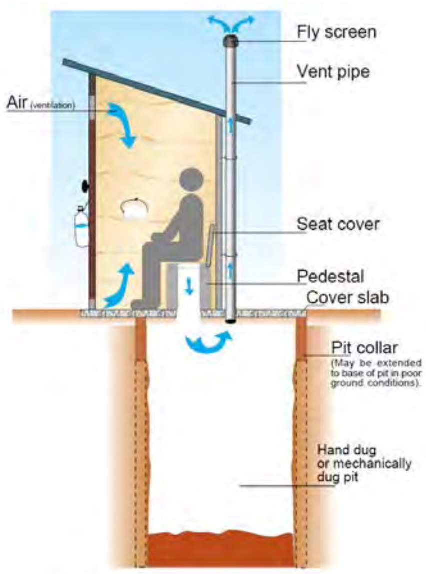
The model was tested with the information available about the informal settlements in Cape Town, one of the five metropolitan areas of South Africa. There are about 220 informal settlements spread all over its territory with an estimated population of about 900.000. In most of the cases socio-economic conditions of the townships are characterized by low income profiles, extreme living conditions and lack of proper financial means to cover basic needs. Water supply and sanitation services in the informal settlements are generally insufficient and poorly maintained. City officials have difficulties to find appropriate sanitation solutions that are consistent with the capital and operational budget of the city, as well as with the characteristics of the informal settlements. According to the decision support model outcome, founded on the information available on the informal settlements, it was concluded that most of the settlements in Cape Town are lacking behind on feasible sanitation solutions. The main barriers to the appropriateness of sanitation systems are the unsuitable location of the settlements such as private land, servitudes, wetlands, flooding prone areas and road reserves, affected by more than 40% of the sites, as well as high and very high settlement densities counting about 55% of the analysed sites.

Appendix A. Technology description and specification list

On-Site

DRY SYSTEMS

1. VIP + Mechanical emptying + WWTW



The ventilated improved pit latrine comprises a top-structure made of concrete over a pit and a pedestal seat with lid. The pit is vented by a PVC pipe over which an aluminium fly-screen is fixed. In addition it is provided with a collar at the surface to stabilize the foundation of the superstructure against collapse of the walls of the pit. In this case the pit can be half- or fully lined as it's recommended where emptying is required. Access tracks are required for vacuum tankers to empty the stored waste. The emptying frequency is about once every 1-2 years. Human waste from the tanker is disposed off into the WWTW. It's a suitable solution where water supply is short or inexistent. Household grey water disposal is unsuitable.

Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

Constraints:

- Access tracks for mechanical emptying

- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 150 households/ha (Muller, 1989). It won't allow the proper use of VIP's. Health risk, space availability and rapid filling up of the pits are the main causes.

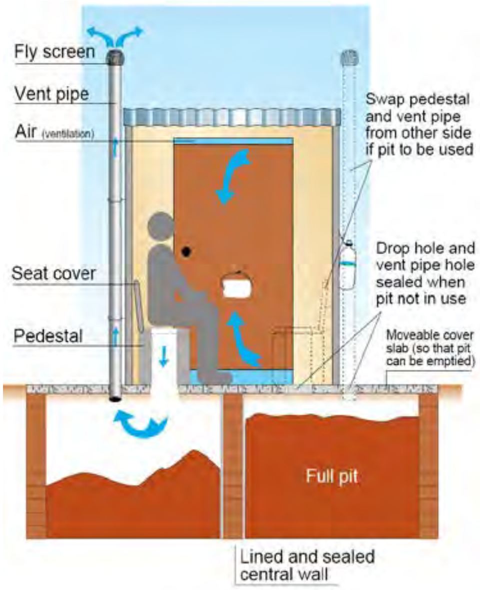
- Water table depth: in order to prevent groundwater pollution and being a solution that relies on soil absorption, a water table depth lower than 5 meters will restrict the use of VIP's. In the case of groundwater extracted from the same area a minimum of 5 meters depth will be necessary (Loetscher, et.al., 2002).

- Soil type: VIP relies on soil absorption and thus will be constrained by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay) as well as by the presence of sandy soils where retention time is too low (Brown RB, 1998).

- Flooding prone: in the areas defined as flooding prone, soil absorption will be jeopardized and thus VIP's.

- Slope: VIP's are less suitable for use in steep topography as the flow from the pit my seep back to surface level further down the slope (Central Witwatersrand Regional Services Council, 1994). In this way a slope higher than 25º will constrain its use (WRC Sanitation decision support model, 2006).

2. VIDP + Manual emptying + Composting + Reuse (fertiliser)



The ventilated improved double pit latrine comprises a bigger single top-structure than VIP made of concrete over two shallow pits and a swappable pedestal seat with lid. Only one pit - vented by a PVC pipe protected with an aluminium fly screen - is in use at any time. Generally lined and the central wall fully sealed to ensure isolation of one pit from the other. Promotion of manual emptying by the householder is usual, and use of decomposed waste as a soil conditioner possible. The contents of the first pit must be dug out after a period of at least two years. It's a suitable solution where water supply is short or inexistent, reuse of excreta is demanded and/or access tracks inexistent. Household grey water disposal is unsuitable.

Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

Constraints:

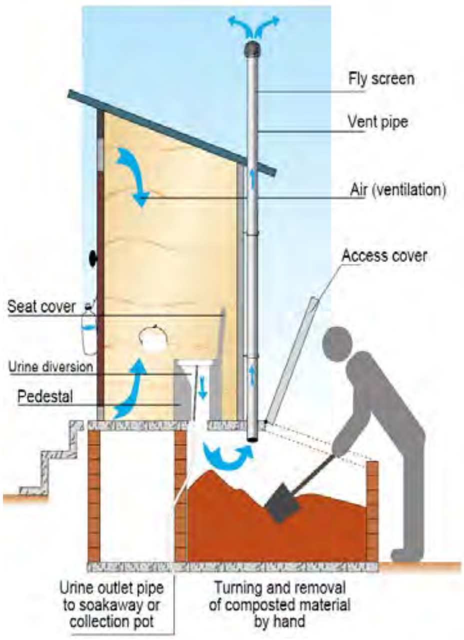
- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 150 households/ha (Muller, 1989). It won't allow the proper use of VIP's. Health risk, space availability and rapid filling up of the pits are the main causes.

- Water table depth: in order to prevent groundwater pollution and being a solution that relies on soil absorption, a water table depth lower than 5 meters will restrict the use of VIP's. In the case of groundwater extracted from the same area a minimum of 5 meters depth will be necessary (Loetscher, et.al., 2002).

- Soil type: VIP relies on soil absorption and thus will be constrained by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay) as well as by the presence of sandy soils where retention time is too low (Brown RB, 1998).
- Flooding prone: in the areas defined as flooding prone, soil absorption will be jeopardized and thus VIP's.

- Slope: VIP's are less suitable for use in steep topography as the flow from the pit my seep back to surface level further down the slope (Central Witwatersrand Regional Services Council, 1994). In this way a slope higher than 25º will constrain its use (WRC Sanitation decision support model, 2006).

3. Composting/Urine diversion (UD) Toilet + Manual emptying + Faecal matter composting + Urine drainage/reuse



Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

The UDT comprises a top-structure made of concrete over a desiccation chamber or lined pit and a pedestal seat with lid. The chamber is vented by a PVC pipe over which an aluminium fly-screen is fixed. Dry absorbent organic material, such as wood ash, straw or vegetable matter is added after each use to deodorise decomposing faeces and/or control moisture and facilitate biological breakdown (composting). Urine is separated for reuse or diverted to soil infiltration through use of urinals. Manual emptying by the householder is required, and use of decomposed waste and/or urine as a soil conditioner and fertilizer possible. It's a suitable solution where water supply is short or inexistent and reuse of human waste is demanded (DWAF, 2002). UDT's are not constrained by access tracks, water supply, soil condition, water table depth or terrain slope. Household grey water disposal is unsuitable.

4. Double Composting/Urine diversion (DUD) Toilet + Manual emptying + Faecal matter composting + Urine drainage/reuse

The DUDT comprises a bigger single top-structure than UDT made of concrete over two shallow pits or desiccation chambers and a swappable pedestal seat with lid. Only one pit - vented by a PVC pipe protected with an aluminium fly screen - is in use at any time. The chambers are separated by a wall and when one pit becomes full, the drop hole is covered and the second pit is used. After a period of time, the contents of the first pit can be removed safely and reused. Urine is separated for reuse or diverted to soil infiltration through use of urinals. It's a suitable solution where water supply is short or inexistent and reuse of human waste is demanded (DWAF, 2002). DUDT's are not constrained by access tracks, water supply, soil condition, water table depth or terrain slope. Household grey water disposal is unsuitable.

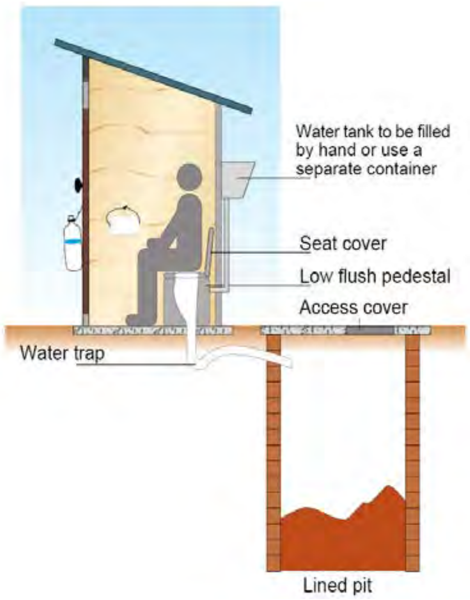
Constraints:

- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 150 households/ha (Muller, 1989). It won't allow the proper use of UDT's. Insufficient biodegradable wastes such as straw and space availability for reuse are the main causes (Kalbermatten, et.al., 1980).

- Flooding prone: in the areas defined as flooding prone, dryness condition can be easily jeopardized and/or moisture greatly increased and thus UDT's are not recommended.

WET SYSTEMS

5. Pour-flush + Lined Pit + Mechanical emptying + WWTW



The pour-flush lined pit toilet comprises a top-structure made of concrete over a lined pit and a pedestal seat with lid. The pit is vented by a PVC pipe over which an aluminium fly-screen is fixed. In addition it is provided with a collar at the surface to stabilize the foundation of the superstructure against collapse of the walls of the pit. Appropriate for small volumes of water and can accept domestic wastewater – generally carried by hand to the latrine. The water retained in the pan provides a seal against smell, flies and mosquitoes. Access tracks are required for vacuum tankers to empty the stored waste. The emptying frequency is about once a year. Human waste from the tanker is disposed off into the WWTW. It's a suitable solution where water supply is short.

Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

Constraints:

- Access tracks for mechanical emptying

- Population density: slum areas and informal settlements located in urban and peri-urban areas posses densities higher than 50 households/ha. It won't allow the proper use of pour-flush lined pits (Kalbermatten, et.al., 1980). Health risk, groundwater pollution, space availability and rapid filling up of the pits are the main causes.

- Water supply: depends on the availability of a reliable water supply nearby.

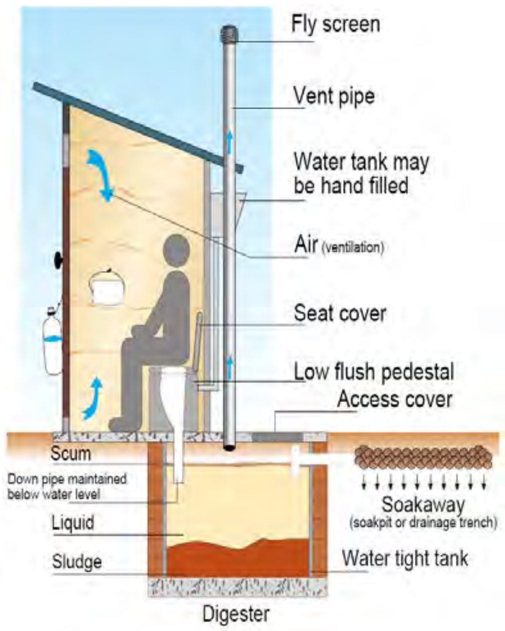
- Water table depth: in order to prevent groundwater pollution and being a solution that relies on soil absorption, a water table depth lower than 10 meters will restrict its use.

- Soil type: it relies on soil absorption and thus will be constrained by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay) as well as by the presence of sandy and sand/loam soils where retention time is too low (Brown RB, 1998).

- Flooding prone: in the areas defined as flooding prone or low lying areas, soil absorption will be jeopardized and thus constrained.

- Slope: lined pits are less suitable for use in steep topography as the flow from the pit my seep back to surface level further down the slope (Central Witwatersrand Regional Services Council, 1994). In this way a slope higher than 25º will constrain its use (WRC Sanitation decision support model, 2006).

6. Pour/Low-flush + Aquaprivy + Soakaway + Mechanical emptying + WWTW (sludge)



Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

The pour/low-flush toilet, aqua-privy with soak-away comprises a top-structure made of concrete over a water tight tank (digester) and a pedestal seat with lid. The digester is vented by a PVC pipe over which an aluminium fly-screen is fixed. Water is sealed by straight or curved chute running from the seat to below the water level in the tank. An aqua-privy requires the addition of water to keep the end of the chute submerged. The effluent is disposed through a drainage trench. Appropriate for small volumes of water and can accept domestic wastewater. Access tracks are required for vacuum tankers to empty the settled sludge about once a year. The sludge from the tanker is disposed off into the WWTW. It's a suitable solution where water supply is short.

Constraints:

- Access tracks for mechanical emptying

- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 50 households/ha (Muller, 1989). It won't allow the proper use of aqua-privy (Kalbermatten, et.al., 1980). Space availability, groundwater pollution from effluent disposal are the main causes.

- Water supply: depends on the availability of a reliable water connection or supply nearby.

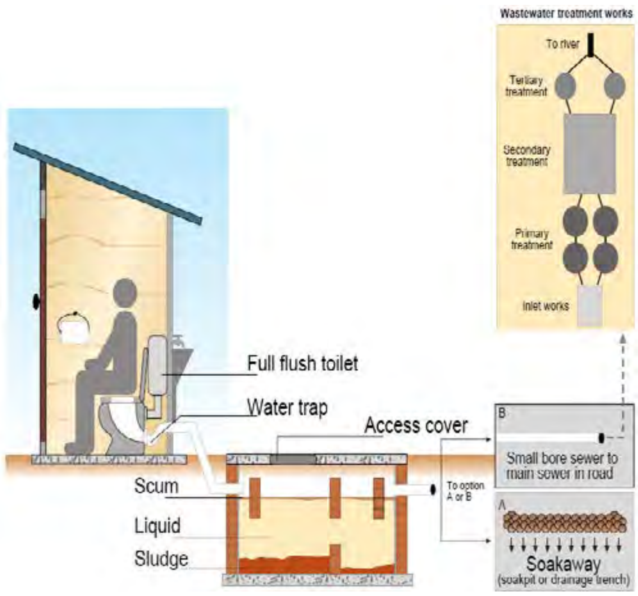
- Water table depth: in order to prevent groundwater pollution and being a solution that relies on soil absorption, a water table depth lower than 10 meters will restrict its use.

- Soil type: it relies on soil absorption and thus will be constrained by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay) as well as by the presence of sandy and sand/loam soils where retention time is too low (Brown RB, 1998).

- Flooding prone: in the areas defined as flooding prone or low lying areas, soil absorption will be jeopardized and thus constrained.

- Slope: lined pits are less suitable for use in steep topography as the flow from the pit my seep back to surface level further down the slope (Central Witwatersrand Regional Services Council, 1994). In this way a slope higher than 25º will constrain its use (WRC Sanitation decision support model, 2006).

7. Full-flush + Septic Tank + Soakaway + Mechanical emptying + WWTW (sludge)



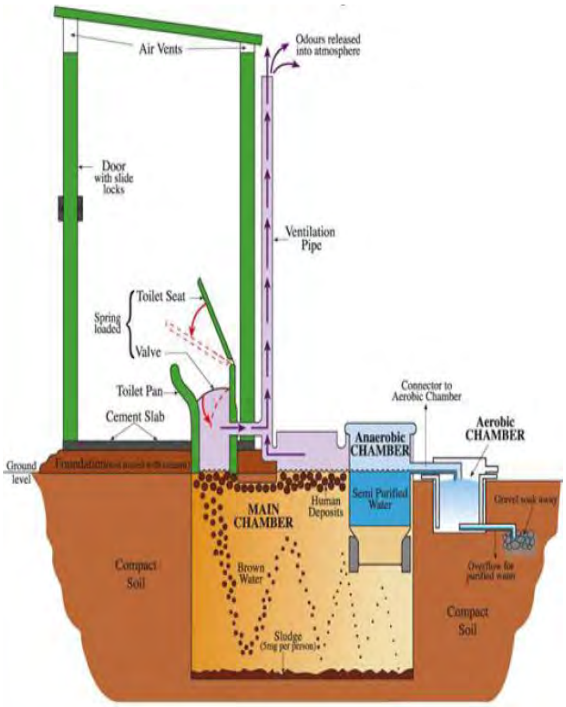
This system comprises a top-structure made of concrete, a water cistern for flushing and a pedestal seat with lid. The water retained in the pan provides a seal against smell. The toilet is connected via pipe and plumbing fixtures to an underground watertight settling chamber (the 'digester') with a liquids outlet to a subsoil drainage/soak-away system. The sludge needs to be removed about once a year by the use of vacuum tanker. It requires a reliable and uninterrupted water connection and it can also accept domestic wastewater.

Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

Constraints:

- Access tracks for mechanical emptying
- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 50 households/ha (Muller, 1989). It won't allow the proper use of soak-away (Kalbermatten, et.al., 1980). Space availability, groundwater pollution from effluent disposal are the main causes.
- Water supply: depends on the availability of a reliable water connection.
- Water table depth: in order to prevent groundwater pollution and being a solution that relies on soil absorption, a water table depth lower than 10 meters will restrict its use.
- Soil type: it relies on soil absorption and thus will be constrained by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay) as well as by the presence of sandy and sand/loam soils where retention time is too low (Brown RB, 1998).
- Flooding prone: in the areas defined as flooding prone or low lying areas, soil absorption will be jeopardized and thus constrained.
- Slope: soak-away's are less suitable for use in steep topography as the flow from the drain my seep back to surface level further down the slope (Central Witwatersrand Regional Services Council, 1994). In this way a slope higher than 25º will constrain its use (WRC Sanitation decision support model, 2006).

8. NOWAC + Anaerobic upflow filter + Soakaway + Mechanical emptying (sand)



Source: DWAF (2002) “Sanitation Technology Options”, DWAF, Pretoria, South Africa

No Water Consumption toilet comprises a top-structure made of concrete over a polyethylene water tight tank (digester) and a pedestal seat with lid. The digester is vented by a PVC pipe over which an aluminium fly-screen is fixed and it’s composed of two chambers. The main chamber where the organic material decomposes must be filled with water and no more water is needed. The second chamber is supplied with anaerobic filters to remove pathogens. The effluent is drained into the soil free of pathogens. The solid particles settled into the main chamber must be removed once every 15-20 years, therefore access tracks are not considered as constraining. NOWAC toilets are not constrained by reliable water supply, water table depth or terrain slope. Household grey water disposal is unsuitable.

Constraints:

- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 150 households/ha (Muller, 1989). It won’t allow the proper use of NOWAC toilets. Space availability and limited retention time before disposal are the main causes.

- Soil type: it relies on soil absorption and thus will be constrained by low percolation rates such as for clayey or fine textured soils (sandy clay, silty clay, and clay) (Brown RB, 1998).

- Flooding prone: in the areas defined as flooding prone, soil absorption will be jeopardized and thus constrained.

Off-site

DRY SYSTEMS

9. Container + Manual replacement + WWTW

The container toilet comprises a superstructure made of concrete with a steel door and a removable 100 L polyethylene container with detachable seat and lid. They are owned by the city of Cape Town but they are operated and maintained by private contractors. Access tracks are required in order to service the toilets. The 100 L container is manually removed and replaced for an empty clean one between 1-3 times per week. Normally containers are filled with some chemicals to disinfect and deodorize. The human waste from the container is disposed into the WWTW. Container toilets are not constrained by population density, water supply, soil conditions, water table depth or flooding situations. Household grey water disposal is unsuitable.

Constraints:

- Access tracks for mechanical emptying

10. Chemical + Mechanical emptying + WWTW

A chemical toilet is a privy having a water tight tank containing a chemical solution placed immediately beneath the seat used to disinfect and deodorize. They are leased by the city of Cape Town and therefore they are owned, operated and maintained by private contractors between 1-3 times per week. The service of this type of toilets is an expensive solution. Access tracks are required for vacuum tankers to empty the stored waste. The human excreta from the tanker is disposed off into WWTW. Chemical toilets are not constrained by population density, water supply, soil conditions, water table depth or flooding situations. Household grey water disposal is unsuitable

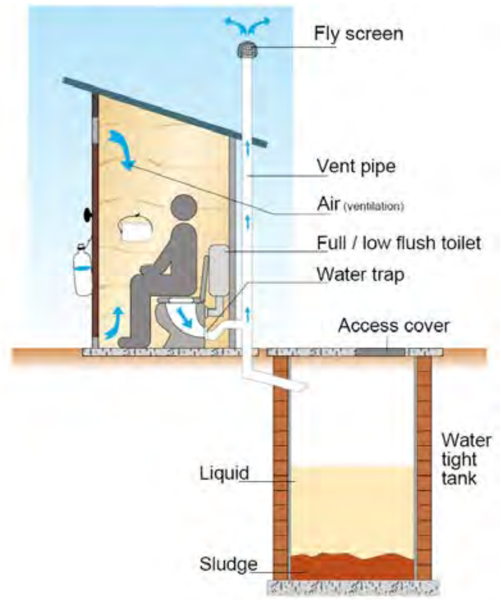
Constraints:

- Access tracks for mechanical emptying

Vacuum Tanker

WET SYSTEMS

11. Pour/Low-flush + Conservancy Tank + Mechanical emptying + WWTW



Source: DWAF (2002) “Sanitation Technology Options”, DWAF, Pretoria, South Africa

The pour/low-flush toilet with conservancy tank comprises a top-structure made of concrete over a water tight tank and a pedestal seat with lid. The sealed chamber is vented by a PVC pipe over which an aluminium fly-screen is fixed. The water retained in the pan provides a seal against smell, flies and mosquitoes. Appropriate for small volumes of water and can accept domestic wastewater. Access tracks are required for vacuum tankers to empty the stored waste. The emptying frequency is about 2-4 weeks. Human waste from the tanker is disposed off into the WWTW. Conservancy tanks are not constrained by population density, water table depth, soil condition or terrain slope.

Constraints:

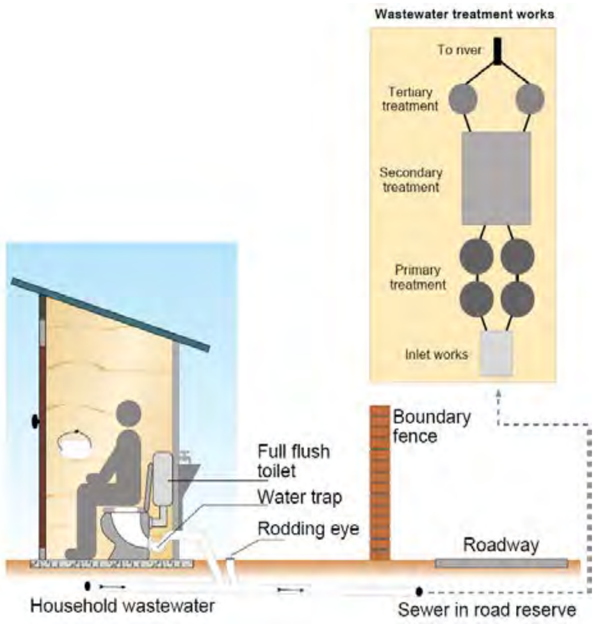
- Access tracks for mechanical emptying

- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 150 households/ha (Muller, 1989). It won’t allow the proper use of conservancy tanks. Space availability and rapid filling of the tank are the main cause (Kalbermatten, et.al., 1980).

- Water supply: depends on the availability of a reliable water connection or supply nearby.

- Flooding prone: in the areas defined as flooding prone, overflow risk due to surface infiltration constrain the system.

12. Full flush + Conventional sewer + WWTW



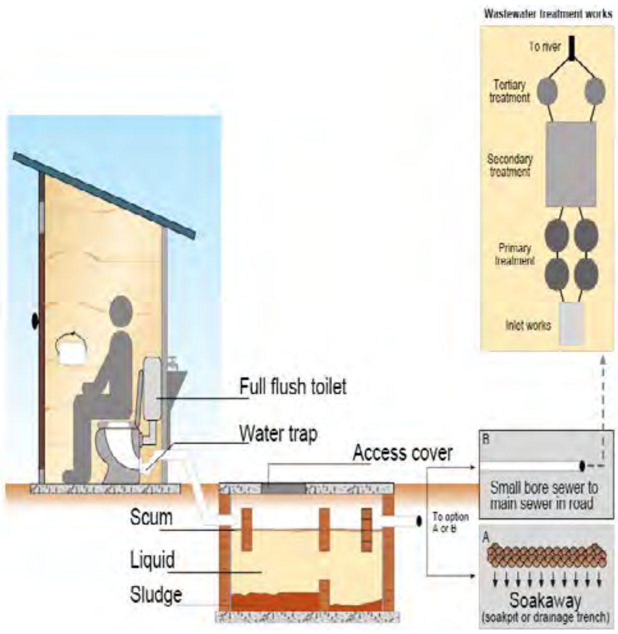
Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

The water borne toilet comprises a top-structure made of concrete, a water cistern for flushing and a pedestal seat with lid. The water retained in the pan provides a seal against smell. It's connected to a sewer pipe network which drains to a wastewater treatment facility. It requires a reliable and uninterrupted water connection and spatially regular permanent settlements. It can also accept domestic wastewater. Conventional sewerage is not constrained by access tracks, population density, water table depth or flooding situations.

Constraints:

- Water supply: depends on the availability of a reliable water connection.
- Soil type: unsuitable system where presence of bare rock. It significantly increases the costs and difficulty of a sewer network construction.
- Distance to main sewer: based on economic grounds a distance higher than 1000 meters from the settlement to the main sewer as well as a leading WWTW with a capacity higher than 95% in use is considered unsuitable.
- Anal cleansing method: the use of hard or bulky material makes this option unfeasible.

13. Full flush + Septic Tank + Small bore sewer + (Conventional sewer) + WWTW + Mechanical emptying (sludge)



This system comprises a top-structure made of concrete, a water cistern for flushing and a pedestal seat with lid. The water retained in the pan provides a seal against smell. The toilet discharges into a septic tank (or on-site digester) with liquids disposal via a small diameter sewer to a central collection sump or existing sewer system. The sludge needs to be removed about once a year by the use of vacuum tanker. It requires a reliable and uninterrupted water connection and spatially regular permanent settlements. It can also accept domestic wastewater. It's not constrained by population density, water table depth, soil condition or terrain slope.

Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

Constraints:

- Access tracks for mechanical emptying

- Population density: informal settlements and slum areas located in urban and peri-urban areas normally possess densities higher than 150 households/ha (Muller, 1989). It won't allow the proper use of septic tanks. Space availability is the main cause (Kalbermatten, et.al., 1980).

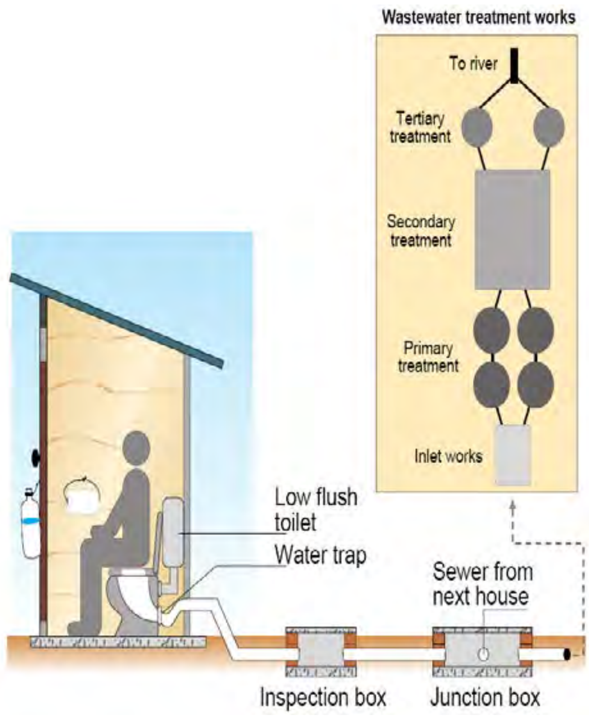
- Water supply: depends on the availability of a reliable water connection.

- Distance to main sewer: based on economic grounds a distance higher than 1000 meters from the settlement to the main sewer as well as a leading WWTW with a capacity higher than 95% in use is considered unsuitable.

- Flooding prone: in the areas defined as flooding prone, WWTW overload risk due to surface infiltration constrains the system.

- Anal cleansing method: the use of hard or bulky material makes this option unfeasible.

14. Low-flush + Shallow sewer + (Conventional sewer) + WWTW



Low-flush shallow sewer comprises a top-structure made of concrete, a water cistern for flushing and a pedestal seat with lid. The water retained in the pan provides a seal against smell. It flushes using lower volumes of water than either conventional sewerage or septic tanks, to smaller diameter sewers laid at flatter gradients and shallower depths between dwellings on a block. On-site shallow inspection chambers are also provided. It requires a reliable and uninterrupted water connection and it can also accept domestic wastewater. Conventional sewerage is not constrained by access tracks, population density, water table depth, soil condition, flooding prone situations or slope.

Source: DWAF (2002) "Sanitation Technology Options", DWAF, Pretoria, South Africa

Constraints:

- Water supply: depends on the availability of a reliable water connection.
- Distance to main sewer: based on economic and operational grounds a distance higher than 1000 meters from the settlement to the main sewer as well as a leading WWTW with a capacity higher than 95% in use is considered unsuitable.
- Anal cleansing method: the use of hard or bulky material makes this option unfeasible.