AN INVESTIGATION INTO THE APPLICATION OF MULTIPLE CRITERIA DECISION ANALYSIS AS A DECISION SUPPORT TOOL FOR MUNICIPAL ENGINEERS

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Declaration

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Abstract

A Multiple Criteria Decision Analysis (MCDA) was developed for the selection of sanitation systems. This decision support system was aimed at assisting municipal engineers to design and implement sustainable solutions to meet the municipality's obligation to provide Free Basic Sanitation (FBS).

The literature review investigated the factors which determine the success of sanitation projects and the sustainability framework in which the MCDA would be structured. Different multiple criteria methods were investigated with particular reference to those which have been applied to sanitation. Multi-Attribute Value Theory (MAVT) was selected as the method most suited to the problem under consideration. This requires the selection of indicators for which alternatives can be evaluated as well as the development of a multi-attribute value function which aggregates the partial values assigned to the indicators to arrive at an overall value for each alternative.

The implementation of FBS by the eThekwini Municipality and the research projects carried out by the University of KwaZulu-Natal on the sanitation systems used by the municipality were analysed. Data from this research informed the allocation of indicator values to the sanitation alternatives under consideration: initially Ventilated Improved Pit latrines (VIPs) and Urine Diversion Dehydrating Toilets (UDDTs). Later a third option, the pour-flush latrine, was added.

Criteria which determine the sustainability of sanitation were selected and a spreadsheet-based MCDA with stakeholder and expert user interfaces was developed. Stakeholders will determine the weighting of each indicator and expert users will determine the values to be entered for the alternatives against each indicator. The partial values are aggregated using a weighted sum function.

The MCDA was populated with values derived from the eThekwini research. Sensitivity analysis was carried out for the weighting of the three main criteria: environmental, financial/technological, and socio-cultural. An innovative scenario analysis method was used to determine the effect of different weightings and/or values.

The MCDA was found to provide a guiding framework for municipal engineers in their efforts to implement sustainable sanitation. The process of deriving values for the MCDA is likely to prove even more useful than the overall value scores of the options under consideration.

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List of Abbreviations

AHP	Analytical Hierarchy Process
BOD	Biological Oxygen Demand
CBA	Cost Benefit Analysis
COD	Chemical Oxygen Demand
DALY	Disability-Adjusted Life-Year
DEWATS	Decentralised Wastewater Treatment System
DM	Decision Maker
DM	Dry Matter
DSS	Decision Support System
DWAF	Department of Water Affairs and Forestry
EAWAG	Swiss Federal Institute of Aquatic Science and Technology
EcoSan	Ecological Sanitation
EFF	Economic Freedom Front
EM	eThekwini Municipality
EWS	eThekwini Water and Sanitation
FBS	Free Basic Sanitation
GIS	Geographic Information Systems
HSRC	Human Sciences Research Council
LCA	Life Cycle Assessment
LDC	Less Developed Country
MAVF	Multi-Attribute Value Function
MAVT	Multi-Attribute Value Theory
MCA	Multiple Criteria Analysis
MCDA	Multiple Criteria Decision Analysis
MDG	Millenium Development Goals
NH_4^+-N	Ammonium Nitrogen
NPV	Net Present Value

O & M	Operations and Maintenance
p	person
pe	person equivalent
PF	Pour-Flush latrine
PHAST	Participatory Hygiene and Sanitation Transformation
PPE	Personal Protective Equipment
PRG	Pollution Research Group
RDP	Reconstruction and Development Programme
SIA	Social Impact Assessment
SIDA	Swedish International Development Cooperation
SIWI	Stockholm International Water Institute
S-LCA	Social Life Cycle Assessment
StatsSA	Statistics South Africa
SuSanA	Sustainable Sanitation Alliance
TSS	Total Suspended Solids
UASB	Upflow Anaerobic Sludge Bed
UDDT	Urine Diversion Dehydrating Toilet
UKZN	University of KwaZulu-Natal
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children’s Fund
VIP	Ventilated Improved Pit latrine
VS	Volatile Solids
WAWTTAR	Water and Wastewater Treatment Technologies Appropriate for Reuse
WCED	World Council for Economic Development
WHO	World Health Organisation
WRC	Water Research Commission
WSA	Water Services Authorities
WWTW	Waste Water Treatment Works
ZAR	South African Rand

Chapter 1. Introduction

In terms of the Constitution of the Republic of South Africa (Act 108 of 1996), access to basic sanitation is the right of all South Africans. The free basic sanitation policy is intended to ensure that the country's poorest citizens have access to hygienic excreta disposal facilities (Department of Water Affairs and Forestry, 2003). Legislation enacted since 1994 devolves responsibility for the provision of this service to municipalities, with infrastructure to be funded through the annual Municipal Infrastructure Grant and operation and maintenance through the Local Government Equitable Share (Water Services Act (Act 108 of 1997), Division of Revenue Act (annual)).

In the past, South African municipalities provided the infrastructure for waterborne sewerage to residents who could afford to pay for this service, and possibly a vacuum tanker service to empty septic tanks. This generally constituted the extent of their responsibilities, and hence the expertise of municipal engineers was focused on large-scale treatment plants and the maintenance of sewers and associated technologies (Still et al., 2009).

In response to the needs of less developed countries (LDCs), a number of alternative systems have been developed for household sanitation and for the disposal of waste from these facilities (Wagner and Lanoix, 1958; Franceys et al., 1992; Tilley et al., 2008). There has been a shift to decentralised technologies deemed more appropriate for areas where water supply is less certain (van Lier et al., 1999). Economic and environmental considerations may also favour these options.

The water and sanitation engineers in many municipalities find themselves technically and institutionally ill-equipped to design and operate decentralised sanitation systems. Engineering managers are required to make decisions about which options to offer, and how to plan the implementation of sanitation strategies, often with insufficient technical and financial information, given the traditional emphasis on waterborne sewage and centralised treatment (Tilley et al.., 2010). Although much has been written about decentralised sanitation systems as appropriate technology for developing countries, it has mostly been from a qualitative and activist point of view, and little can be found in municipal engineers' handbooks. In view of the crucial role that these systems play in government policy, the Water Research Commission (WRC) has initiated a series of research projects to provide a systematic scientific and engineering basis for the provision and management of low cost sanitation on a large scale (Still et al., 2009).

Numerous projects have been launched to increase sanitation coverage in LDCs. The successful initiatives have been those where the scope has been extended beyond the purely technical to encompass entrenched cultural practices, political imperatives and social structures (Brikké and Bredero, 2003, Starkl et al., 2013). The ability and willingness of communities to maintain systems, and the continuing financial investment in operation and maintenance are also crucial. To be deemed successful by society at large, a sanitation solution must consider not only the needs of the community obtaining services, but also the environmental impact of waste disposal (Department of Water Affairs and Forestry, 2003, p. 45).

The aim of this research was to analyse the course and outcomes of the large-scale decentralised sanitation projects carried out by the eThekwini Municipality (EM) in the framework of a decision support system (DSS) and to assess whether this DSS would allow municipal engineers to compare a range of sanitation options, to find those most suited to their particular situation and to estimate their infrastructural, manpower, operational, maintenance and financial requirements. The objective was to lay the foundation for a systematic framework in which to capture the experiences of current and past municipal engineering projects that provide free basic sanitation. The intention was to provide a DSS to assist municipalities to carry out future projects of this kind in a more sustainable and cost effective manner.

The WhichSan decision support tool, developed for the Water Research Commission by Partners in Development (Still et al., 2009) provides a sound basis for technical feasibility assessment and financial projections. This research sought to add a further dimension to that process which would assist municipal managers in choosing and implementing systems which are not only feasible, but sustainable.

The framework which structured the research approach was the sustainable development concept embodied in the World Commission on Environment and Development report of 1987, also known as the Brundtland Report (WCED, 1987), which recognised that humans and the environment are inextricably linked. The report states that *"Humanity has the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs."* and this has become a widely used definition of sustainability (WCED, I. 27.3). Elkington (1998) brought this idea into the world of business with the concept of the Triple Bottom Line *"economic prosperity, environmental quality and ...social justice."*

Chapter 2. Literature review

The literature review which follows examines some of the technologies available for low cost sanitation and the sustainability criteria or indicators which may be used to predict or judge the success of these systems in different circumstances. Multiple criteria decision analysis is explored as a management support system which may be implemented to assist municipal engineers in developing sustainable sanitation solutions.

2.1. Low cost sanitation options

Conventional waterborne sewerage was first introduced on a large scale in Britain in the middle of the 19th Century (Fisher et al., 2005). While very successful in its intended function of removing excreta from the vicinity of those producing them, it has some limitations, particularly in the context of Less Developed Countries (LDCs) (Panesar and Werner, 2006). Sewers require a reliable and plentiful water supply, a high level of maintenance by skilled personnel, and an effective system of treatment for the waste products (Flores et al., 2008). A system which dilutes human excreta with large amounts of potable water and then attempts to reclaim this water downstream is hard to justify in water-scarce countries (Panesar and Werner, 2006).

In South Africa, the waste water treatment works are already under severe strain (Wall et al., 2006), and sanitation has yet to be extended to 11.5 million people, approximately 23% of the population (World Health Organisation / United Nations Children's Fund Joint Monitoring Programme (WHO / UNICEF JMP, 2010 p. 49). This study shows that there is a daunting backlog in the provision of sanitation, particularly in sub-Saharan Africa. Even more ominously, there is a failure of many systems introduced in the last 20 years (Austin, 2003, Smith, 2006, Montgomery et al., 2009, Starkl et al., 2013). While 12.89 million people gained access to improved sanitation in South Africa between 1990 and 2008, the population increased by 12.92 million (WHO / UNICEF JMP, 2010, p. 49). Those as yet without coverage have decreased as a fraction of the population, but increased in number.

In their landmark paper, published by the World Health Organisation in 1958, Wagner and Lanoix described a range of technologies suitable for excreta disposal in developing countries. They discussed pit latrines, pour flush latrines and composting latrines, among others. Tilley et al. (2008) produced the Compendium of Sanitation Technologies, published by EAWAG. Innovations since the 1950s consisted of the addition of a vent pipe to the pit latrine in Zimbabwe in the 1970s (Morgan and Mara, 1985) and the development of flush type urine diversion toilets in Sweden in the 1990s (Kvarnström et al., 2006).

2.1.1. Ventilated Improved Pit Latrines

The Ventilated Improved Pit latrine (VIP) consists of a pedestal or squatting pan fixed over a pit in which excreta is collected (Morgan and Mara, 1985). A vent pipe creates air currents to remove odours and to trap insects which may breed in the pit. The pit may be lined to prevent it collapsing (Department of Water Affairs and Forestry, 2002). Decomposition of excreta takes place in the pit and liquid is able to leach through the lined but unsealed walls so that the pit fills up at a rate of approximately 40 litres/user/year (Still and Foxon, 2012).

Over a million VIPs have been built in South Africa in the last 10 years, but a survey of Water Services authorities in 2009 indicated that many of these are nearly full (Still and Foxon, 2012). When a VIP is full, it must be emptied, or the superstructure located over a new pit, if it is to continue to provide sanitation (Gounden et al., 2006).

2.1.2. Urine Diversion Dehydrating toilets

Urine diversion, or source separation of faeces and urine, allows the collection and use of relatively pathogen-free urine for agriculture. With the removal of the liquid excreta, faeces can be dehydrated and composted for use as a soil conditioner. The purpose of this technology is to “close the loop” in sanitation systems to allow the recycling of nutrients in excreta to produce food in a sustainable manner (Benoit, 2012). A specially designed pedestal or squatting pan is required to achieve this separation (Tilley et al., 2008). Urine enters a pipe from the front of the pedestal and is directed to a collection container. Faeces drop into a vault or collecting container. Covering material is used, usually ash, to prevent faeces from smelling and to assist with composting. In double vault systems, the pedestal is moved once one vault is full and placed over the other vault. The vault contents can then stabilise and need only be removed once the second vault is full.

The Vietnamese composting toilet mentioned in Wagner and Lanoix (1958, p.115) was described in more detail by Rybczynski et al. (1982, p. 62). This early form of double vault urine diversion dehydrating toilet (UDDT) was introduced by the Vietnamese government in the 1950s, and a booklet published by the Department of Hygiene and Epidemiology in the Ministry of Health reported a drop in disease and improved crop production as a result of the use of this system. (Rybczynski et al., 1982 p.62). A living standards survey in 1992-1993 reported that 7.6% of urban and 8.4% of rural Vietnamese households used double vault composting latrines while in 2006 these figures were 5.1% and 24.8% respectively (WHO / UNICEF JMP, 2008). This suggests that these latrines may be increasing in popularity in rural areas, where only 20% of residents use flush toilets as opposed to urban areas, where 70-80% have flush toilets and the popularity of composting toilets is diminishing (WHO / UNICEF JMP, 2008).

UDDTs are the primary form of sanitation advocated by the Ecological Sanitation (Ecosan) movement (Zurbrügg, and Tilley, 2009). International organisations which promote Ecosan include: the European Commission sponsored Network for the development of Sustainable Approaches for large-scale implementation of Sanitation in Africa (NETSSAF), the Swiss Federal Institute of Aquatic Science and Technology (EAWAG), the Sustainable Sanitation Alliance (SuSanA), the German Gesellschaft für Technische Zusammenarbeit (GTZ) and the Ecological Sanitation Research project (EcoSanRes) funded by the Swedish International Development Cooperation Agency (SIDA).

In Durban, eThekwini Water and Sanitation (EWS), the unit of the eThekwini Municipality responsible for sanitation service delivery, has implemented a project providing UDDTs to peri-urban residents (Gounden et al., 2006).

2.1.3. Pour flush latrines

Pour-flush (PF) latrines have been the technology of choice for the Indian Integrated Low Cost Sanitation scheme, which has been in place since the 1980s (MHUPA, unknown date, Mara, 1985). Pour flush latrines may be used as an on-site system, with the pedestal located over the pit or off-set (Franceys et al., 1992, p.54). The excreta may also be directed into a sewerage system and disposed of off-site (Mara and Alabaster, 2008). This technology offers some of the benefits of waterborne sewerage, such as reduced smell due to a water filled S-trap between the toilet and the storage pit, without the requirement for a piped water supply to the toilet.

A pour-flush latrine designed for periodic emptying has been proposed by an expert group of UN Habitat (Coffey, 2008). A research project conducted in KwaZulu-Natal has shown promising results (Still and Louton, 2012).

2.2. Sustainability criteria for sanitation systems

Sustainability is defined by the Oxford Dictionary as to "keep from…failing". In the context of sanitation, sustainable solutions are those which provide users with a safe, hygienic facility for the disposal of human excreta in a way which is economically viable in the long term, does not threaten the environment and meets the social and cultural needs of people in a stable manner (Balkema et al., 2002). Where technologies have a limited lifespan, planning should include their replacement or improvement so that sanitation is sustained indefinitely (Brikké and Bredero, 2003, p.1).

Sustainability depends on a range of factors, of which technology is only one. Social factors may affect users' acceptance of a particular option, their maintenance of sanitation facilities and hence the lifespan of the system (Assefa and Frostell, 2007). Financial or economic sustainability requires that money is available when maintenance or replacement are required, whether this finance is supplied by the user or by government (Bracken et al., 2005). An adverse environmental impact may render an otherwise attractive technology non-sustainable (Aalbers and Sietzema, 1999). Bracken et al. (2005) set the boundaries of the sanitation system to include users, collection, transport, treatment and management of the end products of the process. They defined a sanitation system that is sustainable as one that "*...protects and promotes human health, does not contribute to environmental degradation or depletion of the resource base, is technically and institutionally appropriate, economically viable and socially acceptable.*"

Balkema et al. (2002) suggested that environmental issues are the "reverse salient" or weakest link in wastewater systems. They examined decentralised alternatives to conventional wastewater systems and developed a multiple criteria approach to the assessment of technologies. They identified three sustainability dimensions: economic, environmental and socio-cultural. While a broader economic approach could include social and environmental resources, these authors restricted this dimension to financial costs and benefits. The environmental dimension incorporated indicators of long term support of human life and the socio-cultural aspects took into account equity and stability in human relations. There are conflicts between different objectives, and hence a need for tradeoffs in achieving an optimal solution.

Drangert (2005) proposed a sanitation selection algorithm which takes into account environmental, technical, social and economic management criteria. The screening of alternatives took the form of a set of questions which investigate what the constraints are for each sustainability parameter.

The environmental sustainability principles which should guide the development of a sanitation solution were defined by Flores et al. (2008) as *"...adaptability to local conditions, resource conservation, resource recovery, and waste minimization"*. These principles were translated into operational features which contribute to environmental sustainability. Water and energy are resources to be conserved and recovered. Nutrients and organic matter in human wastes may be recovered and reused in agriculture, thereby minimising waste. Waste flow separation contributes to all these features. Decentralisation, and the use of locally available and affordable resources (land, energy, materials and labour) provide adaptability to local conditions. These authors then assessed a range of alternative sanitation components and assessed their inclusion of the operational features described above.

Upon examining sustainability assessment techniques, including exergy analysis, economic analysis and life cycle assessment, Balkema et al. (2002) concluded that these are more limited than a general system analysis which can incorporate aspects of each. Flores et al. (2008) also described the tools used to assess the sustainability of engineered wastewater systems and found that sustainability indicators provide coverage of all three dimensions while other techniques including Life Cycle Assessment (LCA), Material Flow Analysis and Economic Analysis take only one or two dimensions into account. As a result, they recommended the use of sustainability indicators to assess the relative sustainability of different technical options, once these have been screened for their ability to meet local technical requirements. They suggested that other tools be incorporated into the development of indicators. LCA, for example, could be used in developing environmental indicators, and economic analysis for evaluation of the economic dimension.

Sustainability assessment using indicators was used by both Balkema et al. (2002) and Flores et al. (2008). Several possible indicators were listed under each sustainability dimension, as well as functional or technical indicators such as adaptability and robustness. While Balkema et al. (2002) used an optimisation approach for the selection of a sustainable option, by minimising the weighted sum of the normalised indicators, Flores et al. (2008) did not attempt to quantify the differences between sanitation systems. They compared the VIP and UDDT options for the provision of sanitation in the eThekwini Municipality. A total of 34 indicators were chosen based on a literature review and local issues of concern. They used these to elucidate the differences between the options but not to arrive at a numerical index and no weighting system was used.

Table 2-1.Criteria used to assess the sustainability of sanitation systems

	Criteria for assessment	Measurement scale
Health		
• Pathogen exposure	risk of infection	qualitative (2, 4)
o drinking water	proximity to water sources	m
o skin contact	requirements of system for contact with faeces	qualitative: high to low (3)
o ingestion	risk of contamination of food sources	qualitative: high to low (3)
• Contaminant exposure	use of heavy metals	qualitative (2, 4)
• Health benefits	reduced morbidity	qualitative (4)
Environment		
Emissions		
• Soil		
o Pathogens	extent of and duration of soil contamination	% removal(5)
o Contaminants	soil contamination	qualitative (4)
• Water		
o Pathogens	risk of contamination	% removal(5)
o Contaminants	risk of contamination of ground and surface esp. with heavy metals	mg/pe/y (2)or kg (1,4 -DCB eq) /pe . y (3)
o TSS	efficiency of reduction in TSS	%removal(5)
o N	efficiency of removal of N	g/pe/y (1) % removal(5)
o P	efficiency of removal of P/eutrophication risk	g/pe/y (1) % removal(5) kg PO_4^{3-} eq./ pe. Y (3)
o BOD/COD	efficiency of reduction in BOD/COD	g/pe/y (1) %removal(5)
• Air		
o Odour	amount and spread	qualitative (2, 4)
o CO_2	production	kg/y (2)
Use of resources		
• Water	water required for operation of system	m^3 (1) m³ /pe.y (3)
• Energy	energy required for operation of system	kWh (1) MJ/pe (2) kWh/pe.y (net) (3) kWh/m^3(5)
• Land required	area of land required for operation of system	m^2(1,3) m^2/pe(2) qualitative (4)
• Quality of land req'd	arable area required for operation of system	qualitative (1)
• Construction materials	nature and volume of materials required (3)	

	Criteria for assessment	Measurement scale
• Chemicals	use of chemicals for construction and operation	kg /pe/y(3)
Resource recovery		
• Biogas	energy value of biogas collected	m^3(1)
• Organic material	value as a soil conditioner	% of in(2)
• Nutrients	usable nutrients for agriculture	% of in(2) kg /pe/y (3)
• Water (domestic reuse)	water recovered from system	% of in (2) m^3(1)
• Energy	energy recovered from system	% cons (2)
Technology		
• Construction	ease of construction, simplicity of design	qualitative (1,2)
• O & M	requirement for outside intervention	qualitative (1,2,4)
• Monitoring	ease of monitoring to ensure appropriate disposal	qualitative (2,4)
• Robustness	ability to withstand abuse	qualitative (2,4)
o Failure record		h /pe /y (3)
o Shock load resistance		h /pe/y (3)
o Operation & Maintenance		h /pe/y (3)
• Flexibility, adaptability	adaptability for different groups of users, circumstances	qualitative (2)
• Durability	life expectancy of system	qualitative (2,4)
• Reliability	ability to deliver sanitation service at all times	qualitative (1)
• Waste	amount to landfill	m^3 (1)
• Complexity	requirement for expert intervention	qualitative (1,2,4)
• Local involvement	job creation	qualitative (1,2.4)
• Compatibility c existing systems	cost saving through conversions	qualitative (2,4)
• System invisibility		
o space	intrusion of facility into limited space	m^3/pe (3)
o area	intrusion of facility into limited space	m^2/pe (3)
o nuisance		qualitative (3)
Financial		
• Cost construction		cost/pe/y (2) Euro/hh y (3) \$/1000p/y (4) \$/vol/d (5)
• Cost O & M		\$/1000p/y (4) \$/vol/d (5)
• Employment creation		

	Criteria for assessment	Measurement scale
• Local development		
• Value of improved health		
• Affordability		% of income (2,4)
• Financial benefits of reuse		ZAR/pe/y (4)
Socio-cultural		
• Acceptability	user perceptions of fitness for purpose	qualitative (4)
• Adaptability (age, gender, etc)		qualitative (2,4)
• Convenience	provision of sanitation where users require it, distance from dwelling	qualitative (1,2,4)
• Equity	fulfilment of requirements of all gender groups. equivalence of sanitation provision for different income groups	qualitative (4)
• Expertise	availability of necessary expert support	qualitative (1)
• Legal/institutional	fit with legal requirements, institutional support for construction, O & M	qualitative (2,4)
• Participation	facility for user involvement in planning and execution of project	qualitative (1)
• Stimulation of sustainable behaviour/awareness	facility for social marketing	qualitative (1)
• Food security	contribution of system to sustainable household based food production	qualitative (4)
• Anal cleansing material	compatibility of anal cleansing material with proposed system	
• Effects of system failure	environmental, health, social effects of failure	
• Willingness to pay	ability of users to contribute to the cost of sanitation	% of income (2,4)
Key to sources of measurement scales: 1. van der Vleuten-Balkema 2003 2. Bracken et al, 2005	3. Agudelo et al, 2007 4. Flores et al, 2008 5. Muga and Mihelcic, 2008	**Other sources:** Cotton and Saywell, 1998 Loetscher, 1999 von Münch, 2007

The criteria which different authors have recommended for the assessment of sanitation systems are summarised in 0. The broader categories of Health, Environment, Technology, Financial and Socio-Cultural are broken down into sub-criteria and sometimes these are broken down still further. The criteria are then described in broad terms. Where authors have recommended indicators or measures for these criteria, they are included in the last column of the table. Many criteria appear in several different studies

2.3. Measurement of sustainability criteria

If the criteria which determine the sustainability of a sanitation system are to be used in decision making, they need to be assessed in some way. While a number of studies describing sanitation selection through the use of sustainability criteria base their choice of alternatives on qualitative assessments, quantitative data on some aspects of the performance of sanitation systems are available. In order to develop value functions for these indicators for use in a Multiple Criteria Decision Analysis, it is necessary to decide which units of measurement to use for the raw scores. Reasonable minimum and maximum values must also be ascertained for use in the standardisation process.

2.3.1. Measurement of environmental sustainability

The literature provides numerous ways of measuring the environmental impact of sanitation. Life cycle analysis (LCA) requires the quantification of these indicators (Hellström et al, 2000, Palme et al., 2005, Jones and Silva, 2009).

Ideally, the effluent returned to stream should contain a minimum of nutrients that might lead to eutrophication or other negative impacts on the environment. Chemical Oxygen Demand (COD) "*measures the amount of oxygen required to completely oxidise a sample of organic material to CO_2, H_2O and NH_3*" (Buckley et al., 2008a, p.17). An important role of the sanitation system is to reduce the load of organic compounds and other elements in the excreta before these are transferred to the wider environment.

While Veenstra et al. (1997) reported the COD levels in domestic wastewater in Europe to be 0.28 to 2.5g/L, Heinss et al. (1998) reported initial levels as high as 50 g/L for COD in faecal sludge from public toilets. Nwaneri et al. (2008) characterised the levels of these indicators in pit latrine sludge as being between 0.95 and 1.28 mgCOD/mg dry sample. With moisture at approximately

80%, this is roughly the equivalent of 220g/L. This illustrates the huge range of COD concentrations in the output from sanitation systems. Pit sludge is immensely more concentrated than the influent of a wastewater treatment works.

Different sanitation systems are reported to have varying success in reducing the potential environmental impact of waste. Koné and Strauss (2004) reported removal rates of 60 – 80% for Total Suspended Solids (TSS) in settling tanks and drying beds. COD removal was between 30% for settling tanks and 90% for drying beds. A UASB reactor combined with pond systems was found to achieve a 47% reduction in COD (El-Gohary, 2001). Subsequent trials by this and other authors achieved a reduction of 93% of COD, 91% of TSS, 98% of ammonia and 78% of total phosphorus in a similar system (El-Shafai et al., 2007). Drying beds provided removal of 40-60% for NH_4^+-N (Koné and Strauss 2004). van der Vleuten-Balkema (2003, p.46) cited the European standards for wastewater treatment as requiring a 75% reduction in COD, 90% reduction in soluble solids, 80% reduction in total phosphorus and 70-80% reduction in total nitrogen. Çiçek et al. (1999) compared the performance of membrane bioreactors and conventional activated sludge treatment of wastewater and found that the latter achieved removal rates of 61% for TSS, 66% for VS, 95% for COD, 99% for ammonium 89% for total phosphorus removal. These studies provide some idea of the range of removal rates possible for wastewater treatment systems. The performance of on-site systems is discussed further in section 3.3.1.

Energy requirements for decentralised sanitation systems differ greatly from those for centralised wastewater treatment. In her Doctoral thesis, van der Vleuten-Balkema (2003, p.45) cited a range of 29 – 45 kWh/p/y for conventional wastewater treatment which may be considered one of the most energy intensive sanitation options. Buckley et al. (2011) analysed energy requirements for the Southern Wastewater Treatment Works in the eThekwini Municipality and established that the energy requirement for collection and treatment was 0.58 kWh/kL. Assuming that wastewater production is 100 L/p/day (see below) this would equate to 20kWh/p/y. In contrast, the energy required for VIP latrines and UDDT is zero, unless pit emptying and off-site disposal is considered (Flores et al., 2008).

Water use is high for conventional sewerage (100 – 150 L/p/day, Veenstra et al., 1997). This is the equivalent of 36.5 – 55 m^3/p/y. With dry on-site sanitation this figure may be as low as zero if water required for hand washing is not taken into account. The Free Basic Water policy provides a minimum of 25 litres of water per person per day (Muller, 2008). This is equivalent to 9 m^3/p/y.

However, little of this could be attributed to sanitation although use of some for hand washing should be part of a complete sanitation solution since without this few of the health benefits of improved sanitation are realised (Curtis and Cairncross, 2003).

In contrast to the conventional notion of human waste as nuisance to be minimised, the idea of ecological sanitation is that human excreta contains valuable nutrients that should be recovered for use in agriculture (Schuen and Parkinson, 2009). Jönsson et al. (2004) produced guidelines for the use of human excreta in agriculture and compared results from a range of different countries. Snyman and Herselman (2006) produced guidelines for South Africa, but these were mainly concerned with sludge from wastewater treatment works. The highest values for the nutrients in faeces and urine produced per person per year were reported from China and were 4 kg of Nitrogen, 0.6 kg of Phosphorus and 1.8 kg of Potassium (total 8 kg of nutrients). The total nutrients produced per person per year in South Africa were 5.5 kg (Jönsson et al., 2004).

2.3.2. Financial aspects of sanitation provision

The costing of sanitation systems may be approached from the financial or the economic aspect. Earlier studies tended to focus on a narrow area of the financial costs, namely the provision of sanitation hardware (Cotton et al., 1995 p.37). Other studies have taken a broader, economic approach which values the social and environmental benefits associated with appropriate management of human waste (McKibbin et al., 2008; Pinkham et al., 2004). For example, Haller et al. (2007) used a cost effectiveness ratio to assess the cost per disability-adjusted life-year (DALY) for different interventions to improve health. Hutton and Haller (2004) refer to cost benefit analysis as a tool for the allocation of government resources to the activities which return the best economic value per unit spent. Economic costs might include lost working days due to ill-health, the loss of valued recreational facilities through pollution and the damage to the environment transformed into a monetary value. Many of these costs are difficult to quantify and impacts may be assessed through non-financial measures.

A financial costing takes into account the costs, measured directly in currency, incurred in the provision of a service (Franceys et al., 1992). The financial costs of a sanitation system extend beyond the purchase of hardware for excreta collection, storage, transport, treatment and disposal. Costs which may be incurred range from social marketing to ensure correct use of facilities, to costs for the management of downstream processing by municipalities (Strauss and Montangero, 2002, p.17).

Expenditure may be expressed per capita or per representative household size (Schuen and Parkinson, 2009). Net Present Value is often used to report these and it allows comparison of different options on a chronologically standardised scale. Since these authors were studying the impact of ecological sanitation (urine diversion technologies), they included the value of fertiliser produced from the sanitation system as having economic value for the household. They divided their model between financial analysis at the household level and economic analysis at the level of the implementing agency. In South Africa, the financial responsibility for providing Free Basic Sanitation to poor households lies with municipalities and economic considerations could be seen as the concern of national and provincial government.

Table 2-2. Summary of capital and operations and maintenance costs for different sanitation systems(after Haller et al. (2007)

System	**Capital cost (R per household of 6 people) * (1USD or €:R10)**	**Operations and Maintenance (R /p/y)***
Sewer connection	5050-19000 (1) 15 940 (4)	125 (1) 80-210(2) 1 910 (4)
VIP	500-3280(1) 3190 (4) 2870 (5) 3260 (6)	35 (6) 80 (1) 65-100(2) 320 (4)
UDDT	440-5050 (1) 7030 (3) 2390 (4) 3000 (6)	0 (4) 35 (6)

1: Rosemarin et al. (2008) 2.Hutton and Haller (2004) 3. Schuen and Parkinson (2009)

4. Holden et al. (2004) 5. Loetscher and Keller (2002) 6. Mayumbelo, 2006

*Costs are adjusted to 2012, using a discount rate of 6% p.a.

Rather than discounting revenue and operating expenditure to a single point in time and hence calculating net present value (NPV), many authors choose to report costs divided into capital expenditure and cost of operation and maintenance (O & M) (Holden et al., 2004, Hutton and Haller, 2004, Rosemarin et al., 2008). This analysis choice might be more useful to municipalities in South Africa where separate funding mechanisms provide for infrastructure (Municipal Infrastructure Grant) and operations and maintenance (Local Government Equitable Share).

Rosemarin et al. (2008) summarised costs from a range of sources, including Holden (2004) and Mayumbelo (2006). Hutton and Haller (2004) used cost estimates from the Global Water Supply and Sanitation Assessment 2000 Report (WHO and UNICEF, 2000), to arrive at the costs for different types of sanitation. Mayumbelo (2006) estimated construction and operations and maintenance costs to provide VIPs or UDDTs in Lusaka, Zambia. He calculated costs for emptying pit latrines including truck transport and the operation of a faecal sludge treatment plant. For UDDTs he assumed that urine would be transported and stored in tanks before re-use. The calculated construction costs for a city of 1.2 million people were 38.6 euros/p for VIPs and 35.2 euros/p for UDDTs. operations and maintenance was estimated at 2.5 and 2.3 euros/p/y for VIPs and UDDTs respectively.

Holden (2004) provided costs for the South African situation. His cost for the UDDT was for an in-house addition to an existing dwelling and not the twin-vault UDDT system offered in the eThekwini Municipality. The studies of Loetscher and Keller (2002) took place in South East Asia. A summary of these estimates is shown in Table 2-2. It can be seen that estimates in the literature vary widely except for the capital costs for VIPs. This may be because the construction is fairly simple and design may not vary as widely as other options. It is likely that construction standards and designs differ for the other systems from country to country. Furthermore, costs to provide waterborne sewerage are highly dependent on the availability of existing networks and the type of centralised wastewater treatment system. Schuen and Parkinson (2009) included the construction costs for UDDTs in the eThekwini Municipality in their analysis.

White et al. (2006) combined an analysis of quantifiable costs to the utility and household with MCDA in a model for integrated resource planning for water supply in Australia. They considered a range of management options, and calculated the unit cost of each option relative to the cumulative contribution to reducing the water supply-demand deficit (in $/ML). They included greenhouse gas emissions in the cost analysis, but other intangible societal and environmental effects (public health, river health) were assessed in an MCDA which would eliminate unacceptable options.

The WhichSan program provides a detailed costing of the different sanitation options, allowing for different site characteristics (Still et al., 2009). Furthermore, it takes into account variables such as the cost to connect to the existing sewerage network when providing estimates for a particular site. It also provides for an escalation in costs from the year 2006 on the built-in costs. Users may elect to provide their own budgets for any particular technology option. This program was developed for South African conditions and takes into account the most important cost drivers for the systems considered. As an example, for a site serving 2 500 people and at a distance of 1km from the existing sewerage network, WhichSan estimated a cost of R17 400 per household (adjusted to 2012 prices) for the construction of fully waterborne sewerage, and R6 700 to provide a double vault UDDT. In addition to WhichSan, Partners in Development have developed a spreadsheet-based costing for pit emptying which constitutes the main cost driver in the operations and maintenance of VIP projects.

2.3.3. Indicators of social sustainability

Quantifying social sustainability is a difficult task, particularly since there is no consensus on the definition of this dimension (Assefa and Frostrell, 2007).

Murphy (2012) noted that social indicators are often picked for political reasons and may reflect the interests of more powerful and hence influential groups. He identifies four concepts common to much of the literature on social sustainability: *"equity, awareness for sustainability, participation and social cohesion"*. In some cases social and cultural indicators form part of a broad economic, environmental and socio-cultural assessment framework (Lähtinen et al., 2014).In developing a set of sustainability criteria to assess bioenergy systems, Buchholz et al. (2009) identified *participation, monitoring of all criteria, compliance with laws and food security* as the social criteria considered most important in a survey of experts. Other social criteria, such as *cultural acceptability* and *social cohesion* were ranked as having low importance. This may reflect the gap between community concerns and those of technical experts and highlights the challenges to be faced when selecting social sustainability criteria. *Social justice, participation, safety, social cohesion, employment* and *health* were among the factors identified by Dempsey et al. (2009) in their review of the urban social sustainability literature.

Social sustainability itself is a subjective construct, peculiar to the community in which a project is proposed (Valentin and Spangenberg, 2000). Surveys and focus groups which assess the response to the different aspects of acceptability in the target population provide some measure of this dimension. When a system is rated on these indicators, the scale is almost invariably a qualitative one (van der Vleuten-Balkema 2003, Bracken et al., 2005, Flores et al., 2008).

Social Life Cycle Assessment (S-LCA) is a method used in industry to assess the social impact of products during their life cycle (Macombe et al., 2011). It has its origins in environmental Life Cycle Assessment (LCA) but extends this concept to the preservation of human dignity and wellbeing (Dreyer et al., 2006). These authors also note that the social impact of a product may be positive (e.g. job creation) or negative (poor working conditions). They suggest identifying "*areas of protection*" which define what needs to be safeguarded and then developing an assessment of social impact which is specific to the business under consideration. They point out that one of the challenges in S-LCA is the qualitative nature of many of the assessments.

Assefa and Frostrell (2007) discussed the concept of social sustainability, and suggested that this aspect could be addressed in terms of social acceptance. They also included political sustainability in this dimension, which requires that systems include a framework for continued governance. The social criteria which they suggested for inclusion in the ORWARE (ORganic WAste Research) model for technology assessment are knowledge, perception and fear or concern. These elements were included in a Social Impact Assessment (SIA) to be included in the planning stage of new technology introduction. When it came to measurement, they used a survey where respondents rated themselves on the three criteria with respect to the proposed technology, and the results were therefore an analysis of these subjective responses. This approach attempts to measure social impact on the individual but ignores the measures of social sustainability which address impacts on society in a broader sense.

2.4. Multiple Criteria Decision Analysis

Multiple Criteria Decision Analysis (MCDA) is a management support tool which has been applied to sanitation by some researchers. In this section, the principles of MCDA are explained, and some of the computer programs which apply it to water and sanitation are described.

2.4.1. General theory of Multiple Criteria Decision Analysis

MCDA is "*... an umbrella term to describe a collection of formal approaches which seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter..*"

(Belton and Stewart, 2002, p.2). These authors cited the Chambers Dictionary definition of criterion as "... *a means or a standard of judging*". Hence, the objective of MCDA is to assist decision makers in choosing the best course of action or alternative where the alternatives available may be compared on the basis of a number of different aspects. These criteria are often conflicting, with alternatives performing well against some criteria and poorly against others (Belton and Stewart, 2002, p.14).

Belton and Stewart (2002, p.80) described the process of preference modelling within the MCDA system as a constructive, rather than a descriptive process. MCDA takes the preferences of decision makers (DM) into account. These are often developed in the course of the analysis since the decision support system is required precisely because the DM lacks an understanding of the available options.

The performance of an alternative must be assessed for each criterion, either against a standard or by a comparison between options. The relative importance of the different criteria must be decided, and thereafter the results from the different assessments must be combined to provide an overall preference (Belton and Stewart, p.79).

Hajkowicz and Higgins (2008) describe a generic Multiple Criteria Analysis (MCA) model as consisting of a matrix X of n decision options or alternatives and m criteria or indicators. The elements of this Evaluation Matrix are raw performance scores, whether ordinal or cardinal, of the different alternatives against the selected criteria. The Evaluation Matrix X for n alternatives with m indicators or criteria can be represented as follows:

$$X = \begin{bmatrix} x_{1,1} & \cdots & x_{n,1} \\ \vdots & \ddots & \vdots \\ x_{1,m} & \cdots & x_{n,m} \end{bmatrix}$$

where the score for alternative i with respect to indicator j is denoted by $x_{i,j}$. In addition, weights may be assigned to each criterion and these could be described by a vector

$$W = w_1 \ldots w_m$$

where w_j is the weight of the jth criterion.

2.4.2. Different methods used in MCDA

Some of the methods of preference modelling described by Belton and Stewart (2002) are Multi-Attribute Value Theory (MAVT) (pp. 85-103), the Analytical Hierarchy Process (AHP) (pp. 119-161) and Outranking (pp. 106-110).

2.4.2.1. Multi-Attribute Value Theory (MAVT)

According to Belton and Stewart, MAVT requires that the scales or value functions for all criteria are constructed in such a way that trade-offs between different criteria are possible. Decision makers are required to assess what gain in one criterion will compensate for a measured loss in another. Weightings are applied to the marginal values for the different criteria in order to achieve this *full compensation* (Stewart and Losa, 2003). Belton and Stewart (2002, p. 86) recommended that these marginal values are aggregated to arrive at a value *V(a)* for each alternative *a* using an additive function of the form

$$V(a) = \sum_{i=1}^{m} w_i v_i(a)$$

where *m* criteria are used to evaluate the alternatives, w_i represents the weighting of the *i* th criterion and $v_i(a)$ the marginal value of alternative *a* for the *i*th criterion. The values may be aggregated at each hierarchical level of the value tree and the values thus arrived at are further aggregated using weightings developed by comparison of the relative importance of the criteria at each level.

Hajkowicz and Higgins (2008) describe an MCA as an algorithm that defines a function $u_i = f_2(X, W)$ to provide a utility value for the alternative. They also indicate that the scores in the Evaluation Matrix must be transformed into unitless value scores before they are combined to produce the utility values for the different alternatives. This description is analogous to Belton and Stewart's MAVT.

These authors warn that the use of a weighted sum function requires the different criteria to be compensatory so that poor performance on one is compensated for by good performance on another. This is the trade-off described by Belton and Stewart (2002). Furthermore, they warn that simple linear transformations of raw scores into value scores may not accurately capture decision makers' preferences. Belton and Stewart (2002) elaborate at length on different methods used to derive partial value functions or scales for different criteria so that they reflect decision makers' values.

2.4.2.2. Analytical Hierarchy Process (AHP)

AHP requires paired comparisons of alternatives to elicit partial preference scores, with the preference of one alternative over another in terms of each criterion expressed as *equally preferred, weak preference, strong preference, demonstrated preference* and *absolute preference* , giving scores of 1,3,5,7 and 9 respectively (Belton and Stewart, 2002, p.153). A comparison matrix for all the alternatives is created for each criterion, and this is reduced to a set of relative preference scores for all the alternatives, normalised to sum to one. These values are then aggregated by a process which similarly elicits scores for each criterion and aggregates across all criteria to arrive at an overall score for each alternative (Guitouni and Martel, 1998).

2.4.2.3. Outranking

This is a decision support method developed by French researchers (Roy and Bouyssou, 1993, cited by Belton and Stewart, 2002, p.106). It requires paired comparisons of alternatives using their partial preference functions, with the preference of one alternative over another in terms of each criterion expressed as *indifference, weak preference* or strong *preference* (Belton and Stewart, 2002, p.107). These preferences are then aggregated across all criteria to arrive at an overall preferred alternative. Weights are used to give effect to the relative importance of different criteria, and hence their influence on the overall assessment (Belton and Stewart, 2002, p.110). The strength of evidence leading to the preference of one alternative over another can be termed the *concordance* of the analysis, while *discordance* refers to the amount by which one alternative can outrank another in terms of one criterion before the second criterion becomes totally unacceptable (Belton and Stewart, 2001, p.110). Stewart and Losa (2003) referred to the need to set minimal levels of acceptability for criteria, with alternatives performing below this level considered unacceptable.

In summary, MCDA methods all require that a set of criteria be selected on the basis of which alternatives can be compared by whichever method is chosen. In order to arrive at a comprehensive set of criteria, the general areas of concern (e.g. environmental, financial, sociological) may be broken down into more specific aspects in a hierarchical fashion until criteria are identified which may be defined to allow an unambiguous assessment of the options (value measurement) or comparison between options (outranking models) (Belton and Stewart, p.80-84).

2.4.3. Approaches to the weighting of criteria in MCDA

Once value scores have been assigned to the alternatives under consideration, the different criteria must be weighted to allow aggregation of the scores to arrive at an overall score for each alternative. Various authors have described possible approaches to this problem.

2.4.3.1. Ranking methods

Rank sum weighting requires decision makers to place the criteria in order of importance. The most important criterion is assigned the largest rank number and the least important receives a rank number of 1 (Edwards and Newman, 1982, p. 54). These numbers are added and each is divided by the sum to obtain a normalised weight. Rank reciprocal weighting allocates a value of 1 to the most important criterion and n to the least important criterion where n is the number of criteria. The reciprocals of these values are normalised to provide weights (Edwards and Newman, p.54). These authors indicate that these simple methods of weighting may provide a useful approximation of the feeling of decision makers regarding the importance of different criteria and suggest that they may produce similar results to more complicated methods (Edwards and Newman, p.53).

2.4.3.2. Swing weights

Belton and Stewart (2002, p.135) point out that weights act as scaling factors in that they imply tradeoffs between the value scales for different criteria. A weighting for one criterion of twice that for another criterion implies that the decision maker attaches the same value to a one point increase for the more heavily weighted criterion as he or she does to a two point increase in the other criterion. They term this *swing weighting* and explain that this means that the weighting system used cannot be said to be independent of the measurement scales used for the criteria.

When weights are elicited from decision makers, they should be asked to select the criterion for which the swing from the lowest to the highest value on the measurement scale would have the biggest impact on the overall value of an alternative. Subsequently the criterion for which this swing would have the second highest impact would be identified and so on until all the criteria were ranked in order of intrinsic importance. The most important criterion could then be assigned a value of 100 and decision makers could then be asked to rate the relative impact on overall value of a swing from the best to the worst value on the next highest ranked criterion. If these best and worst values do not represent a wide range of performance then the swing weighting process will assign a low ranking even if the criterion seems to have a high intrinsic importance. This will result from decision makers attaching little value to the impact of the swing in values for this criterion. Gaudreault et al. (2009) cited by Rowley et al. (2012) suggest removing indicators from the MCDA if they do not make a significant discrimination between alternatives possible.

The swing which decision makers are asked to evaluate could also be between two selected reference values on the measurement scale rather than the highest and the lowest. During this process the raw scores behind each normalised value would be made explicit so that the swing could be evaluated by the decision maker. Belton and Stewart (2002, p.138) describe a method of eliciting swing weights in which decision makers would be asked to assign a percentage to the value of a certain increase in standardised score for lower ranked criteria when compared with the same value increase for the highest ranked criterion.

Once this weighting process has been carried out, the weights must be normalised to sum to 1 within a particular level of the value tree (Belton and Stewart, p. 139). To assign weights to the criteria in the next level, one sub-criterion (possibly the highest ranked sub-criterion in each group) could be used to allow swing weighting between main criteria.

Belton and Stewart (2002, p.142-143) acknowledge that the process described may be onerous for the decision maker and that this individual may find the questions difficult to answer. They suggest that once the rank order of criteria could be used to generate weights. They allude to the *SMARTER* method of generating weights from ordinal information and express reservations about this method for larger sets of criteria since the impact of lower ranked criteria becomes progressively more negligible. They suggest that a geometric decrease in weights as they decrease in importance would result in a less dramatic decrease in the weight of the lower ranked criteria.

Stewart and Joubert (2003) attempted to overcome the burden on decision makers of assigning weights by convening expert workshops and dividing participants into groups. Each group was only required to evaluate 3 or 4 criteria. They followed the process described above of first ranking the criteria in order of importance and then assigning relative importance to swings in value of lower ranked criteria compared with the same swing in the highest ranked criterion. A collection of similarly qualified experts with similar goals would be required for this process to be reproducible if, for example, the groups were assigned to a different set of criteria. It is debatable whether this level of expertise would be available within a single municipality and the swing weighting process would be extremely time-consuming for an individual to perform, given the number of pairwise comparisons required if the number of criteria is large.

Another problematic area with regard to weighting is the definition of the “decision maker”. In many situations, there may be a range of stakeholders influencing the outcome of a project. These stakeholders may be influence decision making but may have widely differing views on the importance of different criteria. Rowley et al. (2012) point out that the nature of the decision makers will affect the possible methods used for weight elicitation. Furthermore, the existence of a “committee” of decision makers presents the analyst with difficulties associated with aggregating the preferences of different stakeholders. It may be necessary to incorporate a further weighting process to take the different decision makers’ importance into account.

2.4.3.3. Ratio weighting methods

Edwards and Newman (1982, p. 62) recommend the use of a ratio weighting methods to assign weights to different criteria. Decision makers are asked to rank the criteria in order of importance. The least important attribute is assigned a value of 10 and the decision maker then considers each other attribute in comparison with this least important one, and indicates how many times more important it is. This coefficient is multiplied by 10 to assign a value to each criterion. Once all values are assigned, they are added together and the normalised weights for the criteria are calculated from the ratio between their assigned value and the total of all the values. This method clearly applies the idea of weights as importance coefficients rather than scaling factors.

The ratio weighting method requires a large number of comparisons to be made by the decision maker (Edwards and Newman, 1982, p.58). This number is increased if the recommended process of triangulation takes place, in which decision makers compare other pairs of criteria and check whether the resulting weights are consistent with the initial judgement.

2.4.3.4. Importance coefficients

In contrast to the emphasis on trade-offs described above, Munda (2004) describes the use of weights as importance coefficients. He contends that when there is a range of ethical positions among stakeholders there is also a range of ideas of criterion importance and trade-offs are not feasible. The use of this type of weight allows the interests of minorities to be represented and influence the outcome of the MCDA. This author does not favour participatory processes for deriving weights, but refers to a *"plurality of ethical principles"* as the only consistent way of deriving weights. Garmendia and Gamboa, (2012) elaborate further to explain that this requires the inclusion of considerations such as "*economic prosperity, ecological stability, or social equity*". They also propose that conflicts must be recognised and managed and that it may not be possible to reach consensus on weights but that the MCDA should be run repeatedly to take account of differing priorities. These authors used an outranking method to compare alternatives and their results elucidated the various alternatives preferred by different stakeholders. They described this as a "*social sensitivity analysis*".

2.4.4. Multiple Criteria Decision Analysis applied to sanitation

SANEX© is a MAVT DSS developed at the Advanced Wastewater Management Centre at the University of Queensland in Australia by Loetscher (1999). Palaniappan et al. (2008) described the Water and Wastewater Treatment Technologies Appropriate for Reuse (WAWTTAR) program developed by Finney and Gearheart of the University of Humboldt as a decision support tool for water and sanitation. This program also focuses on sanitation and wastewater treatment technologies, with particular emphasis on the cost elements. This tool has particular application to centralised wastewater systems and pays little attention to on-site and decentralised technologies.

WhichSan is a spreadsheet based sanitation selection program developed by Partners in Development for the Water Research Commission (Still et al., 2009). It is designed to compare on-site sanitation options with one another and with fully waterborne sewerage and was developed specifically for the South African context.

A group of researchers from Umgeni Water developed a decision aid to assist communities in selecting a sanitation technology (Howard et al., 2001). Four options were considered: VIP, low flush with soakaway, and full flush with soakaway or mains sewerage. The computer based system calculated indices aggregated from scores which were generated from the technical data entered by the analyst. The scores were weighted for importance. A GIS linked module generated maps showing the suitability of different areas for particular technologies. The authors used the acronym SSPRA (Site Sanitation Planning and Reporting Aid) to describe their program. The authors emphasised that this was not a decision making tool but rather a foundation for discussion. The results of the program were presented as a table comparing the performance of sanitation alternatives on six technology indices (water availability, operations and maintenance, financial planning, soil suitability, site suitability and ground and surface water pollution) for any given site. The program also provided checklists to indicate user preferences, user awareness and institutional readiness.

2.4.4.1. Approaches to MCDA for sanitation

Most MCDA for sanitation apply a MAVT-type approach, with alternatives rated on a range of criteria and these scores aggregated to provide an index for comparison between options (Wiwe, 2010, Al Sa'ed and Mubarak, 2005, von Münch, 2007, de Silva, 2007, Muwuluke and Ngirane-Katashaya, 2006, di Mario et al., 2010, Katukiza et al., 2010). Van Moeffart (2002) describes using outranking methods for wastewater and sanitation selection in Sweden. He argues that the NAIADE (Novel Approach to Imprecise Assessment and Decision Environments) is appropriate for water systems as it takes into account the perspectives of a range of stakeholders and allows for uncertainty in some scores.

SANEX© evaluates sanitation systems organised as trains of facilities for excreta collection, transport, treatment and reuse (Loetscher, 1999). Each train represents an alternative in terms of the MCDA. The program screens the alternatives for feasibility in a process of Conjunctive Elimination.

In his Doctoral thesis, Loetscher describes this screening as a procedure with a single adequacy or utility function. If the performance of a sanitation option falls below a certain level for any of the criteria in this section of the program, then it is has an adequacy or utility of 0 and is eliminated. This process is based mainly on technical criteria, but also includes socio-cultural criteria such as anal cleansing method and privacy requirements. Questions are asked of the decision maker and the answers determine whether a particular sanitation option is viable or not.

WhichSan guides the decision maker through questions about the important technical and financial criteria (Still et al., 2009). Scores are generated by the program, and aggregated. In a similar fashion to the Conjunctive Elimination process used by Loetscher (1999), infeasible options are eliminated when certain requirements are not fulfilled. The program indicates options which are technically feasible and displays the scores for each. In addition, the order of user preference of the feasible options is shown. The costs for construction and operation and maintenance are calculated and displayed.

The feasibility screening in SANEX© is similar to the process followed by WhichSan The criteria/questions used by the two programs are compared in Table 2-3.

Table 2-3. Questions addressed in the feasibility section of SANEX© and in WhichSan

SANEX©	**WhichSan**
Project design life	
Project type (interim, long-term)	
Settlement stability (permanency of settlement)	
Accessibility of building	
Proneness to flooding	Is the site prone to flooding?
Groundwater table	
Presence of bedrock	soil depth
Soil type	characteristics of the soil: permeability
	slope
Population size	
Population density	Plot size
Population growth	
Type of water supply	On-site water supply or not?
Reliability of water supply	Volume of water available for sanitation
	Are users prepared to pay for additional water?
	Facilities inside or outside dwelling?
Acceptability of public facilities	
Method of Anal Cleansing	Type of anal cleansing material
Demand for Resource Recovery	
Biochemical Oxygen Demand of final effluent	Is there additional capacity at the treatment works?
Maximum allowed concentration of Faecal Coliforms (FC) in the final effluent	
maximum allowed concentration of Suspended Solids (SS) in the final effluent	
Requirement for greywater disposal	

The feasibility screening in SANEX© is similar to the process followed by WhichSan The criteria/questions used by the two programs are compared in Table 2-3.

It can be seen that the principal difference between the two programs is that SANEX© includes questions on the quality of the effluent required from the system. Loetscher (1999) notes that these questions apply only to off-site disposal of waste. WhichSan assumes that if the treatment works have the capacity to deal with the additional effluent, then off-site disposal can be considered, since the only option which is not on-site in this program is fully waterborne sewerage. SANEX© considers communal septic tanks and Imhoff tanks as small off-site options, as well as activated sludge treatment, waste stabilisation ponds and primary treatment as larger scale off-site options.

2.4.4.2. Criteria and aggregation methods

The SANEX© program then subjects feasible alternatives to analysis using the MCDA (Loetscher, 1999). Two indices form the output for each alternative: one for implementability and the other for sustainability. Each has subordinate factors: Project facilitation and Construction for the Implementability index and Project facilitation, Community needs and Operations and Maintenance for the Sustainability index. These are further broken down into sub-factors, for example Community motivation and Community involvement, and each is rated through a set of questions.

Various other authors have used spreadsheet-based MCDA models to assess sanitation options. Many authors create MCDA models using simple scales to rate alternatives for each indicator. These are often 5 point scales from 1 (poor) to 10 (good) (e.g.Wiwe, 2005) or 1 to 5 (undesirable to desirable) (e.g.Al Sa'ed and Mubarak, 2005, von Münch, 2007, de Silva, 2007, di Mario, 2010, Katukiza et al, 2010). Provided all the rating scales are commensurate, these can be aggregated using weighting factors from 0 to 1 and which sum to 1 so that the final score for an alternative will be on an equivalent scale.

Where different indicators are measured on different scales, it is necessary that all these scales be standardised, if the scores are to be aggregated. A scale of 0 to 1 or 0 to 100 is most often used. Belton and Stewart (2002, p.123) suggest that this standardisation is of the utmost importance, and that it is done using partial value functions to transform the raw values into standardised values. These partial value functions should be carefully constructed with a view to incorporating the trade-offs required.

Some authors develop value functions without the final step of aggregation in an MCDA. The UNESCO-led SWITCH project produced a multi-criteria framework in which the sanitation alternatives are presented using radar plots (Agudelo et al., 2007). Nevertheless, standardised scales using the range 0 – 100 were developed for the indicators which were used. In their section on health risks, they worked with three levels, high, medium and low and assigned these values of 0, 50 and 100 respectively. For the quantitative indicators, they used a linear value function of the form:

$$v_j = 100\frac{x_j - x_{min}}{x_{max} - x_{min}} \qquad (1)$$

Where v_j is the value score of the jth alternative, x_{min} is the minimum value of the raw data, x_{max} is the maximum value and x_n is the raw score of that indicator for the nth alternative.

This is the function recommended by Edwards and Newman (1982, p.66) and adopted by Loetscher (1999) for all continuous data. Agudelo et al. (2007) included costs among their indicators and normalised the raw scores using this linear method. This function can only be applied where a larger value is considered to be better.

If smaller is better, then the linear function is Equation 2.

$$v_j = 100\frac{x_{max} - x_j}{x_{max} - x_{min}} \qquad (2)$$

In addition to that described above, Loetscher (1999) used a number of different functions to obtain standardised values for input into the MCDA. He described these functions as being similar to the utility functions suggested by Edwards and Newman (1982 p.66). These have the general form $x = f(user\ input)$ where x is the standardised value and the function used depends on the type of raw score being standardised. Loetscher standardised scores to values between 0 and 1.

An example of Loetscher's function for a Boolean variable might be to assign a value of 1 to the answer "Yes" to the question "Were community leaders consulted?" and a value of 0 to "No".

Loetscher (1999) is the only author who describes methods other than the weighted average recommended by Belton and Stewart for the aggregation of partial scores to arrive at an overall index for a particular alternative (2002, p. 86). With SANEX ®, the aggregation of partial scores is done at multiple levels, using a number of different techniques - the arithmetic mean, geometric mean, multiplication and mutual equivalence. The technique used depends on the underlying nature of the data resulting in the rating.

SANEX ® was validated on nine case studies from Asia, South America and Africa. All but one of these projects were still in the planning or construction stage, so that their ultimate success or failure could not be assessed (Loetscher and Keller, 2002). The outcome of the MCDA was compared with the findings of local planners and other stakeholders. While the screening process for feasible options was favourably received, criticisms of the rating section included the lack of transparency of the process and difficulties in rating qualitative criteria. Other authors have asserted that transparency of the decision making process was sacrificed in favour of a user-friendly interface for this particular software (Balkema et al., 2002). A fundamental difference between the approaches used by Loetscher and other authors assessing sustainability is that, in order to make the selection tool useful to users who have little knowledge of sanitation, questions asked of decision makers elicited details of community circumstances, rather than examining the different sanitation systems directly (Loetscher, 1999; p92). The ability of alternative systems to meet the needs of the community were assessed within the program, and it is this process which was not necessarily apparent to users. Loetscher (1999, p.22) describes this as a "*what for*" rather than a "*how*" and "*what*" approach.

2.5. Discussion

The last 50 years have seen very little progress in the technical development of low cost sanitation options. With few radical new designs, it seems possible that the options already developed are adequate for the sanitation requirements of the world. Nonetheless, projects implementing these options often fail due to factors other than the fundamental technical functionality and it is these other factors which this research will seek to capture.

There is a wealth of information on factors affecting the sustainability of sanitation projects in the literature. Some studies have organised this information into decision support systems for institutional decision makers, but few meet the rigorous requirements of multi-attribute value theory (MAVT).

A decision support system for municipal sanitation engineers needs to present the different options available and guide decision makers through the factors which will determine sustainability under different circumstances. This process should result in the construction of a fuller understanding of the implications of the different choices. Municipal engineers also need to develop a full understanding of the cost implications of their preferred system, taking into account construction, operations and maintenance and social and environmental costs.

The weighting method chosen will inevitably affect the scores obtained for the different alternatives in an MAVT MCDA. The effects of changes in the weights on the outcome of the process should be investigated using sensitivity analysis. There is little evidence in the literature on MCDA applied to sanitation to suggest that rigorous processes of, for example, swing weighting are applied. Importance weighting based on a judgement of the relative significance of different criteria is a method commonly used to allow the interests of different stakeholders to be considered. The process by which weights are elicited for use in the MCDA is considered to be outside the scope of this project and sensitivity analysis was used to assess the impact of different weights without developing the instrument which would be required for elicitation of weights as described in the literature.

WhichSan is a locally developed program which provides a firm technical and financial basis on which to eliminate infeasible sanitation options. However, there is a need to take further factors into consideration before a particular option can be selected as the best for a given situation. Multi-criteria decision analysis has been used in an attempt to reconcile a range of different and sometimes conflicting requirements.

This project focused on developing a decision support tool for municipal engineers to guide them to a fuller understanding of the sanitation options which are available, and assist them to implement a management system to ensure the sustainability of the chosen system.

Chapter 3. Sanitation projects in the eThekwini Municipality

In South Africa, Local Government is charged with the responsibility of ensuring that water and sanitation services are provided (Constitution of the Republic of South Africa, RSA, 1996). Under the Water Services Act (RSA, 1997), Water Services Authorities (WSA) are defined as "*any municipality, including a district or rural council ...responsible for ensuring access to water services*". The eThekwini Municipality (EM) is the WSA for an area covering 2 297 km^2 and three and a half million people in urban, peri-urban and rural settlements (StatsSA, 2011). The eThekwini Water and Sanitation unit (EWS) is charged with providing water and sanitation to the residents of eThekwini.

Ventilated Improved Pit latrines (VIPs) and Urine Diversion Dehydrating Toilets (UDDTs) are the two low-cost on-site sanitation systems which have been supplied by the eThekwini Municipality at different stages of its sanitation service provision programme. This chapter is an analysis of the outcomes of these projects in the Ethekwini area and a summary of the research which has been carried out on VIPs and UDDTs with particular reference to the South African experience.

3.1. On-site sanitation systems in the eThekwini Municipality

Some areas in the EM are designated as being outside the "*waterborne edge*" in that they are too far from the existing network for it to be economically viable to provide residents with waterborne sewerage (eThekwini Municipality, 2003). Under the Free Basic Sanitation policy, the municipality must ensure that these householders have access to a minimum standard of sanitation.

The on-site sanitation systems described below were discussed in more detail in the literature review in Chapter 2.

3.1.1. Ventilated Improved Pit Latrines

VIPs have been designated as the minimum acceptable level of basic sanitation by the South African government (National Sanitation Policy – White Paper, DWAF, 1996). They provide a robust sanitation solution in that they can accept a range of wastes into their pits without complete failure to function, and can be used even after the superstructure (roofs, walls, doors, pedestals and vent pipes) has been vandalised.

3.1.2. Urine Diversion Dehydrating Toilets

UDDTs which have been built by EWS are designed so that urine is diverted to a soakaway and not collected for reuse. A double vault system allows faecal matter to decompose before householders need to remove it. Once one vault is full, the urine diverting pedestal is moved above the other chamber. Only when the second chamber is full does it become imperative to empty the first. This should be at least a year after the last fresh material was added and the faecal material should be fairly innocuous (Gounden and Buckley, 2008). It is buried on site and residents are not encouraged to use any products from the UDDT in agriculture or household food production in eThekwini.

3.2. Sanitation activities of the eThekwini Municipality

The EM, through the eThekwini Water and Sanitation Unit (EWS) has a water and sanitation policy which aims to put in place:

- *"A solution which is sustainable i.e.*
    - *has a limited cross subsidy*
    - *is capable of being maintained*
    - *is acceptable to the community*
    - *provides parity with other customers*
- *A solution which is environmentally satisfactory*
    - *prevents pollution*
    - *results in a healthy residential area*
    - *is compliant with National and Provincial legislation"*

  (eThekwini Municipality, 2014, p.198)

3.2.1. VIP construction

The first VIP latrines constructed by the then Durban Metro were built in the late 1990's. VIPs were designated as the preferred sanitation system for households receiving basic water (200 L/day) (Durban Metro Wastewater Management, 1998). By the time the EM changed its policy to offer only UDDTs, more than 45 000 VIPs were in existence in the municipality. A serious concern was that pit latrines ceased to provide a sanitation solution when the pits were full, and this was occurring more rapidly than expected (Bhagwan et al, 2008). The number of VIPs in the EM dropped to 35 000 in 2013 (EM, 2013).

The Strategic Framework for Water Services was approved by cabinet in 2003 (DWAF, 2003). According to Tissington (2011) this policy changed the emphasis from a demand-led programme to a supply-driven one where the municipality, rather than individual households, became responsible not only for construction but also maintenance of sanitation systems. The EM was already actively seeking solutions for the provision of sanitation which would be constructed by the municipality but maintained by the users.

3.2.2. UDDT construction

According to Roma et al. (2011) the planning of the UDDT project started in 2002 and a pilot project was implemented in Mzinyathi in 2003. In its business plan for the provision of water and sanitation, the EM emphasised its commitment to community participation in the project (EM, 2003). The business plan stated that:

"*Households are involved in a number of ways as follows:-*

- *They decide with the contractor where the toilet will be constructed.*
- *They are required to excavate the trench from the communal supply point to the position of the water supply tank*
- *They are responsible for backfilling the trench once the pipe has been laid*
- *They are required to operate the urine diversion toilet and empty the vault contents as required."*

Local labour was used in construction. Each project had a project steering committee on which community representatives sat. Community members were trained by the Institutional and Social Development (ISD) consultants as facilitators to assist residents with the operation of the system and ongoing health and educational support was provided by EWS (Gounden et al., 2006). Residents received five visits during the implementation of the project to inform them about their responsibilities and to educate them in operation and maintenance as well as health and hygiene.

Gounden and Buckley (2009) reported that the UDDT construction project enjoyed local and national political support at the time of its implementation. The project improved construction skills in the community which could have other applications and it made a contribution to local economic development.

By the end of the 2010/2011 financial year, 89 307 UDDTs were recorded in the EM. This number declined to 80 083 by the end of 2012/2013 (EM, 2013).

3.2.3. VIP maintenance in eThekwini

The maintenance required for VIPs falls into two categories: infrastructure repairs and emptying. In eThekwini, infrastructure repairs are deemed to be the responsibility of the owner, but emptying is undertaken by the municipality, at no cost to the users. In order to carry out this function efficiently, EWS made the decision to empty the pits on a planned, area by area basis rather than emptying individual pits as they become full. This would be done every 5 years.

A pilot study was conducted in 2004 to determine the costs and methods best suited to the eThekwini situation (UWP, 2004). It was concluded that a system of manual emptying, followed by transport to a hopper connected to the nearest sewerage inlet would be the most economical method (Macleod, 2005). Pit contents were screened to remove rubbish. The full-scale pit emptying programme in eThekwini started in 2007 (Bhagwan et al., 2008). The pits were emptied manually, using rakes and spades, and sludge was moved in drums to the nearest point on the road where it could be collected.

Once it was discovered that the concentration of the sludge was detrimental to the wastewater treatment works (WWTW), EWS investigated other options for disposal of the sludge. One of these was the pelletising of the sludge for use as compost, using the Latrine Dehydration and Pasteurisation (LaDePa) machine (Still and Foxon, 2012). A feasibility study has been conducted and a contractual system for the operation of the machine proposed by EWS (Harrison and Wilson, 2012).

Other possible methods for the disposal of VIP sludge include specialised faecal sludge treatment works, co-composting with municipal solid waste, deep row entrenchment in forestry areas, biogas production and drying beds (Still and Foxon, 2012).

3.2.4. Maintenance of UDDTs

One reason for choosing UDDTs for the provision of FBS in peri-urban eThekwini was to avoid the burden of maintenance falling on the municipality. It was originally envisaged that small businesses would develop to offer an emptying service to those who were prepared to pay for it (EM, 2003). Gounden et al. (2006) expressed concern that if the municipality emptied the vaults, there would be no incentive for residents to operate the toilets correctly. This presentation also indicated that the municipality was providing ongoing maintenance, replacing faulty doors and improving the design of vent stacks and vault covers.

A pilot project for the collection of urine was implemented in 2010 and expanded in 2012 (Etter et al., 2014). One of the experimental procedures associated with this project was the removal of phosphorus from the urine using struvite reactors (Grau et al., 2013). Andersson et al. (2011) found that the application of urine to rain-fed maize crops in the Thukela basin had the potential to increase yields by a median amount of 30%, suggesting that there could be potential for the use of urine as fertiliser in KwaZulu-Natal. Benoit (2012) reported that there was resistance among farmers to the idea of using urine in agriculture but that it was used for medicinal and spiritual purposes. Farmers interviewed suggested that future generations might be more open to the idea of urine application.

The EM appointed the Human Sciences Research Council (HSRC) to monitor the effectiveness of the UDDT sanitation project. They conducted a survey of 1 100 households between 2003 and 2004 (Roma et al., 2013). The level of satisfaction in that survey stood at 78.4%.

3.2.5. Current capital projects

In June 2013, the eThekwini Municipality estimated that just fewer than 77% of residents had access to basic sanitation (EM, 2014). They placed the sanitation backlog at 218 248 consumer units (roughly equivalent to households), an increase of 8 400 units over 2 years. They stated their capacity to reduce this backlog at the rate of 8 000 to 10 000 per year (EM, 2014, p.44).

The EM targets for the delivery of Free Basic Sanitation are defined in terms of "*The number of consumer units provided with access to free basic level of sanitation either by means of a UD toilet, an existing VIP or, for informal settlements, by a toilet/ablution block within 200m*". This stood at 170 476 units provided for at the end of the 2012/2013 year (EM, 2013). The number of UDDTs and VIPs in the municipality has stabilised or even declined even though Starkl et al. (2010) reported that EM planned to build a further 20 000 UDDTs . The number of community ablution blocks which serve informal settlements increased by over 20 000 between 2011 and 2013. The capital expenditure on water and sanitation declined by 46% between the 2011/2012 financial year and the 2012/2013 financial year. The capex budget for water and sanitation was under spent by 34% in 2012/2013 (EM, 2013, p.221).

3.3. Research conducted in the eThekwini Municipality

The University of KwaZulu-Natal has been engaged in a range of research projects in the eThekwini area. Four of the university's five campuses are located in the Metro and disciplines ranging from health and microbiology to town planning have been involved. The Pollution Research Group of the University of KwaZulu-Natal has contributed to many of these studies and has itself conducted a range of analyses on the technical aspects of on-site, decentralised and centralised sanitation systems. Researchers from the university have worked with organisations such as Partners in Development to investigate solutions to many of the problems facing municipalities in their attempts to meet sanitation targets.

This research provides an insight into numerous aspects of the performance of VIPs and UDDTs.

3.3.1. Processes taking place in on-site sanitation systems

Studies have been conducted in eThekwini to quantify the change in the contents of on-site sanitation systems. Understanding the biological processes in sanitation systems is central to the understanding of their environmental impact. Pit filling rates are critical in the planning of maintenance of VIPs.

3.3.1.1. Ventilated Improved Pit Latrines

Buckley et al. (2008a) described the processes which occur in the pits of VIPs. These include rapid aerobic digestion of organic matter and slower anaerobic digestion. The latter process produces more gas and a small amount of new cell mass from the biodegradable material, as well as NH_4^+ and phosphates. Aerobic digestion occurs on the surface of the pit contents and results in a slower reduction in mass due to greater production of new cell material. The proportions of these processes taking place in the pit will affect the rate at which the pit fills. Both processes produce CO_2, but these authors argued that little methane gas is produced in VIPs due to the amount of material in the anaerobic layers that is poorly or un-biodegradable.

Nwaneri (2009) characterised fresh faeces and VIP sludge in terms of total solids (TS), organic or volatile solids (VS) and total chemical oxygen demand (tCOD). She found that there was a decrease from 1.11 mgCOD/mgDM in fresh faeces to 0.25 mgCOD/mgDM in the bottom layer of the pit, a change of 77%. She measure organic solids as g VS/g TS and this value dropped from 84% in fresh faeces to 34% at 1m below the surface of the VIP sludge, a decrease of 60%. Buckley et al. (2008a) found a lower value for organic solids in fresh faeces (69%). Brouckaert et al. (2013) modelled the degradation processes in VIP pits to arrive at an estimate of filling times. They noted that the addition of un-biodegradable matter to pits, which is in the form of household rubbish, shortens filling times out of proportion to its volume, since the volume of human excreta decreases over time due to decomposition while the un-biodegradable material remains constant in volume. Estimates of COD reduction should take into account the addition of household rubbish to pits.

Bakare et al. (2012) found that the COD and the amount of volatile solids (VS) in VIP pits was higher at the surface but changed little between 1 and 1.5m below the surface. This suggested that the sludge had stabilised at this level, with the average dropping from 0.61 g COD/g dry sample at the surface to 0.25 g COD/g dry sample at the lower level. (59% decrease) and VS from approximately 59% to 28% (53% decrease). NH_4^+-N ranged from 3 to 13 mg/g dry matter, PO_4^--P from 0.73 to 0.83 mg/L (Bakare et al., 2008) . The difference in concentrations between the surface sludge and the deeply buried sludge could provide an indication of the proportional decrease taking place in these facilities. However, it is the decrease from fresh faeces to the levels found in sludge that is of interest for COD and VS. The figures from Bakare et al. (2008) reflect a decrease of 77% for COD and 67% for VS, using Nwaneri’s (2009) figures for fresh faeces.

For ammonia and phosphates the range of values could provide an indication of the reduction: 77% and 12% respectively. However, the fate of the nitrates is unknown. Fourie and Ryneveld (1995) warn that nitrates from on-site systems pose a risk to groundwater but add that phosphates do not normally travel through the soil.

Studies by Buckley et al. (2008a) and Bakare et al. (2012) found that the sludge in VIPs reaches a stable level of approximately 20g COD / g dry matter from an initial level of approximately 80g COD / g dry matter.

3.3.1.2. Urine Diversion Dehydrating Toilets

Austin (2006) presented his findings on the die-off of pathogens in UDDTs. He suggested that faecal material would be safe to handle after 12 months, when faecal coliforms would be reduced to below the maximum for sewage sludge (103 per 10g) and Ascaris eggs would be reduced to zero. Although Buckley et al. (2008b) found that emptying UDDT vaults posed a risk to waste handlers and that spillage posed a risk to householders, especially children, Lutchminarayan et al. (2007)

found that the health benefits of the installation of UDDTs in eThekwini were significant, with a 31% reduced risk of diarrhoea.

Buckley et al. (2008b) concluded that little degradation takes place in UDDTs after material is covered and aerobic decomposition has ceased. While COD and organic solids were low in the material sample from UDDT vaults, this was in proportion to a high loading of inorganic material (sand) which had been added to the vault. If a similar degradation takes place in UDDTs to that on the surface of VIPs then a decrease of 0.54mgCOD/mgDM (from 1.11mgCOD/mgDM in fresh faeces to 0.57mgCOD/mgDM in the surface layer of a VIP (Nwaneri, 2009)) would represent a 49% decrease in COD. Velkushanova (2013) presented results from faecal sludge from UDDTs in eThekwini which showed 0.48g COD /gDM and 0.45g VS /gDM . This represents a reduction closer to 57% for COD and 46% for volatile solids. The level for ammonia was 0.001g/g dry sample. This last value is very low as a result of urine separation, and a similarly low level would be expected for phosphorus.

Odong (2007) pointed out that the soakaways used for urine in the eThekwini UDDT project pose a nitrate hazard to groundwater. Effectively discharging urine directly to the soil means that this system does not offer a reduction in nitrogen and phosphorus. However, Flores et al. (2008) disagree with this contention. They assert that the greatest difference between VIPs and UDDTs is that the possibility of N and P being mobilised from the pits of VIPs and contaminating groundwater is far greater than the risk when urine is discharged to the sub-soil than in the UDDT soakaway. UDDTs confer an economic advantage if users empty the latrines themselves and even more so if excreta has value as a fertiliser.

3.3.2. Costs and technological indicators from the eThekwini Municipality

Costs for sanitation systems incorporating VIP and UDDT latrines identified from the literature vary widely. South Africa has a different set of constraints from many other developing countries in that the cost of providing basic sanitation to poorer residents has become the responsibility of government under the Free Basic Sanitation (FBS) policy. Municipalities are responsible for ensuring continued operation (DWAF, 2003). Furthermore, if the disposal of sludge is to be controlled, the municipality will need to be involved. Construction and maintenance of systems must be planned to fit into municipal budgets with little or no contribution from users. A 2008 study indicated that beneficiaries of FBS expect government to take responsibility for emptying (Maharaj, 2012). Furthermore, South African standards for health and hygiene may be more restrictive and costly than those in force in other LDCs. The VIP emptying programme and the UDDT construction programme in the EM have both been carried out under these constraints and the costs associated with them are indicative of the costs which municipalities in South Africa will face if they implement FBS programmes of these kinds.

eThekwini Municipality is acknowledged as a leader in the water and sanitation field, winning international awards including the UN “Water for Life” Best Practices Award (Sithole, 2011; WRC, 2011) and the Stockholm International Water Institute award (SIWI, 2014). Their sanitation programmes incur technical costs (e.g. provision of sanitary hardware, vehicles and equipment for maintenance.) social costs (e.g. health and hygiene education for contractors and residents, community liaison in the planning and execution phases) and environmental costs (e.g. monitoring of disposal sites). The municipality has been generous in sharing information both with local researchers and with other municipalities.

3.3.2.1. VIP construction

At the AfricaSan conference in 2008, Neil Macleod from EWS quoted a figure of $140 to $420 to build a new VIP latrine. At the prevailing exchange rate, approximately R8 per US dollar, this is a range of R1 120 to R3 360 (R1 410 to R4 240 adjusted to 2012 values). Walker et al. (2006) surveyed a number of sanitation projects including those in eThekwini and updated the costs to 2006. They calculated the cost for VIPs in these projects at between R2 737 and R3 465 (R3 880 to R4 920 adjusted to 2012 values). WhichSan budgeted R3 770 in 2006 and R4 743 in an updated version in 2009 (R5 650 adjusted to 2012 value).

3.3.2.2. UDDT Construction

Initial financial costs for the UDDT project in eThekwini Municipality, including construction of the sanitation facility and the health and hygiene education which is provided were R 5 904.67 (Schuen and Parkinson, 2009). A more recent study by Roma et al. (2011) reported that the 75 000 UDDTs built in the eThekwini area had cost R5 600 per toilet for construction, excluding project management costs and health and hygiene education (R5 940 adjusted to 2012 value). The 2009 cost from WhichSan which is based on a BOM and includes labour costs, health and hygiene education and construction management, was R5 646 (R6 720 adjusted to 2012 value).

3.3.2.3. Operation and maintenance of VIPs

The most costly aspect of the maintenance of VIP latrines is the emptying of full pits where space or financial constraints do not allow for the building of a new latrine when the old one is unusable. In eThekwini, this cost had reached R2 100 between 2008 and 2010 (Still and Foxon, 2012, p.107). If pits are emptied every 5 years, and serve 6 people, this is a cost of R70/p/y (R85 adjusted to 2012 value). This did not include a cost for disposal of the sludge. A range of costs for the disposal of sewage sludge can be found in the literature and decentralised, environmentally friendly options are often cheaper than co-treatment with wastewater sludge. Deep row entrenchment of sewage sludge cost $99/ton TS, approximately R500 for 0.5tons TS from a 2.5m3 VIP pit at 80% moisture (Kays et al., 2007). Co-treatment with sewage would cost $599/ton TS (calculated from Whittington, 2006).

In her study of sanitation service delivery in eThekwini, Maharaj (2012) found that the service every 5 years was insufficient in some areas where pits were filling up more rapidly. This author found that the onus of sanitation provision was perceived to lie with the government, and that residents were reluctant to take responsibility for their own facilities.

Partners in Development, owners of the WhichSan program, have developed a spreadsheet costing for pit emptying based on the eThekwini experience (Still and Foxon, 2012). This is included in an expanded version of WhichSan.

3.3.2.4. Operation and maintenance of UDDTs

Maintenance costs for UDDTs should be negligible if construction is sound and if householders are prepared to empty the vaults themselves (Flores et al., 2008).

After the HSRC survey in 2004, EWS returned to the sites where UDDTs had been constructed and carried out repairs including changes to the vent stacks and vault covers. Maharaj (2012) found that residents were still having problems with the quality of UDDT construction and with vandalism. Their attitude was that repairs and maintenance were the responsibility of the municipality. This indicates that there is a need for a continued maintenance budget.

Results from various studies have also suggested that ongoing health and hygiene education is needed if UDDTs are to continue to provide effective sanitation (Duncker et al., 2006, Mnguni et al., 2008, Roma et al., 2013).

3.3.3. Socio-cultural aspects of the eThekwini FBS programme

Studies have been conducted in the EM to investigate the levels of satisfaction with water services. In a study by Narsai et al. (2013) almost all residents (97-100%) of informal settlements, RDP houses and traditional rural dwellings considered their toilet facilities to be inadequate. The UDDT project has been particularly closely scrutinised. EWS committed to ongoing monitoring at the outset. In addition to this there has been considerable interest in the project as one of the largest examples of ecological sanitation implementation in the world.

3.3.3.1. VIP latrines in eThekwini Municipality

Maharaj (2012) found high levels of dissatisfaction with VIP latrines in the Inanda area. Many of these concerns related to the rapid filling of pits and the length of time between emptying services by the municipality. Mnguni (2008) reported that residents preferred VIPs to UDDTs.

VIPs are well established as the bottom of the sanitation ladder and little work has been done specifically to ascertain if users are happy with this system. Eales (2008) contends that anything other than a flush toilet will be perceived as "*second-best, discriminatory, and at best an interim option*." She ascribes this to the value of flush toilets as symbols of "*dignity and aspiration to a better life*" following the discrimination in terms of service provision against certain sectors of the population under the apartheid government. However, she argues further that South African municipalities do not have the resources to maintain and operate flush toilets for all.

3.3.3.2. Outcomes of the eThekwini UDDT project

Duncker et al. (2006) investigated user perceptions of UDDTs in a number of areas across the country. In KwaZulu-Natal they surveyed residents of Umnini and eHlanzeni where EM had constructed UDDTs and these had been in use for less than a year. 20% of the households surveyed also had a pit latrine and this was used by children or by households who did not use their UDDT (13%). They found that respondents preferred the toilet to be separate from the house. 67% of the eThekwini respondents said that they liked the UDDT, but a significant proportion of residents expressed concerns about emptying of the vaults and operation and maintenance of the system. The authors expected that satisfaction with the toilets would diminish as users had to empty them. This was confirmed by the drop from a 78.4% user satisfaction level in the HSRC survey of 2003/2004 to 30% in 2011 (Roma et al., 2013). One third of respondents indicated that they would be willing to use the contents of the vaults as fertiliser. 60% of respondents were unaware of the continued existence of a Sanitation Committee to provide community representation and 90% did not know of an Environmental Health officer in the area.

Roma et al. (2013) conducted a study to determine user perceptions of UDDTs and to assess the condition of these facilities in the eThekwini area. 74 606 UDDTs were recorded as having been constructed in the eThekwini Municipality between the implementation of the UDDT programme in 2003 and the survey, conducted between January and May, 2011. 17 448 households were surveyed, with a random selection process to avoid bias in the choice of surveyed households.

1 468 households had converted their UDDT into flush systems and were not included in the survey results, leaving a balance of 15 983 households. Of these approximately 1 884 had a VIP which was in use as well as the UDDT. Most households reported that they always used the UDDT, with 80% of users falling into this category. The proportion of unused UDDTs was under 7% overall, while in some areas it was as high as 14%. Urinals were used by 51% of male respondents.

Most households of the 65% who reported emptying the UDDT vault did so themselves rather than employing a contractor. Maharaj (2012) indicated that Inanda residents taking part in focus group discussions were very reluctant to empty the vaults themselves and that they felt that the municipality needed to empty the vaults every two to three months. In the area surveyed, 10 or more people using the toilet may have resulted in this rapid filling rate. The high sand content (Buckley et al., 2008b) may also contribute to rapid filling. Mnguni et al. (2008), in a study to evaluate the health risks of UDDT vault emptying, found users reluctant to help in this task. They found that resident's fears of health risks were well founded but that these risks could be mitigated with the use of protective equipment and deworming of children. Starkl et al. (2010) found that the health risks were medium to high for both VIPs and UDDTS, based on the exposure of users to coliform bacteria. While the sludge from the UDDTs was less hazardous, emptying by householders increased the health risk.

The major challenge associated with UDDTs was the smell, with doors not closing (and hence a lack of privacy) the second major concern. Poor workmanship in construction and problems with urine pipes were the two other important issues raised by respondents. While the toilets were mostly found to be in working order, the enumerators confirmed the householders' perception of unpleasant smell.

In spite of the extensive use of the UDDTs, the survey discovered that the majority of the users (70%) were not satisfied with this sanitation system. Only 7% declared themselves very satisfied. The authors suggested that the sources of this dissatisfaction were poor construction and smell, distance from dwelling and the perception that UDDTs are inferior to flush lavatories. They hypothesised that if users could perceive the benefits of the reuse of waste they would be more accepting of this technology.

Maharaj (2012) confirmed many of the findings of the study by Roma et al. (2013). Residents of Inanda were unhappy with the construction of the facilities and had problems with vandalisation and theft of doors. Flies and smells were a concern for many residents. Many toilets were constructed up to 30m from the dwelling, and this was perceived as problematic for the disabled. Residents viewed UDDTs as a "*punishment*" for poorer people. The toilets were seen as unhygienic and hazardous to residents' health. Eales (2008) advocates decentralised wastewater treatment (DEWATS) as a more viable option to extend sanitation provision in urban areas.

In another study, Starkl et al. (2010) found that satisfaction with UDDTs varied from area to area in eThekwini.

A study by by Kariuki (2008) of the Ohlange Township found that in spite of the provision of waterborne sewerage and piped water, residents were unhappy with the level of service. They felt that the water supplied was insufficient, reconnection fees too high and water outages too frequent. They complained of frequent blockages in the sewerage system and a slow response from the municipality to repair these. Their perception was that, as poor people, their concerns were unimportant to the municipality. This was in spite of the existence of Community Forums, which many did not attend because they felt that their grievances were not addressed. The author recommended a demand driven approach to sanitation provision. He commented on the absence of personal responsibility among residents for issues such as littered streets with a shifting of blame to the authorities. Working with EWS, Wilson et al. (2008) conducted a participatory study to inform the municipality of residents' concerns and found that the research process itself is valuable in contributing to dialogue between residents and the municipality.

Sutherland et al. (2014) also argue that the spatially differentiated sanitation provision model adopted by the eThekwini Municipality, which provides waterborne sanitation to urban residents and on-site sanitation to those on the urban fringe creates dissatisfaction with nearly 50% of the residents surveyed not using their UDDT toilets.

Roma et al. (2013) concluded that addressing issues of user satisfaction is fundamental to the success of the implementation of environmental sanitation. They suggested that education in resource reuse and monitoring of projects would increase sustainability.

From a socio-cultural perspective, Flores et al. (2008) contend that user acceptability is similar for UDDTs and VIPs, while VIPs are more robust and simpler to construct and UDDTs have a higher level of institutional support in the eThekwini area, a longer lifespan and reduced risk of pathogen exposure. They concluded that UDDTs were superior to VIPs on the basis of their performance on sustainability criteria.

3.4. Discussion

A wealth of information about on-site sanitation has emerged from research which has been carried in the eThekwini Municipality. This information has not been collated and structured in a single study before. The sustainability framework and the structuring of an MCDA is an ideal way to bring information from diverse aspects of a situation together and to make this information useful to those who need to apply it.

The next chapter documents a process whereby the studies described above inform an MCDA aimed at municipal engineers contemplating new Free Basic Sanitation projects.

Chapter 4. Methodology

WhichSan, the program developed by Partners in Development (Still et al., 2009) provides a feasibility assessment and costing for sanitation systems in a South African context. This research endeavoured to provide a further decision support tool for municipal engineers, to be used in conjunction with WhichSan. This tool assesses technically feasible options for their ability to provide a long-term solution which meets the needs of humans while preserving the environment as far as possible. Furthermore, for a system to be sustainable it must be supported by the financial and technical resources required for its continued operation and this aspect was included in the decision support tool.

Multiple Criteria Decision Analysis (MCDA) was chosen as a possible method to assess sustainability. The MCDA was developed using criteria and indicators derived from the literature. A user interface was developed for the stakeholder and for the expert user (municipal engineer).

In order to demonstrate the decision support tool, values for the two sanitation systems to be considered, VIPs and UDDTs, were taken from the work done in eThekwini (Chapter 3) and the MCDA was populated with these values. The researcher therefore played the role of expert in providing the ratings required for the spreadsheet for most of the scenarios investigated. The former head of eThekwini Water and Sanitation (an experienced expert) also provided ratings and these were entered into the MCDA to provide a further demonstration of the functionality of the tool.

4.1. WhichSan

The WhichSan sanitation selection software developed by Partners in Development provides a detailed analysis of the technical requirements for a range of sanitation options (Still et al., 2009). A user friendly interface guides the engineer or other decision maker to score the alternatives for each criterion through a series of questions. This software does not incorporate the full range of sustainability criteria recommended in the literature and does not attempt to weight the partial values in order to aggregate them into a single index. Nonetheless, it provides a sound financial and technical basis for the elimination of infeasible options.

The user manual of WhichSan states that "*The WhichSan Sanitation Decision Support System has been developed to assist planners and engineers to consider the relative merits and costs of* *different sanitation options for a given situation."* (Still et al., 2009). The program prompts users to answer questions, the answers to which are converted into scores in a decision matrix for technical feasibility or provide the input for costing calculations.

4.1.1. Technical feasibility assessment

The questions asked of users elicit information on the following technical criteria:

- availability of water (on-site water supply or not)
- plot size
- soil depth
- slope
- planned location of sanitation facilities (indoor or outside the dwelling)
- anal cleansing method
- soil type
- risk of flooding
- if on-site water supply is available:
    - volume of water available
    - capacity of local treatment works for additional demand
    - user willingness to pay for additional water

The answers to these questions enable the program to eliminate infeasible options (e.g. waterborne sewerage infeasible without on-site water supply, VIP latrines infeasible if a facility inside the dwelling is required). If one criterion receives a score of 0 (infeasible) for any of the sanitation options offered, then the option is allocated an overall technical feasibility score of 0. Feasible options are scored 3 (not ideal, but possible) or 5 (fully feasible) for each question and an average score of 1 – 5 is calculated. This allows feasible options to be ranked.

The scoring page where the decision matrix is displayed is accessible for expert users to change scores if they see fit.

4.1.2. Financial costing and feasibility assessment

WhichSan provides a costing for the construction and operation of treatment works, a pipe size calculator to be used if waterborne sewerage is feasible and a budget sheet to calculate the construction costs for the different options.

A financial feasibility assessment is carried out which takes into account factors including household income, financial and technical resources available for maintenance, waste disposal, water costs, potential for waste reuse and road access for tanker evacuation of pits. If waterborne sewerage is technically feasible, an additional set of questions probes the costs of sewer construction. Household and other sources of finance are investigated and these are compared with the costs to arrive at an assessment of whether the financial resources are available for each technically feasible option.

Finally, WhichSan combines the technical and financial assessments to give each alternative a tick if it is feasible or a cross if it is not.

Factsheets are provided with the program to allow users to read about the different sanitation options included in the program.

4.2. Sustainability Indicators

The concept of sustainability was used as the starting point for the further assessment of different sanitation systems. While the Millenium Development Goals urge that the number of people with access to sanitation is increased, this cannot be achieved if hardware is supplied to users but is not used appropriately or maintained. Similarly, a system which threatens the environment will ultimately compromise the survival of the community it seeks to benefit. The aim of sanitation interventions must be to provide long-term solutions. The performance of sanitation systems can be assessed against sustainability criteria and hence suitable systems selected (Hellström et al., 2000, Palme et al., 2005, Jones and Silva, 2009).

Sustainability criteria were derived from the literature (Cotton and Saywell, 1998, van der Vleuten-Balkema, 2003, Bracken et al., 2005, Agudelo et al., 2007, Flores et al., 2008, Muga and Mihelcic, 2008) and these criteria were organised into a hierarchy or “value tree”, consisting of a number of levels having progressively more criteria at each level.

At the first level, the criteria encompass the broad areas of concern for decision makers: health, technology, environment, socio-culture and the economy. The last level of the hierarchy, or "leaves" of the tree, consists of criteria which allow alternatives to be assessed or ranked in an unambiguous way (Belton and Stewart, 2002, p.80). The intermediate level was included to allow a meaningful breakdown of the concept of sustainability into first level criteria (main categories) and then into more specific areas of comparison. Initially a comprehensive list of criteria was compiled.

These criteria are represented in Figure 4-1 which shows the hierarchical nature of the value tree. The shaded criteria are those which are assessed by WhichSan.

The list of criteria produced was too extensive to be incorporated into a meaningful MCDA because the effect of each criterion becomes too diluted, and there is a danger of user fatigue. Mendoza and Martins (2006) reviewed accounts of over 50 different MCDA applications, and found that the number of criteria ranged from 3 to 21. Loetscher (1999) used 32 indicators under two principal headings. He used a range of amalgamation methods in an effort to avoid the excessive diminution of the effect of individual criteria.

In this study, the need to reduce the number of criteria was balanced against the need to consider as many aspects of the issue as possible. It was decided to use a maximum of 25 indicators and the original selection was reduced to those which represented the most crucial aspects of each of the five overarching criteria.

Careful consideration was given to the peculiarities of the South African situation. The Free Basic Sanitation policy has resulted in a complex of expectations with regard to sanitation which, although not unique to South Africa, carries with it particular considerations which are not at issue in a developing country where no subsidy is available for sanitation and where the social issues can be addressed through marketing and communication.

In the following sections, the criteria which were finally used in the MCDA or which are assessed in WhichSan are in bold print.

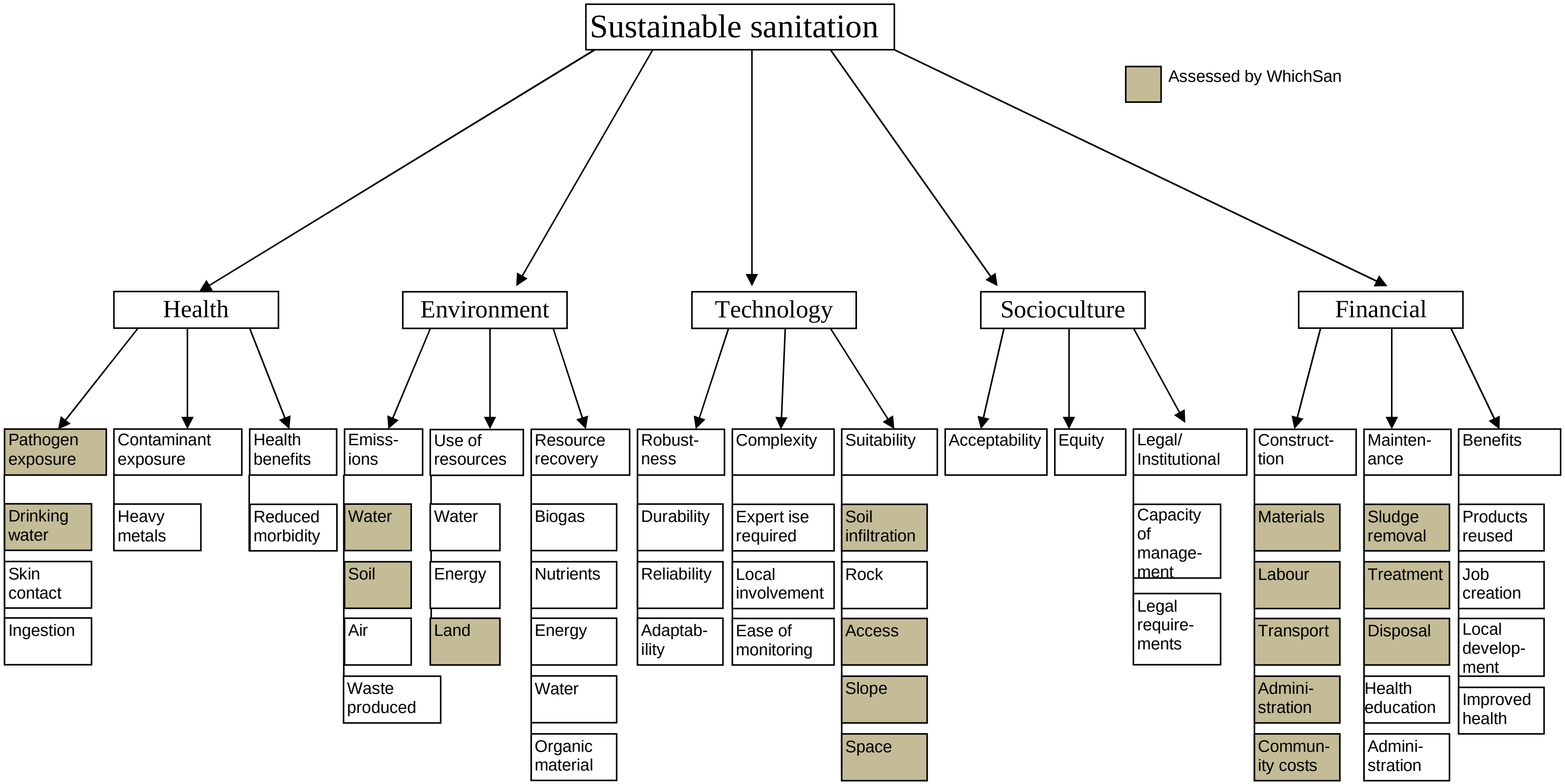


Figure 4-1. Value tree for assessing the sustainability of sanitation systems

4.2.1. Health sustainability

The primary aim of sanitation provision is to safeguard health. The health of the household should be enhanced by reduced contact with faeces, but this must be coupled with the protection of the wider community from the same faecal material. Waterborne sewerage may transport faeces away from those producing them, but may threaten the health of communities downstream of the disposal point. Urine diversion latrines may retain the faeces within the environment of those producing them, thereby safeguarding the wider community, but may provide reduced health benefits for the household if faecal material is not disposed of safely (Austin, 2006).

In considering the likely health benefits, the following questions need to be asked:

- **Will the sanitation system contaminate drinking water, either of the household or other communities?** On-site systems create a risk that ground water will be contaminated. This question could be considered concurrently with the contamination of water addressed in the section on environmental issues, and addressed in the feasibility stage of the selection process.
- **Will the household be exposed to faecal matter in the management of the sanitation system, or will the sanitation system provide a reduction in contact with faeces compared with the *status quo*?** Handling of faecal material by users may expose them to various disease organisms and intestinal parasites but this risk may be lower than the exposure resulting from current sanitation practices.
- Will food sources be contaminated with faeces, or will the sanitation system provide a reduction in contamination from the *status quo*?
- Will the sanitation system expose households or communities to heavy metals or toxic compounds?
- What will the impact of the sanitation system be on the health of the household and community? (Root, 2001; Barreto et al., 2007).

The first two of these questions were selected for inclusion in this MCDA. They were considered important in the South African context because every sanitation alternative must compete with conventional flush toilets and full sewerage. This option is enjoyed by the wealthier members of society and is favoured by most potential users as being the most desirable sanitation system. Along with running water for hand washing, a full flush system offers a high level of protection for users from their own excreta, since it is removed from the household environs immediately after urination or defaecation has taken place.

The other three items were left out for the following reasons:

- Contamination of food sources is most likely to be a consequence of the hand washing practices rather than the latrine used. Flies are another possible vector for the contamination of food, but any improved sanitation design should exclude flies from contact with faecal material.
- Heavy metal contamination is not generally a high risk with domestic waste alone.
- The impact of the system on health is usually a consequence of its effectiveness in reducing contact with faecal matter and contamination of drinking water, so the fifth item has an element of repetition. Where a cost-benefit analysis of sanitation is carried out, health benefits may be quantified and an economic value assigned to them (Hutton and Haller, 2004). This was not included in the financial approach used in this project.

4.2.2. Environmental sustainability

The world faces a future with a burgeoning population and diminishing natural resources. A sanitation system should seek to conserve resources and protect the soil, water and air from contamination. The sustainability issues in this area can be subdivided into emissions, resource use and resource recovery.

4.2.2.1. Emissions

Soil and water are vulnerable to contamination with pathogens, toxic compounds and heavy metals. Odours may be considered as air contaminants, and carbon dioxide (CO_2) and methane emissions may be arouse fears of global warming.

Questions which may elucidate the potential for harmful emissions include:

- What is the extent and duration of soil contamination from the sanitation system? This question seeks to investigate the effect of the sanitation system on the wider community rather than the household.
- What is the extent and duration of heavy metal or other toxin contamination of soil? As noted above, it is generally accepted that domestic sanitation should not contain high levels of toxins or heavy metals. There is some concern about pharmaceuticals and the breakdown

products present in human excreta, but this question was considered less crucial and omitted from the MCDA.

- **What is the risk of water contamination by pathogens?** This question also seeks to address the risk which a system poses to the wider community and the environment. When considering on-site systems, this may best be addressed in the feasibility stage rather than in the MCDA, since minimum standards have been set by the DWA for emissions into water courses.
- What is the risk of water contamination by heavy metals or other toxins? As above, this risk is not considered to be significant in most domestic sanitation systems, and hence it was omitted.
- **How effective is the system in reducing volatile solids (VS) emitted to bodies of water?**
- **How effective is the system in removing Nitrogen (N) and Phosphorus (P) from outflows to bodies of water?**
- **How effective is the system in reducing the biological or chemical oxygen demand (BOD/COD) loading of outflows to bodies of water?** The release of material with a high COD into water courses may result in eutrophication and damage to the plant and animal life in the downstream ecosystem.
- What are the odours emitted by the system? The extent to which odours are problematic depends on the location of the sanitation system and the final disposal method used. This could also be considered an element of the social aspect of the MCDA.
- What quantity of CO_2 is emitted by the system? The largest source of CO_2 may be the energy source for the system, and hence this question was considered redundant.

From this section, the questions on the efficiency of nutrient removal were considered the most important, and hence included in the final list.

4.2.2.2. Resource use

Water, non-renewable energy and land are resources which may be required for the storage, processing and disposal of the products of the sanitation process. These requirements should be interrogated during the decision making process in an effort to establish:

- **How much land is required for the operation of the sanitation system?** This should include land required for both collection and disposal of waste.

- **How much energy does the system require for its operation?** The availability and cost of energy sources could affect the feasibility of some innovative sanitation systems such as a vacuum system. Most low-cost systems do not require an external energy source.
- What is the quality of the land available for this purpose (e.g. is it arable, or does it have potential as residential land)?
- What quantity and type of materials will be required for the construction of the system? In South Africa, the construction of latrines in any formal program is likely to use conventional building materials. The cost of these materials will vary but their nature is unlikely to create a significant differentiator between systems.
- What chemicals will be required for construction and maintenance of the system? This would be worth considering in the MCDA if a particular system requires different chemicals from others, but an assumption is made that the only chemicals required for the alternatives under consideration will be cleaning materials, and that these will not differ significantly between systems. The cost of these would form part of the affordability criterion under socio-cultural considerations.
- **How much water is required for the operation of the system?** This will affect the feasibility of the system in situations where the household water supply is limited.
- How much time must be invested in the maintenance of the system? While this may not be an issue in households where some members are unemployed, time must be considered important to urban or peri-urban families in which users are working away from home and where considerable time spent commuting may limit the time available for home cleaning and maintenance.

The resources considered most critical were area of land, energy requirement and water, since these relate directly to the nature of the community being served by the sanitation system. Water requirements are of particular concern where residents do not have access to piped water or where economic constraints prevent the use of large amounts. Area of land required may not be a consideration in rural areas, but in urban areas, and particularly in informal settlements, land may be limited and hence the requirement for this resource may play a critical role in determining the suitability of a sanitation solution.

4.2.2.3. Resource recovery

There has been a shift from the nineteenth century European paradigm which regards faeces and urine as waste products to a perception of these as resources which should be returned to the soil as plant nutrients. Resource recovery is also an integral part of the effort to minimise the contamination of water and soil. Sanitation systems can incorporate the facility to recover nutrients for reuse.

- **What fraction of the nutrients including Nitrogen, Phosphorus and Potassium (N, P and K) in the faeces and urine is recovered from the system?** These nutrients, present most significantly in urine, are required for agricultural purposes and may represent an economic benefit as well as a benefit to the environment if the system allows their recovery.
- **Is energy recovered, for example as biogas?** There is potential to address the energy requirements of communities and to reduce the emissions from sanitation systems through the establishment of energy recovery systems.
- **Is organic matter recovered** e.g. for use as a soil conditioner? Organic matter poses a pollution risk but can also be viewed as a valuable resource.
- **What fraction of the water required for the system is recoverable**? The recycling of water from sanitation systems may offset the water used to remove faecal matter from contact with householders.

4.2.3. Technological sustainability

While a range of sanitation options may be technically feasible, in order to provide a sustainable solution it may be necessary for the proposed technology incorporate some of the following features:

- **Is the design simple and easy to implement?**
- **Can it be operated with minimal need for outside intervention?**
- **Is the design robust design and able to withstand misuse?**
- **Can the system cope with shock loading and demonstrate a low failure rate?**
- Does the system offer flexibility to adapt to the needs of different groups of users?
- **Will the system be durable for the intended lifespan?**
- Does the system minimise the production of waste requiring disposal?
- Is there efficient substance flow through the system?
- Is the system compatible with existing systems?

- Does the design minimise the intrusion into available space and nuisance to users?

Robustness was considered to be a criterion from this list that could be rated in a qualitative fashion and which would encompass a number of the other aspects listed above. A robust system could be one which is not prone to failure, simple and easy to operate. The need for outside intervention was considered an important issue in South Africa where institutional support is not always guaranteed. Included in this would be the requirement for monitoring to ensure continued operation and suitable waste disposal. The durability or life expectancy of the system should be considered since replacement carries significant costs.

Substance flow and the production of waste are aspects incorporated into the emissions aspects of the analysis, while flexibility and nuisance to users could be included in the analysis of social sustainability, as a component of acceptability or convenience.

4.2.4. Financial sustainability

While the municipal engineer is usually concerned with issues of affordability, the following issues may also need to be considered for a financially sustainable system:

- **What are the construction costs?**
- **What are the maintenance costs of the system?**
- **What job creation can the implementation of the sanitation system provide?**
- **Does the system contribute to local development?**
- Is the system affordable to users?
- Are there financial benefits from resource recovery?

Costs of construction and maintenance will be dealt with separately as a budgetary issue, but some kind of cost rating should be included in the MCDA if it is to consider all the important aspects of the sanitation system. Job creation and local development are also important, particularly in the South African context, where municipalities receive financial incentives for these.

Affordability for users is repeated under the socio-cultural aspect, and the financial benefits of resource recovery were omitted due the inclusion of this issue under economic sustainability.

4.2.5. Socio-cultural sustainability

"Technology does not fail humans; humans fail technology if the introduced technology cannot be sustained in the socio-economic, personal or cultural environment. The users are often blamed for the failure but the reality is that failure occurs because the technology is inappropriate to the circumstances." (Holden, 2008)

The aspects of a sanitation system which make it acceptable to a certain group of users must be incorporated into the planning phase if the project is to provide the improvements to health and wellbeing which are intended.

No improvements to health can be achieved without changes in behaviour. These require changes in the attitude of users to practices like hand-washing after defaecation: this must become habitual, and users must experience a sense of dirtiness if hand washing has not occurred.

Successful sanitation programs are those where a demand is created among users for sanitation, and where the options provided are considered desirable.

The following issues should be addressed:

- **Do users see the system as fit for purpose?** In South Africa, the provision of Free Basic Sanitation creates a problematic situation where sanitation is seen as a right but where users are not satisfied with the options offered by municipalities and are hence not inclined to maintain these systems. If there is no "buy-in" from the beneficiaries of a project, the sustainability of the system is compromised.
- **Are the needs of all income and gender groups met – is it an equitable solution?** Issues of safety for infants and children using latrines, and safe access for women at night must be considered if sanitation systems are to be used consistently by all members of the community.
- **Will the system provide the convenience required by prospective users?** Sanitation must be accessible at all times to encourage universal use.
- Is the expertise available for construction and maintenance of the system? Users must be involved and expertise developed within communities to maintain systems. This may be redundant since local development and job creation are among the economic criteria.
- **Does the solution meet existing legal requirements and is there institutional support for sustained operation?** Municipalities must also provide maintained infrastructure to

support the operation of sanitation systems. If emptying is required, for example, it might be more desirable for this to be performed by the Water Services Authority so that waste is disposed of in a controlled manner. Is there political support from all parties for this solution?

- **Is there the facility to maintain education and awareness programs to ensure that improved sanitation is achieved?** Urban neighbourhoods may change in composition and newcomers must be inducted into sanitation practices if the health of the community is to be maintained. This implies that health and sanitation education must be continuous and not only provided at the outset.
- **Is there the facility for user involvement in the planning and execution of the project?** A sense of ownership is essential if communities are to sustain desirable sanitation behaviours and if infrastructure is to be maintained.
- **Does the system address food security issues?** Poorer communities may need a sanitation system to be integrated into urban agriculture.
- **Is the typical anal cleansing material of the users compatible with the proposed system?**
- **Are users willing to pay if this is required to ensure the continued functioning of the system?** While Free Basic Sanitation should include maintenance, most sanitation systems require users to spend money on cleaning materials and anal cleansing materials which are compatible with the system. Replacement of hardware may also be the responsibility of users.

All of these socio-cultural issues, except expertise for maintenance, were incorporated into the MCDA on the basis of the evidence that the reasons for sanitation system failure are most often a result of failure in this sphere rather than in the technical aspects of implementation.

Many of the questions asked above are interrelated, and some desirable features of a sanitation system may even be in conflict with one another. The benefits of resource reuse may be reduced if there is an increased risk of human contact with pathogenic material. Environmentally sound technology might not provide the user with a sustainable level of convenience, and cultural barriers may preclude communities from adopting the most affordable technology. Multiple Criteria Decision Analysis is designed to incorporate the trade-offs which may be necessary in order to arrive at the most favourable option.

The abbreviated list of criteria which emerged from the selection process is shown in Table 4-1. This set includes 31 criteria.

The environmental criteria for water and energy resources required and recovered can be combined into net water and energy requirements. It was decided to use volatile solids (VS) as a measure of the organic matter present in the sludge as the addition of other material such as non-organic household waste and sand (in the case of UDDTs) would have less influence on this indicator as opposed to TSS.

Table 4-1. Proposed list of criteria to be used in an MCDA to assess the sustainability of sanitation systems

Criterion (highlighted criteria are covered by WhichSan)	**Description**
Health	
• Pathogen exposure - water	proximity to water sources
• Pathogen exposure -skin contact	requirements of system for contact with faeces
Environment	
Emissions	
• Soil	
o Pathogens	extent of and duration of soil contamination
• Water	
o Pathogens	risk of contamination of ground and surface
o TSS	efficiency of reduction in TSS
o N	efficiency of removal of N
o P	efficiency of removal of P
o BOD/COD	efficiency of reduction in BOD/COD
Use of resources	
• Water	water required for operation of system
• Energy	energy required for operation of system
• Land required	area of land required for operation of system
Resource recovery	
• Nutrients	usable nutrients for agriculture (N, P, K)
• Organic material	value as a soil conditioner
• Water (domestic reuse)	water recovered from system
• Energy	energy recovered from system

Criterion (highlighted criteria are covered by WhichSan)	Description
Technology	
• Robustness	ease of construction, simplicity of design, ability to withstand abuse
• Outside intervention	requirement for outside intervention, requirement for monitoring to ensure appropriate disposal
• Durability	life expectancy of system
Financial	
• Cost construction	
• Cost O & M	
• Employment creation	
• Local development	
Socio-cultural	
• Acceptability	user perceptions of fitness for purpose
• Convenience	provision of sanitation where users require it, distance from dwelling
• Equity	fulfilment of requirements of all gender groups. equivalence of sanitation provision for different income groups
• Legal /institutional / Political	fit with legal requirements, institutional support for construction, O & M, political support
• Facility for ongoing hygiene education	
• Participation	facility for user involvement in planning and execution of project
• Food security	contribution of system to sustainable household based food production
• Anal cleansing material	compatibility of anal cleansing material with proposed system
• Willingness to pay	ability of users to contribute to the cost of sanitation

Since this MCDA is designed to be used with WhichSan, with the latter providing the feasibility component as in the SANEX® model (Loetscher and Keller, 2002), some criteria could be eliminated to create a still shorter list. The criteria considered to be redundant were:

- Pathogen exposure (water) and risk of soil and water contamination included in WhichSan with the following questions:

- *"Is the soil depth less than 1m? Sanitation technologies that rely on percolation require a soil depth of greater than 1m to allow this to happen.*
- *What is the soil type? Different soil types have different percolation rates. Soils with either very low or very high percolation rates can be problematic for soakpits (if very low the soakpit will not work, while if very high groundwater contamination may result).*
- *Is the area prone to flooding? If the area is prone to flooding then sanitation options that require pits or soakpits would not be suitable."*

- Land required for operation
  - *"What is the mean plot size? Septic tanks with soakaways require plot sizes greater than 500m2, and VIPs are generally not used with plot sizes less than 200m^2.*
  - *Is there room on plots to bury waste? To cut the cost of transporting the waste off site, the waste can be buried on the householders' plots."*

- Willingness to pay
  - *"How much money is each household contributing to the construction, either in cash or the relative value of sweat equity? Each household may either be contributing cash to the construction of their sanitation facilities, or may be contributing sweat equity, for example by digging their own pit.*
  - *What percentage of the monthly household income would be available to pay for water? This question provides the budget for water requirements."*

- Anal cleansing material
  - *"What type of anal cleansing method is used? If hard or bulky material is used, and the users are unwilling to change to soft paper or water, then water borne sanitation is not feasible."*

Although WhichSan includes a full costing for the sanitation options under consideration, it was decided to retain the financial criteria for capital expenditure and operations and maintenance, since the aim of the MCDA is to obtain a balanced assessment and the cost of a system is always an important consideration. Because an accurate costing will be available for the engineer, the cost criteria in the MCDA can be approached in a less precise fashion if necessary.

Table 4-2. Final list of criteria used in the MCDA

Criterion	Description
Environmental	
Emissions	
• VS	efficiency of reduction in VS
• N	efficiency of removal of N
• P	efficiency of removal of P
• BOD/COD	efficiency of reduction in BOD/COD
Use of resources	
• Water	water required for operation of system less water recovered
• Energy	energy required for operation of system less energy recovered
Resource recovery	
• Nutrients	usable nutrients recovered for agriculture (N, P, K)
• Organic material	recovered for use as a soil conditioner
Finance and Technology	
• Robustness	ease of construction, simplicity of design, ability to withstand abuse
• Outside intervention	requirement for monitoring and assistance with disposal
• Durability	life expectancy of system
• Cost construction	cost of materials, labour, institutional requirements
• Cost O & M	cost of repairs, servicing (e.g. emptying)
• Employment creation	jobs created by construction and maintenance
• Local development	local business in construction and maintenance
Socio-cultural	
• Acceptability	user perceptions of fitness for purpose
• Convenience	provision of sanitation where users require it
• Equity	provision for different gender and income groups
• Legal /Political	fit with legal requirements, institutional support , political support
• Hygiene education	commitment of government to fund ongoing hygiene education
• Participation	facility for user involvement in planning and execution of project
• Food security	contribution of system to household based food production
• Pathogen exposure	requirements of system for contact with faeces

This rationalisation process reduces the list to 23 criteria. Of these, 8 are environmental, 7 socio-cultural, 1 health, 4 financial and 3 technological. In order to avoid a situation where the weightings of the overall criteria give undue weight to a few sub-criteria, the criterion of reducing contact with faeces was included in the *Socio-cultural* grouping. This was considered valid since it had been decided to rate the requirements of the system for contact with faeces, and this is a cultural as well as a health issue. The feasibility stage, in this model the application of WhichSan, should eliminate sanitation systems which do not promote health. Since the nature of the technology and the cost of its implementation are closely linked, it was decided to group these two concepts together, to create the overall criterion *Finance and Technology* with seven sub-criteria. *Environmental*, with 8 sub-criteria, formed a third category.

The division of the indicators into these three groups might be expected to reflect three possible groupings of stakeholders in the South African Free Basic Sanitation scenario: the wider community, concerned with the environmental impact of the system; the municipality and municipal engineers, concerned with the costs of construction and maintenance and life span of the intervention; and the users, concerned with comfort, privacy, and other sociological issues.

These three groupings also reflect the so-called three pillars or dimensions of sustainable development: social, economic and environmental (Assefa and Frostrell, 2007).

It is important to be aware that some of the sustainability criteria could be considered as intrinsic features of the sanitation system(s) being considered, while others are extrinsic features which describe and are affected by its relationship with external factors, such as the community in which it is applied. A urine diversion latrine is intrinsically a system in which nutrients are conserved, but extrinsically this only confers sustainability if its users show acceptance of the practice of excreta use in agriculture, or if another system is in place to facilitate removal and reuse of faeces elsewhere. Sustainability is thus contingent upon both the intrinsic property of the sanitation facility and the relationship which users have with it.

A decision support tool must inform users about these extrinsic characteristics, as well as eliciting the necessary information from decision makers to describe the intrinsic characteristics which make the sanitation system sustainable or otherwise. Hence the criticism of Thomas Loetscher's SANEX program (Balkema et al., 2002) that it lacked transparency, because the user interface was primarily concerned with eliciting the relational determinants of success, while the intrinsic features of the sanitation systems under consideration were concealed. However, there was a database, or encyclopaedia, of technologies incorporated into it to provide information for users. The MCDA developed for this project would also require users to access additional information.

The process of developing a list of criteria which has been the focus of this section therefore leads to the next section, in which scalable indicators are chosen for each criterion before the Multiple Criteria Decision Analysis can be developed.

4.3. Indicators for the chosen criteria and development of value functions

The indicators chosen for the MCDA were a mixture of quantitative and qualitative measures. Environmental criteria could be measured quantitatively, while financial and technological criteria were divided between quantitative and qualitative indicators, and the socio-cultural indicators were all qualitative.

In all cases but one the simple linear normalisation function recommended by Edwards and Newman (1982, p.66) was used rather than the complex partial value functions described by Belton and Stewart (2002). The value scores ranged from 0 to 5, to maintain consistency with those developed for the WhichSan program.

4.3.1. Environmental indicators

It was decided to use % removal rates as an indicator of the performance of alternatives for the criteria VS, N, P and COD. These were seen as valid measures of the effectiveness of sanitation systems towards returning a less harmful product to the environment. While some authors suggested measures such as N to water per person equivalent and year (Hellström et al., 2000), this is likely to be valid for centralised sewage treatment while for on-site systems it would be difficult to anticipate the eventual disposal method, and hence to arrive at this value. There is an enormous range in COD when measured in g/L when dry sanitation systems are considered alongside centralised wastewater treatment. Trying to develop a scale for comparison could be challenging. While using both VS and COD is to some extent repetitive, it was decided to retain both indicators to allow users to enter both values, or only one if they have limited data available. If a value is entered for only one indicator, the missing value would be given a weighting of 0 for the aggregation function.

Table 4-3. Indicators and scaled indicator values for environmental sustainability

Criterion	**Indicator and range**	**Scale**
efficiency of reduction in VS	% removal 0-100	0=0 1=20 2=40 3=60 4=80 5=100
efficiency of removal of N	% removal 0-100	
efficiency of removal of P	% removal 0-100	
efficiency of reduction in COD	% removal 0-100	
energy required for operation less energy recovered	MJ/p/y) 0-30	0=30 1=24 2=18 3=12 4=6 5=0
water required for operation of system less water recovered	m^3/p/y 0-40	0=40 1=32 2=24 3=16 4=8 5=0
nutrients recovered	kg N+P+K/p/y 0-5	0=0 1=1 2=2 3=3 4=4 5=5
organic material recovered	kg DM/p/y 0-10	0=0 1=2 2=4 3=6 4=8 5=10

The range of values for each of these indicators is 0 – 100%. A linear transformation was used to produce the scaled indicator values shown in Table 4-3. In all cases greater removal was better and the relationship was therefore a positive linear one.

The indicators chosen for net energy and net water required were kWh/p/y and m^3/p/y respectively. If dry on-site sanitation is assumed to reflect a zero value for these two indicators this would be the minimum value required for normalisation. The maximum value for energy use was assumed to be 30 kWh/p/y, a compromise between the estimates of European systems of up to 44 kWh/p/y and South African estimates of 20 kWh/p/y for centralised wastewater treatment. Fully waterborne sewerage is also estimated to require the maximum amount of water and an estimate of 40 m^3/p/y was used (see Section 2.3.1). Since less is better for both of these indicators, the linear value function normalised the maximum value to a score of 0 and the minimum to a score of 5. This is illustrated in Figure 4-2.

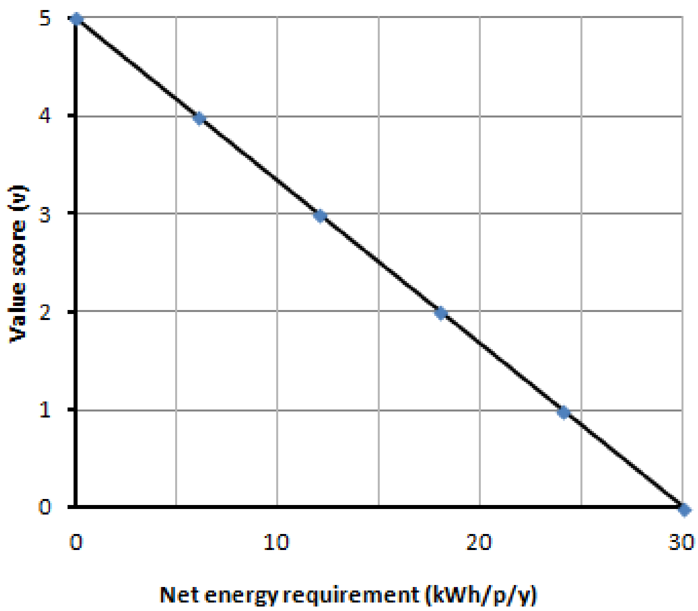


Figure 4-2. Value Function for the indicator "Energy requirement"

The mass of nitrogen, phosphorus and potassium recovered was chosen as an indicator for the recovery of nutrients, measured in kg/ person/year, while organic matter recovered was measured in kg dry matter/person/year. The minimum value for both of these was 0 kg. The maximum values possible are the annual amounts produced per capita in excreta. According to Jönsson (2004) this figure for Nitrogen, Phosphorus and Potassium is 5.5kg in South Africa. Since recovery is highly unlikely to reach 100% a figure of 5 kg of nutrients was chosen as a maximum. This also simplifies the allocation of rating values to rounding to the nearest kilogram. The recommended value of 10kg organic matter offers a similarly simple transformation (Jönsson et al., 2004).

Since the environmental indicators are continuous variables, these will be entered as raw scores rounded to the nearest integer in the range described in Table 4-3 and these will be scaled to value scores between 0 and 5 shown to 2 decimal places in the MCDA.

4.3.2. Financial and technological indicators

Only two of the seven indicators under the heading Finance and Technology were treated as purely quantitative variables. These were construction cost (R/household), operations and management cost (R/person/year).

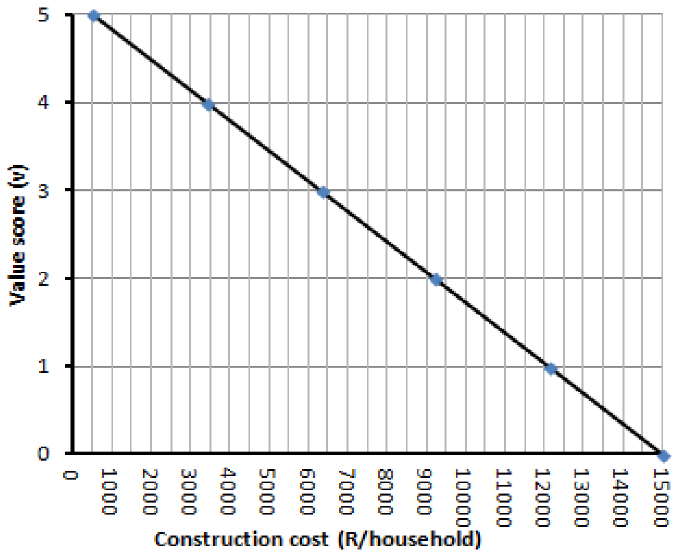


Figure 4-3. Value Function for "Construction cost"

While it is conceivable that a sanitation solution might cost more than R15 000/household, this is likely to be eliminated in advance due to the infeasibility of funding this option. The graph of this function is shown in Figure 4-3.

It was decided to use the range R500 to R15 000/household for capital expenditure on construction (Rosemarin et al., 2008 costs adjusted to 2012 values). The minimum value might be a simple improvement to an existing pit latrine where a vent stack is added and the maximum amount is not unlikely if waterborne sewerage is added to the MCDA. Edwards and Newman (1982, p.67) assert that the boundary values chosen should be "minimum and maximum plausible values, rather than minimum and maximum possible, conceivable, or actual values".

Minimum and maximum values for the Operations and Maintenance cost criterion were set at R0/person/ year and R1 200/person/ year (a compromise between the estimates for waterborne sanitation of Rosemarin et al., 2008 of R125 and Holden et al., 2004 of R1 910, both costs adjusted to 2012 values).

Standardisation of these financial indicators was performed using a linear transformation since a monetary scale is already interval scaled and compensatory. Since lower cost is more desirable, a value of 5 was assigned to the minimum value and 0 to the maximum value, hence producing a linear function with a negative gradient.

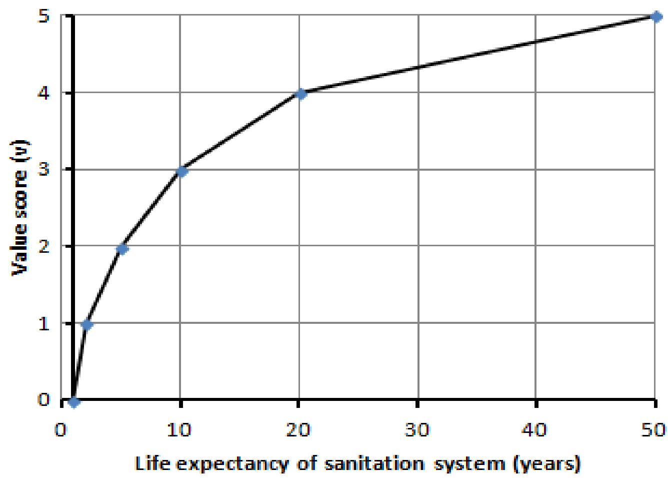


Figure 4-4. Value function for "Durability"

Durability was measured as life expectancy in years, with 50 years as a maximum (the design life estimated by Schuen and Parkinson (2009) for sewerage and treatment infrastructure). This longest life expectancy does provide an ideal situation, but a linear function seems inappropriate for this criterion. While system lasting 1 year is fairly undesirable, 20 years is an excellent lifespan for on-site sanitation and was hence rated as 4 on the standardised scale. The value function for durability is illustrated in Figure 4-4. Since this is likely to be an estimated value, no values in between are considered and effectively this becomes analogous to a qualitative variable.

Table 4-4. Indicators and scaled indicator values for financial and technological sustainability

Criterion	Indicator/ range	Scale
Robustness: ability to withstand abuse, ease of construction, simplicity of design,	qualitative	0= susceptible to misuse, challenging construction, advanced technology. 1 = more robust, challenging construction, advanced technology. 2 = robust, challenging construction, advanced technology. 3 = robust, challenging construction, simpler technology. 4= robust, simpler construction, simpler technology. 5= robust, simple to construct, simple design
Requirement for outside intervention, requirement for monitoring to ensure appropriate disposal of waste	qualitative	0= monthly intervention 1= six-monthly intervention 2= annual intervention 3=intervention every 2 years 4= intervention every 5 years 5= intervention every 10 years or more
Durability: life expectancy of system	years 1-50	0=1 year 1=2 years 2=5 years 3=10 years 4=20 years 5=50 years
Construction cost: materials, labour, institutional requirements	R/household 500-15 000	0= 15 000 1= 12 100 2= 9 200 3= 6 300 4= 3 400 5= 500
Cost of O & M: repairs, servicing (e.g. emptying)	R/person/ year 0 – 1 200	0= 1 200 1= 960 2= 720 3= 480 4= 140 5= 0

Criterion	Indicator/ range	Scale
Employment: jobs created by construction and maintenance	qualitative values are approximate	0=no jobs created / 1 000 households 1=1 new job created/ 1 000 households 2=5 new jobs created / 1 000 households 3=10 new jobs created/ 1 000 households 4=15 new jobs created/ 1 000 households 5=20 new jobs created/ 1 000 households
Local development: promotion of local business in construction and maintenance	qualitative	0=All construction and maintenance by international agency 1=Some international assistance, national construction agency 2=National and regional agencies 3=All regional construction, O&M 4=Some local community, some regional construction and O&M 5=All construction and maintenance performed within the local community

The remaining indicators were also considered to be qualitative. In describing the different levels an attempt was made to make the underlying rationale for including the criterion explicit. This was so that when a new sanitation option is added to the MCDA, the basis for comparison is clear. As an example the criterion "Requirement for outside intervention" was described by the scale: 0: monthly intervention, 1: six-monthly intervention, 2: annual intervention, 3: intervention every 2 years, 4: intervention every 5 years, 5: intervention every 10 years or more. Effectively the numbers are simply there to make it easier to assign a value to an option than terms such as "frequent" or "seldom" and not as exact numerical measures. There would be no non-integer values assigned and a process of approximation would assign values to different systems. Similarly, job creation has figures assigned to the different ratings, but these are intended as a guide only.

Some criteria incorporate some different aspects of the central concept. Robustness is intended to cover the ability of the system to withstand misuse, but also the complexity of design and construction. The performance of these different aspects is described as the indicators are developed. Thus an option must be robust, simple in design and easy to construct if it is to score 5 on the scale.

4.3.3. Socio-cultural sustainability

This dimension of sustainability is addressed through a range of criteria selected from the literature.

Table 4-5. Indicators and scaled indicator values for socio-cultural sustainability

Criterion	**Indicator/range**	**Scale**
Acceptability: user perceptions of fitness for purpose	qualitative	0= totally unacceptable 1= accepted with reluctance 2= accepted after persuasion 3=accepted without influence 4=willingly accepted 5=sought after
Convenience: provision of sanitation where users require it, distance from dwelling	qualitative	0=very inconvenient 1=inconvenient 2= fairly inconvenient 3= fairly convenient 4=convenient 5=very convenient
Equity: fulfillment of requirements of all gender groups. equivalence of sanitation provision for different income groups	qualitative	0=women and children not provided for 1=children not provided for 2=inferior system for less advantaged 3= less advantaged people have inferior system in their opinion but adequate from external perspective 4=less advantaged people have equivalent but not same system 5=sanitation for all same system as that of most advantaged group
Legal /institutional: fit with legal requirements, institutional support for construction, O & M, political support	qualitative	0= construction and O & M are outside available support structure and existing legal framework, political will is against proposed solution 1= fit with legal requirements, but no support available at government level and political will is against proposed solution 2= fit with legal requirements and some support available at government level but political will is against the proposed solution 3= fit with legal requirements and some support available at government level and political will is neutral on the proposed solution 4= fit with legal requirements full support available at government level, political will is neutral 5= fully supported by all parties, institutional plan in place to support construction and O & M

Criterion	Indicator/range	Scale
Facility for ongoing hygiene education: commitment of local authority or national government to fund	qualitative	0= no hygiene education available 1= some initial education available but no provision for ongoing support 2= fully adequate budget for initial education available but no provision for ongoing support 3= fully adequate budget for initial education available but insufficient provision for ongoing support hygiene education 4= fully adequate budget for initial education available and adequate provision for ongoing support hygiene education 5=initial and ongoing hygiene fully provided for and support at a national level (e.g. TV campaigns)
Participation: facility for user involvement in planning and execution of project	qualitative	0= No user participation 1=User representatives consulted before start of project. No further involvement. 2=Users consulted throughout planning process. No involvement in execution. 3= Users consulted throughout planning process. Some involvement in execution 4= Users fully involved in planning and execution 5=Users fully involved in planning and execution with users committed to ongoing involvement
Food security: contribution of system to household based food production	qualitative	0=No contribution to food security. 1=Some use of urine at household level 2=Some use of urine and faeces at household level 3=Use of products within the community. Institutional support for food production 4=Products used at household level without institutional support. 5=All products of system reused at household level. Effective support for food production.
Pathogen exposure: requirements of system for contact with faeces	qualitative	0= Daily contact with faeces. PPE not used 1= More often than monthly contact with faeces. No PPE 2= More often than monthly contact with faeces. Full observance of PPE use. 3= More often than annual contact with faeces. Full observance of PPE use. 4=Approximately annual or less often contact with faeces. Full observance of PPE use. 5=No contact with faeces

Equity requires that all groups of people be treated fairly. This incorporates socio-economic equity, gender equity and equity for children. Some attempt at ranking these in order of importance is incorporated into the construction of the rating scale: lack of access for women and children results in a very low score, while socio-economic equity is graded at the higher end of the scale. The socio-cultural indicators are described in Table 4-5.

4.4. Development of the spreadsheet MCDA

A Multiple Criteria Decision Analysis (MCDA) was developed for the selection of feasible sanitation alternatives. Two possible methods were considered for the analysis: the multi-attribute value theory (MAVT) approach and the analytic hierarchy process (AHP).

Both of these methods require the development of a value tree, but while MAVT requires that a partial value function be developed for each criterion, the AHP uses pairwise comparisons of alternatives for each lowest level criterion followed by pairwise assessment of the importance of the criteria themselves in order to arrive at an overall index for each alternative.

It was decided to apply the MAVT method for this MCDA. In this method, value scores (e.g. as a fraction of optimal performance, or through a normalisation process) are allocated to different possible levels of performance for each sustainability indicator. A multi-attribute value function (MAVF) is constructed to aggregate the scores of a sanitation option to give a final score or index, in the process applying weightings to each component value score according to the preferences of the decision makers or stakeholders involved. The indices or overall value scores thus calculated for different options allow comparisons and ranking of alternatives.

The decision was made to use the MAVT method for a number of reasons. Lai (2011) argued that the allocation of weights to the various criteria was more intuitive than the pairwise comparisons required for outranking methods and that this method is more transparent for stakeholders (p.36). Furthermore, the stakeholder’s role is to allocate weights to the different criteria rather than scoring the different alternatives for their performance against the criteria. This means that stakeholders are not required to have a technical understanding of the alternatives on offer. While AHP allows decision makers to rank alternatives for each criterion, AHP also requires a large number of pairwise comparisons and hence a cumbersome process for the decision maker if there are a large number of alternatives and/or criteria.

The intrinsic characteristics of the system, which are specific to the users and the location of the project, must be investigated by an expert (the municipal engineer) in the decision making process. MAVT does not usually provide for this, but in this study the spreadsheet based MCDA has the facility for the expert to enter qualitative ratings or raw scores for the indicators. These are transformed by the MCDA into appropriate value scores.

Microsoft Excel® was used to perform the calculations of the MCDA.

4.4.1. Stakeholder user interface: entering criteria weightings

The values to be entered by the non-expert user are captured in a dialogue box created in the spreadsheet using Visual Basic®. When the MCDA file is opened, the user is prompted to enter a name, date, project location and the number of sites at which sanitation is to be provided. This input is required by WhichSan and could be linked and filled from this program eventually. Further buttons on the Stakeholder page allow the user to enter weightings which will be used in the MCDA calculations. A screenshot of the Input sheet as it appears on opening the file is shown in Figure 4-5.

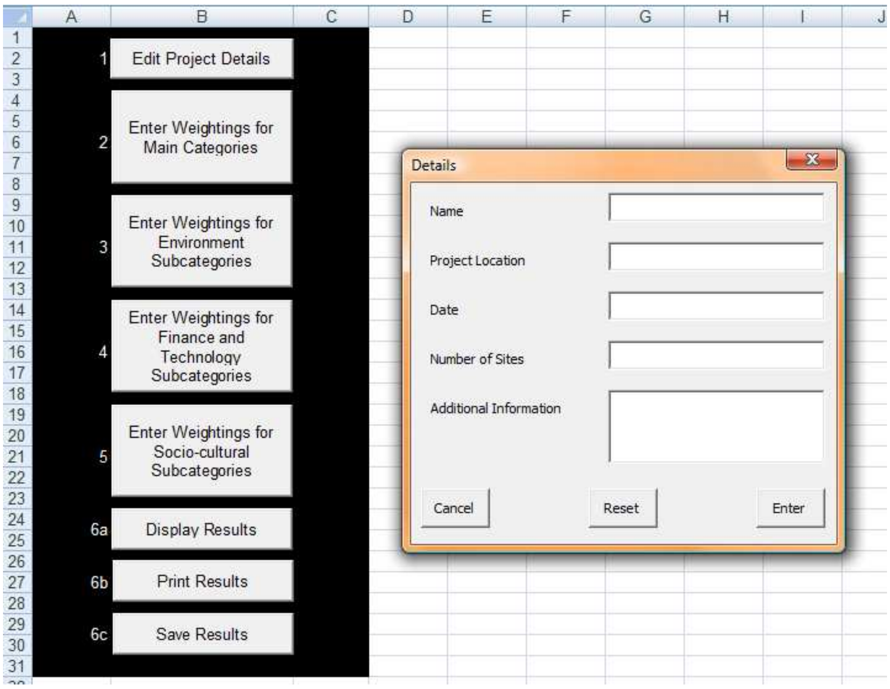


Figure 4-5. Stakeholder sheet in the MCDA workbook with project details dialogue box open

The weighting of the different criteria is performed at two levels. Initially, the three main criteria, Environment, Finance and Technology, and Socio-Cultural are weighted against each other. These weightings must sum to 100% and the user is prompted to adjust the values if this requirement is not met. This dialogue box is shown in Figure 4-6.

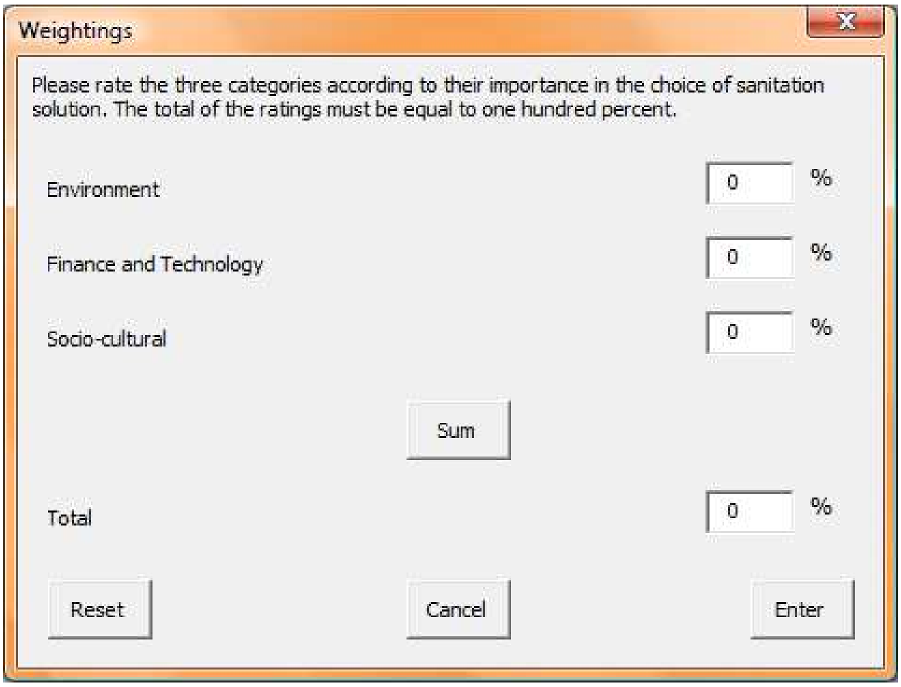


Figure 4-6. Dialogue box for the entry of weightings for main categories

Once this process is complete, the user enters weightings for the sub-categories. They are prompted once again if the sum is not equal to 100%.

Figure 4-7 shows the opening dialogue box open for the entry of weightings for the sub-criteria under the heading "Socio-cultural". The user is first asked if all sub-criteria are of equal importance, in which case all are weighted equally.

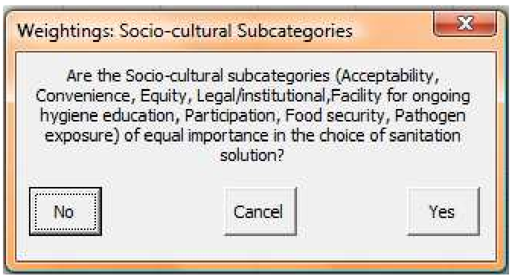


Figure 4-7. Opening dialogue for entry of sub-criteria weightings

If the answer is "no" then the user is prompted to enter weights (Figure 4-8).

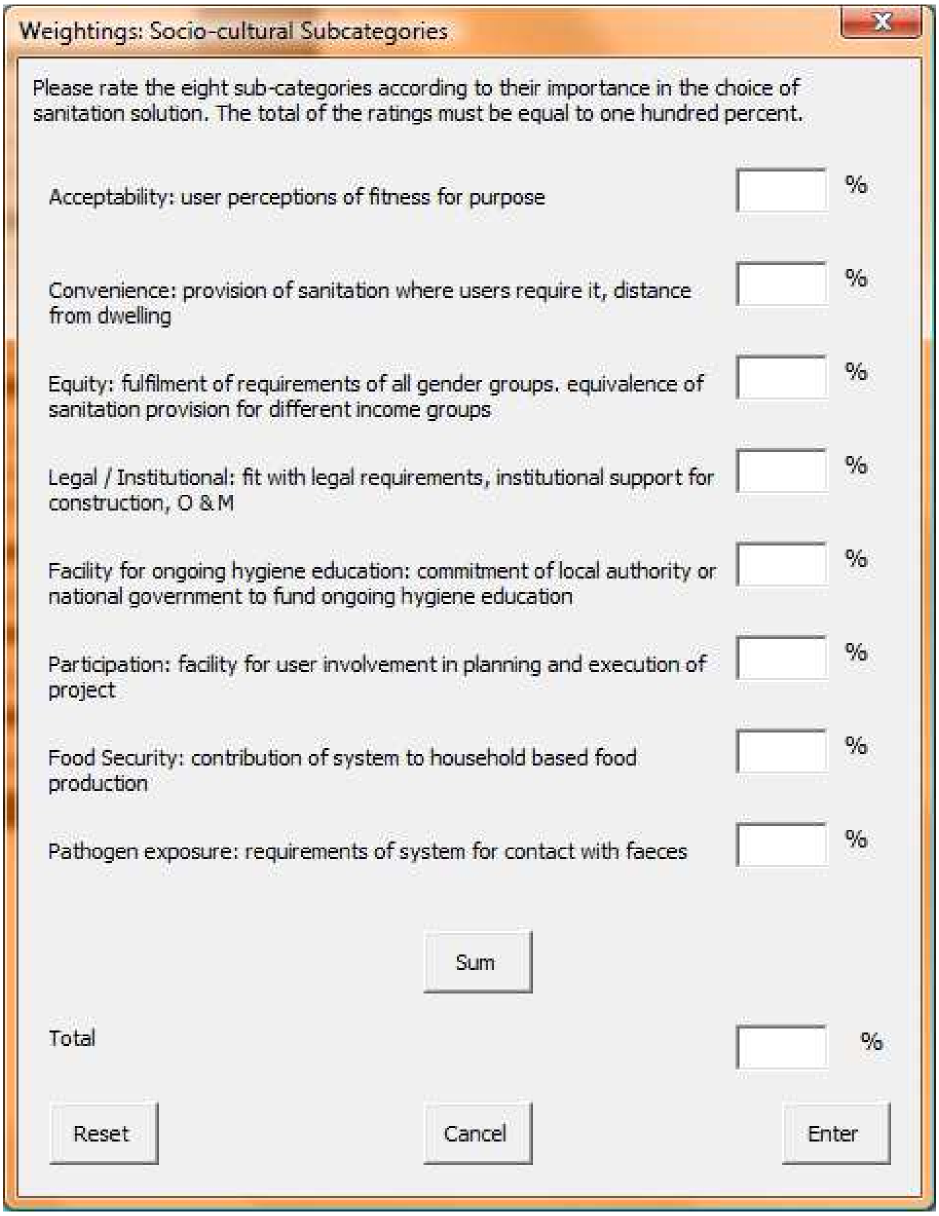
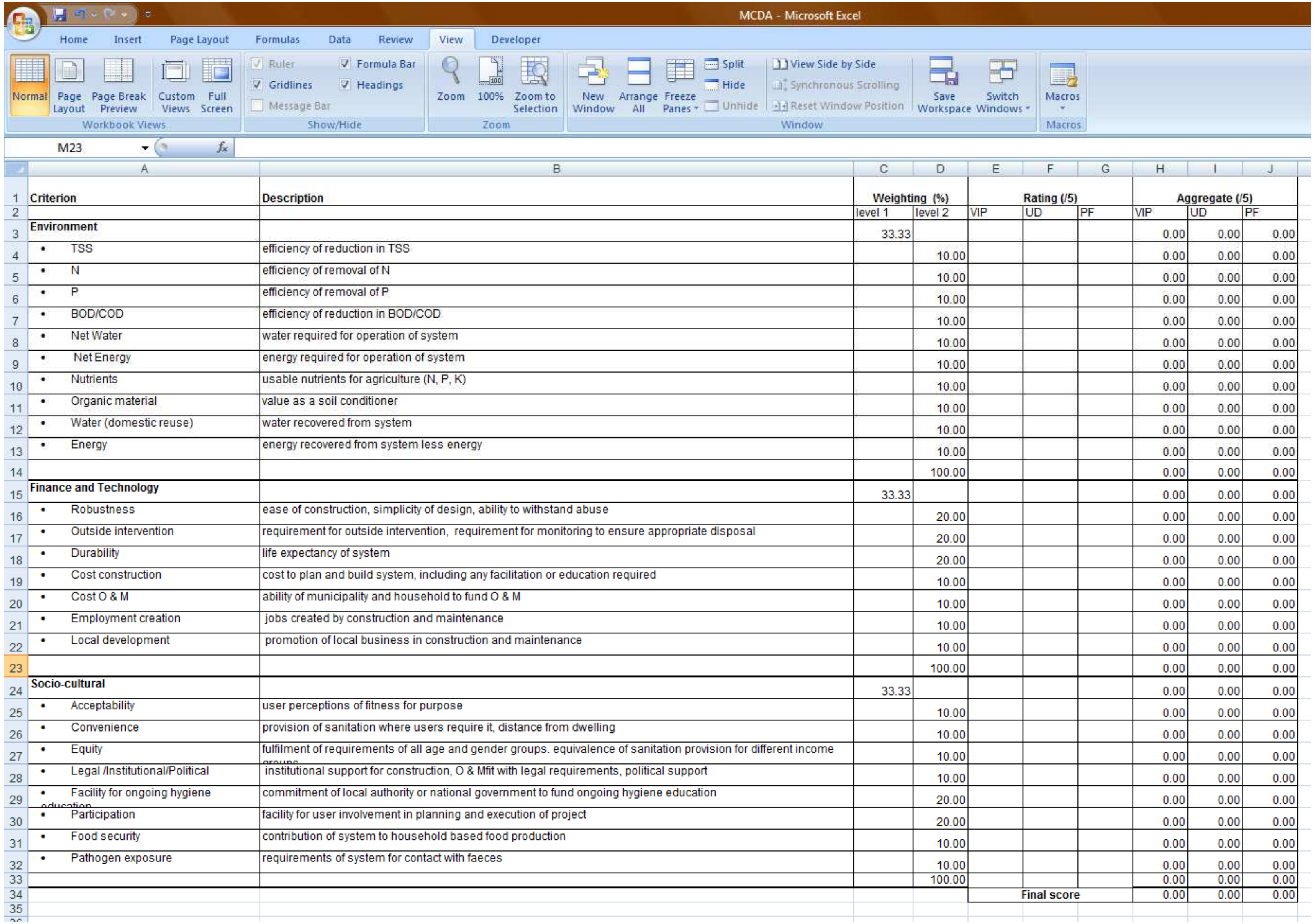


Figure 4-8. Dialogue box for weighting of sub-criteria

4.4.2. Calculation sheet

The functional or calculation spreadsheet of workbook contains the matrix of ratings for the sanitation options against the set of criteria which were selected. In addition to this, it provides for the weighting of the criteria and the additive aggregation which will calculate an overall score for each alternative. Figure 4-9 is a screenshot of the calculation page.



Criterion	Description	Weighting (%) level 1	Weighting (%) level 2	Rating (/5) VIP	Rating (/5) UD	Rating (/5) PF	Aggregate (/5) VIP	Aggregate (/5) UD	Aggregate (/5) PF
Environment		33.33					0.00	0.00	0.00
• TSS	efficiency of reduction in TSS		10.00				0.00	0.00	0.00
• N	efficiency of removal of N		10.00				0.00	0.00	0.00
• P	efficiency of removal of P		10.00				0.00	0.00	0.00
• BOD/COD	efficiency of reduction in BOD/COD		10.00				0.00	0.00	0.00
• Net Water	water required for operation of system		10.00				0.00	0.00	0.00
• Net Energy	energy required for operation of system		10.00				0.00	0.00	0.00
• Nutrients	usable nutrients for agriculture (N, P, K)		10.00				0.00	0.00	0.00
• Organic material	value as a soil conditioner		10.00				0.00	0.00	0.00
• Water (domestic reuse)	water recovered from system		10.00				0.00	0.00	0.00
• Energy	energy recovered from system less energy		10.00				0.00	0.00	0.00
			100.00				0.00	0.00	0.00
Finance and Technology		33.33					0.00	0.00	0.00
• Robustness	ease of construction, simplicity of design, ability to withstand abuse		20.00				0.00	0.00	0.00
• Outside intervention	requirement for outside intervention, requirement for monitoring to ensure appropriate disposal		20.00				0.00	0.00	0.00
• Durability	life expectancy of system		20.00				0.00	0.00	0.00
• Cost construction	cost to plan and build system, including any facilitation or education required		10.00				0.00	0.00	0.00
• Cost O & M	ability of municipality and household to fund O & M		10.00				0.00	0.00	0.00
• Employment creation	jobs created by construction and maintenance		10.00				0.00	0.00	0.00
• Local development	promotion of local business in construction and maintenance		10.00				0.00	0.00	0.00
			100.00				0.00	0.00	0.00
Socio-cultural		33.33					0.00	0.00	0.00
• Acceptability	user perceptions of fitness for purpose		10.00				0.00	0.00	0.00
• Convenience	provision of sanitation where users require it, distance from dwelling		10.00				0.00	0.00	0.00
• Equity	fulfilment of requirements of all age and gender groups. equivalence of sanitation provision for different income groups		10.00				0.00	0.00	0.00
• Legal /Institutional/Political	institutional support for construction, O & Mfit with legal requirements, political support		10.00				0.00	0.00	0.00
• Facility for ongoing hygiene education	commitment of local authority or national government to fund ongoing hygiene education		20.00				0.00	0.00	0.00
• Participation	facility for user involvement in planning and execution of project		20.00				0.00	0.00	0.00
• Food security	contribution of system to household based food production		10.00				0.00	0.00	0.00
• Pathogen exposure	requirements of system for contact with faeces		10.00				0.00	0.00	0.00
			100.00				0.00	0.00	0.00
					Final score		0.00	0.00	0.00

Figure 4-9. MCDA calculation page without ratings for different alternatives

It is this overall rating which is returned to the input page for consideration by the user. The input spreadsheet allows the user to print a summary of results to the default printer, to save them as a printed document format (pdf) document on the desktop or to display them on the output sheet (Figure 4-10).

Name	Test project
Date	15/10/2014
Project Area	eThekwini
Number of Sites	2 500
Additional Information	
Results	The aggregates for the various sanitation solutions are as follows: VIP : 2.130 UD : 2.392

Figure 4-10. Results shown on output sheet

4.4.3. Expert user interface: entering values for sanitation systems

The matrix of values initially entered in the spreadsheet was for the two sanitation options (VIP and UDDT) and the 23 selected criteria. The process by which these values were arrived at is described in section 4.5. The Microsoft Excel® workbook developed for the MCDA allows the expert user to add a further three sanitation systems and to enter values for any one or combination of these for the purposes of comparison. In this section the expert user interface of the workbook is described.

A screenshot of the Expert sheet in the workbook is shown in Figure 4-11.

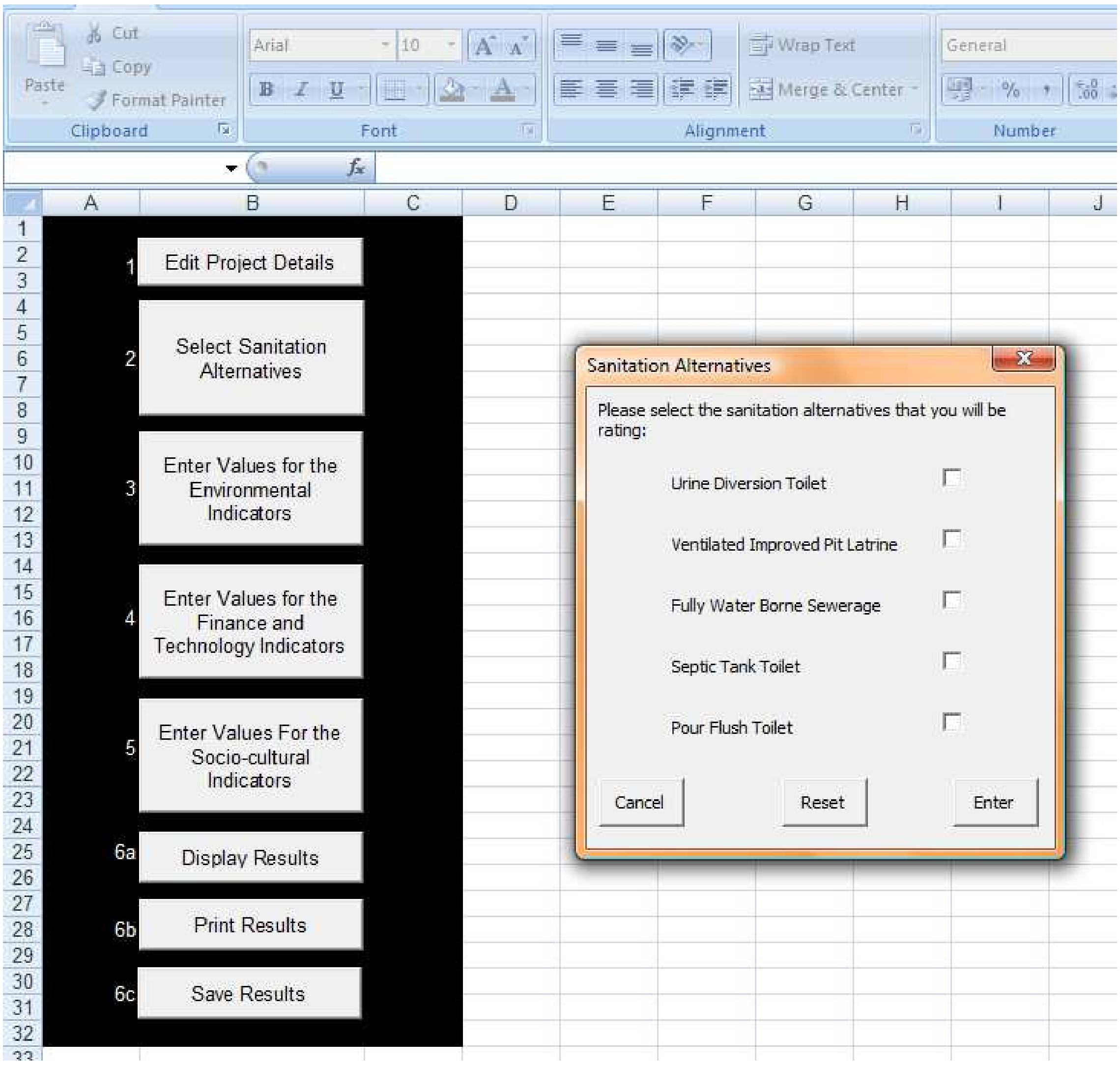


Figure 4-11. Expert sheet showing dialogue box for selection of sanitation alternatives to be considered

Once the sanitation alternatives have been selected, the remaining alternatives are hidden on the calculation sheet and do not appear in the value entry dialogue boxes. While the alternatives have been given names for the purposes of illustration, any five alternatives could be selected and compared.

The expert then enters the indicators using the three dialogue boxes for the of Environmental, Finance and Technology and Socio-cultural criteria.

4.4.3.1. Environmental indicators

The environmental indicators are entered in a variety of ways, depending on the nature of the transformation which will produce the values entered into the MCDA. The dialogue box is shown in Figure 4-12 .

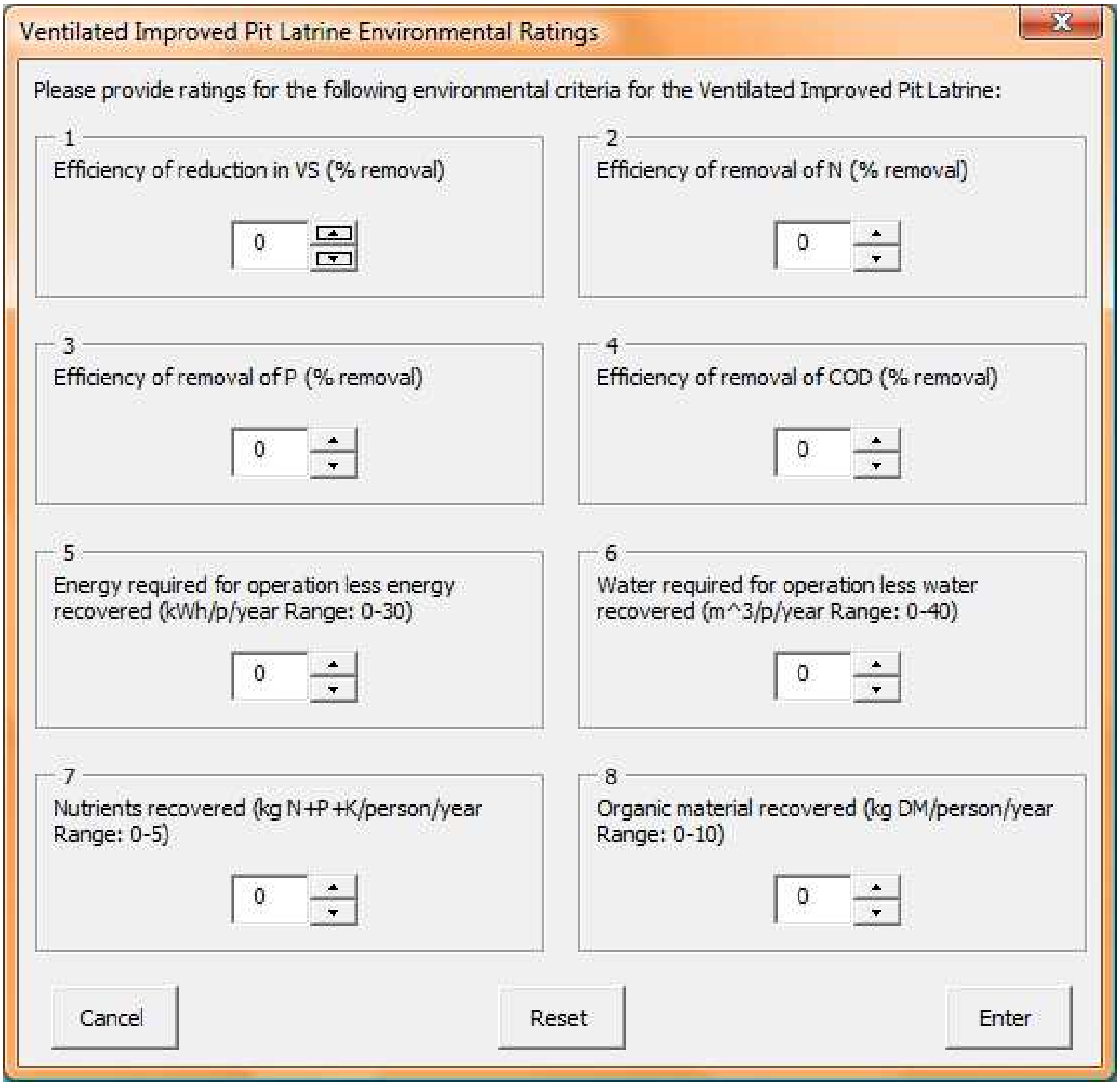


Figure 4-12. Dialogue box for entry of raw scores (ratings) for environmental indicators

Should some information not be available, for example if only COD or VS reduction is known (see 4.3.1), the user would weight the unknown indicator at 0 on the Stakeholder sheet. The other indicators would then need to have an increased weight.

The raw scores for reduction in VS, COD, N and P are entered as percentage values and are standardised according to the positive linear transformation:

$$v_j = 5\frac{x_j - x_{min}}{x_{max} - x_{min}} \qquad (1)$$

Since the $x_{max} = 100\%$ and $x_{min} = 0\%$, this formula could be simplified to

$$v_j = \frac{x_j}{20} \qquad (2)$$

Where x_j is the raw score (%) and v_j is the value on a scale of 0 – 5 which is entered into the matrix.

Net energy and net water consumption are both variables which should be minimised, and as a result the linear transformation formula used to calculate the values for input into the MCDA is

$$v_j = 5\frac{x_{max} - x_j}{x_{max} - x_{min}} \qquad (3)$$

For energy consumption, the $x_{min} = 0\ kWh/person/year$ and $x_{max} = 30\ kWh/p/y$. For water consumption, these values are $x_{min} = 0\ m^3/p/y$ and $40\ m^3/p/y$.

The positive linear transformation is used for nutrients recovered ($x_{max} = 5kg$ and $x_{min} = 0\ kg$) and for organic matter recovered ($x_{max} = 10kgOM/kgDM/y$ and $x_{min} = 0\ kgOM/kgDM/y$).

The values are entered as integers in the range between x_{max} and x_{min}, using the spin buttons on the dialogue box. Pressing Enter enters these values into the Calculation sheet.

4.4.3.2. Finance and Technology indicators

Only two of these indicators are entered as quantitative values, the construction cost and the operations and maintenance costs. The other ratings are estimates which the expert enters using radio buttons. A screenshot of the section of the dialogue box for Robustness and Requirement for outside intervention is shown in Figure 4-13.

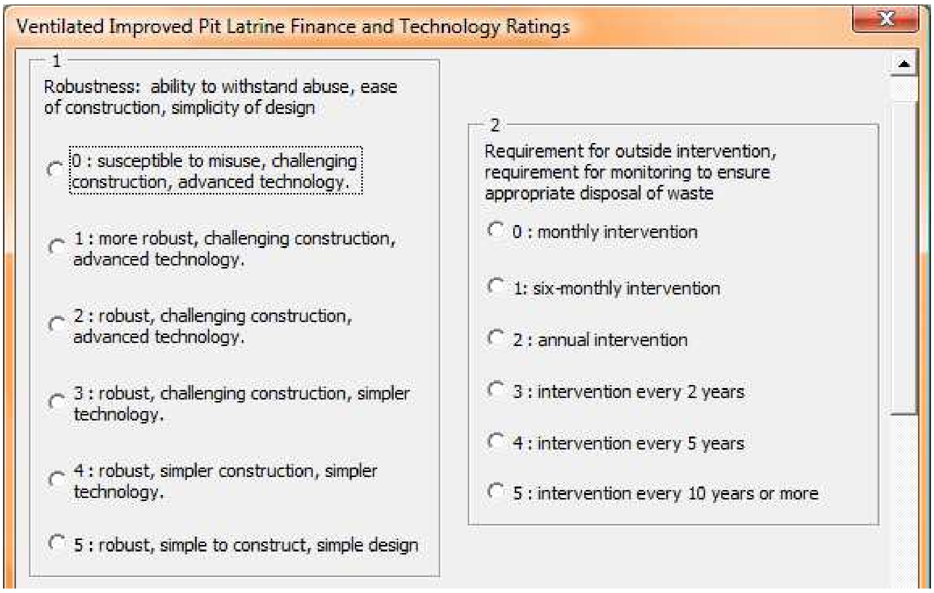


Figure 4-13. Section of dialogue box showing radio buttons for ratings

The costs are entered using spin buttons which allow increments of R500 for construction costs and R50 for operations and maintenance costs (see Figure 4-14).

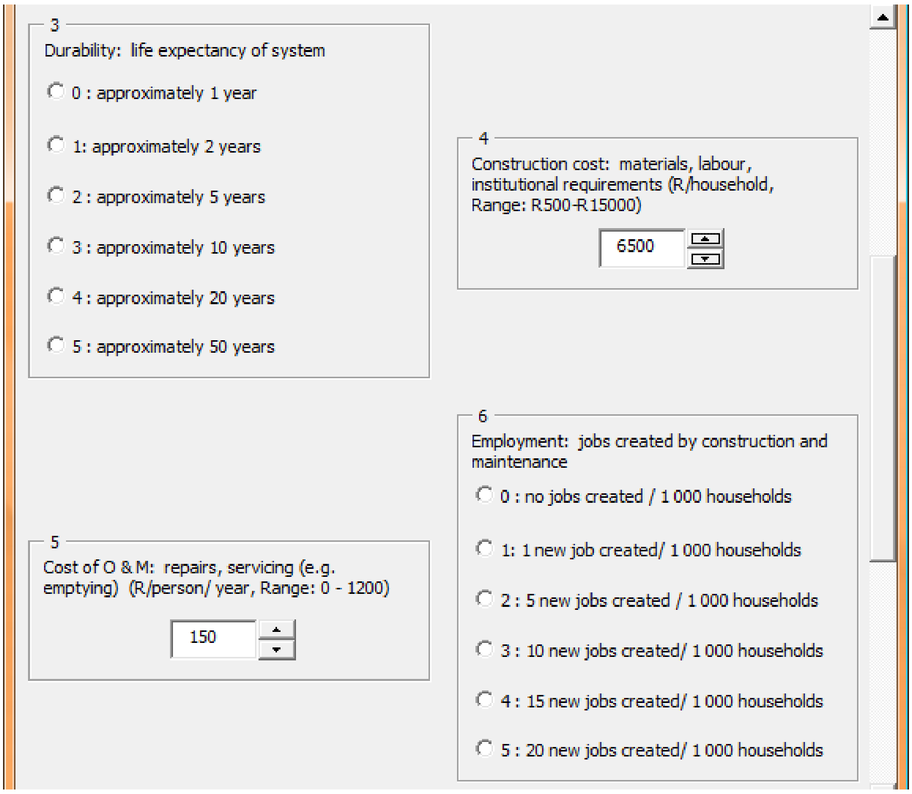


Figure 4-14. Section of dialogue box showing spin buttons for cost entries

The costs used above are relevant to the South African situation in 2013. They are converted to value scores using the linear transformation (equation 1, section 4.4.3.1). However, the expert user can adjust the Visual Basic® formulae used to calculate the value scores for these indicators to reflect different financial parameters: the user would replace the x_{max} and x_{min} values as needed.

Once the expert user has entered the values for the first sanitation option, the dialogue box for the next option pops up until all the values for Finance and Technology for all alternatives is complete.

4.4.3.3. Socio-cultural indicators

The socio-cultural indicators are all qualitative variables and the ratings are chosen using the description of each level in the dialogue box (see Figure 4-15).

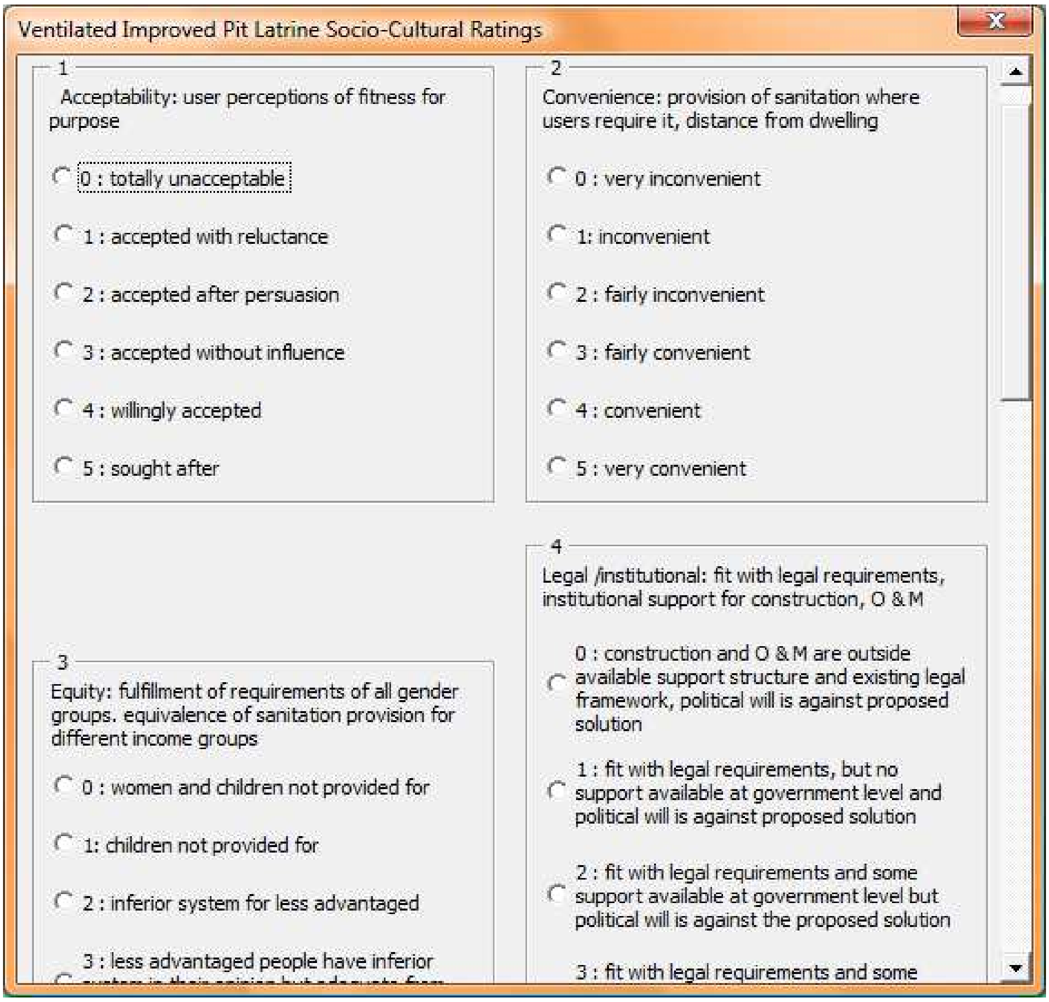


Figure 4-15. Dialogue box for entry of socio-cultural ratings

Once all the ratings have been entered under the appropriate headings, the expert may return to the Stakeholder sheet and perform some sensitivity analyses using different weightings for the criteria. Results may be saved, displayed or printed from either the Stakeholder or the Expert sheet.

4.5. Performance of VIPs, UDDTs and Pourflush latrines against criteria

The University of KwaZulu-Natal has done a considerable amount of work in the eThekwini/Durban area on the performance of VIP and UDDTs. This data was used to develop ratings for these two types of on-site sanitation against the different criteria in the MCDA. Where situations were comparable, international data from the literature was used as well.

4.5.1. Performance on environmental criteria

The performance of VIPs and UDDTs on the environmental criteria is similar in a situation such as that which prevails in eThekwini. The value scores used in the MCDA are summarised in Table 4-6.

- It is assumed that less reduction in volatile solids and COD occurs in the UDDT compared with the VIP (see section 3.3.1.2). Values of 75% for COD reduction and 65% for VS reduction, calculated from the studies of Nwaneri (2009) and Bakare (2012), gave the VIP standardised ratings of 3.75 and 3.25 for these two criteria. COD and VS reduction are closely related as both measure the reduction in biodegradable content. In this study, both could be estimated and were used in the MCDA. If only one was available it could have been used but this would require an adjustment of criteria weights (see Section 5.1.2.1).
- Characterisation of UDDT sludge from Velkushanova (2013) suggest that both COD and VS may be reduced by around 55% and 45% respectively, or scores of 2.75 and 2.25.
- Due to the use of a soakaway for urine, it is surmised that the ability of the UDDT to effect a reduction in nitrogen and phosphorus is greater than that of the VIP (Flores et al., 2008). This will, however, depend on the fate of the nutrients in the soakaway. Ratings for the latter were estimated from the range of values in Bakare (2008) at 75% and 12% the UDDT was given a high rating of 95% for both of these characteristics.
- No water or energy is required for these two systems provided sludge is manually emptied and disposed of on-site. Both therefore have a rating of 5 for these two criteria.
- If no agricultural use is made of the VIP sludge nor the UDDT vault contents, then the rating for the criteria Nutrients recovered and Organic material recovered is zero.

Table 4-6. Value scores allocated to VIP and UDDT systems for environmental indicators

Criterion	Indicator	VIP	UDDT
efficiency of reduction in VS	% removal	3.25	2.25
efficiency of removal of N	% removal	3.75	4.75
efficiency of removal of P	% removal	0.6	4.75
efficiency of reduction in COD	% removal	3.75	2.75
energy required for operation less energy recovered	MJ/person/year	5	5
water required for operation of system less water recovered	m^3/person/year 0-40	5	5
nutrients recovered	kg N+P+K/person/year	0	0
organic material recovered	kg DM/person/year	0	0

4.5.2. Performance on financial and technical criteria

In rating VIPs and UDDTs for financial and technological criteria, the situation as it prevails in eThekwini was used for reference. WhichSan is based on costings developed in the Durban and Pietermaritzburg areas and was developed under a WRC project in these areas. Furthermore, it will provide the cost estimates to be used in conjunction with the MCDA and these should therefore be consistent. across the different decision support tools.

The rationale behind the ratings for these criteria was as follows:

- VIPs are considered to be one of the most robust sanitation technologies. Household rubbish thrown into the pits may cause them to fill up more rapidly but they continue to provide sanitation until they are full. They are relatively simple to construct and no advanced technology is involved. UDDTs have a more complicated design and are less robust. Vandalism of vault covers allows rain into the dehydrating vaults, compromising their function.
- While VIPs require emptying periodically, UDDTs require a more intensive programme of outside intervention. The eThekwini experience has indicated that ongoing education is

essential. If residents are unwilling to empty the vaults they will need to hire contractors at least once a year. There is also a risk of irresponsible disposal of waste if householders are left to do this themselves.

- Life expectancy for both systems was estimated at 20 years. This will depend on ongoing maintenance.
- Cost for construction was estimated at just over R6 000 for a VIP and R7 500 for a UDDT (WhichSan (Still et al., 2009) costing corrected to 2012 and rounded to nearest R500).
- Pit emptying and for VIPs was estimated at R70 /p/y and repairs at R30/p/y to give a total of R100. For UDDTs operations and maintenance (O&M) costs including ongoing hygiene education and repairs were estimated at R50/p/y.
- UDDT construction in eThekwini had job creation as a stated objective and it was expected that this phase would produce at least 5 jobs per 1000 households. The employment of facilitators from within the community for continued education must also be considered. VIP construction is less labour intensive, but there is potential for at least 1 job/1000 households during the construction phase
- Local development is promoted in eThekwini during construction projects. Skills are sourced within the municipality and transferred to local communities. Expertise from beyond the municipality is not required.

Table 4-7. Value scores allocated to VIP and UDDT systems for financial and technical criteria

Criterion	**Indicator**	**VIP**	**UDDT**
Robustness: ability to withstand abuse, ease of construction, simplicity of design,	qualitative	5	3
Requirement for outside intervention, requirement for monitoring to ensure appropriate disposal of waste	qualitative	4	2
Durability: life expectancy of system	years	4	4
Construction cost: materials, labour, institutional requirements	R/household	3.10	2.59
Cost of O & M: repairs, servicing (e.g. emptying)	R/person/ year	4.58	4.79
Employment: jobs created by construction and maintenance	qualitative	1	2
Local development: promotion of local business in construction and maintenance	qualitative	4	4

4.5.3. Performance on socio-cultural indicators

It is essential that the entries made by the expert in this section are informed by the particular community to which the sanitation system will be applied. This is likely to require extensive dialogue with community members and a study of the political context in which the project will be implemented. For this research project, the indicator values were derived from the surveys conducted by various UKZN researchers (section 3.3.3). This was therefore achieved with the benefit of hindsight. If a sanitation project is to be initiated, then dialogue with the community should follow a model such as Participatory Hygiene and Sanitation Transformation (PHAST) which is recommended in the National Sanitation Policy (DWAF, 2005). PHAST, an initiative of the World Health Organisation, seeks to ensure the sustainability of sanitation through developing an understanding in the community of the health benefits of improved sanitation and engendering motivation for behaviour change (Simpson-Herbert et al., 1997). This should take place within a planning framework such as that described by Barnes et al. (2011). These approaches would not only allow the assessment of socio-cultural indicators but would be formative in the sense that the sustainability of a sanitation project could be enhanced through community participation.

- VIPs are an established and accepted technology. Nonetheless, there is still a widespread perception that they are inferior to flush toilets. UDDTs seem to have been accepted initially, but satisfaction levels have declined. It is to be expected that it will become harder to persuade people to accept UDDTs.
- Most sanitation facilities are built close to houses but not in them. This rating would vary from project to project, but while technically UDDTs can be provided inside a dwelling if users require it, this does not happen in eThekwini municipality (EM).
- VIPs are considered to be adequate as a basic level of sanitation in terms of legislation, but residents do not necessarily hold the same view, hence a value of 3. From an external perspective, a UDDT system is equivalent to the flush systems provided within the waterborne edge of EM. This is not the perception of residents and hence in the eThekwini situation the rating is also 3. Residents certainly do not seem to perceive UDDTs as superior to VIPs.
- While both systems enjoy legal and institutional support, there is political opposition to options other than flush toilets. Stolley (2014) quotes the EFF's Julius Malema as declaring"*Freedom is a flushing toilet.*"
- In the EM, provision is made for ongoing health and hygiene education.

- While no data is available for community involvement in eThekwini, evidence from the Alfred Nzo District Municipality (Still, 2013) suggests that VIP construction has the potential to involve users extensively in planning and construction. While users were involved in planning the UDDT construction, they were not given any choice of technology, and research suggests poor knowledge of community forum structures a few years after construction was completed. The two technologies both receive a rating of 4 since user involvement is a priority for EWS.
- As the situation stands, neither VIPs nor UDDTs contribute to household food security.
- While VIPs require pit emptiers to have contact with faeces these workers should be protected by personal protective equipment. Residents are not required to have contact with faeces. However, there may be a risk of contamination by flies: this system does not provide the level of protection of waterborne sewerage. Starkl et al. (2010) gave UDDTs a medium to high risk rating if households empty their own vaults.

Table 4-8. Value scores allocated to VIP and UDDT systems for socio-cultural criteria

Criterion	**Chosen indicator**	**VIP**	**UDDT**
Acceptability: user perceptions of fitness for purpose	qualitative	3	2
Convenience: provision of sanitation where users require it, distance from dwelling	qualitative	3	3
Equity: fulfillment of requirements of all gender groups. equivalence of sanitation provision for different income groups	qualitative	3	3
Legal /institutional: fit with legal requirements, institutional support for construction, O & M	qualitative	4	4
Facility for ongoing hygiene education: commitment of local authority or national government to fund	qualitative	4	4
Participation: facility for user involvement in planning and execution of project	qualitative	4	4
Food security: contribution of system to household based food production	qualitative	0	0
Pathogen exposure: requirements of system for contact with faeces	qualitative	4	1

4.6. Sensitivity analysis

It was considered to be beyond the scope of this study to develop a system for the elicitation of weights from stakeholders in a way that would satisfy the requirement for trade-offs between criteria. Instead sensitivity analyses for the model were carried out by repeating the analysis for the same set of value scores but using different weightings for the main criteria. This would mimic the influence of three different groups of stakeholders on the choice of sanitation system: those concerned with the environment (e.g. the wider community), those concerned with the financial and technological aspects (e.g. the municipality) and those concerned with the socio-cultural implications (e.g. communities or political groupings).

Changing the weightings of the three main categories (environmental, financial/technological and socio-cultural) cannot be done independently as all weightings must always sum to 100%. As the weighting of each criterion under consideration was increased, from 0% through to 100%, the weightings of the other two categories were balanced to ensure that this sum was achieved.

The weighting of each main category was set at 0 and the other two at 50% each. The MCDA score for the two sanitation options as generated by the MCDA was recorded. The weighting of the main category under consideration was then increased to 20% and the other two were reduced to 40% each. This was repeated with weightings of 40%, 60% 80% and 100% and at each change the overall scores for the two sanitation options were recorded.

The sensitivity analyses for the sub-categories are described in section 4.7 since these were done by choosing weightings which could match the input of a particular stakeholder and each of the weightings was not varied across the full range of values as described above.

4.7. Scenario analysis

Rather than changing the criterion weights systematically, to produce hundreds of different combinations, or developing a probability distribution for the overall ratings, a scenario approach was used. This bears some similarity to the approach of Stewart et al. (2013) which combines MCDA with Scenario Planning, but rather than use the scenarios (abbreviated to S_j) in place of specific technology alternatives, the alternatives are retained and different combinations of weights reflect different stakeholder scenarios. In further scenarios, not only weights but also indicator values are varied in order to mimic performance under different circumstances.

The first four scenarios which were proposed involved only the changing of weights for various criteria from a baseline scenario where all the criteria carried equal weight.

S_1 was proposed for a situation where access to electricity and water was a major constraint. These two sub-criteria therefore carried a weighting of 40% each. The remaining 20% within the environmental grouping carried weights of 5% except for the recovery criteria which were given a zero weighting.

S_2 envisaged a situation where recycling was a strong imperative and the reduction indicators were considered of no importance. The remaining four sub-criteria were given a weight of 25%, since the need to use minimal energy and water was also likely in a rural scenario. These weightings were retained for S_3 but the weights of the three main criteria was changed to 40/20/40 for environment/finance/socio-cultural to mimic a situation where external funding might supplement the municipality's contribution and hence lessen the importance of financial considerations.

S_4 required changing the weighting of the socio-cultural criterion to 60%, environment to 10% and financial / technical to 30%. This could be a situation where the political impact is significant and the project is seen as succeeding or failing on the factors which concern the recipient community.

In each scenario above, the altered scores for VIPs and UDDTs were recorded.

Joubert and Stewart (2004) recommend that the outcomes of an MCDA are analysed for sensitivity to both weights and scores. The latter analysis was carried out for some of the criteria which were contentious, such as the acceptability to users. This becomes particularly important if different stakeholders have divergent views on the importance of different criteria as well as the ratings which they should receive.

S_5 proposed a scenario where the potential for nutrient reuse which is inherent in the design of UDDTs was realised. This changes the value scores for the UDDT alternative from the minimum to the maximum score for nutrient and organic matter recovery. In S_6 the weightings were also changed to those used in S_2 since nutrient removal was considered unimportant in this situation. S_7 follows from the previous scenario with a change in the values for user acceptance (to a maximum value of 5) and food security (to 4) since these two socio-cultural sub-criteria would be affected by the change in approach to an Ecosan system. The change in the score for UDDTs was recorded for S_5 to S_7.

S_8 was tested to explore the possibility of using the MCDA to take different sludge disposal options into account. If sludge were disposed of at wastewater treatment works, the operations and maintenance cost would increase as would the energy requirement. Nitrogen and phosphorus removal would be improved. The values for these sub-criteria were therefore adjusted and the overall score for VIPs was recorded.

S_9 was a scenario in which political influences induced a resistance to on-site systems. The values for some of the socio-cultural sub-criteria were adjusted accordingly. The values for acceptability were reduced for both UDDTs and VIPs. The legal/institutional fit sub-criterion was given a lower value for both systems due to the political support component of this indicator. Community participation was scored at 1 rather than 4 for both alternatives. Furthermore, the socio-cultural criterion was weighted 60% against 20% for each of the other two main criteria. The scores for both VIPs and UDDTs were recorded.

Finally, an experienced municipal engineer was asked to set values and weightings for the two sanitation systems under consideration and this data was used to generate a further score for VIPs and UDDTs.

4.8. Introduction of an additional sanitation option

The last section of the results introduces an additional sanitation option, the pour-flush latrine, into the MCDA. This was done using data from the literature, and the values used were considered to require less rigorous development, since the purpose of this exercise was to demonstrate the potential for the introduction of further sanitation options into the MCDA rather than to arrive at a definitive score for the pour-flush alternative.

4.9. Summary and Discussion

A list of sustainability criteria, emanating from the literature, was developed. Criteria were grouped under five categories initially: health, environment, economy, socio-culture, and technical. Subsequently this was narrowed down as the list of indicators was reduced. The final categories were environment, finance and technology and socio-cultural. Both quantitative and qualitative indicators were included.

The process is intended to be a transparent and interactive one, with stakeholders guided through the process of weight allocation by the expert. It is also intended that the allocation of values by an expert user be accompanied by an improved understanding of the sustainability issues for decision makers, and this is seen as being more important than the final score. The process of eliciting stakeholder preferences or weightings required a user friendly interface, and Visual Basic® was used to achieve this.

It was envisaged that the MCDA would be used to enhance the understanding of Municipal Engineers of the factors that need to be taken into account when implementing an intervention to improve sanitation. This project was aimed particularly at the provision of Free Basic Sanitation in the poorer areas of a municipality. It was for this reason that the first two sanitation systems incorporated into the MCDA were VIPs and UDDTs.

It is the role of experts to provide the ratings of performance and the Municipal Engineer might feel qualified to do so. If this is the case, it is extremely important that the non-technical aspects of the system are carefully evaluated. These are the aspects that most concern the target community. These are also intrinsic aspects of the system insofar as their value is dependent upon the community being supplied. Convenience is a particularly good example. In the mind of an engineer, particularly one used to a flush lavatory, to have a toilet inside the house may seem the height of convenience. However, in the survey conducted by Duncker et al. (2006), 78% of the respondents indicated that they preferred to have a toilet separate from the house. Some were concerned about the smell, but most said that this was what they were used to. This might not be the case for a different community.

Similarly, what is considered equitable may vary from one place to another. In South Africa, anything other than a flush toilet is considered second-rate. This may mean that another option such as a pour-flush latrine is perceived as considerably more desirable than a UDDT (Still and Louton, 2012)

At present there is a greater chance of pit sludge returning nutrients to agriculture if the eThekwini plan to pelletise the sludge proves viable. However, this would change other ratings, such as that for energy requirements which is presently set to 0 for both VIPs and UDDTs.

An engineer entering value scores for one of the two existing sanitation options or adding another would have to ensure that he or she was extremely well informed as to the physical, economic and socio-cultural conditions prevailing in the project area.

Chapter 5. Results

The results of the sensitivity analyses, scenario analyses and the introduction of pour-flush as another sanitation option are described below. It is important to note that the scenarios presented here are only intended to demonstrate how a municipal engineer might use the MCDA, not to give definitive answers to the relative value of VIPs and UDDTs in any situation. The weightings and values entered are specific to the particular circumstances in which the proposed project is situated and will almost certainly be different from those described below.

5.1. Sensitivity to weightings

Changing the weightings of the three main categories (environmental, financial/technological and socio-cultural) cannot be done independently as all weightings must always sum to 100%. This becomes even more complicated once the weightings of the sub-categories must be varied. Here the scenario approach is applied.

5.1.1. Sensitivity to main category weighting

Initially, all weightings were set to the same value. Under these circumstances, the overall values or scores for the VIP and UDDT were 3.06 and 2.96 respectively. This confirms the observation by Flores et al. (2008) that there is not a great deal of difference between the two systems in the eThekwini situation.

Sensitivity analysis was then carried out for the three main criteria while keeping the other two evenly balanced. For example, when the rating for the environmental category was increased from 40% to 60%, the weights of the other two dropped from 30% to 20%.

The results of these three analyses are shown in Figure 5-1 to Figure 5-3. Graphs are plotted showing the change in performance for each of the two sanitation options with the change in criterion weighting. As the environmental rating increases in importance, the performance of the UDDT improves gradually and that of the VIP drops. Both score the same when the environmental criterion is weighted at approximately 45%.

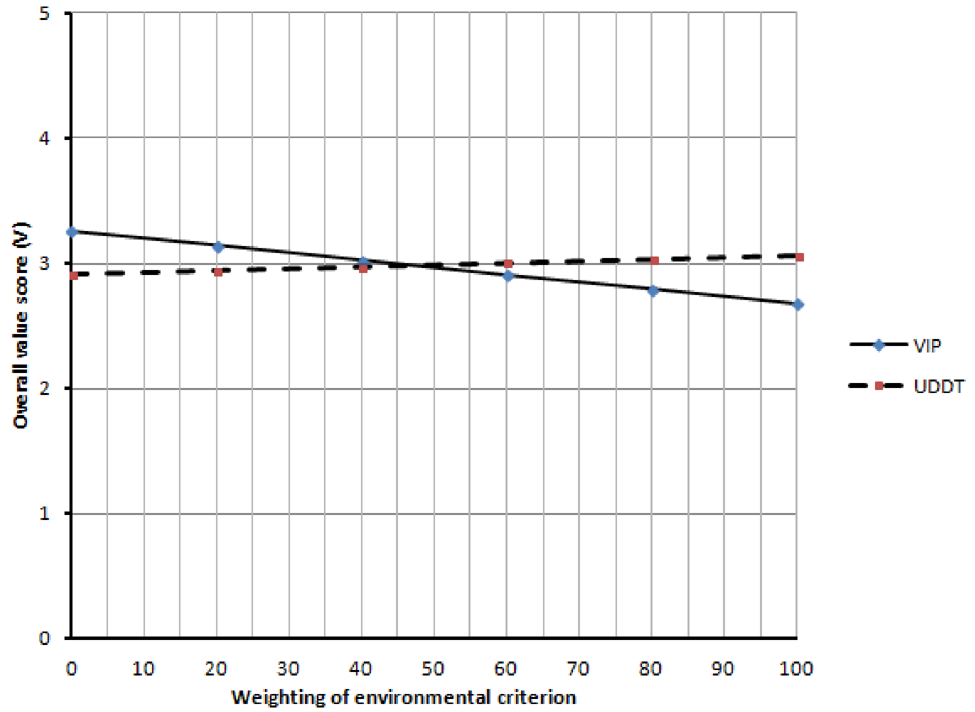


Figure 5-1. Sensitivity analysis for the environmental criterion weighting

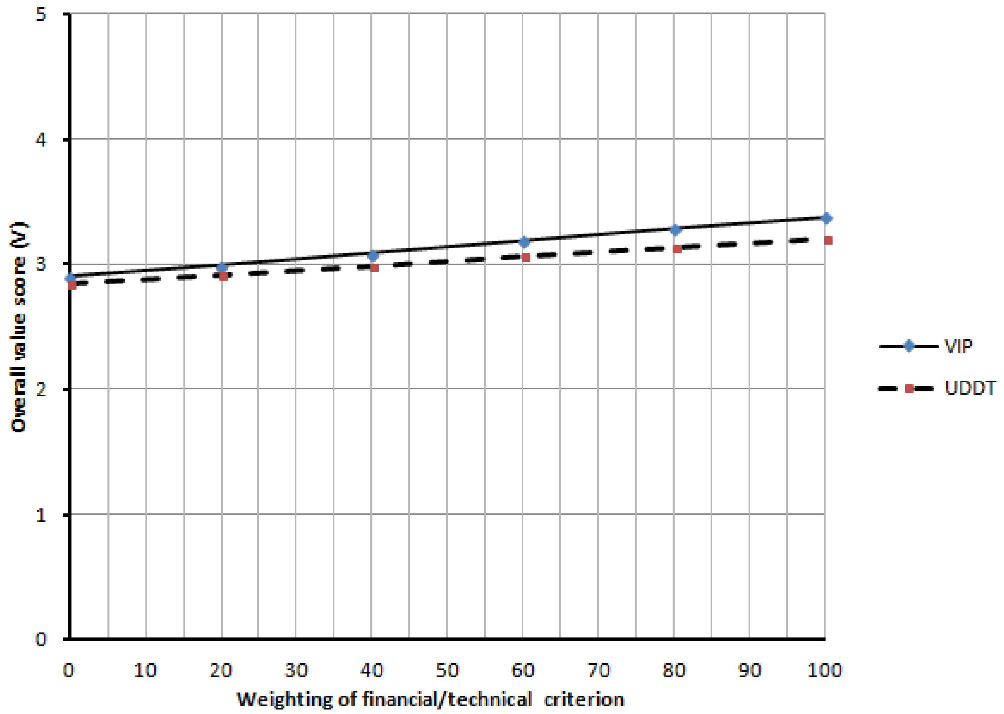


Figure 5-2. Sensitivity analysis for the financial/technical criterion weighting

Figure 5-2 suggests that as financial and technical considerations become more important, the difference between the two options increases slightly. When it is the only criterion to be considered (weighting 100%) then VIPs score 3.38 overall and UDDTs score 3.20. This suggests that if only financial and technical issues were considered, these technologies would score considerably better than they do when other aspects of sustainability are taken into account.

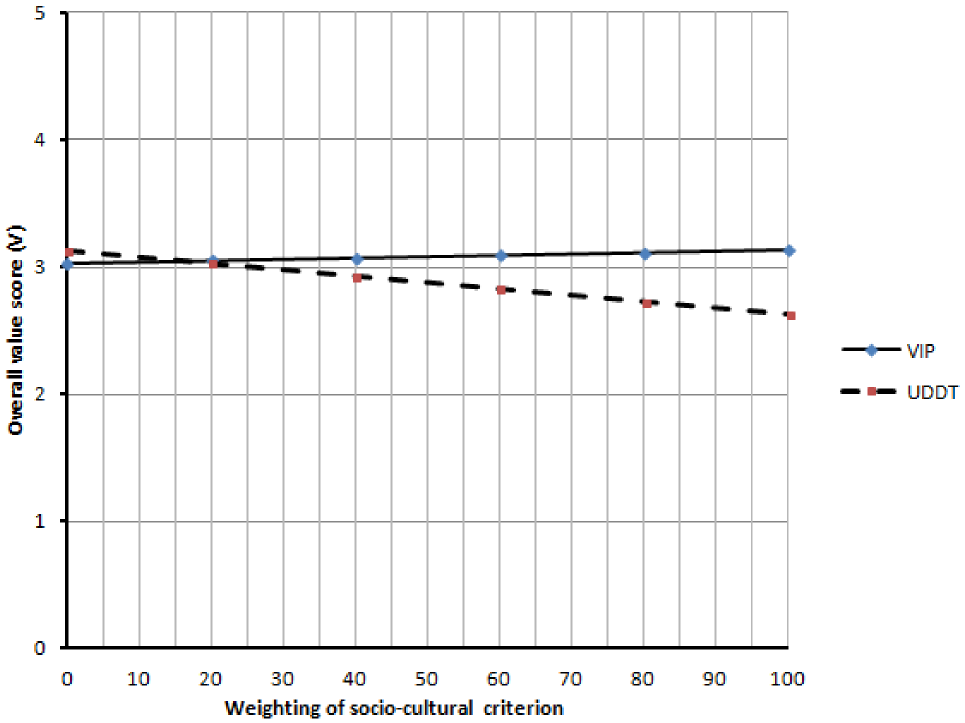


Figure 5-3. Sensitivity analysis for the socio-cultural criterion weighting

If the Socio-cultural criterion is given no weight, UDDTs perform slightly better than VIPs. As socio-cultural considerations become more important, the score for VIPs increases slightly. However, UDDTs perform progressively less well, so that if this were the only consideration, VIPs would score 3.13 and UDDTs 2.63. The breakeven point is a weighting of 15%.

5.1.2. Sensitivity to scenarios with different weightings

The different scenarios proposed in this section mimic the weighting allocations of possible stakeholders. If weightings are not mentioned specifically, then they have been distributed evenly among the remaining criteria.

5.1.2.1. S_1: Major constraints energy and water

A situation was considered where the important issues for the environment were that water use and energy use were low. This might be where sanitation is needed at a fairly remote location where there is no electricity or piped water. These indicators were therefore given a weighting of 40% each. Furthermore, recycling of nutrients was given no weight and the reduction of VS, COD, N and P were all given a low weighting of 5%.

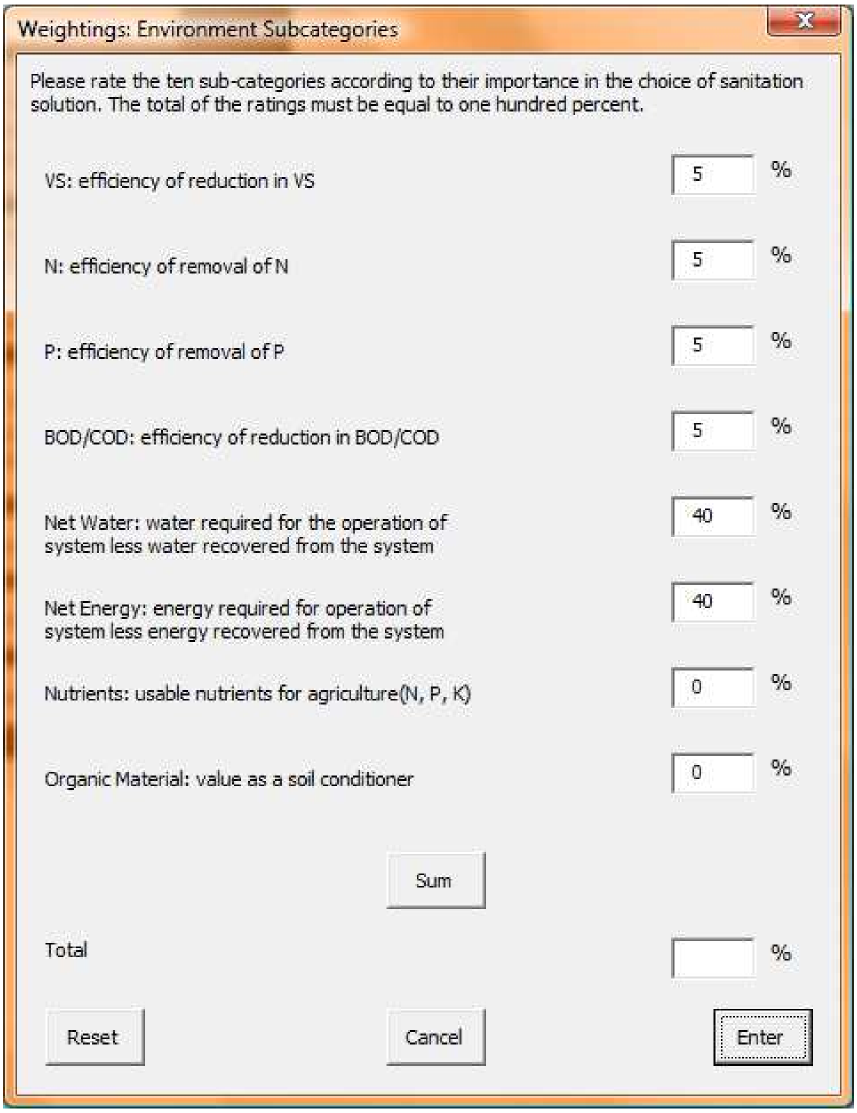


Figure 5-4. Screenshot of environmental indicator weightings for S_1

The input screen for environmental sub-criteria would appear as it does in Figure 5-4. The resulting scores are 3.79 for VIPs and 3.52 for UDDTs. Since estimates of both COD reduction and VS reduction were known, both were included in the analysis. In a situation where information was only available on COD or VS, the known indicator would have been weighted appropriately and the unknown would have been given a weight of 0%. A weighting of 6% each for N and P removal and 8% for VS removal leaves changes the score for VIPs to 3.77 and leaves the UDDT score unchanged.

5.1.2.2. S_2 and S_3: Ecosan imperative: recycling is crucial

If it is considered essential that nutrients are recycled, there is no need for the system to reduce the nutrient and volatile solids content of the excreta. However, VS reduction may be desirable to reduce the unpleasantness of handling the material recovered from the system. For the purposes of this scenario, the reduction indicators were given a weighting of 0%.

Since nutrient recycling would probably be desirable in a situation where water and energy might also need to be conserved (a rural context, for example), these and the recovery criteria were all weighted equally at 25%. In this scenario, it might also be surmised that financial considerations carry less weight (e.g. with external funding), so the MCDA was run with equal weightings for the three main criteria (S_2**)** and then again with a 40/20/40 split for environment/finance/socio-cultural weightings (S_3**)**.

Not surprisingly, the two sanitation options considered under the eThekwini circumstances do not perform well with these constraints since nutrients are not recycled (see section 5.2.1.1). With equal weightings for the main criteria VIPs and UDDTs score 3.00 and 2.77 respectively. With a higher weighting for the environment and socio-cultural categories, this drops to 2.93 and 2.69.

5.1.2.3. S_4: People over environment

Another scenario might be that the environment is not considered important (10%) and while financial and technological considerations cannot be ignored (30%) the socio-cultural dimension is the most crucial. With these weightings, the performance of VIPs is improved over the baseline equal weighting scenario, but only to a score of 3.16, while the overall rating for UDDTs drops to 2.84.

In the next section scenarios are considered where different values are allocated to the two systems. This could be the result of a consultation process with stakeholders, or if the situation in eThekwini should change, or the MCDA be applied in a different municipality altogether.

5.2. Sensitivity to changes in values

When allocating values to different alternatives, there is often a considerable amount of uncertainty involved. Even a quantitative variable such as COD removal might take on different values in different VIPs, depending on the moisture content of the pit contents and ingress of rain or groundwater. A sanitation system such as a UDDT might perform completely differently in a situation where excreta are reused in agriculture and where people are happy with this practice. Qualitative variables such as convenience are subjective and different stakeholders will not only attach different weightings to these but also have different perceptions on how well an alternative system scores on them. In this section, weightings were changed if this was logical in a given scenario and values were changed to fit different possible sets of circumstances.

5.2.1. Sensitivity to changes in UDDT values

UDDTs performed very differently under different circumstances, as described above.

5.2.1.1. S_5 , S_6 : Excreta from UDDT reused at household level

Increasing the values for nutrient reuse and organic matter recovery to 5 improved the rating of the UDDT to 3.38 (S_5).

It is unlikely that if excreta were reused these would be the only values that would change. Furthermore, the weightings for removal of VS, N, P and COD may be changed to zero where nutrients are recycled (see Section 5.1.2.2). If this was not the case, their values would have to be changed to take into account any removal taking place in the agricultural system attached to the sanitation system rather than the system itself.

It was assumed that the requirement for energy and water were still important criteria and thus the four criteria under environment which were not concerned with nutrient removal received weightings of 25% each. A screenshot of these entries is shown in Figure 5-5. This increased the rating of the UDDT system still further, to 3.61 (S_6).

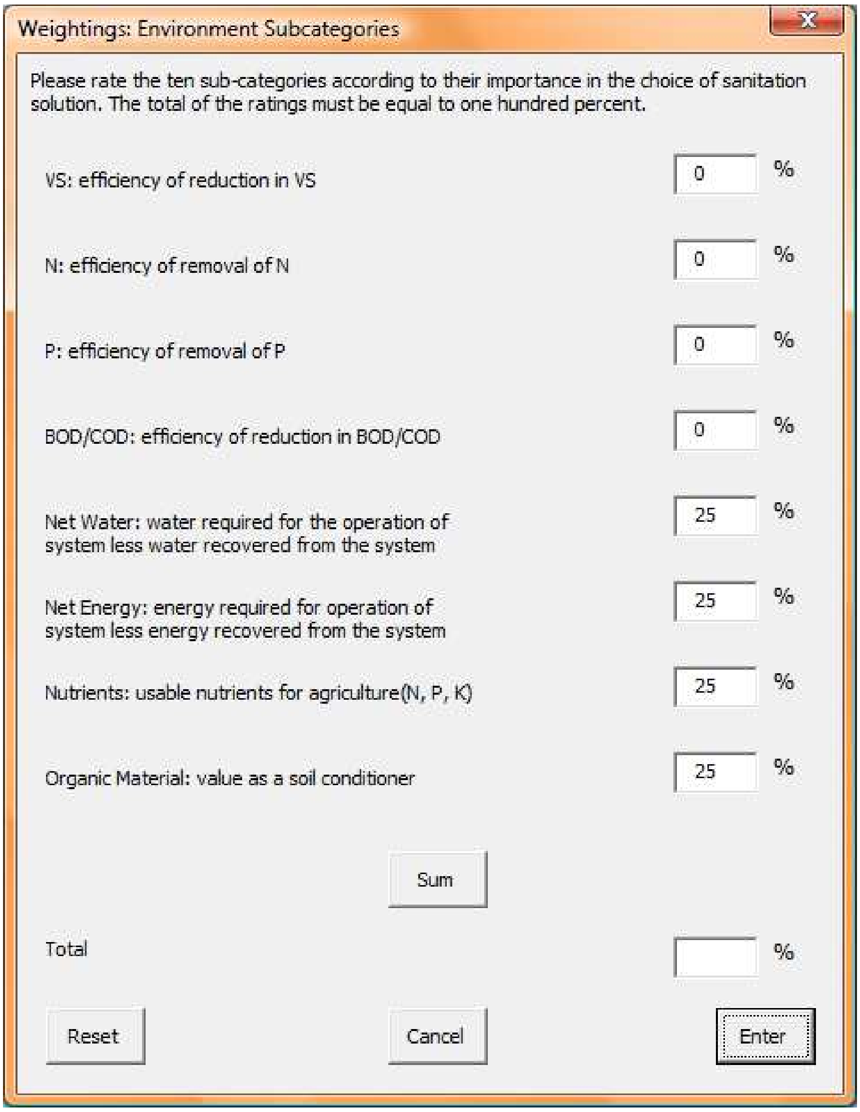


Figure 5-5. Screenshot of environmental indicators for S_6

5.2.1.2. S_7: Excreta from UDDT reused with changes to socio-cultural values

Furthermore, it could be assumed that the user acceptance of UDDTs would be high if nutrients were recovered and used on-site. If they were not being used on-site, the situation would become much more complicated, with energy required to remove the nutrients to another location. S_7 therefore assumes that environmental values and ratings remain as they are in S_6, but in addition the user acceptance is increased to 5 and food security is increased to 4 since the condition "Products used at household level without institutional support." is met.

The section of the Socio-cultural ratings on the Expert page which reflects these changes is shown in Figure 5-6. This increases the final rating for UDDTs to 3.86 (S_7) over a score of 3.00 for VIPs with the same weightings applied.

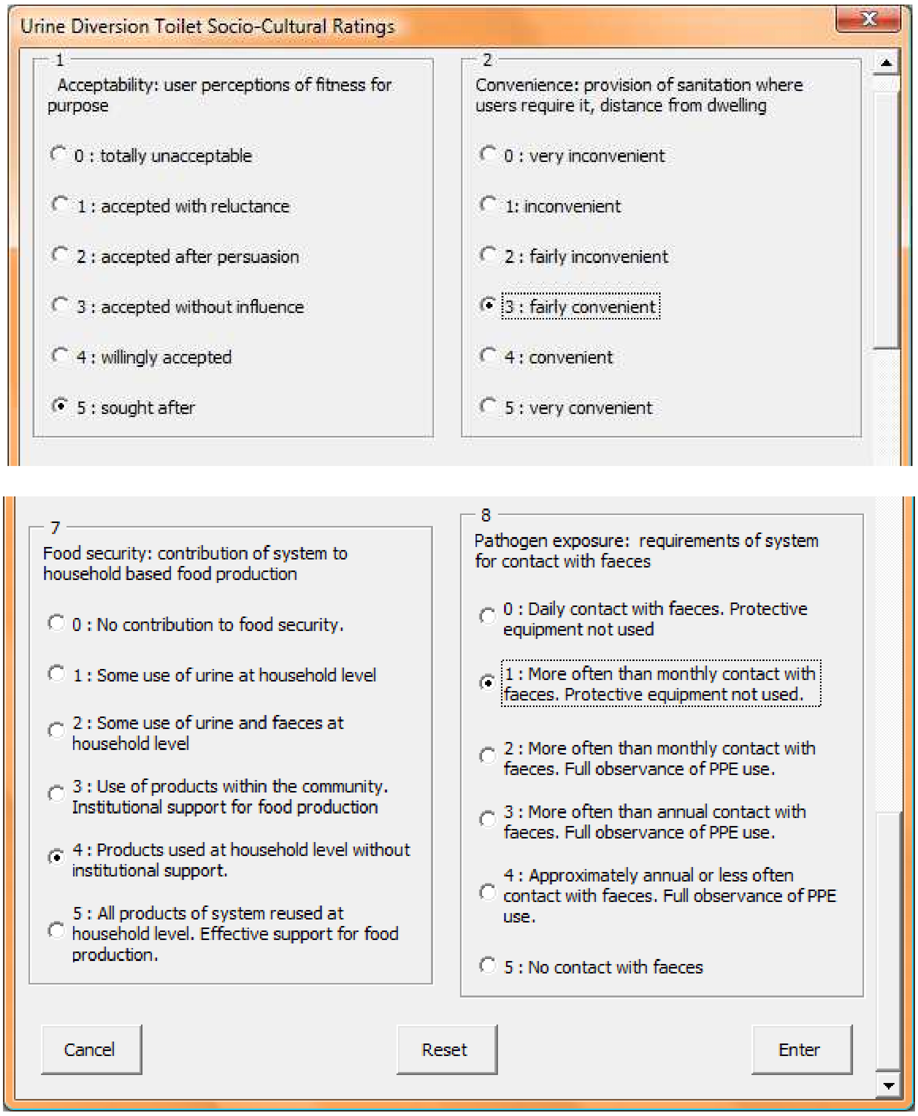


Figure 5-6. Ratings for socio-cultural factors with acceptance of excreta reuse.

5.2.2. Sensitivity to changes in VIP values

VIPs are a well established, robust systems used by rural households for hundreds of years. Under conditions where household solid waste is disposed of elsewhere they may not need emptying for the life of the system which is assumed in the MCDA to be 20 years. However, their performance is very different under urban circumstances. User acceptance is lower where those close by have flush lavatories and the addition of solid waste to the pits shortens their useful life. If flooding occurs, pathogen risk to residents and the risk of contamination of water become greater. Two scenarios were envisaged where the value and/or the weightings for criteria might change and affect the overall rating of VIPs.

5.2.2.1. S_8 : Disposal of sludge to wastewater treatment works

In this scenario, some attempt is made to account for the energy required to process the sludge from pit latrines. While more environmentally friendly options such as the LaDePa machine processing sludge to fertiliser and the deep row entrenchment in forests are still under investigation, many municipalities are likely to process the sludge at their wastewater treatment works (WWTW). In this scenario, energy use would be increased significantly due to the need to transport the sludge and for other processes in the WWTW.

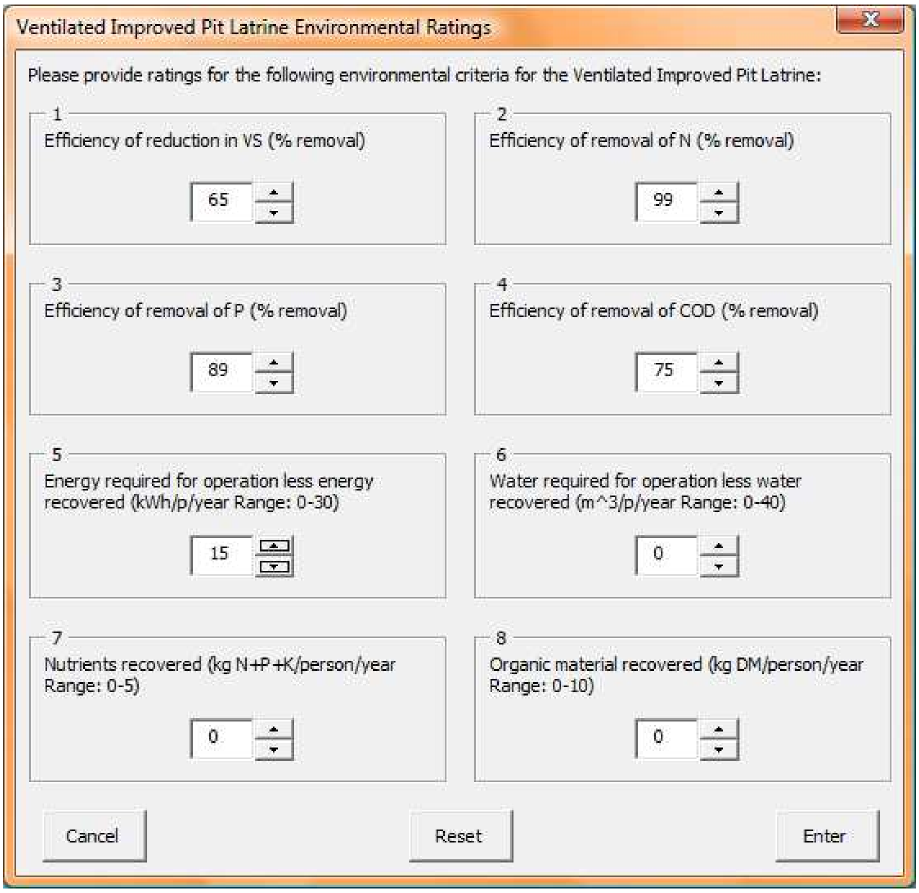


Figure 5-7. Ratings for environmental impact of VIPs with sludge treated at WWTW

The energy requirement for aeration would be reduced since the sludge would already have undergone most of its potential biodegradation in the on-site sanitation facility. The energy requirement was set at 15kWh/p/y. Overall, COD and VS removal was the same as for VIPs (75% and 65% respectively) since the sludge is assumed to have stabilised. N and P removal would be the values for the WWTW. Using Çiçek, et al. (1999) as a guide, the values for removal were adjusted to 99% for nitrogen and 89% for phosphorus (Figure 5-7). Furthermore, the cost of operations and maintenance would increase to the maximum value. The resulting score for VIPs with weightings equal across all criteria was 3.04 (S_8).

5.2.2.2. S_9 : Urban resistance to on-site systems

On-site systems are often better accepted in peri-urban or rural settings. In urban areas, there may be greater resistance to any alternative other than a flushing lavatory. Political opposition might also be brought to bear on the situation.

Table 5-1. Changes in Socio-cultural ratings for S_9

Criterion	**VIP**		**UDDT**	
	S_0	S_9	S_0	S_9
Acceptability: user perceptions of fitness for purpose	3	0	2	0
Convenience: provision of sanitation where users require it	3	3	3	3
Equity: fulfillment of requirements of all gender groups. equivalence of sanitation provision for different income groups	3	3	3	3
Legal /institutional: fit with legal requirements, institutional support for construction, O & M, political support	4	2	4	2
Facility for ongoing hygiene education: commitment of local authority or national government to fund	4	4	4	4
Participation: facility for user involvement in planning and execution of project	4	1	4	1
Food security: contribution of system to household based food production	0	0	0	0
Pathogen exposure: requirements of system for contact with faeces	4	4	1	1

The socio-cultural forces might be thought to carry more weight in a politicised situation.

S_9 envisages the ratings changing as shown in Table 5-1 and the weightings changing to 20/20/60 for environment/finance/socio-cultural. The resultant rating for VIPs is 2.49 and for UDDTs 2.30.

5.2.3. S_{10}: An experienced municipal engineer's perspective

An engineer and former head of eThekwini Water and Sanitation (EWS) was asked to provide weightings and values for the MCDA (Neil Macleod, 2015, email communication, 16 January.). For the main categories, he suggested that the environmental, financial/technological and socio-cultural criteria be weighted 20:50:30. The suggested socio-cultural weightings are shown in Figure 5-8.

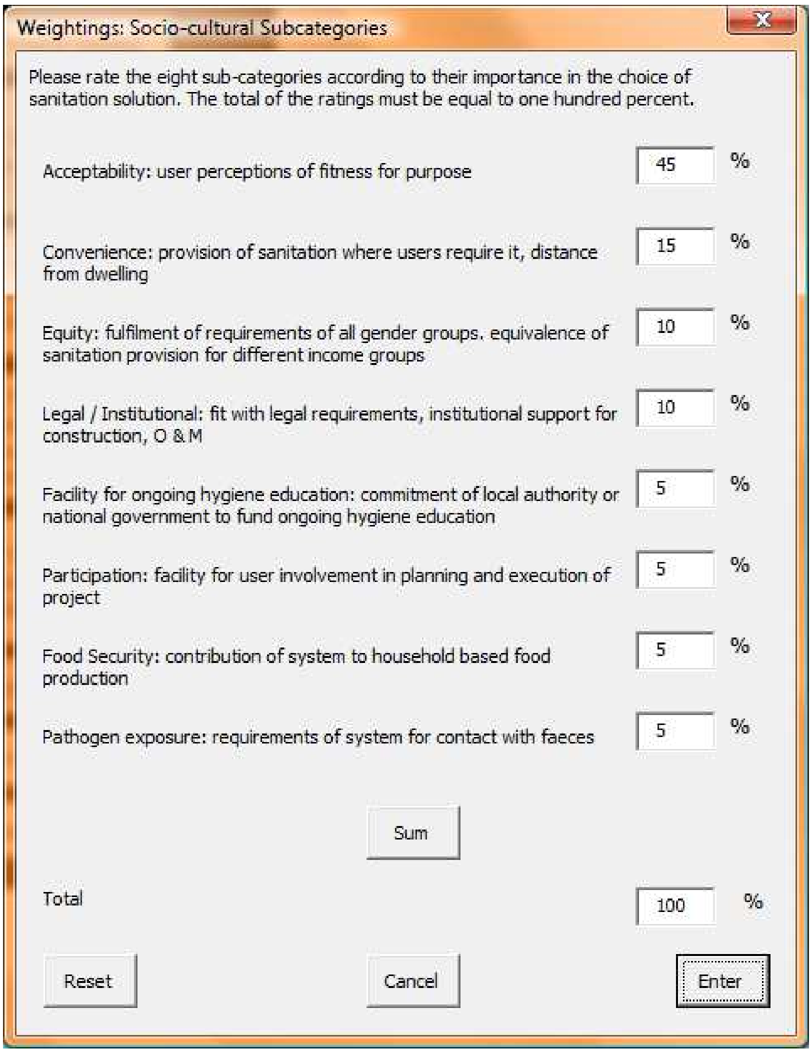


Figure 5-8. Socio-cultural weightings suggested by Neil Macleod

This expert also suggested the environmental values be changed to those shown in Table 5-2.

Table 5-2. Value scores allocated for environmental indicators from the researcher (FS) compared with those suggested by Neil Macleod (NAM)

Criterion	**Indicator**	**VIP**		**UDDT**	
		FS	**NAM**	**FS**	**NAM**
efficiency of reduction in VS	% removal	65	70	45	50
efficiency of removal of N	% removal	75	70	95	90
efficiency of removal of P	% removal	12	10	95	10
efficiency of reduction in COD	% removal	75	50	55	40
net energy required	MJ/person/year	0	0	0	0
net water required	m^3/person/year	0	1	0	1
nutrients recovered	kg N+P+K/p/y	0	0	0	0
organic material recovered	kg DM/p/y	0	0	0	0

While this expert agreed with the researcher as to the robustness scores of the two systems (5 for VIPs and 3 for UDDTs), he suggested that UDDTs might require six-monthly rather than annual intervention. He agreed that the lifespan of both systems was approximately 20 years. Cost estimates were higher for construction, at R7 000 for a VIP and R10 000 for a UDDT. Maintenance costs were lower, at R50/p/y for VIPs (based on R1 200 every 5 years for 5 people) and R5/p/y for UDDTs. Both systems would create 5 new jobs per 1000 households.

The socio-cultural ratings suggested by this expert were very different from the researcher's. VIPs were considered to be totally unacceptable (score 0) while UDDTs were accepted with persuasion (score 2). Both systems were considered to be inconvenient and while VIPs do not provide for children, both women and children are disadvantaged by UDDTs. He also scored both systems 2 for legal/institutional fit, indicating less certainty about political support for these options.

The changes to inputs suggested by the expert resulted in a score of 2.71 for VIPs and 2.50 for UDDTs.

5.3. Addition of a further sanitation option

An additional on-site sanitation technology which has not been tested extensively in South Africa is the pour-flush latrine. A Water Research Commission report published in 2012 presented the results of research into the application of this system by Partners in Development (Still and Louton, 2012). The research was done in the Msunduzi Municipality which is centred on the city of Pietermaritzburg, South Africa.

The results of the study were promising:

- The system could accept both toilet paper and newspaper as anal cleansing material
- No piped water was required and grey water could be used for flushing
- The volume of water required was small: 1 – 2 litres per use
- The presence of a water seal meant that the system could be installed inside dwellings
- Requirement for maintenance was low, with only one blockage occurring among 20 systems over 18 months of testing
- The requirement for emptying was similar to a pit latrine in eThekwini: once every five years
- The pit contents were generally free of solid waste except in one community where no solid waste collection occurred. This was an area of concern.
- Pit contents should be emptiable with a vacuum tanker or smaller pit emptying technology e.g. Vacutug

For the purposes of the MCDA, it is assumed that the technology used would be a twin pit pour flush latrine which allows one pit to rest and degrade while the other is used to reduce the risk of pathogen transmission. This is the design used in the Msunduzi project (Still and Louton, 2012).

5.3.1. Performance of PF on environmental criteria

The contents of the pit of the pour-flush which are in use might be expected to be wetter than a VIP and hence anaerobic conditions might prevail. However, once the pit is not in use dehydration is likely to occur. The removal of VS, COD, N and P was assumed to be similar to those of a VIP.

No energy is required for the system, but with 1.5 litres average per flush and 7 flushes per day, the average user would require 3 800 litres or 4m^3 /p/y. The values in Table 5-3 were entered into the MCDA.

Table 5-3. Environmental indicator values for the pour-flush system

Criterion	Raw score	Indicator value
efficiency of reduction in VS	65%	3.25
efficiency of removal of N	75%	3.75
efficiency of removal of P	12%	0.6
efficiency of reduction in COD	75%	3.75
energy required for operation less energy recovered	0 MJ/person/year	5
water required for operation of system less water recovered	4 m^3/person/year	4.5
nutrients recovered	0 kg N+P+K/person/year	0
organic material recovered	0 kg DM/person/year	0

5.3.2. Performance of PF on financial and technical criteria

The cost of the pour-flush units in 2014 was approximately R8 500. This was on a par with the cost in eThekwini of UDDTs at the time (Dave Still, Director of Partners in Development, 2015, telephonic communication with author, Pietermaritzburg, 25 January.). Both VIP and UDDT cost were increased proportionally to R7 000 and R8 500 respectively. The emptying costs for UDDTs with on-site burial was estimated at R500 at the same time, and this was adjusted in the MCDA as the annual operations and maintenance costs for UDDTs since the eThekwini Municipality is currently investigating the potential for this service and surveys indicate an overwhelming reluctance on the part of householders to do this themselves (R100/p/y with annual emptying). The pour-flush emptying cost might be less than the VIP cost if a tanker or Vacutug could be used, but for the MCDA the same operations and maintenance was used for both at R100/p/y.

Robustness was considered to be similar to the UDDT. Although the test phase was promising, these systems cannot withstand the abuse that a VIP can and continue to function. They would hopefully require less outside intervention, being more similar to a waterborne system in this respect. Life expectancy was 20 years, the same as the VIP and UDDT and job creation similar to UDDTs, since local people would be trained in construction and emptying would provide further local employment. Local development would be similar to the other two systems. These scores are summarised in Table 5-4.

Table 5-4. Finance and Technology indicator values for the pour-flush system

Criterion	Raw score	Indicator value
Robustness: ability to withstand abuse, ease of construction, simplicity of design,	robust, challenging construction, simpler technology.	3
Requirement for outside intervention, requirement for monitoring to ensure appropriate disposal of waste	intervention every 5 years	4
Durability: life expectancy of system	20 years	4
Construction cost: materials, labour, institutional requirements	R8 500 R/household	2.24
Cost of O & M: repairs, servicing (e.g. emptying)	R100/person/year	4.58
Employment: jobs created by construction and maintenance	5 jobs per 1000 households	2
Local development: promotion of local business in construction and maintenance	Some local community, some regional construction and O&M	4

5.3.3. Performance of PF on socio-cultural criteria

While acceptability would not be as high as a fully waterborne system, the pilot project indicated that this system was well received and in most cases preferred to VIPs. While convenience remained an individual perception and not all users preferred the pour-flush toilet to be inside the house, this is possible if users choose this option. No inconvenience was reported with the requirement for maintaining a supply of flush water in the toilet room, so this technology was deemed to be convenient: a fully waterborne system must be the definition of very convenient.

The positive response of users, reported in Still and Louton (2012) suggests that the system could be seen as offering benefits equivalent to fully waterborne sewerage. Excreta are separated from the user by a water seal and users did not find the operation of the system onerous. Hence the rating for the equity indicator was 4. All other indicators were also rated at 4 (see Table 5-5) because the implementation would be likely to be similar to other projects of this kind.

Table 5-5 summarises the ratings used in the MCDA for socio-cultural indicators.

Table 5-5. Socio-cultural indicator values for the pour-flush system

Criterion	**Raw score**	**Indicator value**
Acceptability: user perceptions of fitness for purpose	Willingly accepted	4
Convenience: provision of sanitation where users require it, distance from dwelling	Convenient	4
Equity: fulfillment of requirements of all gender groups. equivalence of sanitation provision for different income groups	less advantaged people have equivalent but not same system	4
Legal /institutional: fit with legal requirements, institutional support for construction, O & M	fit with legal requirements full support available at government level, political will is neutral	4
Facility for ongoing hygiene education: commitment of local authority or national government to fund	fully adequate budget for initial education available and adequate provision for ongoing support hygiene education	4
Participation: facility for user involvement in planning and execution of project	Users fully involved in planning and execution	4
Food security: contribution of system to household based food production	no contribution	0
Pathogen exposure: requirements of system for contact with faeces	Approximately annual or less often contact with faeces. Full observance of PPE use.	4

5.3.4. Overall performance of PF

The scores for the three systems with the adjusted construction and maintenance costs were 3.14 for VIPs, 2.94 for UDDTs and 3.17 for pour-flush with equal weightings for all criteria. With a heavier weighting (60%) for socio-cultural criteria e.g. in a more challenging political climate, the PF scores 3.30 versus 3.13 for VIPs and 2.81 for UDDTs.

Chapter 6. Discussion and Conclusions

The results of the analyses reported in Chapter 5 give some indications of how this MCDA would have predicted the outcome of the Free Basic Sanitation interventions in the eThekwini Municipality (EM).

6.1. Discussion of MCDA results

6.1.1. Sensitivity to main criterion weightings

With a "balanced scorecard" and equal weightings for the three main criteria (Environment, Finance and Technology and Socio-cultural), the performance of VIPs in the MCDA was marginally better than that of UDDTs. This difference would have been insufficient for a decision to be made using the results but would hopefully prompt further investigation of the motivation for one or the other option.

In the case of EM, a very strong driver for the change was to avoid the need to empty pits. If this were only a financial consideration, it would probably not be justified in the light of the results of this MCDA and in view of the current situation with regard to emptying of vaults. UDDTs might require more outside intervention in the form of health and hygiene visits and greater maintenance expenditure due to less robust and more complicated technology, even if this was not originally envisaged by the municipality. If households are not prepared to empty the vaults themselves, as is suggested by the surveys, the municipality will probably incur a further cost of around R500 per emptying visit (Dave Still, Director of Partners in Development, 2015, telephonic communication with author, Pietermaritzburg, 25 January.).

However, the concerns of the municipality were not only financial. The nature of the manual VIP emptying process and risks to the health of pit emptiers as well as the unpleasant nature of the job were motivating factors in the choice of UDDTs (Buckley et al. 2008b). The difficulties encountered in transporting and disposing of pit latrine sludge when it was found that the shock loading affected the operation of the WWTW also played a role. Finally, there is potential for UDDTs to improve food security if the barriers preventing them from reaching their Ecosan potential are overcome. As S_7 indicated, in a scenario where excreta are reused, UDDTs perform well with a rating of 3.86 against 3 for VIPs.

When environmental considerations were given a higher weighting, UDDTs performed better than VIPs, scoring 3.06 against 2.67 for VIPs when the weighting was 100%. This was in spite of the fact that UDDTs were not being used as truly ecological sanitation since no recycling of nutrients was occurring. The lowered risk to groundwater from the use of sealed vaults and urine soakaways make the UDDT the more environmentally friendly option.

The only other main weighting change which would result in a higher rating for UDDTs would be if less than a 15% weighting was given to socio-cultural considerations. The literature informs us that social issues are of primary importance. However, this result does reflect the difficulties with UDDTs which have been elicited by the surveys carried out in the EM.

6.1.2. Scenario analysis

A number of scenarios were proposed which might affect the weightings and/or the values used in the MCDA.

S_1, in which the weightings for water and energy use were increased, indicated that UDDTs and VIPs are both good options where these inputs are severely constrained. There are situations where dry sanitation is the only viable option, for example if water must be carried great distances. This is becoming less common in South Africa as the provision of water outstrips the provision of sanitation at over 90% in 2011 (RSA, 2013, p.100). However, Rietveld et al. (2009), in their MCDA study of water supplies in Limpopo province, found that many relatively new water systems did not provide a continuous supply. In these situations dry systems are essential if they are to provide a reliable sanitation solution.

S_2 and S_3, indicated that if environmental considerations are more important and nutrient recycling is considered to be essential, UDDTs and VIPs both perform poorly if the excreta from the UDDTs is simply buried. S_5, S_6 and S_7 provided alternative scenarios, where the potential of UDDTs is realised and this system performs well. It must be remembered that in eThekwini, the socio-cultural factors are the barriers to Ecosan and unless these are overcome, S_7 remains a hypothetical situation. Thus the excellent performance in S_7 rested on community acceptance and even enthusiasm for the reuse of excreta.

In eThekwini, UDDTs have been the target of some negative commentary. Patrick Bond of the Centre for Civil Society at the University of KwaZulu-Natal labelled them a "*post-apartheid bucket system*" (Bond et al., 2008). The surveys cited in Chapter 3 suggest growing discontent with these toilets. It seems that under the eThekwini circumstances, the VIP may have been a better choice and S_4 bears this out, with UDDTs performing poorly under conditions where socio-cultural and political issues carry considerable weight. On the other hand, those with waterborne toilets are not necessarily any happier (see reference to the study of Kariuki, 2008 in Section 3.3.3.2).

S_8 investigated the impact on the rating of VIPs if sludge was disposed of in WWTW. This scenario highlighted the issues of collection, transport and disposal which should form part of the holistic view of a sanitation system. Setting system boundaries at the user interface level ignores the more wide-reaching consequences of sanitation. These impacts may affect the environment, have a financial and managerial impact at municipal level and concern the wider community where river systems and air emissions are affected.

The next scenario proposed, S_9, should have resonance in the South African situation Where the socio-cultural criterion is weighted above the environment and financial criteria, and with a change to the acceptability of a dry sanitation option, political opposition and resistance to participation by the community, VIPs and UDDTs perform poorly. This would happen to any sanitation option that met with resistance from the community or even a small but vocal sector of the community.

An up-to-date costing and some very useful insights were gained from the input of a municipal engineer into the final scenario (S_{10}). The weightings for the main categories demonstrated that while financial and technical criteria are of primary concern to the municipal engineer, experience gives significant weight to the other two categories as well. The expert rated most of the environmental indicators somewhat lower for both systems, but the only significant point of difference between the researcher and this expert on environmental criteria was the poorer reduction in phosphorus which he allocated to UDDTs. It is important to note that the performance of UDDTs on N and P removal is particularly circumstance-specific, since the disposal to a soakaway may channel the nutrients into the surface soil layer or into surface water where it constitutes an environmental hazard. Furthermore, the reuse of urine in agriculture changes the picture radically.

Little difference of opinion was noted on the technical criteria but construction costs have obviously risen significantly since the data used by the researcher was collected in 2009 (Roma et al., 2011).

This underlines the possibility that the engineer may need to review the scale for the cost indicators when using the MCDA in future.

Possibly the most interesting changes to the researcher's weights and ratings were found in the socio-cultural section. The expert placed a strong emphasis (45%) on acceptability to users, and rated VIPs particularly low on this indicator. Convenience was the next most heavily weighted indicator, and both VIPs and UDDTs were considered inconvenient, a harsher judgement than that of the researcher.

The overall scores with the input of this expert highlighted the difficulties with the provision of on-site sanitation systems and brought into question the value of UDDTs in eThekwini. Although the scores changed for each of the sanitation options, their relative positions were the same as those resulting from the researcher's input values with UDDTs performing worse than VIPs.

6.1.3. Addition of pour-flush option

The pour-flush alternative was easily added to the MCDA since the Excel® workbook is already set up to assess up to 5 alternative sanitation systems. Because a number of assumptions were made regarding its performance, the final score is only a tentative assessment of possible value in comparison with UDDTs and VIPs. Nonetheless the technology seems promising.

The process of entering the values for a technology about which little is known in the South African context highlights the need for further research. The MCDA assists in directing this effort into the following channels:

- What processes take place in the pour-flush pits? This would require an analysis of both active and resting pits to find out if they are similar to VIPs. The addition of water might create anaerobic conditions in which less degradation takes place, but the wetter conditions may be conducive to better breakdown of organic matter.

- What potential is there for the reuse of nutrients from pour-flush latrines? The extensive studies of *Ascaris* survival (Buckley et al., 2008b) would need to be replicated on this technology before recycling could be recommended.

- Will the pits need to be emptied by the municipality? How can pits be cost-effectively emptied and how can the contents be disposed of?

- How robust is the technology in a larger pilot project and how long does it last? How much outside intervention is required to keep it functional?

- How well is the technology accepted in the wider community? Here the techniques of social marketing may be employed so that acceptance is facilitated. It must be remembered, however, that this acceptance must be sustained through the lifespan of the system.

- Can political players across the spectrum be convinced that this is an equitable solution?

The exercise of seeking this information should improve the chance of success if a new technology is to be introduced.

6.2. General discussion

The aim of this research was to investigate whether Multiple Criteria Decision Analysis could offer municipal engineers a useful tool in their attempts to extend sanitation to all residents of their municipalities in a sustainable fashion. Sustainability was viewed in a broad fashion to cover disciplines ranging from Chemical Engineering to Sociology via Financial Management.

Sustainability theory asserts that a system will not continue to work if the environment is not protected for the benefit of the present and future generations. The financial resources must be available not only for the construction of systems to improve the welfare of humans but also to maintain these systems. Systems must be built that are technologically appropriate to the situation at hand. Humans are complex organisms that strive for more than the fulfilment of their basic needs. A sense of security, autonomy, self respect and dignity are some of the aspirations which drive people to improve their circumstances. People are also social animals and are swayed by the opinions of their fellows and of those in authority. Their actions may sometimes appear irrational, but marketers understand that humans are creatures of emotion rather than reason and their responses are not always grounded in logic. Since sanitation is intended for the welfare of humans, it is on the socio-cultural testing ground that systems often pass or fail.

Engineers are usually trained to a high level of technical expertise. Most have acquired skills in the financial management of projects. Environmental engineering is becoming more widely acknowledged as an important field of study. It may be that the socio-cultural dimension is the one that municipal engineers find themselves most ill-equipped to deal with.

In a study of decision making in political contexts, Andersson et al. (2012) commented that political influences often constrain choices which should be rational but instead are made on the basis of the distribution of power. They cite *"rationality and political behavior as opposite ends of one continuum."* In their case studies, they found that Decision Support Systems (DSS) and participatory planning were a waste of time, since they were mostly used as a *"political façade to make people think they have an influence."* In effect, the way that decisions are really made in political contexts does not accord with the principles of participatory planning. In sanitation planning, communities are often "consulted" after the financial and technological decisions have been made. Andersson et al. (2012) conclude that more research is needed in the use of DSS in real situations rather than the development of more methods of decision support.

6.2.1. MCDA as a tool in Participatory Planning

The MCDA developed in this study was conceptually a very simple one. Most of the partial value functions used were linear transformations rather than the meticulously developed relationships advocated by the MCDA literature. Many of the indicators were qualitative ones, with the different levels chosen through a process of guesswork informed by an extensive literature review and many discussions with those in the field. No exhaustive process was carried out with stakeholders to quantify the tradeoffs between criteria which would allow the aggregation process to produce a "true valuation" of each alternative.

A fundamental difficulty with MCDA in practice emerged on consideration of this particular requirement. This is the assumption that there is one interest group which must be satisfied by the outcome of the decision making process. This is the group that would be consulted to determine that one unit's increase in one indicator can be traded off against one unit's decrease in another. When one takes into consideration that each main criterion effectively represents a different interest group, and that each interest group has little or no expertise in or possibly concern for the other two areas, one realises that it is impossible to arrive at a valuation of any single indicator that would satisfy all these divergent groups. One person's indoor convenience is another's mortification, as Still and Louton (2012) found in their survey of failing low-flush latrines. What is a kilogram of valuable recycled nutrients to an environmentally conscious European may be just so much shit to an African aspiring to a more dignified life.

Another difficulty with MAVT lies in making the required tradeoffs clear to those using the MCDA in order to elicit valid weights for the different criteria. The elicitation of weights for MCDA from stakeholders was considered to be beyond the scope of this study. In order to achieve the trade-offs required for a rigorous application of the MCDA method, stakeholders would be required to complete an onerous set of pairwise comparisons. Furthermore, with the range of criteria included in this MCDA, it would be difficult for any one group of stakeholders to evaluate those trade-offs, since the three main criteria represent the interests of three different groupings: community and environmental experts (environmental criteria), municipalities (technical and financial criteria) and target communities (socio-cultural criteria).

While one of the aims of an MCDA is often to allow as many stakeholders as possible to influence the final decision through the process of the weighting of objectives, the results of this process are likely to be predictable and simply to delineate the differences of interest which exist. The sensitivity analysis of weightings (Section 5.1.1) in this study produced just such predictable results, with alternatives changing places in the rankings according to obvious strengths and weaknesses inherent in different technologies for the different criteria. As the environmental criterion became more important, UDDTs exceeded VIPs in the final value score, even without a situation where the full ecological sanitation potential of this technology is realised. As socio-cultural considerations were given more weight, the established technology of the VIP increased its lead over the sometimes contentious UDDT option.

Monnikhof and Bots (2000) in their case studies of MCDA in spatial planning in The Netherlands, record that in a process of “interactive planning” involving different stakeholders, the citizen group would not accept the expert’s MCDA which reflected his own preconceptions. They proceeded to develop their own MCDA which showed a clear bias to their particular interests. The final choice that was made by the municipal council took no account of either MCDA.

The aim of participatory planning must be to develop a better understanding one another’s view of the different pillars of sustainability so that all stakeholders are prepared to make the necessary compromises in order to achieve a truly sustainable solution. In this endeavour, MCDA can really only play an ancillary role to the main process of consultation, discussion and, hopefully, convergence. What the MCDA may do is to frame the debate by making all participants aware of the others’ points of view. It must therefore be developed with as much objectivity as possible.

6.2.2. Strengths of the MCDA

The question that this research sought to answer was "Can MCDA assist Municipal Engineers to achieve sustainable sanitation solutions?" If the engineer is looking for a definitive answer to the question "Which option shall I implement?" then the answer to the research question would probably be a resounding "No". As has been explained above this particular MCDA was bedevilled by the impossibility of following a rigorous quantification process to arrive at a perfect numerical answer. There were many times in the process of constructing the MCDA when it seemed a superficial exercise, even to the developer. None of alternatives under consideration may perform sufficiently well to merit implementation.

However, if the engineer's question was phrased as "What process should I follow in order to arrive at a course of action which has a better chance of success", then the MCDA may have a considerable amount to offer. The MCDA provides a simple framework of questions that the engineer needs to investigate before he or she makes a decision. The engineer is the "expert" who enters the ratings for any given system and must therefore be fully informed before doing so.

Starting with the environmental issues, the engineer needs to make sure that a comprehensive environmental assessment has been carried out. This assessment should provide values for the 8 indicators required by the MCDA. In the course of this study, it became obvious that these apparently simple figures were not easy to find, particularly for on-site sanitation systems. A Google Scholar® search for *pit latrine sludge* or *chemical oxygen demand pour flush latrines* revealed that little is documented on these and that the research by UKZN in eThekwini is at the forefront of this effort. It is also important to note that these figures are specific not only to the sanitation option being considered and but also to the entire train of options which accompany it, from collection to transport to treatment to disposal (Tilley et al., 2008). Furthermore, the physical geography of the area where the system would be installed and the cultural practices of the target community will also influence the environmental outcomes. Even if the engineer makes some rough estimates he or she should end up considerably better informed.

The financial implications of the different options may also be less simple than at first appears. These should also take into account the entire train of technologies from collection to final disposal. The durability, robustness and need for outside intervention have both extrinsic components attributable to the technical design and intrinsic components which depend on topography and current infrastructure (e.g. ease of access for pit emptying) and people’s ability and willingness to care for and maintain the structures. This highlights another point about this type of MCDA: independence of indicators is lamentably absent.

The engineer must put in place a comprehensive Social Impact Assessment. People’s aspirations, cultural beliefs, community structures and political allegiance may all have a bearing on the success or failure of a project. The very process of investigating these may affect the outcome. It is not enough to create facilitating committees once the technical solution has already been decided. Engineers need to offer different options and to try to keep as open a mind as possible so that citizens do not feel that the consultation process is simply window-dressing. Furthermore, political support across the spectrum may crucial to the success of a project.

The “toilet wars” in Cape Town raged over the Democratic Alliance-led City of Cape Town’s attempt to provide individual households with flush toilets (Robins, 2014 , Zille, 2010). They provided the plumbing and sanitary fittings for toilets for each dwelling while the households were to provide the enclosure, which the vast majority of residents did. The remaining open toilets *“created the conditions for the framing of sanitation as a matter of concern for politicians, activists, journalists, citizens and, most significantly, judges.”* (Robins, 2014). Protests, including the dumping of faeces at Cape Town International Airport, followed this controversy. The authorities believed that they had followed a full process of consultation and had arrived at an agreement with residents (Zille, 2010). Furthermore, they believed that they had gone far beyond the legislative requirement for basic sanitation provision. Nevertheless, the intervention became a political issue which must make any municipality considering a similar process pause for thought. The South African Human Rights Commission concluded that the City of Cape Town had violated the rights of residents with open toilets to dignity and privacy and the municipality was ordered to provide enclosures (SAHRC, 2010). Thus an intervention was hamstrung by a single criterion in the MCDA – the need for legal, institutional and political support.

The Cape Town experience emphasises the need for each and every aspect raised by the MCDA to be considered. The list of indicators is not exhaustive as the number had to be limited so that each value could have some impact on the outcome. However, the list is balanced between the interests of different stakeholders and the engineer should encounter other issues as he or she seeks answers to the questions raised by the MCDA.

6.2.3. Combination of scenario planning with MCDA

An innovative feature of this MCDA in the context of spreadsheet based MCDAs of this type is that it offers a user-friendly interface for the entry of values for the matrix. This allows the expert user to change values easily to observe the effect on the ranking of options. Most systems focus on achieving the perfect set of indicator values and allowing the user to manipulate weights only. In Section 6.2.1 the conclusion was that values are situation specific.

Loetscher's (1999) MCDA included more than 80 sanitation alternatives including systems for collection, treatment and disposal. These were organised into trains to allow for the different possible combinations which would achieve an overall sanitation system. All the expert work was done by the researcher and was not obvious to the user. While this is ideal if the program is to be used in the identical context to the one envisaged by the developer, there are many factors affecting the success of sanitation which may be unique to a certain set of circumstances. The municipal engineer may be able to manipulate some aspects of the system to change the performance. For example, the extent to which users of the sanitation are involved in the process depends on the project manager.

The MCDA in this study has not attempted to go beyond the on-site part of the sanitation solution. However, the scenario testing facility may compensate for this deficiency in that it allows the expert user to change those indicators which would be affected by the alternative transport, treatment and disposal options and see how the options would perform. Thus VIPs with sludge disposal at the WWTW (expensive, energy inefficient, good removal of organic matter) could be compared with VIPs with sludge disposal in forestry (less expensive, energy inefficient due to transport and burial, return of nutrients and organic matter to soil). The choice is once again an informed one, since the process of investigating the effect of different disposal options on the indicator values gives the engineer a broad vision but guides him or her to interrogate specific outcomes.

Once again, it is not the results of the MCDA, but the process of engaging with it which may be valuable.

6.3. Conclusions

Multiple Criteria Decision Analysis provides a framework within which municipal engineers can investigate the wide range of factors which will determine the sustainability of sanitation projects. It balances the scorecard between the interests of different groups of stakeholders and encourages the engineer to look beyond the technical and financial considerations. Nonetheless, these aspects, which are of critical importance to the municipality for budgeting and planning purposes, are not ignored in the MCDA. Using the program developed in this research in conjunction with Partners in Development's WhichSan program provides engineers with a detailed technical feasibility analysis and costing. Furthermore, the issues which are of specific concern to the municipality are incorporated into the MCDA to be balanced against the interests of other stakeholders.

This MCDA draws attention to the socio-cultural issues which have been the cause of failure for many interventions world-wide and in South Africa specifically. Social sustainability requires that considerations including equity, participation, food security and health are taken into account and the impact of the sanitation intervention on these factors is given appropriate importance. The engineer is encouraged, through the MCDA, to investigate the nature of the community in which the project will be implemented and to take their attitudes and perspectives into consideration.

The wider community is concerned that their environment is not negatively impacted by the projects undertaken by the municipality. In addition, the engineer must meet a range of regulatory requirements. Both the WhichSan feasibility screening and the MCDA encourage the engineer to undertake an investigation into factors affecting the environmental impact of any proposed project. Once again, these issues are weighted against those financial and socio-cultural factors with which they may be in conflict.

Difficulties were encountered when trying to meet the rigorous requirements of the academic community for weight elicitation and value function development. Further research is required to overcome the burden which would be placed on the engineer if these requirements were to be implemented. However, the sensitivity analysis and scenario analysis demonstrated the value of this method for taking into account different perspectives. These processes can be undertaken by the engineer after his or her investigations are completed as described in the conclusions above.

It may be concluded that the spreadsheet-based MCDA can provide the engineer with valuable insights and has considerable merit as a planning tool.

6.4. Areas for future research

The MCDA itself could be improved if more information were available to inform the values for some indicators. A better approach to weight elicitation and other approaches to decision support could be combined with this MCDA to improve its contribution to participatory planning.

6.4.1. Improved value measurement

This study highlighted some technical areas which could be more extensively investigated and which would improve the quality of data used in the MCDA. The work done by the Pollution Research Group at UKZN (Buckley et al., 2008a and 2008b, Nwaneri, 2009, Still and Foxon, 2012, Bakare et al., 2012) could be repeated in different geographic locations to give a range of values for nutrient removal and organic matter degradation in on-site systems. The analysis of the health risks posed by different options for excreta disposal must be considered essential and further studies similar to that of Mnguni et al. (2008) would be valuable. The risks are often specific to the particular way in which a sanitation option is applied – for example, a different risk assessment needs to be carried out for emptying and on-site burial of UDDT contents by an external contractor (currently under investigation in eThekwini) as compared with emptying and on-site burial by households or emptying and off-site disposal by external contractors.

The research of Benoit (2012) might be usefully extended into a study to establish what social interventions might increase the acceptability of the reuse of excreta in KwaZulu-Natal. This issue is a barrier to the implementation of ecological sanitation and affects a range of indicators in the MCDA. Greater acceptance of the practice of reuse would affect the options for disposal of pit latrine and pour-flush waste as well.

6.4.2. Weight elicitation component

If the MCDA method is to be rigorously applied, weights must be elicited from decision makers in such a way that they can make the trade-offs between criteria. This means that if one criterion has a weighting which is twice that of another, then the stakeholder is prepared to trade off an increase of one unit of value in the more highly-valued criterion for the loss of two units in the less-valued criterion. Swing weighting, as described in Section 2.4.3.2, requires the decision maker to make pairwise comparisons between a swing from the best to the worst value for the most highly ranked criterion and this swing for less highly ranked criteria. Although this would be onerous for decision makers, it could be made less so by the development of a user interface with sliders (as shown in Belton and Stewart, 2002 p.137).

A simpler system of rank order or ratio weights (Sections 2.4.3.1 and 2.4.3.3) could be used in a weight elicitation program, but it is doubtful if these methods would produce better results than the present option of entering weights as percentage values.

6.4.3. Conjoint analysis combined with MCDA

Conjoint analysis may have a contribution to make to the development of participatory decision making methods to be applied to sanitation. Hansen and Ombler (2009) resolve the issue of trade-offs by using a method they call PAPRIKA which introduces elements of the Analytical Hierarchy Process (AHP) method and conjoint analysis in order to arrive at values for each alternative and each criterion through a pairwise comparison in which certain values are obtained through direct comparison and the rest by implication. This method allows researchers and managers to elicit the preferences of stakeholders through comparisons of small subsets of criteria.

For example, a potential user might be given two options:

a. an indoor latrine which requires the user to purchase toilet paper
b. an outdoor latrine where newspaper can be used for anal cleansing

The respondent must indicate whether these options are equally liked or whether one is preferred to the other. This makes clearer the value placed on the two features: location of latrine and anal cleansing material. A series of pairwise comparisons like this allows the researcher to build up a comprehensive picture of the utilities which are associated with the individual features which make up a product: in this case a sanitation system. The utilities are evaluated in a statistically valid fashion without it being necessary to compare every feature with every other feature.

This methodology could possibly be used by municipal managers to ensure that they have carried out a genuine investigation of the community's needs and interests. 1000 Minds® Software combines conjoint analysis and MCDA and might bear investigation (Hansen and Ombler, 2009).

6.4.4. Final thought

In conclusion, it seems that this MCDA can achieve its objectives as stated by Belton and Stewart (2002, p.3) which are to “*facilitate decision makers’ learning about and understanding of the problem faced, about their own, other parties’ and organisational priorities, values and objectives and through exploring these in the context of the problem to guide them to identifying a preferred course of action.”*.

Chapter 7. Reference List

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