GIS-BASED DECISION SUPPORT APPROACH FOR SELECTING A NEW LANDFILL SITE FOR THE CITY OF CAPE TOWN

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GIS-BASED DECISION SUPPORT APPROACH FOR SELECTING A NEW LANDFILL SITE FOR THE CITY OF CAPE TOWN

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By

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Supervised by

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Declaration

I declare that this research project is my own work and where appropriate I have acknowledged the work of others. It is being submitted to the Department of Geomatics in fulfillment for the degree of Master of Applied Science in Geomatics at the University of Cape Town. This thesis has not been submitted in any form, for any degree or examination at any other learning institution.

30 June, 2006

Dedication

This work is dedicated to my relations, my former educators who in a way or another inspired me into following the GIS course, and to all who go out of their way to use every available technology to conserve the environment.

Acknowledgements

Through this piece of work, I would like to acknowledge people who contributed enormously to the success of this research project. Words of thanks go to Terry Richards and Dr. Solomon Bhunu, who without being impatient guided and encouraged me during the initial stages of the research project before they left the university.

I would also wish to express my gratitude to Nick and Thomas of the GIS research laboratory, University of Cape Town and the staff of Chief Directorate Surveys and Mapping, Mowbray for making GIS data for this project available.

The production of this document would not have been feasible without the valuable contribution of respondents who freely gave of their time to be interviewed. It is worth noting that all conclusions drawn are those of the author and not the official view of organizations the respondents work for. All sources used have been acknowledged by means of quotations and complete references.

Special thanks go to my supervisors, Dr. Julian Smit and Shirley Butcher for their invaluable mentorship and without whose help, the research project would not have seen the light of the day.

Synopsis

Recent studies indicate that the population of Cape Town generates approximately 2.2 million tons of waste annually. Numerous waste minimization strategies have been developed which have not been successful in reducing the amount that needs to be disposed of at a landfill site. This results to mounting pressure on existing waste disposal sites thus necessitating an urgent need for a new regional landfill. According to CCA Draft Environmental Impact Report (2006), the former Cape Metropolitan Council (CMC) appointed technical consultants in 2000 to identify and assess the potential sites for a landfill to service Cape Metropolitan Area (CMA), presently referred to as the City of Cape Town (CCT).

The construction of a landfill has significant impacts on the environments. It is for that reason Integrated Environmental Management (IEM) has to be followed to assess the impacts. The principle of IEM is broadly interpreted as applying to the planning, assessment, implementation and management of any project proposal or activity that has a potentially significant effect on the environment. Environmental Impact Assessment (EIA) process, which lies in the heart of the IEM, is enforced to examine the environmental effects of development. These impacts are directly related to the physical location of the project. That makes site selection for proposed project a very important stage of the EIA process. Laws have been enacted to minimize environmental impacts, including strict guidelines for siting landfills. Using landfill siting criteria and site selection methods, the technical consultants identified four potential sites, Atlantis being the only site falling within the City of Cape Town.

Siting a landfill is one example of a spatial problem in which existing guidelines can be expressed spatially in order to achieve the objective. This research followed the same guidelines used by the technical consultants as set out by the Department of Water Affairs and Forestry (DWAF) and implemented GIS to identify potential landfill sites within the CCT. To gain an understanding of the problem, senior staff of companies (Consultants) that were contracted to identify potential landfill sites was interviewed. Of importance to this research was to know the criteria that were used to identify the sites, the methods that were used, problems encountered and the sites that were identified.

The interviews, backed by secondary data sources such as websites and project reports, revealed that the techniques used to identify potential sites for the landfill, even when combined are costly and time consuming.

Several scenarios were run using various ArcGIS extensions, including the ModelBuilder to identify sites that met the stated criteria. GIS analysis yielded agreeable results with the recommendations from the consultants who used techniques other than GIS to identify the regional landfill. The research findings demonstrate that GIS is an efficient and dependable stand-alone technique that can be implemented in landfill site studies thus expedite the decision making process.

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Glossary of Abbreviations

CCA	**CCA Environmental (Pty) Ltd (a firm of environmental consultants based in Cape Town, South Africa)**
CCT	**City of Cape Town (formerly CMA)**
CDSM	**The Chief Directorate of Surveys and Mapping**
CMA	**Cape Metropolitan Area**
DEAT	**Department of Environmental Affairs and Tourism**
DSS	**Decision Support Systems**
DWAF	**Department of Water Affairs and Forestry**
ECA	**Environmental Conservation Act**
EIA	**Environmental Impact Assessment**
EIR	**Environmental Impact Report**
ENPAT	**The Environmental Potential Atlas**
GIS	**Geographical Information Systems**
SDSS	**Spatial Decision Support Systems**
SEA	**Strategic Environmental Assessment**

1. Introduction

1.1 Background to investigation

The Cape of Town is one of the fastest growing cities in South Africa with the population expected to increase tremendously due to influx of people from other provinces. A study by Jeffares and Green (as cited in CCA[1] Draft EIR, 2006) indicates the annual average increase in population was 1.57% between the censuses of 1996 and 2001. The study also shows that the population of Cape Town generates approximately 2.2 million tons of waste annually. Of this only 13% of the total waste generated is recovered through recycling and other composting alternatives. The rest is disposed of at the City's landfill sites. Based on the projected increase in city's population to 4.3million over the next 30 years, it is estimated that between 70 and 90 million tons of waste will need to be disposed of over the next 30 years.

Numerous waste minimization strategies have been developed by the City of Cape Town (CCT). These include recycling and composting projects, waste awareness programs, industrial and commercial waste minimization clubs, and extensive public awareness programs. Despite the waste minimization strategies, the CCT has not been successful in reducing the amount that needs to be disposed of at a landfill site. This result to mounting pressure on the existing waste disposal sites within the CCT. Two sites, Brackenfell and Swartklip, have already been closed while two more, Faure and Vissershok, are expected to close by 2007 and 2008 respectively. However, the Vissershok site will continue to accept waste for a few more years as it is being extended. The remaining landfills are expected to have reached their maximum capacity by 2016 (CCA Draft EIR, 2006). The study area and the existing landfill sites are shown in Figure 1.1.

Other alternatives to landfill have been explored by the CCT. These include among others incineration, reduction and reclamation. For economic reasons, Wright-Pierce (as cited in CCA Draft EIR, 2006) concluded that disposal of waste by landfill remained the best option for waste disposal thus necessitating the urgent need for a new regional landfill site that will receive household and general waste, as well as industrial waste to serve the CCT for the next 30 years.

[1] A firm of environmental consultants based in Cape Town, South Africa.

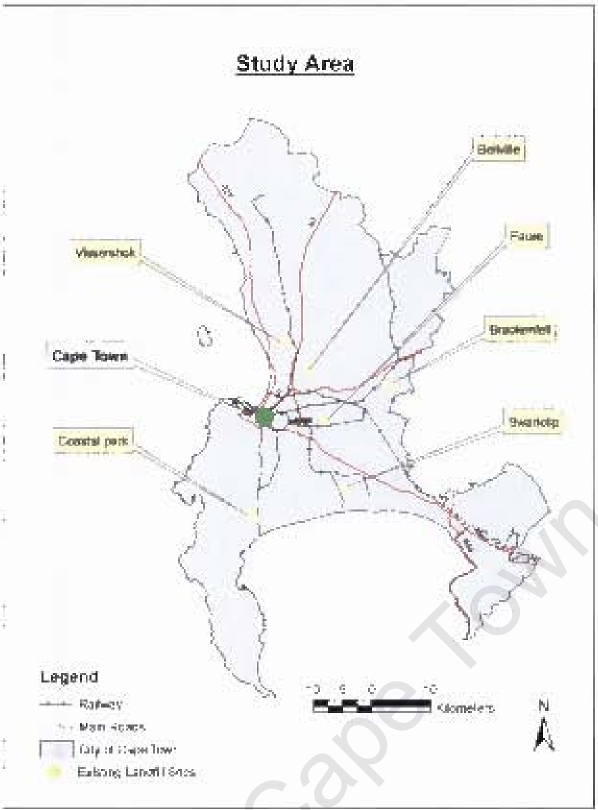

Figure 1.1 The study area

Intended projects or development projects have impacts on the environment. Environmental Impact Assessment (EIA) is a project specific environmental management tool that provides the legislative and policy framework within which the EIA is conducted. Hugo (2004) notes that EIA provides details about methodologies and techniques for identifying, predicting and evaluating the environmental impacts associated with project development. The process provides a procedure for facilitating informed decision-making, in conformity with regulations set out by DEAT (2006) and published under the National Environmental Management Act (NEMA) (Act No. 107 of 1998).

Environmental Authorization[2] by the Department of Environmental Affairs and Tourism (DEAT) or a delegated authority to construct the landfill can only take place when minimum requirements for waste disposal by landfill[3] and other EIA procedures are met.

[2] Previously referred to as Record of Decision and done by the Department of Water Affairs and Forestry (DWAF).
[3] The requirements addresses landfill classification and the siting investigation, design, operation and monitoring

1.2 Problem definition

A report by US Trade and Development Agency (USTDA) of June 1999, recommended that the City of Cape Town (CCT) identify a regional landfill to serve the region. The then Cape Metropolitan Area (CMA) appointed technical consultants in 2000 to identify and assess the potential sites for a landfill to service the region for the next 30 years. Waste management consultants were commissioned to undertake the technical aspects of the project and site studies started in April 2001. Other environmental consultants were commissioned to undertake project scoping, public participation, and the EIA (CCA Draft EIR, 2006).

Using landfill siting criteria, the technical consultants identified numerous candidate landfills. After thorough investigations that included numerous site visits the number of sites was narrowed down to four (Personal Communication, 2006). The final scoping report that entailed the four selected sites was accepted by the approving authority, Department of Environmental Affairs and Development Planning (DEA & DP) in May 2004 and EIA in Feb 2005 (CCA Draft EIR, 2006).

With reference to information in the preceding paragraphs, pertinent issues remain unresolved and which this research will attempt to unravel:

- DWAF has guidelines and criteria that have to be followed when looking for prospective landfill sites. Were the criteria followed in order to obtain the prospective sites?
- There are numerous techniques used in studies that involve site selection. Which techniques were used to identify the candidate sites?
- Of the candidate sites that were identified, which ones fall within the CCT?
- According to CCA Draft EIR (2006) the site selection process started in 2001 and the Final Environmental Impact Report (FEIR) was submitted to the approving authority in November 2006. Why did it take that long to identify the sites? What are some of the obstacles were experienced in identifying the sites?

of landfill sites (DWAF, 2005).The requirements are synonymously referred hereafter as criteria.

The need to identify a location for the regional landfill site marks the initial phase of the EIA process that is required to be addressed urgently. Construction of the landfill marks another phase that takes time. Landfill sites have impacts that last the landfill lifespan and beyond. This requires the balancing of time and effort required to carefully carry out the task in accordance with the minimum requirements and other tenets of environmental sustainability. This entails decision-making on both those contracted to carry out site studies as well as approving authorities.

That mentioned, how can GIS be implemented to address some of the obstacles associated with other site selection methods, and in the process expedite decision-making? Can GIS implementation uphold landfill siting criteria and still present viable sites to decision-makers?

This research describes application of GIS as decision support mechanism used to address some of the issues raised in the preceding paragraphs, and to identify the most ideal site for waste disposal facility for the CCT as case study. Yin (1994) defined case study as an empirical enquiry that investigates a contemporary phenomenon within its real-life context. The rationale behind using the case study is to understand the different processes that were involved in the analysis which used multiple sources of evidence.

1.3 Research aim and objectives

1.3.1 Aim

The study aims to investigate criteria and methods used to site landfills, and to apply GIS as a decision support in identifying suitable locations for landfill sites. New landfill site to serve the City of Cape Town (CCT) is used as a case study.

1.3.2 Research objectives

Based on the general aim above, the research proposes to meet the following specific objectives:

- To identify the criteria used to select landfill sites.

- To investigate the methods used to identify potential landfill sites to serve CCT and to establish the sites that were identified.
- To find out the extent of GIS application in the EIA process and in site selection.
- To implement GIS as a decision support in identifying the most suitable site for a regional landfill to serve CCT.

1.3.3 Research questions

To meet the objectives of the research the following questions will have to be addressed. Each objective has respective questions outlined below and which are addressed in various chapters of the thesis.

Objective one: The EIA process, alternatives and site selection

- What is EIA and what purpose does it serve in development projects?
- What are alternatives and what limitations do they encounter?
- Where does landfill site selection fit in the EIA?
- What criteria are used to find suitable sites for waste disposal facilities?

Objective two: Existing methods and identified sites

- What techniques are used in site selection?
- Which methods were used to identify the regional landfill site to serve CCT?
- What are the problems encountered in methods used and which sites did they identify?

Objective three: Decision support and GIS data

- What are GIS and Decision Support Systems (DSS) and what are their functions?
- What is the extent of GIS application in the EIA process?
- What are the drawbacks of incorporating GIS into the EIA process?

Objective four: GIS Implementation case study

- What kind of data would be required in order for GIS to be implemented?

- How can GIS be used as stand-alone method to identify landfill sites, conform to landfill site specifications and still provide credible results?
- Which advantages can GIS offer as compared to other site analysis techniques?

1.4 Research design and data collection

1.4.1 Research design

"The researcher will naturally implement the research design that will be of the greatest value to his research, and that best fits his theoretical orientation," Smith (1995). In this research the case study of identifying a regional landfill is used. According to Garson (2002), case study research is a time honored, traditional approach that illustrates issues of research design. Garson further argues that since only a few instances are studied, the case researcher will typically uncover more variables.

Investigation into the criteria and methods used in determining suitable landfill locations, and the implementation of GIS required some assignments be carried out. To meet the objectives of the research within the context of the questions raised in the preceding section, the following tasks were identified and completed:

Task one: Carry out an in-depth literature review on EIA and landfill siting criteria.
The related issues include:

- Expounding on the EIA procedure in South Africa. This is to provide background information on EIA guidelines and landfill site requirements, and consequently establish where GIS can fit in.
- Carry out a study on alternatives within the EIA context. Site selection entails selection of alternatives based on well stipulated criteria.
- Identify the criteria set out by DWAF that is used in siting landfills. This forms the basis for research analysis. Analysis results are said to be credible if the minimum criteria are met.

Task two: Conducting investigations into existing site selection techniques and sites that were identified as possible locations for a landfill to serve CCT.

The related issues include:

- Carrying out an investigation into the methods and techniques used in site studies.
- Identify the criteria that were used and the sites that were identified as potential landfill sites by conducting qualitative interviews and acquiring information from secondary sources.

Task three: Identify decision support tools, their functions and applications in the EIA.
The related issues include:

- Defining GIS and other Decision Support Systems
- Reviewing the extent and reasons for implementing GIS in the EIA process

Task four: Implementing GIS to find the best location for regional landfill site.
The related issues include:

- Interpreting the minimum requirements for waste disposal by landfill so as to identify spatial data that would be required for the GIS analysis.
- Assembling the database required for the project. This is by sourcing the datasets required from various organizations, in tandem with the landfill requirements.
- Prepare data for the analysis. These include merging, clipping and defining projections. This is due to the fact that datasets are from different sources.
- Analyzing the data in conformity to landfill site guidelines outlined by DWAF.
- Presenting results of each scenario in ArcMap and in layout view.

The first three assignments are addressed by conducting an in- depth review of literature. This involved a closer look at the Environmental Conservation policy frameworks and other scholarly literature relevant to EIA, site selection and GIS applications in environmental management as well as qualitative data collection through interviews. The last assignment that forms the backbone of this research is achieved by performing spatial analysis.

1.4.2 Data collection

Information for this research was obtained from a variety of sources using different methods. A combination of primary and secondary data collection methods were used as outlined below:

- **Research**

This formed the birth of the idea. A review of literature on site studies indicates that GIS techniques, not withstanding its analytical capabilities, are not embraced. Research involved searching for information relevant to the study. Books, journals articles, technical reports and conference proceedings at University of Cape Town (UCT) libraries and internet search engines such as Science Citation Index were used.

- **Interviews**

This formed the basis for primary data collection which makes application of GIS in site studies feasible. Techniques used in siting landfill sites, and their strengths and weaknesses were enumerated, with the backing of technical reports. Three GIS companies based in Cape Town that deal with environmental management as part of their services were approached and senior staff with a wealth of experience in site studies were interviewed using open-ended questions. The interviews were conducted face-to-face using a note-taking and Dictaphone. A list of questions that featured during the interviews is provided in Appendix C.

- **GIS data collection**

Data used to conduct the analysis was obtained from different sources. These included Chief Directorate Surveys and Mapping (CDSM), Environmental Potential Atlas (ENPAT) and University of Cape Town (UCT) GIS research facility. The South African Weather Services was approached to provide data on areas upwind of residential areas as well as where temperature inversion is experienced. The datasets were not available and were thus not used in the GIS implementation as indicated in Table 5.1.

1.5 Scope and limitations of research

A review of literature indicates that decision support refers to a broad class of systems that help in decision-making. The flexibility offered by the term decision support will be exploited so as to realize the goals of this research. In the same breath this research will not draw a distinction between Decision Support Systems (DSS), Spatial Decision Support Systems (DSS) and Decision Support (DS). The terms will be used interchangeably implying the same thing, the common ground being that they are computerized decision support mechanisms. As such GIS is used as a decision support approach for siting landfills.

A field study that focused on interviewing consultants that were contracted by the CCT to identify potential site for a landfill was carried out. This was aimed at establishing criteria and methods used problems encountered and sites identified. According to EIA the public must fully be involved, which can often lead to serious conflicts that may demand judicial interventions. Consultants who were interviewed requested their names not to be disclosed. That said the names of GIS companies and staff who were interviewed will not be disclosed.

There are several credible sources of GIS datasets in Cape Town. These include CDSM, ENPAT, Surveyor General's office, the CCT, Weather Service among others. Datasets from the CCT were not used as they are not comprehensive and do not cover the entire study area in details. On the other hand, procedures that must be followed to acquire data from the Weather Service are time consuming. Apart from lengthy procedures, datasets for areas upwind of residential properties and prevailing wind directions that would be required for the GIS analysis were not available from the weather service. Limited financial resources made it difficult to acquire datasets from private venders. Due to time and financial constrains, datasets used to implement the GIS analysis was obtained from convenient sources namely, CDSM and ENPAT. The datasets obtained are sufficiently accurate to demonstrate the feasibility of GIS implementation as a decision support for siting a landfill.

Most criteria set out by DWAF are not quantified leaving this to the discretion of the analyst. For instance buffer distances from residential areas or from rivers to the potential landfill site were not specifically set out. For the sake of quantifying the criteria so GIS analysis can be conducted, all datasets used in this study will be buffered to a distance of 1000 meters. The only exception is airports dataset, which according to DWAF's criteria the landfill should be 3000 meters away from them. On the same note, detailed explanations on criteria stipulated by DWAF and reasons for setting out the criteria will not be provided in this research.

The landfill site is primarily intended to serve the CCT. That said CCT will be chosen as the study area. Several criteria are set out by DWAF regarding selecting a location for a landfill. Due to the complexity of the criteria, a combination of techniques is implemented by consultants in landfill site studies. This study will be confined to the application of GIS as a stand-alone tool to identify suitable sites for a landfill within the CCT. Plausible sites that touch or lie very close to the boundary of CCT and other municipalities will not be considered.

1.6 Structure of the thesis

This introductory chapter described the development of the research idea and the rationale for undertaking the study. The objectives, research design and scope were presented. Due to the multidisciplinary nature of the thesis, literature reviewed is wide and incorporates three chapters; 2, 3 and 4. The seven chapters that comprise this research are interrelated as shown in Figure 1.2.

Chapter 2 introduces the concept of Integrated Environmental Management (IEM), EIA in South Africa and development of alternatives. The legislative framework and criteria upon which decisions are made regarding location of landfills is also discussed. The set out criteria, which is important for this research is then translated into GIS format in Chapter 5.

Chapter 3 outlines the various techniques used in site studies. The last section of the chapter dwells on field study (interview) findings with regard to the methods that were used to identify suitable sites for the City of Cape Town (CCT). Problems encountered and remedial measures taken, the extent of GIS application and the best sites that were identified are also presented.

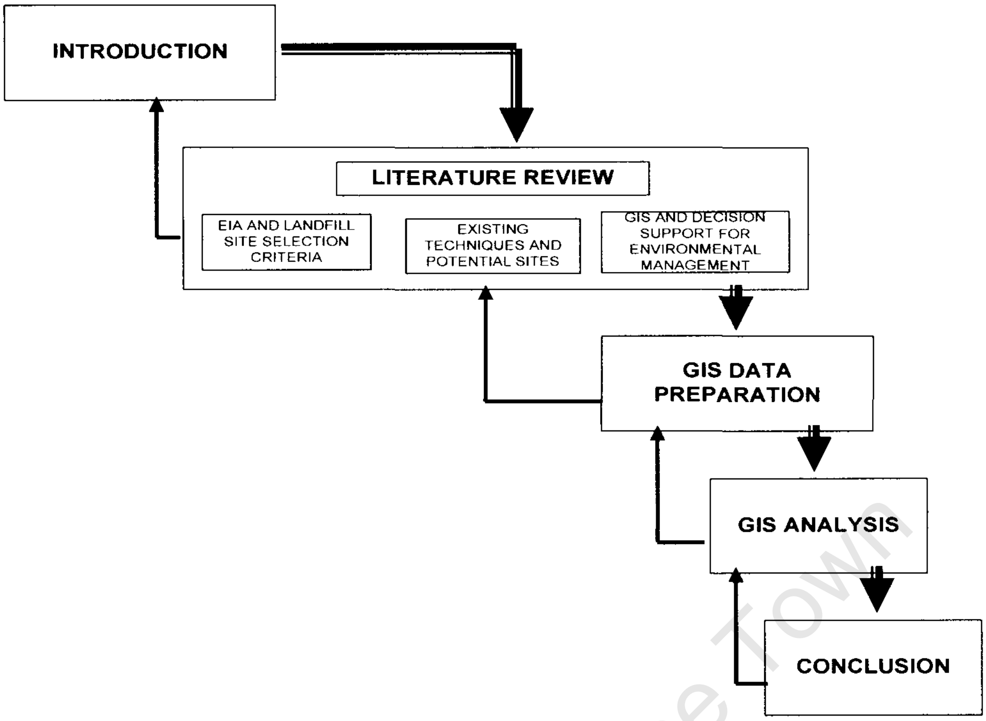

Figure 1.2 Structure of the thesis

Chapter 4 provides an orientation on GIS application in environmental management before embarking on GIS application in site selection. This chapter is divided into two sections; the first section provides the definition and functions of GIS, Decision Support Systems (DSS) and Spatial Decision Support Systems (SDSS). The role and reasons for GIS implementation is also discussed. The second section dwells on GIS and DSS applications in the EIA process. Factors hindering GIS application in EIA are also illuminated towards the end of the chapter.

Chapter 5 describes the tasks that were done in preparation for GIS implementation. Most important is GIS data needs assessment based on criteria outlined in Chapter 2. Data assembly; design and creation of project database as well as data preparation are discussed in this chapter. Chapter 6 entails GIS implementation. A GIS analysis is conducted in conformity to the minimum requirements stipulated by the DWAF. Results of the analysis are also presented.

The last chapter provides conclusions and recommendations of the research according to the structure of the thesis. Future research in implementation of GIS in aiding decision making in environmental management is also presented.

2 Environmental Impact Assessment (EIA) and landfill site selection

Development projects have impacts on the environment, positive or negative. It follows that mechanisms have to be devised to get to know the impacts before the project starts so appropriate action can be taken. Leknes (2001) views Environmental Impact Assessment (EIA) as a tool to help identify potential environmental impacts as well as aid authorities to make the decisions concerning project approval and which conditions must be fulfilled. The EIA process epitomizes alternatives to proposed development projects. Among others, the process lays emphasis on alternatives to the proposed activity as well as alternative location that form the initiation stage of a proposed project. Legislative guidelines have been put in place that guides the selection of potential location of a project, such as the physical location of a landfill site.

This chapter introduces the concept of Integrated Environmental Management (IEM), Environmental Impact Assessment (EIA) in South Africa and development of alternatives. The legislative framework and criteria upon which decisions are made within the EIA context are also presented. The minimum requirements for waste disposal by landfill as stipulated by the Department of Water Affairs and Forestry (DWAF) is discussed. This forms the basis for this research as the requirements set out by DWAF are translated into spatial data (see Section 5.2) that is used in GIS implementation in landfill site selection.

2.1 Integrated Environmental Management (IEM) in South Africa

The Department of Environmental Affairs and Tourism (DEAT) developed IEM, an integrated method of looking in a holistic manner for the complete procedure of environmental development, including the administrative side of the process as illustrated in Appendix A and Figure 2.2. The philosophy of IEM proposes a holistic approach and method to the decision making process and procedure by which a multi-disciplinary analysis and an interdisciplinary synthesis are facilitated (Hugo, 2004). Hugo adds that the purpose of IEM is to mitigate any negative impacts and enhance the positive aspects of project development. Hugo (2004) argues that IEM is an umbrella-like process that includes EIA and environmental auditing, and asserts that it is the process of EIA that lies at the heart of IEM.

2.1.1 Definition, nature and purpose of EIA

Fuggle and Rabie (1996) defined Environmental Impact Assessment (EIA) as the "administrative or regulatory process by which the environmental impact of a project is determined." The Department of Environmental affairs and Tourism (DEAT, 2004) define EIA as a public process, which is used to identify, predict and assess the potential environmental impacts of a proposed project on the environment and is used to inform decision-making.

EIA is a site-specific environmental management tool designed to bring all the relevant detailed information regarding a site specific development to light. This encompasses methodologies and techniques for identifying, predicting and evaluating the environmental impacts associated with project development and actions. On the other hand it is also a procedure for facilitating informed decision-making (Hugo, 2004).

"The purpose of EIA is fourfold: to aid decision-making by providing quality information to decision-makers, to ensure that the positive impacts of a development are enhanced while negative impacts are minimized, to explore ways of solving conflicts that arise between development needs and the environment, and to furnish decision-makers, interested and affected parties with information," Fuggle and Rabie (1996).

2.1.2 The EIA procedure in South Africa

The main steps in South African EIA process can generally be grouped into seven phases as shown as shown in Appendix A. The initial phase entails alternatives. The role of alternatives is to find the most effective way of meeting the need and purpose of the proposal, either through enhancing the environmental benefits of the proposed activity, and or through reducing or avoiding potentially significant negative impacts (DEAT 2004). The EIA places much emphasis on alternatives. For instance in the identification of a landfill site to serve the CCT, it is recommended that more than one site is identified so that the best site where the landfill would eventually be located is obtained after a thorough screening during the EIA process. The issue of alternatives is important for this research and as such more details are discussed in Section 2.1.3.

The second phase is screening which involves pre-application and consultation with the relevant authority once the alternatives are assessed. Screening is the process of determining whether or not an individual project proposal requires a full-scale EIA and what the level of assessment should be. Projects approved (i.e projects that "pass through") as a result of initial application do not require undertaking a full EIA process as portrayed in Figure 2.1.

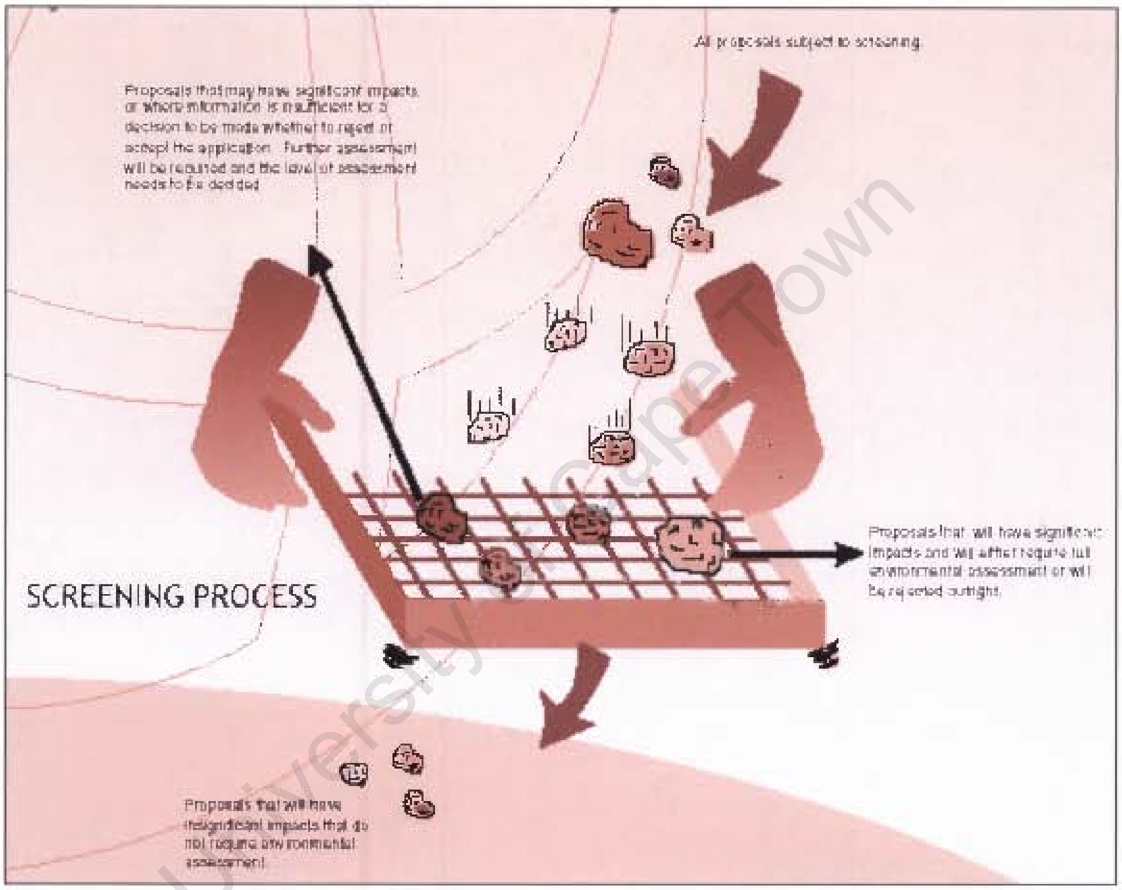

Figure 2.1 The EIA Screening process
Source: DEAT (2002)

Most countries have lists of activities for which EIAs are required and have identified sensitive environments for which EIAs are needed. For instance in South Africa, the Environmental Conservation Act (1989) that has been amended and replaced with the National Environmental Management Act (NEMA) (Act No. 107 of 1998) outlines EIA Regulations and makes provision for two types of environmental investigations in the EIA process namely Basic Assessment and the Scoping/EIA phase. The amended act took effect from 1st July 2006.

According to DEA & DP (2006), Basic Assessment must be applied to activities listed in Listing Notice 1 No. R386. On the other hand Scoping/EIA must be done for all activities listed in Listing Notice 2 No. R387 (refer to Appendix D). Both applications (Basic Assessment and the Scoping/EIA) are informed by guidelines that have been developed by the Department of Environmental Affairs and Development Planning (DEA & DP). Guidelines include how to carry out public participation, decision appeal procedure and submission of exemptions (e.g., exemption from appointing an environmental consultant and exemption from considering alternative activity or location).

Under the NEMA Act 107 of 1998, the establishment of a landfill site falls under Listing Notice 2 No. R387, Sections 1(o), "The construction of facilities or infrastructure, including associated structures or infrastructure or infrastructure, for the final disposal of general waste covering an area of 100 square meters or more or 200 cubic meters or more of airspace" and Section 2 that states, "Any development activity, including associated structures and infrastructure, where the total area of the developed area is, or is intended to be, 20 hectares or more" (DEAT, 2006).

It therefore implies that the full scoping/EIA must be done for the establishment of the landfill. The Scoping/EIA process that has to be followed is outlined in the process flow diagram in Figure 2.2 overleaf. The main phases and tasks undertaken during the EIA process are shown in Appendix A.

In the third phase of the EIA process proponents prepare plan of study for scoping. This phase entails the identification of issues that are likely to be important during the EIA and eliminates those that are not. The scoping report forms the basis for the terms of reference for the next phase that entails EIA report preparation.

In the fourth phase, proponents (EIA consultants contracted by the developer to undertake the EIA process) prepare a plan of study for EIA. The objective of this phase is to identify how the activities of the proposed development will impact on the various components of the environment. The impact assessment entails the identification and analysis of impacts, as well as a prediction of the significance of the impacts.

This phase also include mitigation, which entails the identification of ways in which negative impacts can be avoided and ways in which positive impacts can be enhanced to ensure maximum benefit. Details of impacts and mitigation are contained in the EIA report commonly known as Environmental Impact Report (EIR).

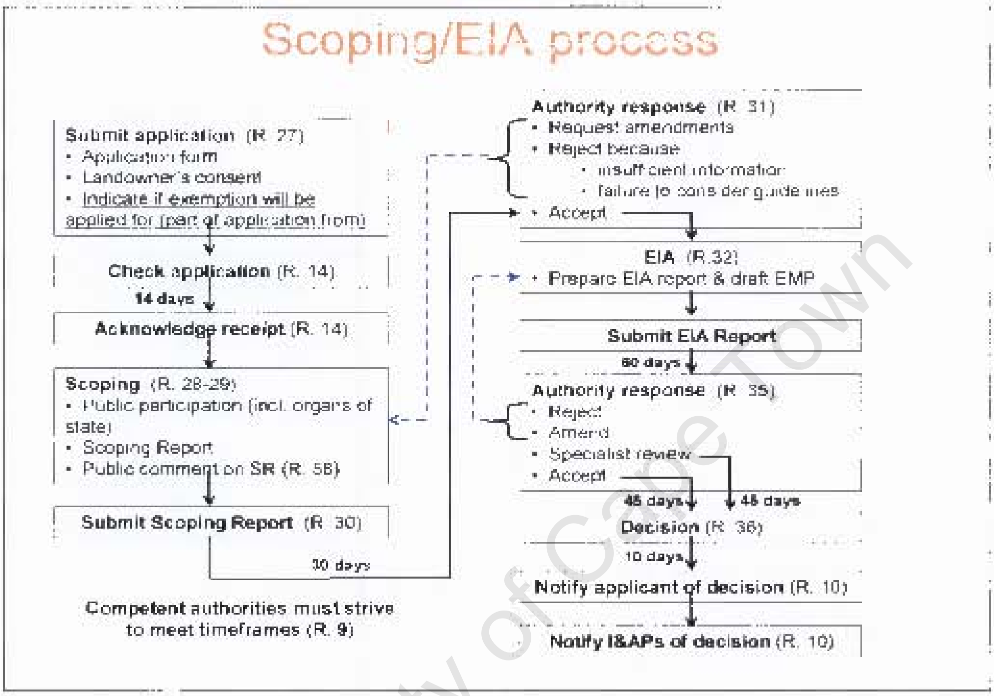

Figure 2.2 Scoping/EIA process flow diagram
Source: DEAT (2002)

In the fifth phase the relevant authority reviews the contents of the EIR. To improve rigour and ensure that relevant information is captured and reflected, the process often includes review by the public and independent specialists prior to finalization and decision-making. The Southern African Institute for Environmental Assessment (SAIEA) is the only institution dedicated specifically to providing a professional external review service in the region (Weaver, 2003). The EIR is used by authorities in decision-making.

The sixth phase entails decision-making which refers to the final approval (by DEA & DP) and authorization of the proposal by DEAT (previously done by DWAF). It usually includes a series of conditions under which development proceed as stipulated in the Record of Decision (RoD). The conditions are translated into the management plan for the project.

The last phase is the implementation and monitoring. If the development is approved, the developer might be required to implement an Environmental Management Plan (EMP) for construction, operation and, in some instances, decommissioning of the project. The EMP is the tool used to ensure that the mitigation actions and the monitoring requirements recommended in the EIA are systematically implemented throughout all phases of the project. This often-neglected aspect of EIA ensures delivery on promises (Weaver, 2003).

2.1.3 Alternatives in the EIA process

DEAT (2006) defined Alternatives as different means of meeting the general purpose and requirements of the activity. The most important part of the EIA process is developing the set of alternatives that become the choice set and the centre of environmental impact analyses. Alternatives are options, choices, or courses of action; they are means to accomplish ends. From the perspective of EIA, these ends include not just a particular agency's goal, but also broader societal goals such as the protection and promotion of environmental quality. The quality of a decision depends on the quality of alternatives from which to choose.

Consideration of alternatives is one of the most critical elements of the environmental assessment process and should be identified as early as possible in the project cycle. Key criteria for considering when identifying alternatives are that they should be 'practicable', 'feasible', 'reasonable', and 'viable' (DEAT, 2006).

Wang *et al* (2003) views alternatives as fundamental to EIA; they encourage open decision-making by virtue of incorporating environmental concerns early into project designs. There are different categories of alternatives in the EIA process. Two of the most important alternatives in the EIA process are activity and location alternatives, both of which are considered early in the project life-cycle. The alternative to the type of activity to be undertaken has been outlined in the background to investigation in Section 1.1.

It is worth noting that in some cases it might not be possible to consider alternative locations for certain activities. For example, in the case of mining, extraction can only occur at the identified location of an ore body. On the other hand alternative sites or a suitable site may not be identified if the area under study does not meet the criteria or minimum requirements unless some compromises and mitigation measures are made. Other than the activity to be undertaken and the property on which or location where it is proposed to undertake the activity, the DEAT (2006) provides other alternatives such as the design or layout of the activity, the technology to be used in the activity and the operational aspects of the activity.

Important to this research is the identification of alternative sites of the proposed activity. In the current study, location alternatives will be given prominence due to the fact that various sites for locating a landfill can be identified based on EIA guidelines and regulations. Alternative sites for the regional landfill to serve the CCT are provided in the GIS implementation. The proceeding paragraphs outline generic problems associated with alternatives and which can be addressed or minimized through GIS application.

2.1.3.1 A general overview of problems associated with development of alternatives

There are problems encountered that create obstacles to the full consideration of alternatives. DEAT (2004) identified three major obstacles namely technological obstacles (where high costs of a particular technology may prevent it from being considered as a viable option); resource availability obstacles (which may limit the range of alternatives in a particular context) and political economy or intellectual obstacles in which barriers may be imposed by people who wish to advance a particular agenda.

Alshuwaikhat (2005) argues that foreclosure of alternatives at the project assessment stage eliminates options, which have potentially different environmental consequences from the chosen one. Alshuwaikhat further lament that decision-making is based on alternatives taken at earlier stages in the planning process, at which no satisfactory environmental assessment may have taken place.

As mentioned earlier, the EIA process under whose structure alternatives lie underscores selection of alternatives such as possible sites for a landfill. Steinemann (2001) outlines problems associated with alternatives as outlined in the proceeding paragraphs.

"Even though agencies are required to take an interdisciplinary approach and explore alternatives outside their jurisdiction, those alternatives may not receive serious consideration," Steinemann (2001). Steinemann argues that alternatives can also be eliminated if they do not meet the stated objectives of the agency.

According to Steinemann (2001), agencies tend to prescribe alternatives that they have used in the past. While this offers agencies both the reduced effort of designing new alternatives and the comfort of familiarity, Steinemann (2001) asserts that by so doing new and perhaps more environmentally suitable alternatives are overlooked thus neglecting the important role of design, adaptation, and creation of new alternatives. He further adds that agencies often put aside new alternatives in favour of common and previously used ones particularly in projects that exhibit similar characteristics. For instance in landfill site studies, agencies may opt to use known locations such as abandoned mines as opposed to searching for new sites that meet set out criteria.

"Alternatives may be 'dummied-up' so that the proposed action appears superior or 'straw men' alternatives may be constructed, only so they can be torn down and thereby add to the perceived attractiveness of the preferred alternative," Steinemann (2001).

The determination of alternatives which make it to the final set occurs in the screening phase. Steinemann (2001) argues that the screening criteria are legally determined by what is reasonable in light of the agency's statement of project purpose and need. Steinemann adds that alternatives are eliminated from further consideration based on weak evaluations, which are not well documented in the EIA. "The reasons for rejection are often one sentence, such as 'not cost-effective.' and since there is little judicial scrutiny of the reasons; an agency need only show that the alternative was not 'reasonable' as it did not meet the objectives as defined by the agency's purpose and need statement" Steinemann (2001).

2.1.3.2 A GIS solution to alternatives development

The problems cited by DEAT (2004) are financial as well as human resource related. Money should be set aside to purchase technology such as GIS that can aid decision-making. To tie with that, personnel ought to be trained on how to implement the new technology. Other problems associated with alternative development, such as those advocated by Steinemann (2001) can be minimized through application of GIS, as long as the criteria set out by approving authorities are followed to the letter. For instance on location alternatives, all the potential landfill sites provided by GIS should be considered as plausible sites unless other salient criteria intervene to identify the most ideal sites.

2.2 Criteria for identification of candidate sites

There are numerous criteria that have to be met when selecting potential sites for a landfill. This section presents criteria upon which decisions are made within the EIA context and more specifically the Minimum Requirements for Waste Disposal by landfill as stipulated by the Department of Water Affairs and Forestry (DWAF, 2005).

2.2.1 Initial site selection approach

According to DWAF (2005), early considerations in site selection are to identify the physical size (area of land required) and the general location of the required site. The size of the site affects the size of the anticipated buffer zone. The cumulative effect of the areas potentially impacted by the disposal site project must be considered and adequate land area must be available beyond the site boundaries to accommodate future buffer zone.

General site selection is determined by the waste generation area(s) to be served. It is economically sound to establish a landfill as close to the generation areas as possible, with a view to minimizing transport costs. The economic radius defines the initial area of investigation, which varies depending on the existing or proposed mode of waste transport. The considerations above, however, are part of criteria discussed in the next sections.

2.2.2 Elimination of areas with inherent fatal flaws

Fatal flaws[1] are situations that may prohibit the development of an environmentally or publicly acceptable waste disposal facility except at excessive costs (DWAF, 2005). It is a minimum requirement that no landfill site can be developed in an area with inherent fatal flaws. There are 18 exclusionary criteria in this fatal flaws category relating to the areas the landfill should be outside of. These include:

- 3000 m from the end of any airport runway or landing strip in the direct line of the flight path and within 5000 m of an airport or airfield boundary. Landfills attract birds creating the danger of aircraft striking birds.
- Areas below the 1 in 100 year flood line. This eliminates areas adjacent to wetlands, vleis, pans and flood plains where waste disposal could cause water pollution.
- Areas in close proximity to significant surface water bodies e.g., water courses or dams.
- Unstable areas. These include fault zones, seismic zones, karst areas where sinkholes and subsidence are likely.
- Sensitive ecological areas. These include nature reserves and areas of ecological and cultural or historical significance.
- Catchment areas for important water resources.
- Areas characterised by flat gradients, shallow or emergent ground water, e.g., vleins, pans, springs etc.
- Areas characterised by steep gradients where stability of slopes could be problematic.
- Areas of ground water recharge on account of topography and or highly permeable soils.
- Areas overlying or adjacent to important or potentially important aquifers.
- Areas characterised by shallow bedrock with little soil cover (also associated with steep slopes).
- Areas in close proximity to land-uses that are incompatible with landfilling, e.g., residential areas, nature reserves and cemeteries.
- Areas where buffer zones are not possible.
- Areas immediately upwind of a residential area in the prevailing wind directions.

[1] Factors or situations which prevents the development of an environmentally acceptable waste disposal facility, except at prohibitive costs (DWAF, 2005)

- Areas that, because of title deeds and other constraints, can never be rezoned to permit a waste disposal facility.
- Areas over which servitudes are held that would prevent the establishment of a waste disposal facility, e.g., Rand Water, ESKOM or road Department servitudes.
- Areas in conflict with the Local Development Objectives (LDO) process and the Regional Waste Strategy.
- Any area characterized by any factor that would prohibit the development of a landfill except at prohibitive cost.

2.2.3 Other criteria for identifying potential landfill sites

While not necessarily fatal flaws, economic, environmental and public acceptance criteria may be critical factors which may represent a severe constraint on the development of a landfill DWAF (2005). Critical factors may become a fatal flaw if it cannot be addressed to the satisfaction of DWAF or its presence should prevent the landfill from meeting a minimum requirement.

Plausible potential sites can be identified once the areas that the landfill site should be outside of are established. The next step is to identify sites that meet other criteria set out by DWAF (2005) as outlined in the proceeding sections.

2.2.3.1 Economic criteria

Economic criteria relate to the cost of obtaining, developing and operating a site (DWAF, 2005). Under economic criteria there are 10 considerations. These include:

- The possible incorporation of the site into the waste disposal system, either immediately or in the future.
- The economies of scale. Larger sites are economically more attractive.
- The distance of the site from the waste generation areas. This is directly proportional to transport costs.

- The size of the operation. A disposal site must cater for the disposal of the waste stream over at least the medium term to justify the capital expenditure.
  In addition to the size of the landfill proper, the anticipated extent of the areas of influence associated with the landfill project and the anticipated extent of the ultimate buffer zone should be considered.
- Access to the landfill site. This has cost convenience and environmental implications, especially if the roads have to be constructed.
- The available of on-site soil to provide low cost cover material. Importation of cover increases operating costs and cover shortage may reduce site life.
- The quality of on-site soil. Low permeability clayey soils on site will reduce the cost of containment liners and leachate control systems.
- Exposed or highly visible sites. High visibility results in additional costs being incurred for screening.
- Land availability and/or acquisition costs. These are dependent on present or future competitive land-uses such as agriculture, residential or mining.
- Other miscellaneous economic or socio-economic issues, e.g., where the displacement of local inhabitants must be addressed.

2.2.3.2 Environmental criteria.

According to DWAF (2005) environmental criteria relate to the potential threat to the biotic and abiotic environment. It is worth noting that some of the considerations under these criteria are similar to that of fatal flaws. These criteria include the following considerations:

- The distance to ground or surface water. The greater the distance, the more suitable the site is in terms of lower potential for water pollution.
- The importance of ground or surface water as water resources. The greater the resource values of the water, the more sensitive the establishment of a landfill on account of the potential for water pollution.
- The depth of the soil on the site. The greater the availability of soil, the more cost-effective it will be for the landfill to meet the minimum requirements for operation.

- The quality of on-site soil. Low permeability soils reduce pollutant migration and are therefore favoured.
- Valleys where temperature inversion could occur. This could promote the migration of landfill gas and odours into populated areas.
- Sensitivity of the receiving environment. The development of a site in a disturbed environment, such as derelict mining land, would be preferable to a development in a pristine environment.

2.2.3.3 Public acceptance criteria

Public acceptance criteria relate to such issues as the possible adverse impact on public health, quality of life, and local land and property values. They also relate to potential public resistance to the development of a waste disposal site. Failure to meet the public acceptance criteria constitutes a fatal flaw. Under this criterion the following are considerations stipulated by DWAF (2005):

- The displacement of local inhabitants. This will usually arouse public resistance.
- Exposed sites with high visibility. These are less desirable than secluded or naturally screened sites.
- The sensitivity of the environment through which the access roads passes. The shorter the distance to the site through residential areas, the more acceptable the site.
- Prevailing wind directions- landfills and other waste management facilities should be sited downwind of residential areas.
- The distance to the nearest residential area or any other land-use which is incompatible with the disposal operation.

2.2.4 Obtaining candidate sites: a DWAF's perspective

By eliminating all areas with associated inherent fatal flaws, and taking note of all the criteria and critical factors, a number of candidate sites can be identified, technically evaluated and compared to determine their acceptability. In the early stages, when there are many candidate sites, a "coarse screening" is carried out to eliminate unsuitable sites and identify top ranking sites using the top ranking matrix (DWAF, 2005).

The matrix is developed with candidate sites on the one axis and selected criteria on the other (refer to Figure 2.3). When using the matrix, each site is evaluated. Scores are assigned for each criterion and added together to provide a total for each site. Sites are then ranked from the highest to the lowest.

Figure 2.3 Example of candidate disposal site ranking matrix
Source: DEAT (2005)

Candidate Site	Economic Criteria					Environmental Criteria					Public Acceptance Criteria					Total Score
	Distance	Size	Available area for buffer zone	Access	Etc	Ground water	Surface water	Soil depth	Setting	Etc	Distance	Visibility	Wind	Buffer zone use	Etc	
Site 1																
Site 2																
Site 3																
Site n																

Once completed, the technical ranking is presented to the Interested and Affected Parties (IAP) for their input and for final ranking. This is then presented in a draft Candidate Disposal Site Report. Once the top ranking sites are identified; they are then compared to one another in a "fine screening" exercise. After that they are further subjected to a more detailed investigation in the form of a feasibility study, done to confirm the environmental and public acceptability of the top site. The requirements for site selection are summarized by the table in Appendix B.

A preliminary EIA is undertaken to re-address all the environmental siting criteria relating to the top ranking site(s). Critical factors are identified, discussed and addressed in the feasibility report. In terms of DWAF's "Minimum Requirements for Waste Disposal by Landfill" the best site(s) are then recommended for a full EIA process.

2.3 Summary

The chapter has looked at the current EIA process in South Africa and problems related to alternative development. The minimum requirements for waste disposal by landfill have also been enumerated. This chapter provided the roadmap this thesis followed. One of the most important items that can be picked from this chapter is the minimum requirements for waste disposal by landfill as stipulated by DWAF. The requirements are interpreted and transformed into GIS format so analysis can be done to identify the most ideal sites for a landfill using GIS. The translation of the minimum requirements for waste disposal by landfill into GIS usable format is discussed in Chapter 5. Before preparing the implementation of GIS to identify potential landfill sites, it is worth looking at other methods used in site studies.

3 Existing site selection techniques and potential regional landfill sites

There are various techniques used in identification of potential sites for development projects. Some are sophiscated while others are simple and based on intuition. This chapter is divided into two sections. The first section provides an overview of common site selection methods. More emphasis is put in the second section, which presents field study findings with regard to methods that were used to identify suitable sites for the City of Cape Town (CCT). Problems encountered and remedial measures taken, the extent of Geographical Information Systems (GIS) application and the best sites that were identified are presented.

3.1 Existing site selection techniques

There are numerous methods that can be used to select suitable sites. The choice of technique will among others, depend on the criteria against which the sites are selected, costs associated with the technique as well as the level of expertise on the part of users. Birkin et al (1996), Jankowski and Nyerges (2001) and Eldrandaly *et al* (2003) present some of the most commonly used methods used in site selection as follows:

3.1.1 Trial and error

One of the simplest in terms of spatial analysis, the trial and error method involves on-site decision of a senior member of staff who gets a 'gut feeling' for a location by walking the entire region under consideration (Birkin *et al*, 1996). Birkin (1996) notes that one obvious drawback with such approach is that it is highly subjective and depends entirely on the experience of decision makers. On the other hand the method is time consuming and expensive.

Davies (as cited in Birkin *et al*, 1996) defends the trial and error method by arguing that it should not be belittled since individuals have the ability to offer good instinctive judgements. Birkin *et al* (1996) add that the importance of site visits does not diminish even when more sophiscated techniques are on offer.

3.1.2 Analogue techniques

The basic approach involves drawing comparisons (analogues) between subjects being studied. This can be done manually or through regression techniques. Birkin *et al* (1996) noted that the success of this approach depends on the experience of the location analyst and his or her team.

3.1.3 Regression techniques

One of the most commonly used statistical techniques is the multiple regression model. According to Birkin *et al* (1996) regression analysis works by defining a dependent variable and correlating it with a set of independent or explanatory variables. Coefficients are calculated to weight the importance of each independent variable in explaining the variation in the set of dependent variables.

The model can be written as

$$Y = a + b_1x_1 + b_2\,x_2 + b_3\,x_3 \ldots + b_mx_{mi}$$

Where

Y	is the dependent variable
x_{mi}	are independent variables
b_m	are regression coefficients
a	is the intercept term.

One of the weaknesses of regression models is that they evaluate sites in isolation and cannot handle spatial interactions. Regression analysis assumes that the explanatory variables in the models are independent of each other and are uncorrelated. This can lead to unreliable parameter estimates and severe problems of interpretation (Birkin *et al*, 1996).

3.1.4 Choice models

Choice models provide assistance in comparing numerous options against each other in terms of criteria in order to select the best options. According to Jankowski and Nyerges (2001), Multiple Criteria Decision Making (MCDM) models are among the most popular, with Analytical Hierarchy Process (AHP) featuring prominently. The scholars view weighted summation as the most popular technique because of its mathematical simplicity. Other techniques noted by Jankowski and Nyerges (2001) include rank order and ideal point, which constructs an "ideal option" by scanning all criterion data values for all options.

3.1.5 Structured-group process techniques

According to Jankowski and Nyerges (2001) these techniques help group interaction by reduce group process loss, i.e. loss of productivity due to wandering social interaction. They provide examples used for structuring computer assisted meetings, which include electronic brainstorming, and other technologies of participation.

3.1.6 Judgement refinement techniques

These techniques detail the character of choices made in relation to the overall pattern of choices. According to Jankowski and Nyerges (2001), Expert Choice is one of the most significant additions to these techniques that are implemented for sensitivity analysis. During sensitivity analysis a criterion weight can be changed relative to other weights.

3.1.7 Analytical reasoning techniques

These include expert systems, mathematical programming packages and more recent, soft computing. According to Jankowski and Nyerges (2001) the basic thesis of soft computing is to imitate the human mind in exploiting the tolerance for imprecision and uncertainty when dealing with complex and imprecisely formulated tasks.

3.1.8 Expert Systems

An Expert System is an intelligent computer program that uses stored knowledge and inference procedures to solve problems that require significant human expertise for their solutions (Eldrandaly as cited in Eldrandaly *et al*, 2003). Expert Systems attempt to solve site selection problems that are heavily dependent on human judgement and experience. Some of the drawbacks of Expert Systems include their inability to generate solutions using spatial data and lack of geoprocessing capacity such as buffering and overlay.

3.2 Regional landfill: a review of existing methods and sites

A field study was carried out to establish whether GIS is used in projects that involve site selection. This took the form of interviews, which sampled a leading GIS consultancy firm in Cape Town that was contracted by the City of Cape Town (CCT) to establish the most ideal site for siting a regional landfill. A senior member of staff with a wealth of experience in site studies, who did not wish his name to be mentioned, was interviewed. The interview questionnaire used was categorized into three subtitles; initial site selection, project data and methods, problems and application of GIS (refer to Appendix C). A summary of the interview findings are discussed in the next sections.

3.2.1 Site selection criteria and approach

According to anonymous respondent (personal communication, 25 January, 2006), various site selection criteria as stipulated by the Department of Water Affairs and Forestry's (DWAF) Minimum Requirements for Waste Disposal by Landfill were used. The criteria entail Primary Exclusion Criteria (PEC), referred to as inherent fatal flaws, environmental, economic and public acceptance criteria. These were discussed in detail in Section 2.2.

The anonymous respondent (personal communication, January 25, 2006) added that the initial search for candidate sites involved meetings and discussions with the relevant authorities and other informed people, accessing CCT web site and review of numerous reports.

An example of a desk study that formed the first part of the inception phase was described. A case in point was a report undertaken by Spoornet in 1996 that was used in the project Terms of Reference as a starting point. The report however concluded that the only available sites were far away from the CCT and as such discarded.

The respondent gave another example of another report by Zietsman dated 1979 that indicated there were feasible sites within or close to the CCT. The report was used in the project. The rest of the desk study involved interviews, meetings and review of reports written by various consultants. Anonymous further added that there were areas that were recommended by DWAF as possible sites for landfills. He gave an example of a case where representatives from the DWAF head office visited De Hoek quarry in October 2001 so that CCT could determine whether it should be short-listed for landfill site or not.

3.2.2 Project data

Anonymous respondent, "Baseline line data that was available included spatial planning and of future developments, heritage sites, zoology, topography, vegetation, geology, transport among others. Baseline data was also sourced from different institutions that are credited for certain type of data. These include academic institutions, government departments and from previous studies. Available data was developed through scoping and screening so as to refine it to suit the requirements of the project," (personal communication, January 25, 2006).

The anonymous respondent emphasized the need to source data from credible sources and provided an example where planning information is best sourced from city planners, economic data from socio-economic department of universities as well as fieldwork. The respondent suggested that basic topographic data can be sourced from the Directorate of Surveys and Mapping; vegetation and sensitive areas data from the Biodiversity Institute, geological mapping from Council for Geoscience and data on water be sourced from DWAF. Credit was given to CCT in terms of detailed and accurate data, particularly on land use boundaries and ownership.

3.2.3 Methods used

According to the respondent (personal communication, January 25, 2006), an internationally accepted method was used. Research on waste management was done to ascertain the use and acceptability of the method. The respondent and the technical team established that in recent years, pair-wise ranking method is regularly used to site landfill facilities. Research on recent papers (2 to 3 years ago) on International Waste Management Conferences was used to identify the most commonly used methods. The respondent quoted the International Landfill Symposium in Sardinia, Italy in October 2005 that demonstrated that pair-wise ranking method is a defensible method.

According to the respondent, unsuitable areas were excluded on the basis of Primary Exclusion Criteria. In order to be defensible, a special ranking model was developed based on the state of the art internationally accepted methodology. Criteria were selected and weighted by a multidisciplinary team using pair-wise comparisons and averages. Weighting was done to determine relative importance of each criterion. For instance groundwater, social impacts distance from generation areas was given more weight.

The sites were then scored on a similar basis for each criterion, using input from specialists. Scoring of criteria involved scoring of the sites in terms of each individual criterion by means of pairwise comparison. To ensure scientific correctness and promote objectivity, the respondent insinuated that it was decided to develop a ranking methodology based on the Analytic Hierarchy Process (AHP), a multi-criteria decision-making approach. Shortlisted sites were compared in terms of the weighted criteria and the AHP scores.

3.2.4 Problems encountered

One of the major problems encountered was availability of data. According to the anonymous respondent (personal communication, January 25, 2006) all the data required for the project was not adequate. The respondent added that the available data was "thin" (i.e., data was patchy, not comprehensive or was incomplete in terms or content and coverage).

This was further compounded by the fact that some data was on a scale of 1:50000 while other was available on a scale of 1:250000 especially data on geology and soils, which in the long run affected the quality of results during the initial stages where overlay technique was used. The data issue was further hampered by inadequacies resulting from obtaining data from third parties especially when original datasets were not available, and generally lack of metadata.

The respondent insinuated that it was decided to develop a ranking methodology based on the Analytic Hierarchy Process (AHP) so as to ensure scientific correctness and promote objectivity. The respondent, however, lamented that the approach had its own problems. The scientific evaluation, comparison and ranking of short listed landfill sites in terms of a number of criteria are a very complex multi-dimensional problem. According to Anonymous (personal communication, January 25, 2006) the method could not be carried out single handedly thus raising issues such as who would be included in the ranking panel, do the weighting and ranking among other responsibilities.

Another problem that was encountered was related to land. Most of the candidate sites that were identified were on privately owned land. This raised the question of land acquisition considering that some land owners were not ready to part with their land. According to the respondent, there was resistance experienced with the communities around the short-listed areas (personal communication, January 25, 2006).

3.2.5 Remedial measures

To address the question of inadequacy of data and methods, the respondent noted that a lot of data had to be generated, and available data reconciled through field validation. The respondent provided an example where a light aircraft was used to fly over the whole study area to check findings and confirm spatial relationships. To ensure better accuracy, negative mapping was done in parallel with field validation, which involved direct observation. Finally, the respondent retorted that in some cases making assumptions becomes inevitable. On sites that fell on privately owned land, expropriation was done. This was done by the CCT on the basis of willing buyer-willing seller (personal communication, January 25, 2006).

3.2.6 Application of GIS

On the application of GIS, the respondent (personal communication, January 25, 2006) said that it was not extensively used. A negative mapping model using digitized GIS data was only used in the initial phase where overlay technology was done, together with field validation to eliminate unsuitable areas.

Regarding non-application of GIS in the entire site studies, the respondent argued that among other setbacks, adequate reliable data for running GIS analysis was not available and that not all site selection criteria are compatible with GIS as the process also entails public participation, whose input are aspatial.

The respondent did however cite several strengths of GIS. These include manipulation of data and presentation, modeling capability of GIS, availability of wide range of data today, translation of one data set to another among other advantages. Despite the aforementioned strengths, Anonymous emphasized that GIS was not used as there were other credible methods that have been in use for many years (personal communication, January 25, 2006).

3.2.7 Suitable sites

According to the respondent (personal communication, January 25, 2006) the initial phase identified a total of 70 sites that could be considered as prospective candidate sites. This was based on recommendations based on the characteristics of the areas, e.g. presence of an abandoned quarry and other land uses that are compatible with landfilling.

After using primary elimination criteria most of the sites were disregarded leaving very few areas. This led the technical committee to search for possible candidate sites beyond the CCT. According to Jarrod Ball and Associates and Africon (as cited in CCA Environmental, May 2006) a total of 29 sites were identified in the areas under consideration. After implementing other site selection criteria four sites were selected.

The sites, ranked in order of preference are Kalbaskraal, Atlantis, Vissershok and Eendekuil. Of the four top ranking sites, only Atlantis is nearest to the waste generation areas and lies within the study area. The other site that is nearer to the waste generation areas and also happens to be the most preferred site is Kalbaskraal, which is located just outside CCT. The relative locations of Atlantis and Kalbaskraal site are shown in Figure 3.1.

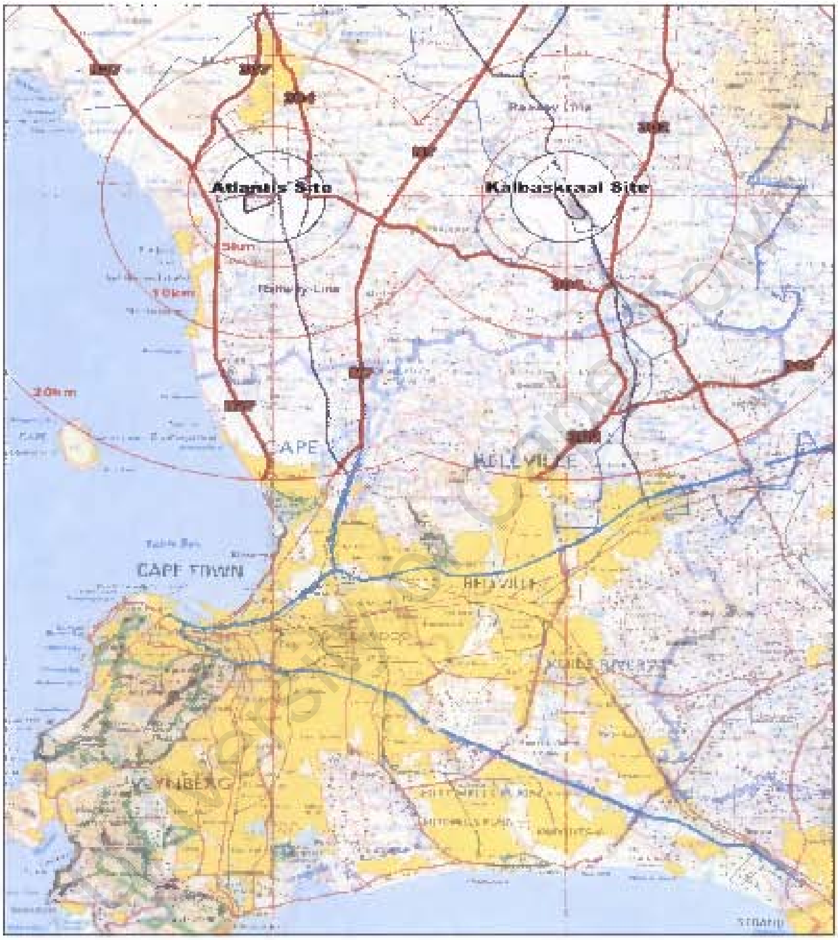

Figure 3.1 Relative locations of top sites (Not to Scale)
Source: Adapted from CCA Environmental (Draft EIR, 2006).

The EIA process emphasizes the issue of alternatives as outlined in Section 2.1.3. Very few sites were identified near waste generation areas. It is for that reason that the technical committee widened their net beyond CCT so they could identify several alternative sites (Anonymous, personal communication, January 25, 2006). All the four sites were recommended for the EIA process.

3.3 Summary

This chapter presented techniques used in site studies as well as field study findings with regard to methods that were used to identify suitable sites, problems encountered and the extent of GIS application. A map showing the relative locations of the best sites that were identified was presented as well. One question emanating from information provided in this chapter is if GIS can be implemented in studies that involve site selection and if the technology can lead to improved EIA process and decision-making. This can be answered by exploring what GIS entails and examining the impact the technology can have on the various components that make up the EIA process. The next chapter discusses GIS and DSS, their potential in abetting decision making.

4 GIS as a Decision Support in Environmental Impact Assessment: a review

The previous chapter presented an overview on various techniques used in site studies other than Geographical Information Systems (GIS) as well as suitable sites that were identified. As an orientation, this chapter introduces GIS and Decision Support (DS) technology as well as their application in environmental management before embarking on GIS application in site selection that will be presented in the proceeding chapters.

This chapter is divided into two sections. The first section provides the definition and functions of GIS, Decision Support Systems (DSS) and Spatial Decision Support Systems (SDSS). The role and reasons for GIS implementation is also discussed in the first section. The second section dwells on GIS and DSS applications in the EIA process. A brief historical background of GIS application in environmental management and EIA is presented. Factors hindering GIS application in EIA will also be illuminated towards the end of the chapter.

4.1 Decision making and decision Support

According to Goel (2000) the process of decision making implies the selection of the best course of action(s) in order to achieve a set of pre-defined objectives within certain constraints. Such a choice of action(s) is made by a decision maker on the basis of logical analysis of facts coupled with his knowledge of the decision making context as well as his experience and intuition. The process involves repeated consideration of feasible alternatives with regard to action, their evaluation, comparison and ultimate selection of the best action. Goel concludes by asserting that decision making process is iterative, integrative and participative.

Decision making issues in a spatial context could be more complex than usual. The process of formulating decision rules in spatial context can be ill structured that it may not be possible to define or model them adequately. A good example can be provided by one of the criteria put forth for siting a landfill site for CMA that the landfill should not be located in any area characterized by any factor that would prohibit the development of a landfill.

In his concluding remarks Goel (2000) argues that in a wider sense a decision support system could be termed as any organizational set up consisting of personnel and other resources which work together in order to provide inputs to high levels using which the management makes decisions. In a restricted sense, Goel refers DSS as a computerized mechanism which tries to emulate human expertise and supports the decision makers' specific on aspects.

4.1.1 Decision support approaches

There are several approaches used to explain decision support. Jankowski and Nyerges (2001) identified analytical and collaborative as the two approaches for decision making. The analytical approach uses mathematical models to analyze structured parts of a decision problem, leaving the unstructured parts for the decision maker. The Collaborative approach views decision making as an evolutionary process that progresses from an unstructured discourse to a problem resolution using discussion, argumentation and voting. The collaborative approach fits very well in the EIA process that emphasizes public participation. There is a decision continuum which ranges from data to information to knowledge as shown in Figure 4.1 below.

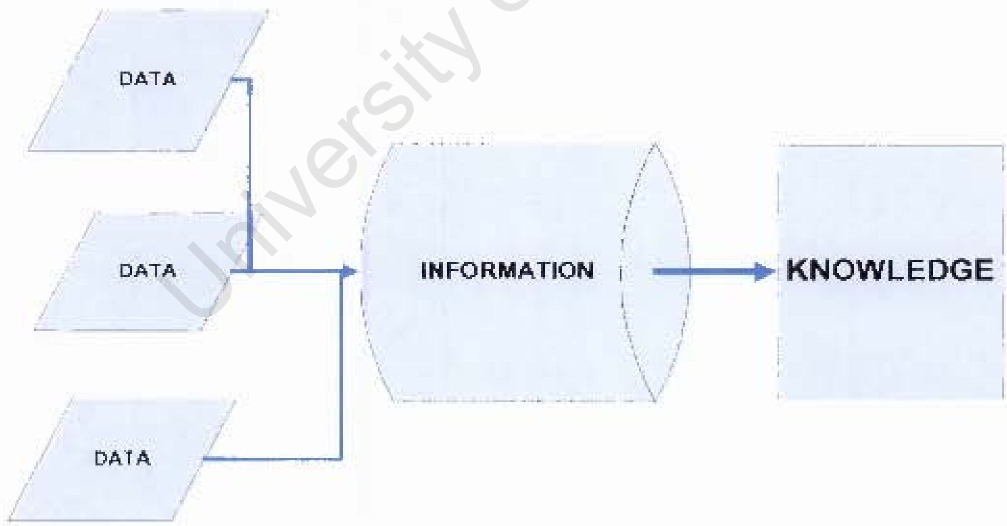

Figure 4.1 A decision making continuum

Source: Adapted from Savitsky, 2000 (as cited in Jankowski and Nyerges, 2001).

4.1.2 Phases of the decision-making process

Simon (as cited in Malczewski, 1997) suggests that any decision-making process can be structured into three major phases: intelligence (a problem or an opportunity for change), design (decision alternatives) and choice (best alternative).

- **Intelligence**

The intelligence phase involves searching or scanning the environment for conditions calling for decisions; exploratory analysis of the decision situation.

- **Design**

The design phase involves inventing, developing, and analyzing a set of possible decision alternatives for the problem identified in the intelligence phase. A formal model is used to support a decision maker in generating a set of alternatives.

- **Choice**

The choice phase involves selecting a particular decision alternative from those available. Each alternative is evaluated and analyzed in relation to others in terms of a pre-specified decision rule which is used to rank the alternatives under consideration. Ranking depends upon the decision maker's preferences with respect to the importance of the evaluation criteria.

4.1.3 The need for decision support

Many scholars provide generalized functions of DSS. Beynon *et al* (2002) postulated three broad categories of tasks performed by an expert and provides constrains of non-application of DSS. The tasks include problem identification, developing alternative solutions and selecting solutions.

In problem identification Beynon *et al* (2002) argues that the problem will typically be presented in broad, imprecise terms pending exploration of the solution space, and the assessment from past experience of possible changes in the environment. In the second task of developing alternative solutions Beynon *et al* (2002) argue that the expert may have no abstract or systematic method of finding solutions. They further add that what is judged to be a satisfactory solution will depend highly upon the specific problem-solving situation, and upon how skilful, fortunate and conscientious the expert has been in their exploration of the situation. The problem-solving activity is typically guided by what is encountered, as it is encountered. Lastly, the expert may not have any explicit heuristic for evaluating and selecting solutions. The criteria applied in evaluation may be qualitative or impossible to preconceive.

Carlsson and Turban (2002) identify three benefits of DSSs to decision-makers, which are summarized as follows. Firstly, decision-makers could, more effectively than before, deal with unstructured or semi-structured, difficult problems which up to that time required extensive experience and expert knowledge. Secondly, decision-makers could make better and more reasoned decisions without using optimization tools and without mastering advanced modeling and lastly decision-makers could start making systematic use of their knowledge and experience in interactive problem solving processes.

4.1.4 Definitions of terminologies

Terms such as Geographical Information Systems (GIS), Decision Support Systems (DSS) and Spatial Decision Support Systems (SDSS) have often been used by different scholars to imply more or less the same thing thus confusing readers. The following sections will provide the definition and characteristics that make them differ from each other. It is envisaged that the definitions will justify why some terms are more used in this paper than others.

4.1.4.1 Geographical Information Systems (GIS)

There are numerous descriptions and phrases put forth by different scholars to define the term Geographical Information Systems (GIS).

Maguire (as cited in Savitsky and Lacher, 1998) lists eleven different definitions some of which place emphasis on the computer processing or analytical procedures. On the other hand, Dickinson and Calkins (as cited in Savitsky and Lacher, 1998) noted that other definitions emphasize the institutional and project context in which the GIS hardware and software reside.

Burrough (1986), defined GIS as a set of tools for collecting, storing, retrieving at will, transforming, and displaying spatial data from the real world for a particular set of purposes. A more comprehensive definition is provided by ESRI (2000), GIS is defined as "an organized collection of computer hardware, software, geographical data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information".

Birkin *et al* (1996) derives the definition of GIS by dissecting the main components of its title. According to Birkin, the term geographical implies data and attributes which have some spatial identity. What defines the term information is its usefulness in decision-making or planning. Lucas (as cited in Birkin *et al*, 1996) view information system as "a set of organized procedures which, when executed, provides information to support decision-making".

Going by the definition offered by Birkin *et al* (1996), it can be inferred that GIS can be a decision support system. This leads to other systems of decision support in the name of Decision Support Systems (DSS).

4.1.4.2 Definition of Decision Support Systems (DSS)

There are several definitions of DSS that have been advanced by different scholars. Carlsson and Turban (2002) noted that early definitions of DSS focused on four novelties: methods and instruments for dealing with unstructured or semi-structured problems; user-oriented systems, which formed a better platform for decision-making; and the separation of data and models in computer applications, which promised to form the basis for more effective modeling.

Scholars such as Shim *et al* (2002) argue that over the past three decades, DSS have taken a broader definition, while other systems have emerged to assist specific types of decision-makers faced with specific kinds of problems. Many changes have occurred in concepts related to DSS as words have been coined, that have more or less the same meaning as DSS. In his contribution Shim *et al* (2002) defined Decision Support Systems (DSS) as computer technology solutions that can be used to support complex decision-making and problem solving.

Other scholars defined DSS differently. Mowrer (2000) defined DSS as computer-based systems that integrate data sources with modeling and analytical tools; facilitate development, analysis, and ranking of alternatives; assist in management of uncertainty; and enhance overall problem comprehension. Keen and Morton (as cited in Chenoweth, Dowling and Loius, 2004) defined DSS as computer-based systems designed to support decision makers and usually include a database and a model base.

Alter (2004) avoids using the term DSS and defines Decision Support (DS) as the use of any plausible computerized or non-computerized means for improving sense making and/or decision making in a particular repetitive or non-repetitive business situation in a particular organization. Fedra and Feoli (1998) views DSS as a mathematical technique or a set of techniques for optimizing something under some constrains. In its broad meaning, DSS is considered as a system that can be used to support decisions.

Going by the varied applications of DSS, the definition by Shim *et al* (2002) and that of Carlsson and Turban (2002) are preferred as they are not restrictive in purpose and by virtue of their comprehensiveness in scope. The definition concurs with earlier definition of GIS. For instance Cowen (as cited in Chenoweth, Dowling and Loius, 2004) defines GIS as decision support system that involves the integration of spatially referenced data in a problem-solving environment. The flexibility in the definition by Alter (2004) who views decision support as a mechanism for improving decision-making is also preferred.

4.1.4.3 Spatial Decision Support Systems (SDSS)

Integration in GIS does not only imply data integration but with other systems as well. According to Dutta (2001) the integration of DSS and GIS gave birth to the concept, Spatial Decision Support Systems (SDSS) as shown in Figure 4.2.

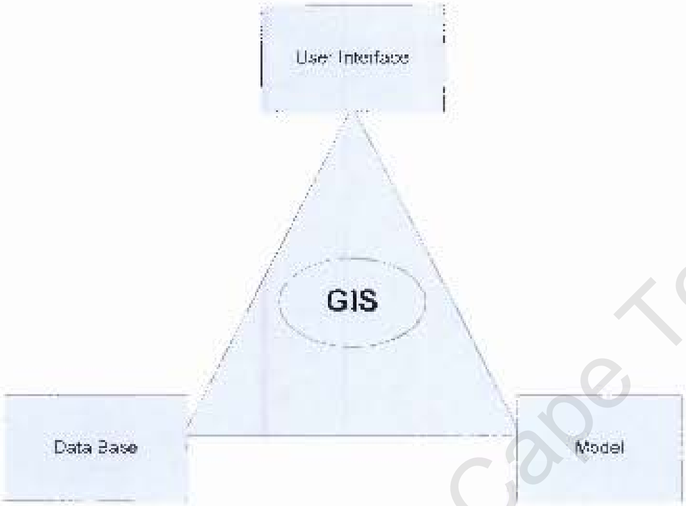

Figure 4.2 Components of SDSS
Source: Adapted from Dutta (2001)

Malczewski (1997) defined SDSS is an interactive, computer-based system designed to support a user or group of users in achieving a higher effectiveness of decision making while solving a semi-structured spatial decision problem.

4.1.5 Functions and capabilities of GIS and DSS

Hess, Rubin, and West (2004) present several technological capabilities of GIS softwares implemented in most GIS packages. Firstly, GIS are capable of storing, manipulating, and displaying rich set of attribute information. One of the most obvious capabilities of GIS software is the ability to visually display the locations of geographic objects. According to Smeleer and Carmel (as cited in Hess *et al*, 2004) the ability to display computer system data graphically has been shown to be an important decision making aid in any information system and GIS are particularly well suited to this purpose when the data of interest has a geographic component.

Another powerful capability of GIS software is the ability to compare the locations of two objects and determine if: the two objects intersect in any way, one object completely contains or is completely contained by the other or if one object is within a specified distance of the other. Further, GIS can find the closest object in a theme to another specified location. Finally, GIS are able to perform powerful database operations such as aggregations and joins based on spatial proximity. (Hess *et al*, 2004).

The potential of GIS is best illustrated by what it can offer in terms of spatial analytical functions (Birkin et al, 1996). Birkin *et al* (1996) provides the functions of GIS under five headings:

- Data storage, retrieval and display
  One of the major advantages of GIS is the ability to store and integrate different datasets within a single system. One of the major ability of GIS is presentation mapping.
- Data linkage
  Data linkage is one of the most fundamental methods of adding value to data. According to (Birkin *et al*, 1996) this is achieved through various GIS capabilities such as polygon overlay and spatial buffering.
- Geocoding and geosorting
  Birkin *et al* (1996) argues that once data has been geocoded (given spatial reference) then the GIS can perform a number of special queries (geosorting).
- Network analysis
  This component of GIS is commonly used in utilities and transportation. Major application areas of network analysis include car navigation systems and global positioning systems (GPS).
- Spatial analysis.
  According to ESRI (2000) spatial analysis is the study of the locations and shapes of geographic features and the relationships between them. It is the process of modeling spatial data and examining and interpreting the results. It is useful when making predictions, and for gaining a better understanding of how geographic features and phenomena are located and distributed.

With reference to the various definitions of DSS, the functions and advantages of DSS encompass those of computer-based information technology, which are numerous. Functions include those offered by GIS as outlined by early definitions by scholars.such as Burrough (1986). Going by the functional definitions offered by Burrough (1986) and other scholars, a DSS should exhibit similar functions.

Fedra (as cited in Matthews *et al*, 1999) suggests that a DSS should support four functionalities of GIS namely; selection and generation of background and thematic maps in various display styles; access to spatially distributed data including model input and saved model scenarios; display of model output as animations and to support comparative analysis of alternative scenarios.

Shim *et al* (2002) adds that one of the critical functions of DSS is to provide system induced decision guidance for proper model formulation and solution. They further suggest that a DSS should make decisions, or at least recommendations, regarding what models should be executed to solve problems most effectively and this information should be generated inductively and used deductively. This information then becomes the meta-model to induce the user to make appropriate choices. Shim *et al* (2002) concludes by asserting that a DSS should execute different formulations of the problem that lead to satisfying solutions guiding DSS users in finding the best approach to solve complex problems.

In his contribution to the discourse on functions of DSS, Vahidov and Elrod (1999) suggests that DSS should watch user's actions and provide proactive feedback to the user, provide both negative and positive critique, substantiate the critique if necessary, be able to deal with violation of "soft" constraints, adapt critique to user's profile and be able to stress diverse processes. In support of Elrod's opinion, Alter (2004) suggests that DSS software be developed to improve planning, production, controlling operations, and identifying and responding to defects.

Another important function of DSS is Data Warehousing (DW). Hess *et al* (2004) argues that data in the DW is not linked to the organization's production databases and users cannot make changes to the data though they can copy it to their personal computers and manipulate it there.

Reformatting may include storing summarized data in addition to raw data. Data may also be stored in a format that makes sense to the expected users rather than in the fragmented formats that support operational efficiency in a transaction-oriented database.

4.1.6 Reasons for implementing GIS

Many scholars (e.g., Korte, 1997; Jankowski and Nyerges, 2001; Prastacos and Diamandakis, 2000; Malczewski, 1997) provide numerous advantages of implementing a GIS. Korte (1997) noted six major benefits provided by GIS. These include: secure and organized data; easy update of information; different maps can be created depending on the need (thematic maps); easy analysis and display of analysis results; easy data sharing between and within organizations and increased productivity.

Jankowski and Nyerges (2001) identify decision support capabilities as the main reasons for GIS implementation. These decision capabilities include:

- Information management:-GIS can handle large amount of data. Prastacos and Diamandakis (2000) view GIS as database management systems for spatial data as they contain analytical functions such as overlay, buffering and neighbourhood analysis.
- Visual aid:-multimedia support is appearing in GIS packages, as indicated by photo and sound manipulation capabilities. Charts, diagrams and tables may be linked to those representations to enhance information presentations.
- Group collaboration support: - techniques that support basic communication. The capabilities make use of hardware technology that includes using data and voice transmission, electronic voting, electronic whiteboards, computer conferencing, and large screen displays. Examples of GIS-support collaborative decision making software packages include INDEX, Smart-Places E and GoeChoice-Perspectives.
- Options modelling:-options in spatial decision making are associated with locations. Location decision options are typically implemented in GIS by means of exclusionary screening procedures. These include selecting location criteria, generating individual suitability maps for each criterion, combining suitability maps through Boolean overlay or weighted linear combination.

With reference to the three phases of decision making presented earlier by Malczewski (1997) in Section 4.1.2 GIS can play a major role in decision making. In the intelligence stage of spatial decision-making, Malczewski (1997) argues that GIS can play a vital role by coordinating decision situation analysis through its ability to integrate and explore data and information from a wide range of sources. Besides, GIS can effectively present information in a comprehensive form to the decision makers. According to Malczewski (1997) the design capabilities of GIS for generating a set of alternative decisions are mainly based on the spatial relationship principles of connectivity, contiguity, proximity and the overlay methods. The use of GIS in the choice phase is the ability to incorporate decision maker's preferences in the decision-making process.

4.2 GIS and Decision Support Systems application in EIA.

Research by various scholars has indicated that application of GIS has not taken root in environmental management especially in developing countries. More recent studies have shown that the extent to which GIS is applied in environmental management continues to rise particularly in the last decade. In the 1990s GIS was widely used in environmental management as demonstrated by the acceptance of GIS as appropriate technology for handling environmental information by its reference and recognition in Agenda 21of the UN (1992) in Rio de Janeiro (as cited in Vanderhaegen and Muro, 2005).

4.2.1 GIS application in environmental management: a historical perspective

Vanderhaegen and Muro (2005) underscore the work of McHarg (1969) who advanced the idea of environmentally sensitive planning using the overlay technique that later became one of the major analysis techniques. According to GIS World (as cited in Antunes *et al,* 2001) a computerized format of analysis technique was developed in early 1970s. Munn (1975) asserts that the first GIS system evolved in the late 1960s and by the mid 1970s they were already being used for EIA.

The overlay technique was adapted to a computerized environment by 1972 and used for siting power lines and roads. Griffith (1980) provides an example of early GIS application.

Griffith (1980) noted that one of the applications of the so called "First GIS" (Canada GIS) was in the preparation of EIA for a dam on river Thames in the late 1970s where it was used to obtain an understanding of the association between agricultural and recreational land utilization and the project.

The transition to GIS centred modelling happened during the 1980s when GIS became the tool for environmental modelling (Haklay, 1998). In the 1990s, the acceptance of GIS as appropriate technology for handling environmental information is widely recognised as demonstrated by its reference in the Agenda 21 of the UN (Vanderhaegen and Muro, 2005).

4.2.2 Why use GIS in the EIA process?

The earliest methodologies for the preparation of environmental assessments relied on checklists and matrices to tabulate the environmental elements, project actions, dependencies between ecosystem components, or to rank and weight project alternatives. The major limitation of such data forms is the missing spatial dimension.

Antunes *et al,* (2001) asserts that given the spatial nature of many environmental impacts, GIS can have a wide application in all EIA stages. The applications range from generation, storage, and display of the thematic information to impact prediction and evaluation for decision support. In the EIA process, Antunes adds that GIS is used for managing data, making map overlays and analysis, sourcing data sets for mathematical impact models, habitat and aesthetic analysis, and public consultation.

According to Joao and Fonseca (as cited in Antunes *et al*, 2001) the most frequent use is presentation of results, followed by modeling and data preparation. GIS have also been used for the presentation environmental baseline information and project description, through the preparation of thematic maps for the several environmental descriptors. Overlay of baseline information maps with project layouts is frequently used for impact identification.

The development of GIS has brought with it many advantages in EIA process. The advantages of GIS include the ability of these systems for storing and accessing of large data sets and performing multiple map overlays and a number of different scenarios can be investigated quickly and efficiently (Hugo,2004). Butcher (as cited in Vanderhaegen and Muro, 2005) argues that the EIA process involves the consideration of many different variables and phenomena presenting complex interrelationships, which vary in time and space.

Butcher views GISs as ideal tools for the analysis of these environmental phenomena with spatial and temporal dimensions. Other scholars such as McConnachie concur with Butcher on the issue of ability and capabilities of GIS. McConnachie (as cited by Vanderhaegen and Muro, 2005) argue that GIS has the ability to store, integrate, analyse and display data, so it can be employed for data preparation, spatial analysis and presentation of results. The advantages of employing GIS include the power of managing and organising spatial data, the good visual capabilities and the ease of changing and updating the information. McConnachie further adds that the use of geo-spatial techniques in environmental studies offers other advantages when compared to conventional procedures, such as identification of spatial and temporal variability of the impacts.

Petil *et al* (as cited in Vanderhaegen and Muro, 2005) adds that use of geo-spatial techniques in environmental studies offers other important advantages when compared to conventional procedures, such as identification of spatial and temporal variability of the impacts. While conventional methods can only assess impacts at a particular location and at a particular time, GIS allow detecting the extent of pollution across larger areas.

GIS can integrate very well with other technologies. These include remote sensing, photogrammetry and CAD, which can conveniently be used in collection, management and analysis of data, and visualize the results of assessment. Vanderhaegen and Muro (2005) note that because of their capacity for data integration and spatial analysis, GIS applications are very good tools to identify assess and present the environmental impacts of plans and projects.

4.2.3 Drawbacks of incorporating GIS into the EIA process

The incorporation of GIS into the EIA process has been slow and can be attributed to various factors. João (1998) observed that while GIS was widely utilized in EIA, its use was largely limited to the basic GIS functions such as map production, classic overlay, or buffering.
Scholars such as João and Fonseca (as cited in Haklay *et al*, 1998) conducted a survey on why GIS is not widely used in practice and noted the following limiting factors:

- The first is the substantial time and cost required for setting up a GIS, compiling the necessary data, and analyzing the system's output. In many cases EIAs are done by private consultants operating in a highly cost-competitive market where they tend to be relatively low-budget projects that may not create the necessary surplus to fund the fixed cost of GIS.

- A second factor that raises the fixed cost of GIS is the need for specialized personnel. High-quality training and technical expertise are needed to operate a GIS and to maintain it. When using GIS for EIA, the personnel would need to be versed not only in the technical side of GIS operation and maintenance, but also in the environmental issues it would address.

- A third feature of GIS that hinders its use for EIA is the lack of digital data, the cost of such data, and often its level of accuracy. This reduces the possibilities for using GIS for low-cost, small-scale projects such as local EIAs. On the other hand, many GISs are not accurate enough due to: limitations of the photogrammetric process; errors in the process of digitizing existing maps; inaccuracies inherent in the maps; the incorporation and use of maps of different scales; and different levels of cartographic representation and cartographic generalization.

Vanderhaegen and Muro (2005) lament that despite the benefits of GIS use in the preparation of environmental studies: utilization of spatial data has not reached its full potential. They cited several barriers that limit the widespread use of spatial data among practitioners of environmental assessments. These include the obstacles to access the existing spatial data, the unavailability of some data, the difficulties to integrate data from different sources and the time and costs needed to perform spatial analysis. These problems represent significant constraints for the analysis of impacts during the preparation of EIA reports.

4.2.4 Sampling GIS implementation in EIA: an overview

There are many areas where GIS has been implemented in the EIA process and in environmental management in general. For example, GIS have been used for the assessment of impacts in specific environmental components, namely for the evaluation of landscape impacts, where GIS are used to generate views from particular points of the scenery for the project alternatives, to perform visibility analysis for structures such as electricity poles, or to evaluate effects of alternative routes for high tension lines (Davidson, 1992).

Rivas *et al* (1994) present a methodology for the evaluation of impacts of land-use plans, based on computation of impact indices obtained by the overlay of the proposed land-uses with thematic maps. Smit and Spaling (1995) refer to several studies where GIS have been applied for the evaluation of cumulative effects through time series analysis. Sankoh (1996) and Sankoh *et al* (1993) applied two EIA methods (ecological risks and utility values analysis) to generate space resistance maps, which allow the identification of route alternatives that present minimum conflict with the environment.

On the other hand, DSS has been implemented in many domains. Maniezzo *et al* (1998) provide a classic example of Decision Support for siting problems. Haastrup *et al* (1998) presented the decision support system for urban waste management. More recent studies are by Murty *et al* (2005) who provide a DSS for operations in a container terminal. The goal of the decision support by Murty is to minimise the berthing time of vessels, resources needed for handling workload and waiting time of customer trucks. It was also aimed at decongesting the roads, storage blocks and docks inside the terminal; and making the best use of the storage space. Recio *et al* (2005) analysed the impact of water restriction policies using a DSS. The DSS was aimed at searching new software tools for managing water resources in the agricultural environment.

4.3 Summary

Most conventional methodologies used in environmental assessments are cumbersome and time consuming as a consequence of missing spatial dimension. Due to their flexibility and compatibility, new computer based technologies such as GIS and DSS can be implemented to augment conventional EIA. Other reasons for GIS implementation as well as factors for non-implementation have been highlighted.

In concluding the chapter, support goes to the sentiments expressed by Keen and Mouton (as cited in Chenoweth *et al*, 2004) who argues that Decision Support technology itself is not important but the support it provides. The usefulness of technology is attributed to its ability to contribute to the solution of problems of real life situations such as in identifying suitable sites for a landfill based on set out criteria.

5 Landfill site selection: GIS data assembly and preparation

5.1 Introduction

The minimum requirements for waste disposal by landfill by the Department of Water Affairs and Forestry (DWAF) and existing techniques that were used to identify the landfill to serve the City of Cape Town (CCT) have been discussed in chapter two and three respectively. Chapter four provided an overview of techniques used in site studies and use of Decision Support (DS) tools in Environmental Impact Assessment (EIA). An alternative approach for landfill site studies using GIS is proposed. Identifying suitable sites for the landfill using GIS involve various assignments. These include conducting GIS data needs assessment based on the criteria set out by DWAF, assembling, designing and creating project database and preparing data for analysis. This chapter details the assignments done in preparation for GIS implementation.

5.2 GIS implementation: needs assessment and design of project database

The first major assignment was to identify the spatial data needed for the analysis was identified, based on the minimum criteria for siting landfills as stipulated by DWAF and discussed in details in Section 2.2. The datasets that were identified are summarized in Table 5.1. It is worth noting that the four categories of requirements namely fatal flaws, environmental, economic and public acceptance criteria do overlap. On the same note, some datasets such as land use, and groundwater, among others are used to satisfy more than one criterion.

The next step was to identify sources of GIS data. Going by the advice given during fieldwork (interview sessions), that it is a good idea to use data from credible sources. Two major sources were identified namely The Chief Directorate of Surveys and Mapping (CDSM) and Environmental Potential Atlas (ENPAT) (GIS Data miners who provide natural/environmental and socio-economic datasets). From the Meta data provided, the source of ENPAT datasets include the Department of Environmental Affairs and Tourism (DEAT), Chief Directorate: Surveys and Land Information (CDSLI), the Council for Geosciences, Cape Nature Conservation (CNC) and Institute for Soil, Water and Climate (ISWC).

The other source worth mentioning here is the GIS Research laboratories (University of Cape Town), who are university's custodians of GIS data from CDSM, ENPAT among other sources. Database design for the project was done by identifying dataset and any attributes required for each criterion, and to identify layers that meet project needs as shown in Table 5.1. An inventory of the available data to determine layers that correspond to the required datasets was created.

Table 5.1 Layers assembled for the project database
Adapted: From minimum requirements for waste disposal by landfill, DWAF (2005).

CRITERIA	DATASET REQUIRED	SOURCE
Fatal flaws		
3000m from any airport	Airports	CDSM
Areas below one in 100 year floodline	Flood prone areas	CDSM
Proximity to significant surface water bodies	Significant wetlands/ Rivers	CDSM
Unstable areas.	Disaster/Risky areas	CDSM
Sensitive ecological areas	Parks/N. Reserves/Protected Areas	CDSM
Steep gradients areas	Contours/landscapes	CDSM
Areas with shallow or emergent ground water	Ground water/wetlands	CDSM
Catchment areas	Catchment/watercourses	ENPAT
Ground water recharges on account of permeable soils	Soils/Sedimentary/Leached Soils	CDSM
Areas adjacent to aquifers.	Groundwater	CDSM
Factor that would prohibit landfill development	N/A	N/A
Conflict with local development strategies	Cadastre	ENPAT
Areas servitudes are held – No landfilling	Special facility	CDSM
Zoned areas with title deeds	Cadastre	ENPAT
Areas upwind of a residential area	N/A	Unavailable
Areas where buffer zones are not possible.	Land use	ENPAT
Areas close to incompatible land-uses	Land use/ mining/quarries/heritage sites	ENPAT

Shallow bedrock with little soil cover	Geology/Soil depth	ENPAT
Economic criteria		
Possible incorporation into the waste disposal system	Waste sites	CDSM
Displacement of local inhabitants	Land use	ENPAT
Land availability/acquisition costs.	Vacant land	ENPAT
Exposed or highly visible sites	Elevation	ENPAT
The available of suitable soil on site	Soils	ENPAT
The size of the operation (medium to long term)	N/A	N/A
Access to the landfill site.	Roads/railway	ENPAT
The quality of on-site soil.	Soils	ENPAT
Distance from waste generation areas	Towns (Athlone)	CDSM
Size. At least 100 hectares	Cadastral	CDSM
Environmental criteria		
The distance to ground or surface water.	Groundwater/Rivers	CDSM
Sensitivity of the receiving environment.	Parks/N. Reserves	CDSM
Where temperature inversion could occur.	N/A	Unavailable
The quality of on-site soil.	Soils	ENPAT
The depth of the soil on the site.	Geology/soils	ENPAT
The importance of ground or surface water	Ground water	CDSM
Public acceptance criteria		
The displacement of local inhabitants	Land use/residential/areas of social significance	ENPAT
Land-use compatible with landfilling.	Land use/mining/quarrying	ENPAT
Prevailing wind directions	N/A	N/A
Sensitivity of environment through which access roads passes.	Transport	ENPAT
Exposed sites with high visibility.	Elevation	ENPAT

5.3 Preparing data for analysis

ArcGIS supports both file-based feature models such as shapefiles[1] and coverages[2], as well as database Management Systems (DBMS). Shapefiles are useful in mapmaking as well as in analysis (ESRI, 2000). Datasets obtained from CDSM and ENPAT were in shapefile format and as such they were retained in that format. However the datasets differed in terms of scale, geographical extent and geographic coordinate systems.

The study area being small in size as compared to the rest of the world, Transverse Mercator projection was preferred. According to ESRI (2000) one of the strong points of Mercator projection is that all local shapes are accurate and clearly defined. Since the projection uses a meridian as contact tangential, the projections of all datasets were projected to Transverse Mercator, the Central Meridian being that of Cape Town, 19^0 E.

Datasets from CDSM were in 1: 50 000 scale and were in tiles that covered the Western Cape Province as well as most of the southern part of South Africa. This required the tiles that cover the study area to be identified and merged[3]. After merging the datasets had to be clipped[4]. On the other hand, datasets from ENPAT covered the Western Cape geographical area and according to metadata that accompanied it, the scale was 1: 250 000 and the coordinate system was that of Albers Equal Area. The datasets had to be clipped and re-projected to the corresponding projection of the input dataset that covers the entire study area. Re-projecting the clipped datasets into Transverse Mercator was necessary so it could align with that from CDSM.

Although some of the data was usable as is, most of it required additional processing and automation. In preparing data for analysis, converting data between formats such as from vector format to raster format was done with the aid of ArcGIS tools. This was aimed at making available data usable during analyses that use ArcGIS extensions such as 3D Analyst and Spatial Analyst.

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[1] A vector data storage format for storing the location, shape, and attributes of geographic features.
[2] A coverage stores features as a set of thematically associated data considered to be a unit.
[3] Appending the features of two or more layers into a single layer.
[4] To extract input features {Southern Africa dataset} that overlay the clip features {CMA dataset}.

For instance the CDSM contour dataset was used to create a Digital Elevation Model (DEM), which was required in visibility analysis. ArcGIS analysis tool, 3D Analyst, was used to derive slope using the DEM that had been created.

It is worth mentioning that the various processing and geoprocessing[5] operations that were done on each dataset depended on the source and the nature of criteria that had to be met. For instance, from the economic criteria, sites that would fall on vacant land would be favoured.

It is not logical to buffer dataset on vacant land as adjacent privately owned can not be said to be vacant. As mentioned in the introductory remarks in Section 5.2, it is worth acknowledging that one type of dataset can satisfy several criteria (e.g., land use and soils dataset) as indicated in Table 5.1. The nature of processing that was done on each dataset in preparation for the analysis is summarized in Table 5.2 on the next page. Other minor preparations include changing the symbology, editing attribute tables by deleting redundant fields as well as freezing important ones. Freezing is locking a field to the leftmost column in table view so as to always see the field when the table is scrolled.

[5] A GIS operation used to manipulate data stored in a GIS workplace e.g., overlay, feature selection and analysis, topology processing and data conversion.

Table 5.2 Dataset processing

DATASET	DATA PROCESSING
Airports	Buffer 3km
Flood prone areas	Buffer 1km
Significant wetlands/ Rivers	Clip, projection change and buffer 1km
Disaster/Risky areas	Buffer 1km
Parks/N. Reserves/Protected areas	Clip, projection change and Buffer 1km
Contours/landscapes	Clip, projection change and Buffer 1km
Ground water/wetlands	Buffer 1km
Catchment areas/watercourses	Clip, projection change and buffer 1km
Soils/Sedimentary/Leached soils	Clip and projection change
Groundwater	Clip, projection change and buffer 1km
Cadastre	Clip and projection change
Special facility	Merge,clip,projection change and buffer 1km
Size/polygon	Buffering
Landuse/ Mining/quarries	None
Geology/Soil depth	Clip and projection change
Waste sites	Merge, Clip and change projection
Land use	None
Vacant land	Clip and projection change
Soils	Clip and projection change
Roads/railway	Merge, Clip and projection change
Soils	Clip and projection change
Towns	Clip and projection change
Parcel/polygon	None
Groundwater/Rivers	Clip, projection change and buffer 1km
Parks/N. Reserves	Clip, projection change and buffer 1km
Soils	Clip and projection change
Geology/soils	Clip and projection change
Ground water	Clip, projection change and buffer 1km
Land use /residential	None
Land use/mining/quarrying	Clip and projection change
Transport	Merge, clip and projection change.
Elevation	Clip, projection change and buffer 1km

5.4 Project Catalog

ArcCatalog is a tool for browsing, organizing distributing and documenting GIS data. It makes accessing and managing data easy (ESRI, 2000). The catalog was used in a number of ways: it was used to preview all the datasets shown in Table 5.1 that was gathered from various sources. It was then used to delete some of the datasets that were not required for the analysis. The catalog was also used to make connections and preview the required data that had been stored in project folder and subfolders. The Metadata tab of the ArcCatalog was used to establish the data type and geographic coordinate system and subsequently used its Toolbox to change coordinate systems of some of the datasets.

The datasets had names that had little meaning for the analysis. The ArcCatalog was also used to edit the names. Once the data set were obtained they were categorized into three classes and then put into a single project folder which had subfolders to store datasets that would be required for each phase of the analysis as shown in Figure 5.1. A single project folder and subfolders to hold the datasets were created. The project folder was organized in a single branch of the catalog tree in order to make it easier to find the data needed during the GIS analysis.

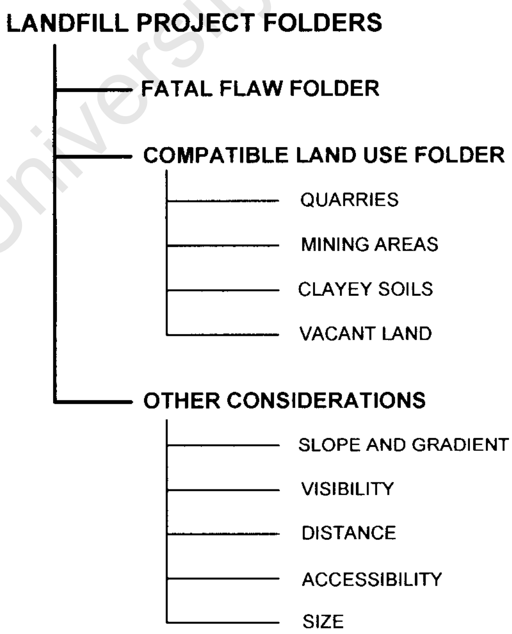

Figure 5.1 Project folders

6 Analysis and implementation of GIS in landfill site selection

6.1 Introduction

Data for the GIS analysis was identified, assembled and prepared as discussed in the preceding chapter. Research has shown that the combinations of techniques that have been implemented to identify potential landfill sites are costly and time consuming. This chapter presents a more proactive GIS-based technique that will be implemented to identify suitable landfill sites. The GIS analysis will conform to the minimum requirements stipulated by the DWAF. It would be interesting to find out if the analysis results compares to what was achieved using conventional methods. The analysis will be in three phases as outlined in the analysis protocol.

6.2 Analysis protocol

The various criteria stipulated by DWAF are not of equal importance. The ranking methodology based on the Analytic Hierarchy Process (AHP) that was used in site selection had each criterion weighted in terms of their relative impacts on the environment. The approach that will be adopted in this GIS analysis is that all criteria are important. Fatal flaws and environmental criteria will be given priority and unlike the AHP technique, all the minimum requirements under this criterion will be accorded equal importance. Fatal flaws and environmental criteria comprise the first phase of the analysis. Minimum requirements in economic and public acceptance criteria will be sorted and grouped into two categories that comprise phases two and three. Datasets under each these categories will be accorded equal importance and used to identify good sites and subsequently the most suitable sites. The next paragraphs outline details of each phase.

The first phase will entail use of inherent fatal flaws and environmental criteria to delineate areas that the landfill should be outside of (No Go Zone). Areas where the landfill site should be located (Go Zone) will be extracted so candidate sites can be identified. The second phase will use datasets that constitute regions where existing land use and other requirements are compatible with landfilling operations. The datasets in this phase will be joined to form one layer which will be referred to as compatible land use. Using this layer, good sites will be extracted from the candidate sites.

The last phase will use additional considerations that would make certain sites most favoured. The considerations stem from economic and public acceptance criteria in which most requirements are able to be mitigated as they have little environmental impacts or none. These requirements will be used to determine the best site(s) in phase three.

An attempt will be made to run several scenarios in each phase. Notable ones will be "once-off" and "derivative". Once-off is the easiest as all layers that meet a particular criterion are rumped together and desired or undesired areas can be established at a glance. Environmental Impact Assessment (EIA) is a people driven process that provide opportunities for Interested and Affected Parties (I&APs) to question the procedures followed to arrive at certain decisions e.g., location for a landfill. It is on this basis that a derivative scenario will deliberately be presented to justify why some sites are eliminated while others will be considered as most suitable. It is worth mentioning the advantages that can be accrued from the use of the Modelbuilder in the derivative analysis.

6.3 Use of ModelBuilder

Wegener (2000) defined a model as a simplified representation of an object of investigation for purposes of description, explanation, forecasting or planning. According to ESRI (2000), a model is a representation of reality. A model represents only those factors that are important to current tasks and creates a simplified, manageable view of the real world. The ModelBuilder window is the interface used to create models in ArcGIS. The ModelBuilder was created from the ArcToolbox from the Tools menu. Creating a model helps manage and automate geoprocessing work flow.

There are numerous criteria that have to be considered during the analysis for siting the landfill thus making the process complicated. According to ESRI (200), Building a model helps manage this complexity in a number of ways. The ModelBuilder makes processes and the relationships between processes explicit, and updates the changes created dynamically. A model helps set parameters of each tool and information recorded, making the model output easily reproducible.

Another functional advantage is that the structure of the model can be edited by adding or deleting processes or changing the relationship between the processes. Using a ModelBuilder, parameter values can be edited and re-defined for tools to experiment with alternative outcomes particularly when performing complex analysis.

Numerous approaches can be used to obtain suitable sites using GIS and the ModelBuilder. The GIS analysis that will be applied in this research is based on personal preference that accord priority to factors that have profound negative impact on the environment. To tie with that, the analysis will conform to the minimum requirements for waste disposal by landfill as stipulated by DWAF (2005).

6.4 Phase one: delineating areas landfill should be outside of.

There are several alternative methods that can be used to delineate unacceptable areas. Based on fatal flaws and environmental criteria as well as personal preference, areas that the landfill should be outside of will be eliminated in this first phase. Two approaches namely "Once-off method" and "Derivative modelling" will be implemented as discussed in the next sections.

6.4.1 Once-off method

This is done by imposing all layers that denote inherent fatal flaws onto a single view. It worth noting that layers that comprise fatal flaws had been merged as stated in Section 5.3. For instance, water sources layer is a merger between wetlands, rivers and ground water. All themes that denote areas where the landfill should not be located have identical symbology (red colour) as shown in Figure 6.1.

Candidate sites are better visualized when the No Go Zone layers is overlaid on another layer (with a different colour) that covers the study area or by use of layer that denotes only the borders of the CCT. In this instance, the layer upon which the No Go Zone is overlaid is symbolized in green colour as shown in Figure 6.1.

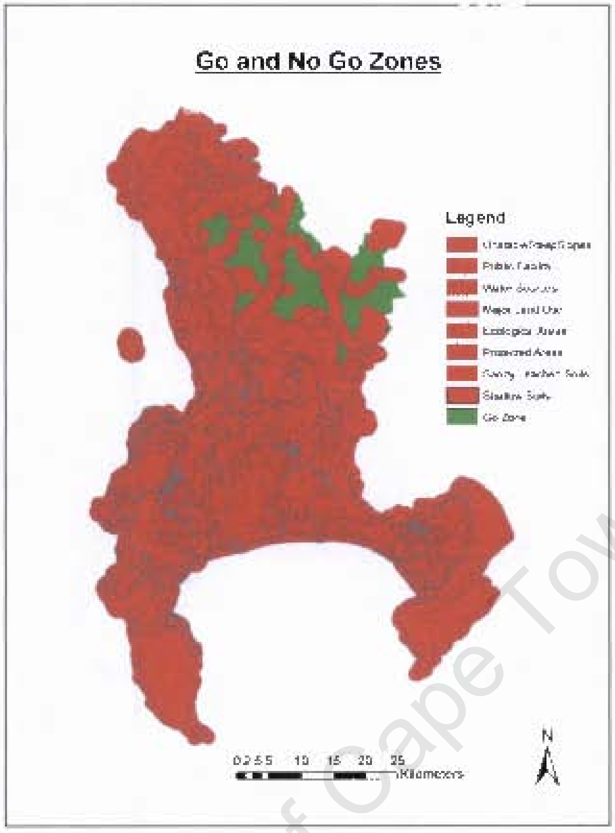

Figure 6.1 Go and No Go Zones (a)

This method is useful when a site has already been identified or when stakeholders would quickly like to know if their areas are delineated. The method reduces the number of scenarios that would have to be run to obtain the No Go Zone. It also works best if the area under consideration is expansive and numerous alternative sites can be identified.

One of the limitations of this method is that layers used are discrete and can not be aggregated into a single layer through the dissolve process. This makes presentability of the map less appealing. Another limitation of this method is that if the entire area under consideration is eliminated, it would be time consuming to fall back and see which group of criteria would be reconsidered.

6.4.2 Derivative modelling

This method eliminates undesired areas (No Go Zones) by running models based on aggregated group of criteria. As mentioned in the preceding paragraphs, the EIA process being people driven, aggregating layers and modeling them provide a more convincing method of delineating undesired areas. It is worth demonstrating the use of the Modelbuilder in derivative analysis. Advantages of modelling have been outlined in Section 6.3. Over and above, a model increases the efficiency during analysis as input data or other parameter values can be altered, or re-executed to produce different results.

6.4.2.1 Water sources

Water sources are one of the fatal flaws criteria that eliminate all areas with surface and ground water sources as potential sites. Although all sites fall within a water catchment area, the size and sensitivity of the catchment is in this analysis used to represent fatal flaw. All areas that represent water sources were buffered (1km) as mentioned in chapter one. To obtain water sources layer, all layers that represent important water sources were unioned[1] as shown in Figure 6.2.

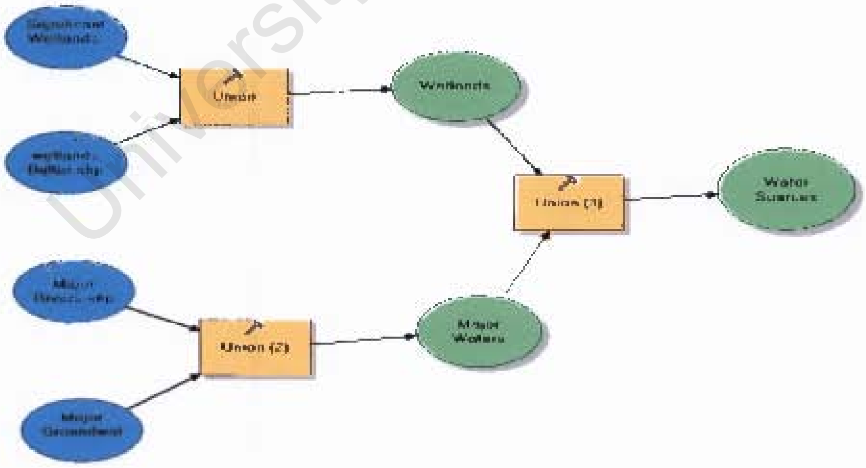

Figure 6.2 Water sources (a)

[1] Combining features of an input layer with the polygons from an overlay layer to produce an output layer that contains the attributes and full extent of both layers.

The model output layer, water sources, was dissolved[2] and symbolised in blue to denote No Go zone on account of water sources as shown on the map in Figure 6.3.

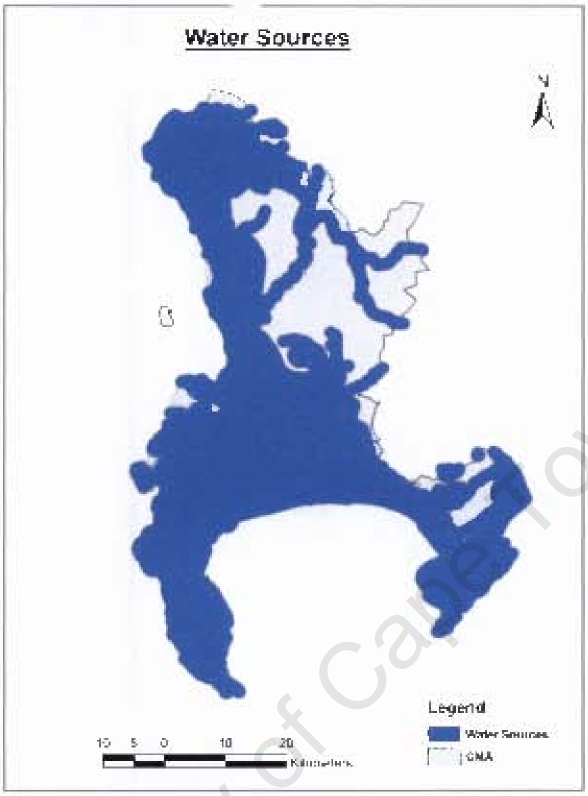

Figure 6.3 Water sources (b)

Most of the study area has important water sources on the southern and western areas as depicted in Figure 6.3.

6.4.2.2 Risky, flood prone and montane areas

Risky, flooded and steep slopes regions are hereby used to denote areas that are flood prone and have risky unstable slopes. Unstable slopes include fault zones, seismic zones and karst areas where sinkholes and subsidence are likely, just to mention a few. Hills and mountains datasets were unioned to create montane layer. Hills and mountains slopes are characterized by shallow bedrock with little soil cover. Risky, flooded and steep slopes and montane layers were unioned to create risky flooded montane layer as shown in Figure 6.4.

[2] Dissolve operation aggregates features that have the same value for an attribute that is specified.

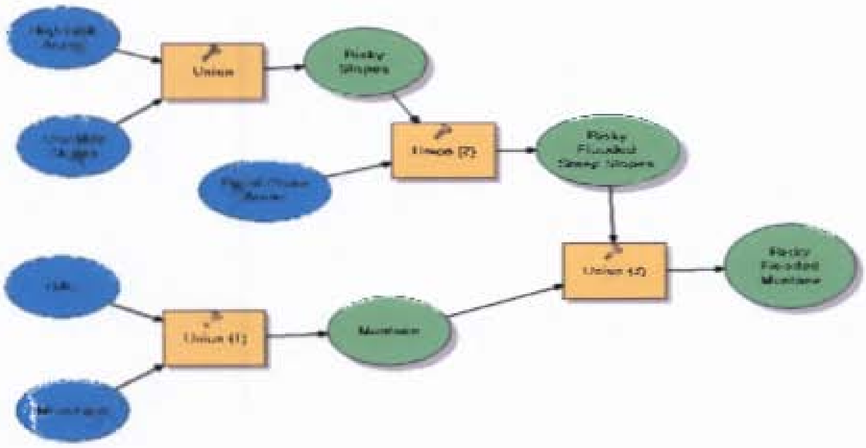

Figure 6.4 Risky flooded montane (a)

The union output layer was dissolved and symbology changed to make it visually appealing as shown on the map in Figure 6.5.

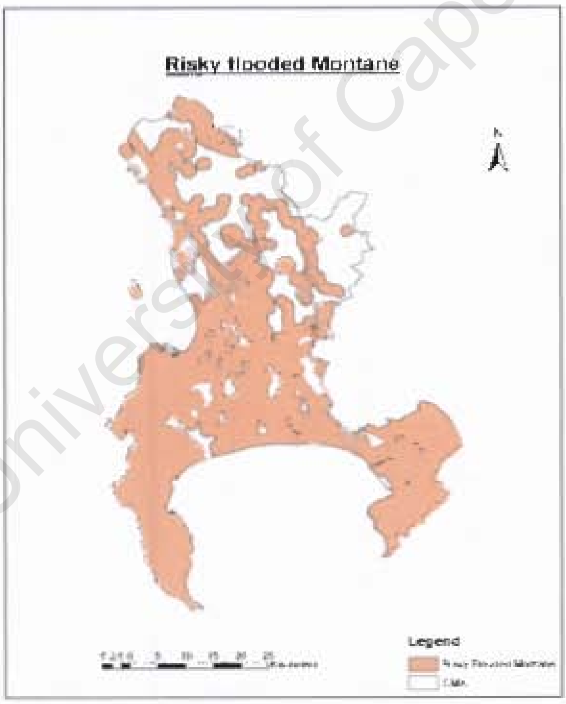

Figure 6.5 Risky flooded montane (b)

Most of the southern part of the CCT is eliminated on account of being flood prone, unstable and due to presence of steep mountain slopes.

6.4.2.3 Ecologically sensitive areas

Forests, parks, nature reserves and protected areas comprise ecological areas. Apart from being ecologically sensitive, they also form part of land use that can not be compatible with landfilling. Forests were unioned with protected areas (union 1) to form protected forests layer, which was unioned with parks and nature reserves (union 2) to form ecological areas layer (Figure 6.6).

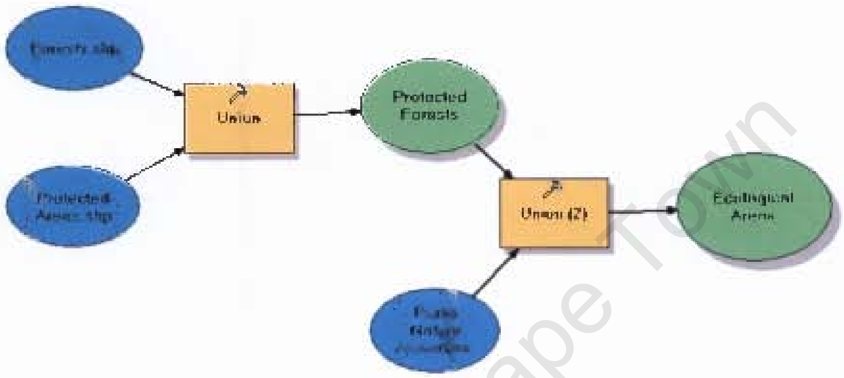

Figure 6.6 Ecological areas (a)

The model output layer was dissolved and symbolised in green to denote areas the landfill should be outside of on account of ecological sensitivity. This is shown in Figure 6.7.

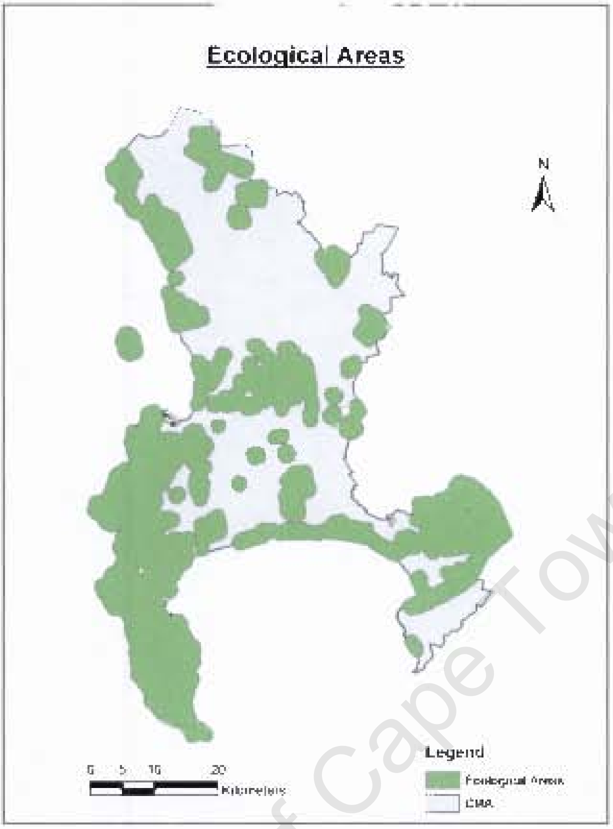

Figure 6.7 Ecological areas (b)

Ecological sensitivity criteria eliminated most of the areas to the south-west, south-east, the west coast and to some extent central part of the study area.

6.4.2.4 Land use

Major incompatible land use include agricultural, residential, commercial and industrial. Informal settlements layer was also been included in this category as part of residential land use as depicted in union 4 (see Figure 6.8). Land uses that are incompatible with landfilling would attract resistance from affected and interested parties. Other land uses such as quarrying and mining are compatible with landfilling and have not been included in this category. Union operation was performed on all the layers in this category to create incompatible land use layer.

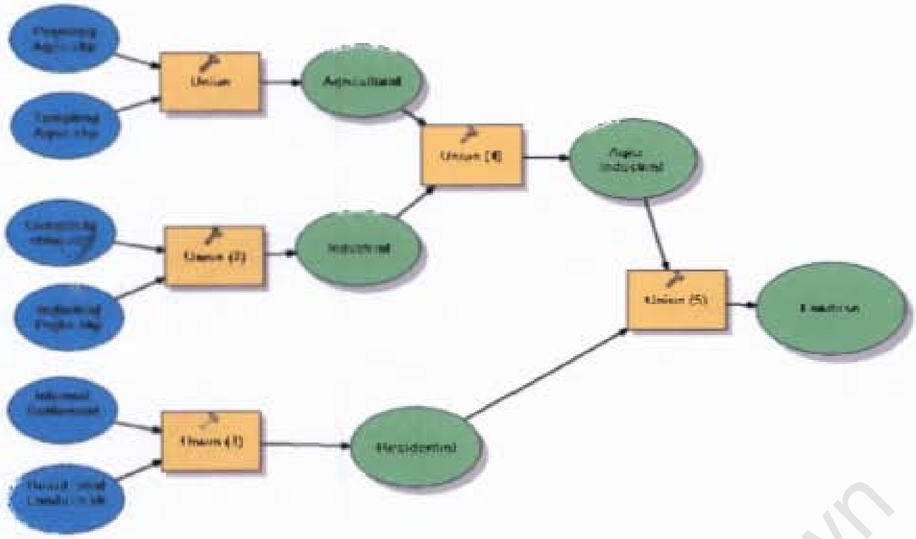

Figure 6.8 Major land uses (a)

The output layer on incompatible land use was dissolved and symbolization changed to denote areas eliminated using the criteria as shown on the map in Figure 6.9.

Figure 6.9 Major land use (b)

Incompatible major land uses are mostly confined to the southern part of the study area. There exists a patch of incompatible land use in the form of industrial parks and residential units to the north of the CCT.

6.4.2.5 Heritage

Heritage sites such as monuments and museums form good tourist attraction centres. Monuments, museums and areas of social significance comprise fatal flaw factors (incompatible land uses). Erecting a landfill near such sites would impact negatively on tourism. Buffered heritage and monuments were unioned to form history layer as depicted in union 1, and then unioned with other areas of social significance (union 2) to create heritage layer as shown in Figure 6.10.

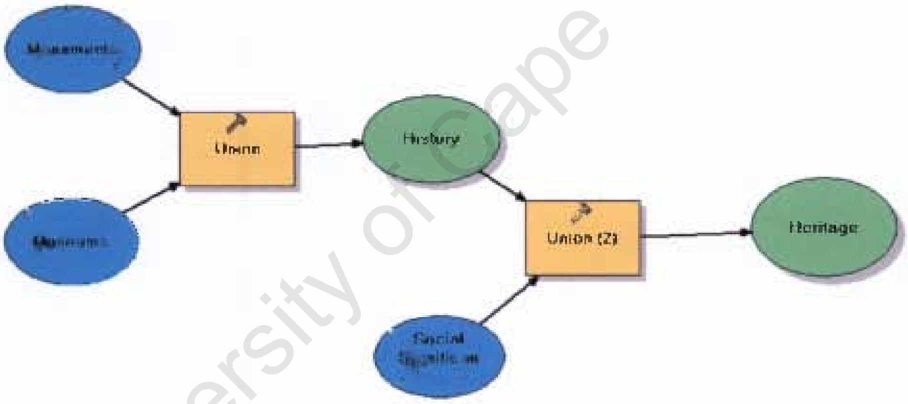

Figure 6.10 Heritage sites (a)

The union output, heritage layer, was dissolved and colour changed using the Symbol Selector dialog box as shown in Figure 6.11 next page.

With reference to Figure 6.11 most heritage sites are located to the southern part of the CCT. Based on this criterion, these areas are disqualified from being considered for siting a landfill.

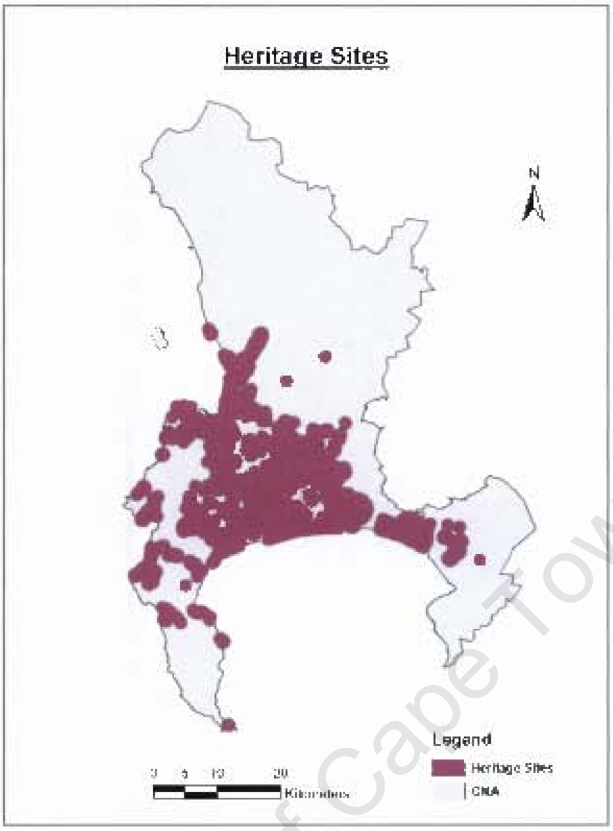

Figure 6.11 Heritage sites (b)

6.4.2.6 Unworkable soils

The quality of on-site soil is considered a very important factor in landfill site studies. Presence of sandy soils poses both environmental and economic implications. Sandy soils are highly permeable thus making subsurface movement of pollutants possible. From economic point of view, presence of permeable soils imply increased costs accrued from importing suitable soils from other regions as well as reinforcing containment liners and leachate control systems.

Both permeable and shallow soils constitute unworkable soils which are not favoured for landfilling. Permeable sedimentary and sandy leached soils were unioned to form permeable sandy layer (union 1), which was unioned with another layer of shallow soils to make unworkable soil layer (see Figure 6.12).

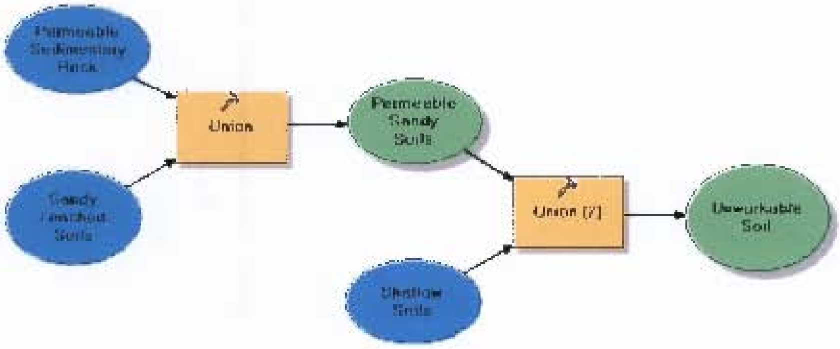

Figure 6.12 Unworkable soils (a)

The unworkable soil layer was dissolved and colour changed from the Symbol Selector dialog box to delineate areas the landfill should be outside of as shown on the map in Figure 6.13.

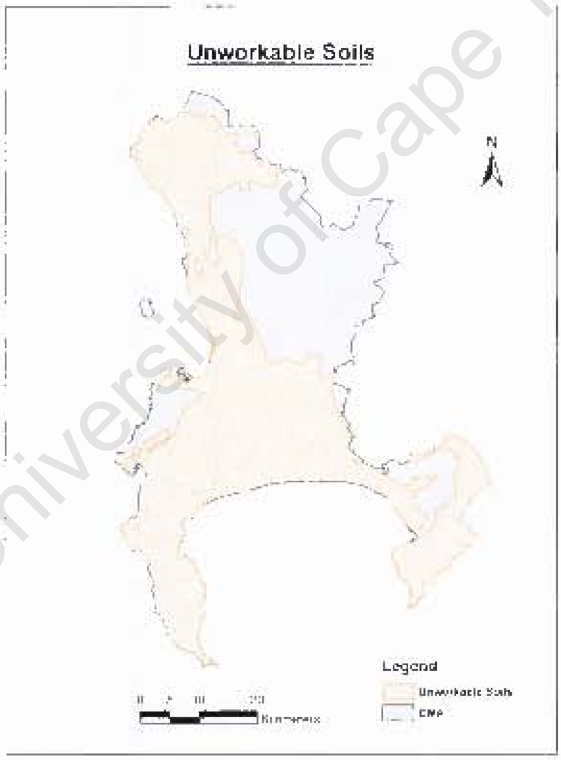

Figure 6.13 Unworkable soils (b)

The southern and western part of the study area is characterized by unworkable soils as shown in Figure 6.13. This leaves the north-eastern part as being the only area where a landfill can be constructed by virtue of having impermeable soils.

6.4.2.7 Public facilities

As a criterion for identifying suitable candidate sites, public facilities are used here to include zoned areas that may not be rezoned to another use. Public facilities also comprise areas over which servitudes are held that would stop construction of a waste disposal facility. Good examples of such areas are ESKOM or Rand Water properties. Other public facilities in this category include sports stadiums and golf clubs.

Waste sites are known to attract huge number of scavenger birds that can wreck havoc to aircraft as shown in Figure 6.14. Such special facilities as airports comprise fatal flaw are incompatible with landfilling and are therefore located far away from waste sites.

Figure 6.14 Compacting of waste and spread of daily soil cover at Vissershok landfill site
Source: CCA Environmental (2006).

Due to threat posed by birds as mentioned in the preceding paragraph, a buffer of 3000m was done for the airports layer as stipulated by DWAF. A union operation between airports and special facilities was done so as to create public facilities layer as shown in Figure 6.15.

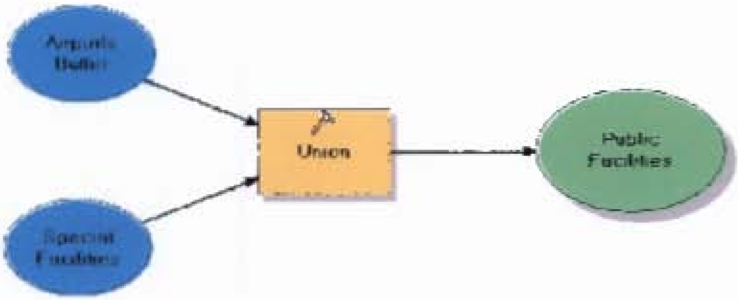

Figure 6.15 Public facilities (a)

The resultant layer, public facilities was dissolved. Another unbuffered layer on airports was added onto the map to amplify the public facility criterion as show in Figure 6.16.

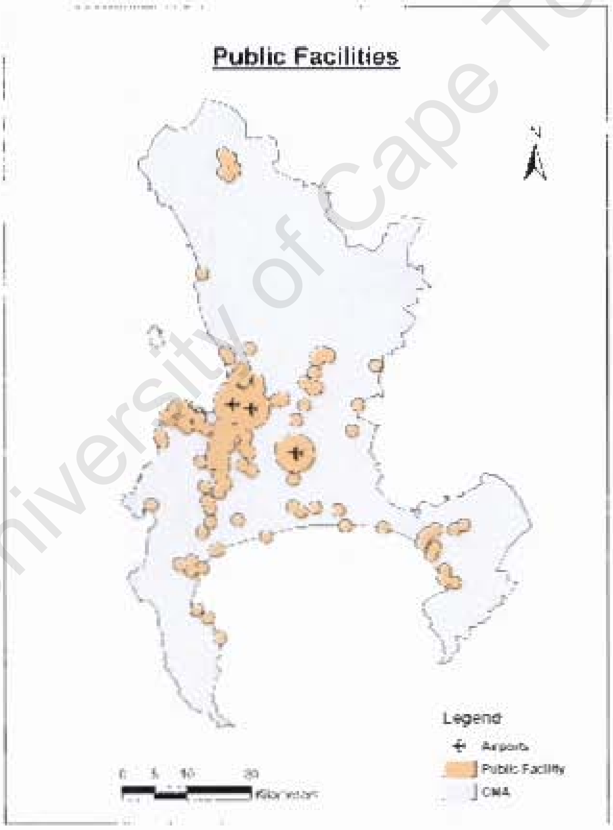

Figure 6.16 Public facilities (b)

From the map in Figure 6.16, it is evident that most public facilities such as airports among others are confined to the south of the study area.

6.4.3 Demarcating the No Go Zone

The last phase of delineating areas excluded from further analysis entails joining all the layers that have been created in the previous stages into a single model. The model is then run in its entirety to create a single layer, No Go Zone, as shown in Figure 6.17.

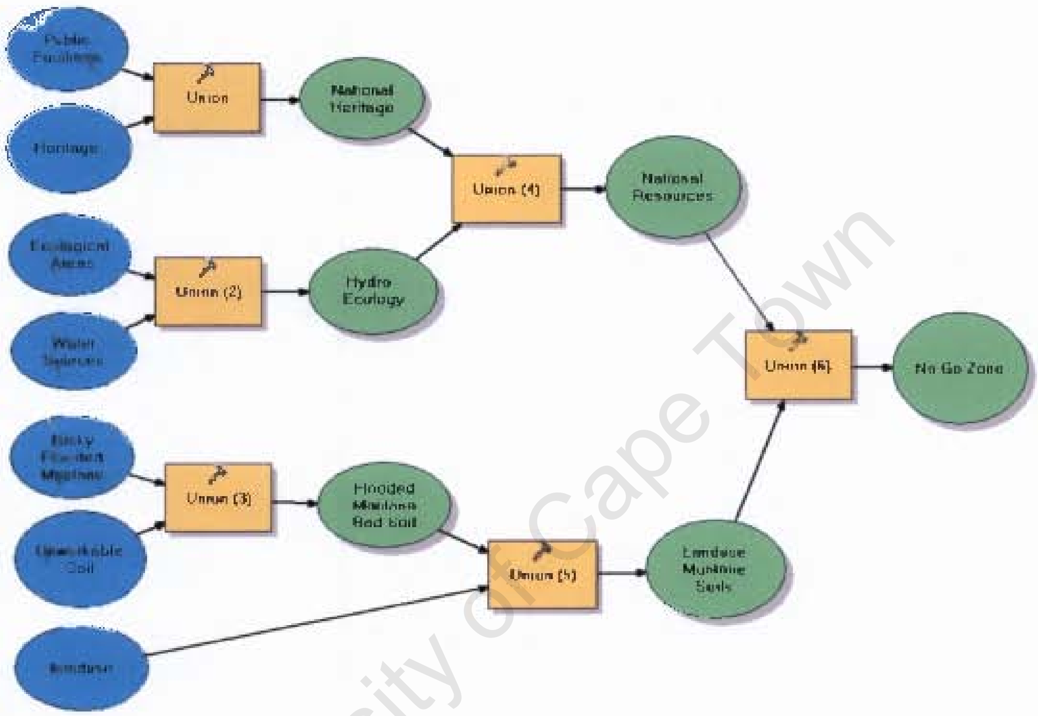

Figure 6.17 The No Go Zone

The product of the model, No Go Zone, delineates areas where the landfill should not be sited. The resulting layer has seams and other lines cutting across making it not appealing (the lines show borders of datasets that had been added). This had to be corrected by dissolve geoprocessing operation that created a contiguous polygon. The symbology of the layer was altered by changing the colour to red. Red colour is deliberately used to warn of imminent danger (negative impacts) to the environment should the landfill be sited in the No Go Zone.

Another layer covering the entire study area was added onto the map in order to show the No Go Zone region in relation to the entire study area. The symbology of the additional layer was changed to green so as to show only the boundaries of the study area as shown in Figure 6.18.

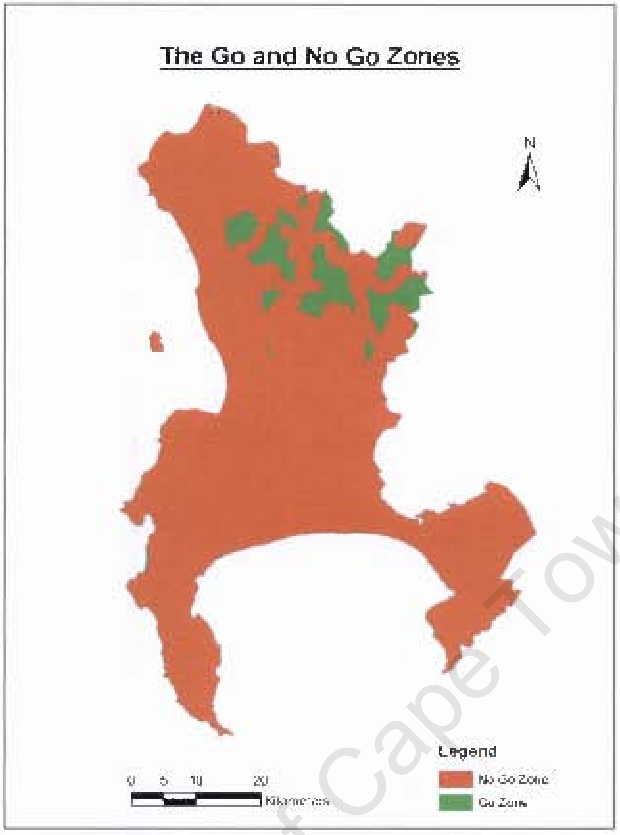

Figure 6.18 Go and No Go Zones (b)

Figure 6.18 shows that a landfill cannot be constructed in more than 90% of the study area.

6.4.4 Extraction of candidate sites (Go Zones)

The next task after delineating the area excluded from further analysis (No Go Zone) is extracting the Go Zones. By having a single layer, it can be easier to use other decision criteria to identify good sites. Identification of areas where a landfill should not be located is discussed in the preceding sections. Of concern is to obtain a single layer showing all candidate sites.

To obtain Go Zone layer, a union operation was done using another layer covering the entire study area. In this case the No Go Zone single layer obtained through derivative method (refer to Figure 6.17) was unioned with that of the entire study area.

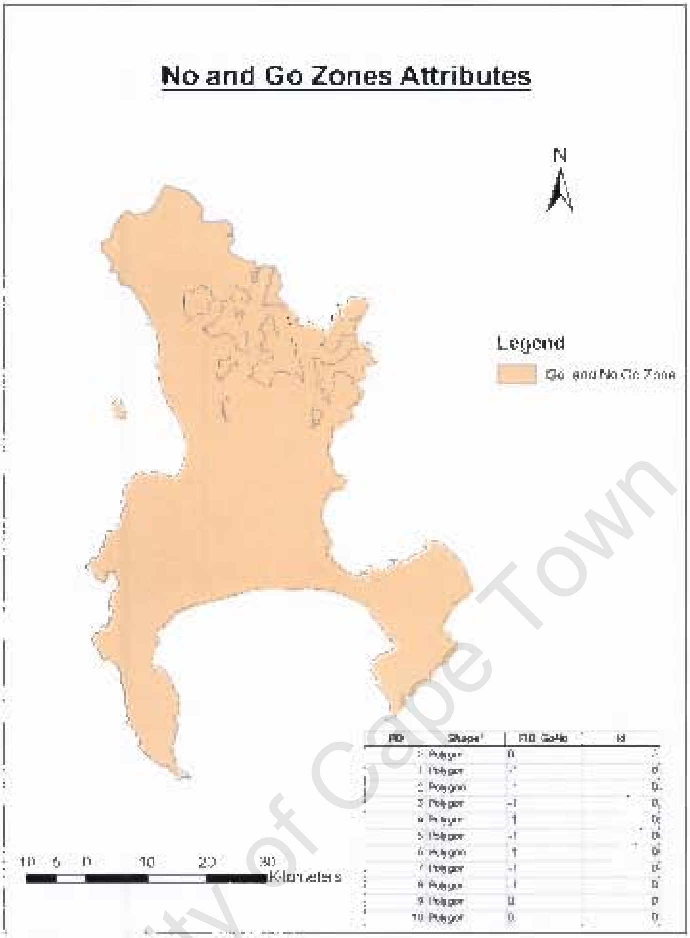

Figure 6.19 Extraction by attributes

The FID field in the attributes table was used in the extraction of Go Zones. According to ESRI 2000, FID is a system managed value that uniquely identifies a record or a feature in the attributes table. The FID values are auto-generated during the union operation between the No Go Zone layer and that of CMA can be used to extract Go Zones. In the attributes table the FID field, the unioned layer has two values (0 and -1). The value, -1 in the FID field of the union output denotes No Go Zones. This is shown in Figure 6.18 that indicates more than 90% of the CCT region is No Go Zone. The few records that have zero value (0) denote empty spaces (Go zones) as shown by the attributes table in Figure 6.19.

By use of the union attribute table above, 0 values that denote Go Zone were selected by attributes from the FID field. With the 0 values still highlighted in the attributes table, exporting the highlighted data created a new layer showing the Go Zones only. A layer covering the study area that was symbolized in a lighter colour was added to the map to show absolute location of the candidate sites within the CCT as shown on the map in Figure 6.20.

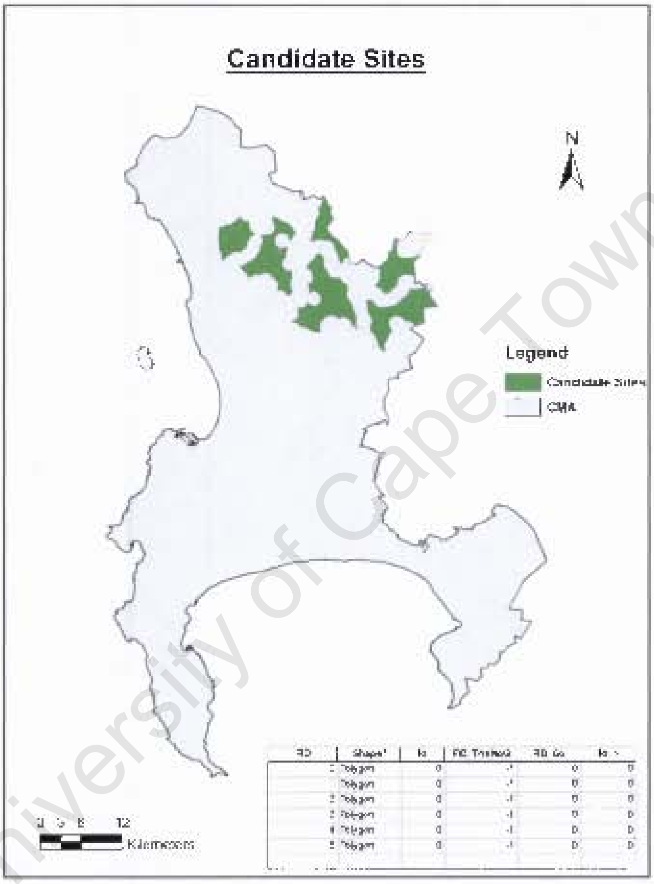

Figure 6.20 Candidate sites

On clicking a single polygon using the Identify tool, all of the polygons blink at the same time, thus creating a generalization. This was rectified by use of Generalization Data management tools, which converted the polygon from multipart to singlepart. The Go Zone polygons become independent entities, each with individual values such as length, perimeter and area. With candidate sites identified, other criteria were brought on board to identify good sites. The procedure to identify good sites is discussed in the next section.

6.5 Phase two: determination of good sites

A landfill site can be constructed in any of the candidate sites shown in Figure 6.20. However, not all sites are appealing. The presence of clayey soils, vacant land and already disturbed lands (presence of mines and quarries) make candidate sites more appealing.

The presence of clayey soils, vacant land, mines and quarries comprise land use that is compatible with landfilling and are in this study grouped together and referred to as compatible areas. To identify top sites (i.e., most suitable sites), two scenarios namely once-off and derivative, were run using the modelbuilder. These are discussed in the following sections.

6.5.1 Scenario One: once-off method

The once-off principle used earlier to delineate the No Go Zone in section 6.4.1 was applied. The only difference is that the ModelBuilder was used so as to create a single layer. All layers under consideration (quarries, mining areas, vacant land and clayey soils) were unioned to produce a single layer named compatible areas as shown in Figure 6.21.

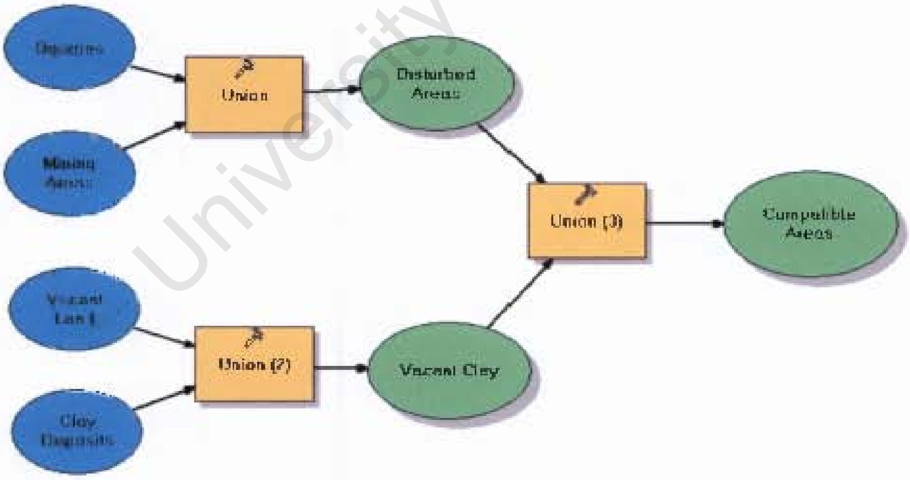

Figure 6.21 Compatible land use areas

The union output (compatible areas) in Figure 6.21 was dissolved and overlaid on a CMA layer show areas that are compatible with landfilling as depicted on the map in Figure 6.22.

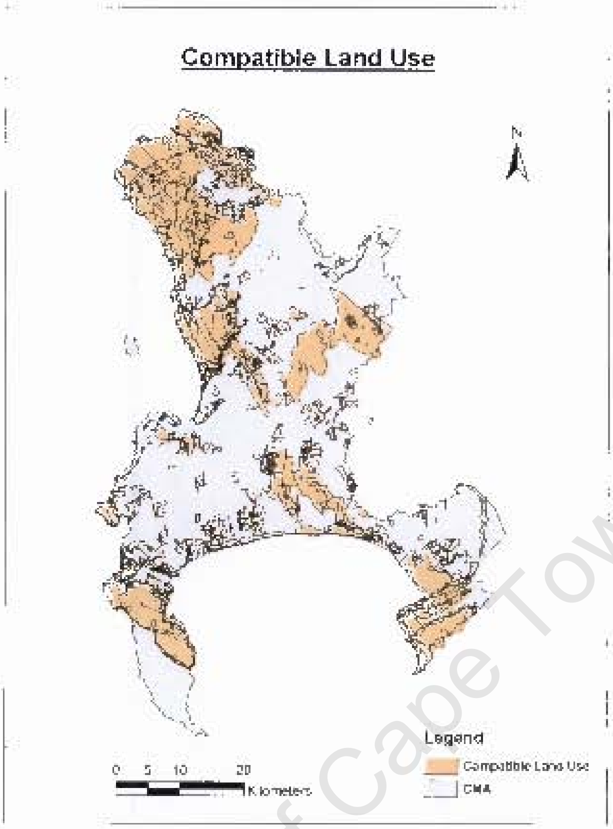

Figure 6.22 Compatible land use

The extraction of the best sites can be achieved in two ways. The first method is by unioning the compatible areas layer with a layer covering the entire study area. The attribute table of the resultant union output can be used to create a new layer of top sites. This is done by selecting the output layer and exporting the highlighted data to create a new layer showing good sites only, the same way Go Zones were created in section 6.4.4. The second and quickest method is by intersecting[3] Go Zone layer with the compatible areas layer that had been created by the Modelbuilder in Figure 6.21. The output of the intersect geoprocessing operation is good sites as shown in Figure 6.23.

[3] Intersect operation cuts an input layer with the features from an overlay layer to produce an output layer with features that have attribute data from both layers.

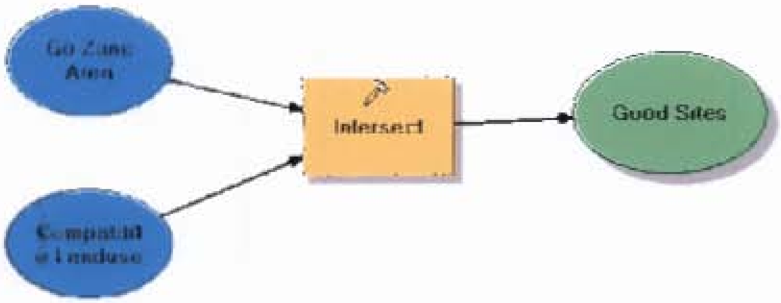

Figure 6.23 Good sites

The location of good sites within the study area is shown on the map in Figure 6.24.

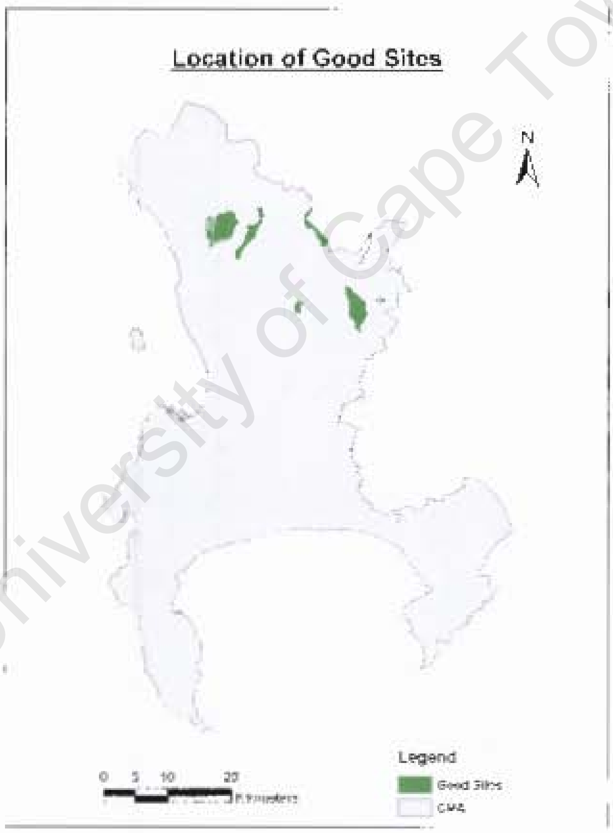

Figure 6.24 Location of good sites

6.5.2 Scenario Two: deriving candidate sites from the Go Zones

In this scenario each layer that fall under compatible land use category is used to run independent analysis. Data sets that comprise compatible land use include quarries, mining, availability of clayey soils and vacant land as shown in Figure 5.1. The scenarios are run by intersecting each layer with Go Zones that were obtained in Section 6.4.4. In the analysis, sites that do not meet major compatible land use (availability of clayey soils and is vacant) requirements are excluded from further analysis.

6.5.2.1 On account of clayey soils

The availability of top quality soil, in this case clayey soils, satisfies both environmental and economic criteria and is therefore considered as one of the most important factors in siting landfills. From an environmental viewpoint, presence of low permeability soils such as clay reduces pollutant migration and is therefore highly favoured. For that reason, sandy soils which are highly permeable were considered earlier in the No Go Zone area analysis. From an economic perspective, on-site clay soils provide low cost cover material, thus reducing the cost of transporting soil from other areas as well as the cost to construct containment liners and leachate control systems.

The clayey soil layer was extracted from the general soils layer provided by ENPAT. Selection by attribute (clay content) and export was done to obtain clayey soils layer. Using the layer for clayey soils and that of Go Zones, parcels that meet the criteria (clayey good sites) can be identified as shown on map in Figure 6.25. ArcMap allows modification of layers such as display and symbology through the Properties dialog box. Using the Display tab in the Properties dialog box, the transparency of Go Zone layer was increased from 0% to 30% to make the clayey soils layer underneath visible.

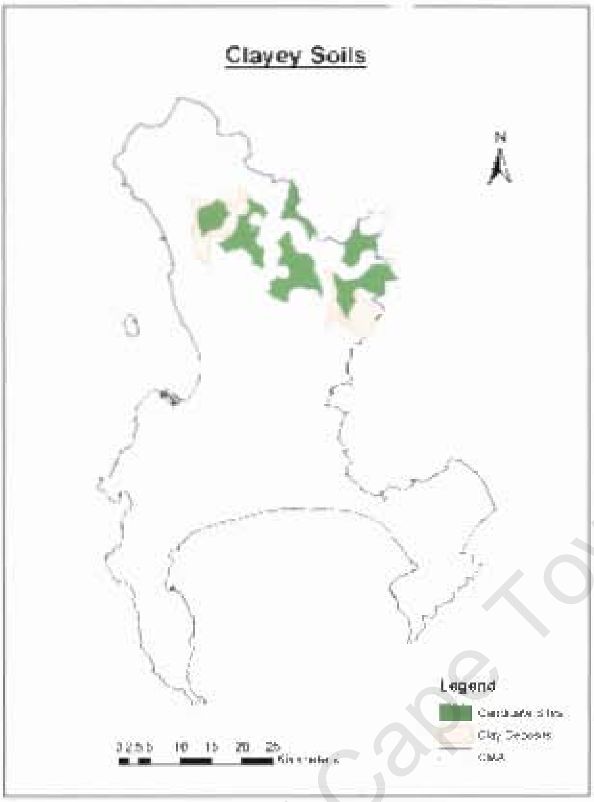

Figure 6.25 Clayey soils

Extracting clayey good sites was done by intersecting the layers on Good sites and Clayey Soils. Using clayey soils criteria, three distinct sites, A B and C can be identified as top sites as shown on the map in Figure 6.26.

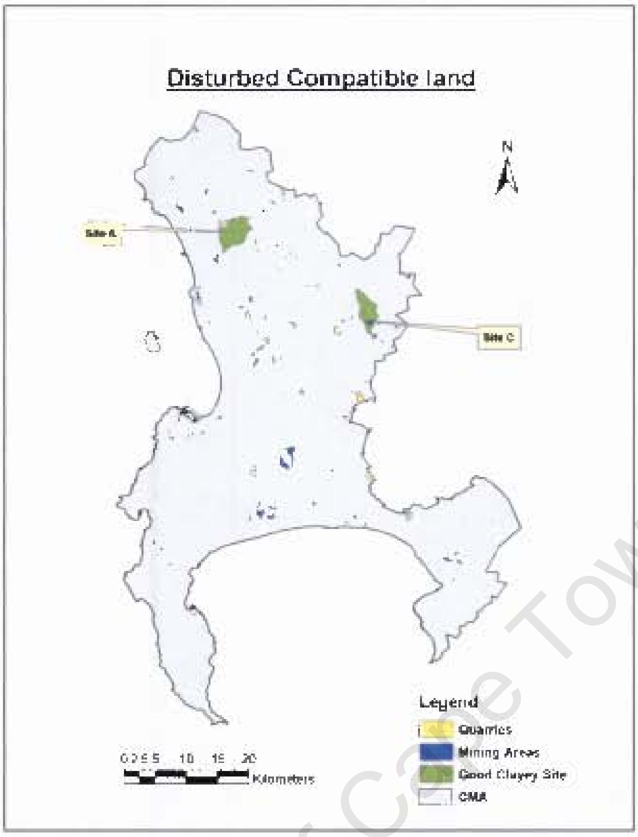

Figure 6.29 Disturbed regions

Based on this criterion, there exist quarries to the north western part of site A and a mine to the south of site C. The quarry on Site A is also depicted in the aerial photograph in Figure 6.27. The attribute table of both the quarry and the mining layers indicates that both the quarries and mines are abandoned. Although not much of the sites are disturbed, the presence of aforementioned activities makes landfilling feasible.

6.6 Additional criteria: deriving top sites

The previous analysis identified two plausible sites: A and C. In this phase, additional criteria, which are part and parcel of DWAF's minimum requirements for waste disposal by landfill, will be used to establish the most suitable location between site A and site C. As mentioned in the analysis protocol, the consideration to derive top sites stems from economic and public acceptance criteria. These criteria have few environmental impacts and which can be mitigated.

6.6.1 Slope and gradient

Slope is the incline, or steepness of a surface. The lower the slope value the flatter the terrain (ESRI, 2000). Steep areas are characterised by shallow bedrock with little soil cover. This can be attributed to soil erosion as well as downward movement of loose soil under the influence of gravity (mass movement e.g., soil creep). Steep slopes pose the danger of interlayer slippage or shearing of compacted waste especially when lubricated by rain water. To tie with that, shallow bedrock and lack of adequate soil make steep areas unsuitable for landfilling.

To make slope layer, 3D Analyst was used to derive slope using the CMA Digital Elevation Model (DEM) that was created from the CDSM contours layer during preparation of data in Section 5.3. In the slope layer Properties dialog box symbology was modified to reflect what was relevant for the study. A new colour ramp was chosen and the 9 default classes changed to 5. The clayey Go Zone layer had its symbol changed to Hollow so as to demarcate the two sites which were imposed onto the slope layer underneath as shown in Figure 6.30.

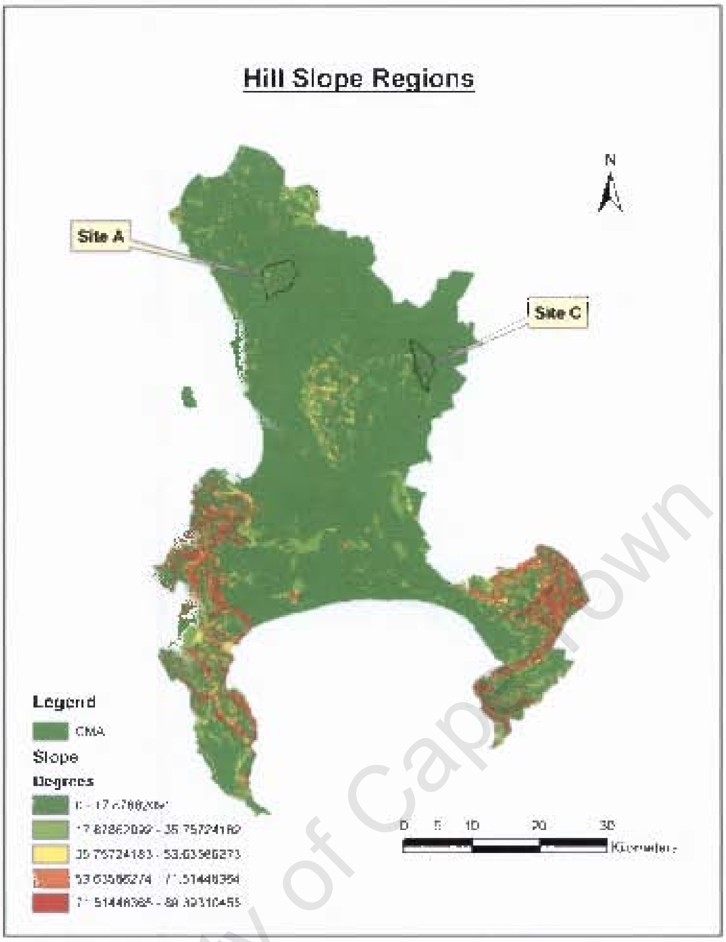

Figure 6.30 Hill Slope regions

Slope values range between 0 and 90 degrees, where 0 indicates no gradient. The slope angle for the location of both site A and C is less than 40 as depicted in Figure 6.30 above.

To expound on inclination and shape of the terrain, profiles of the two sites were drawn using 3D Analyst tools. Profiles show the change in elevation of a surface along a line. Profiles are useful particularly when transport (of waste) by railway is under consideration or when a road has to be constructed along steep terrain. To derive profiles for the two sites, the CMA TIN was used and interpolation done along lines AB and CD for each site as shown in Figure 6.31(a) and 6.31(b). Using the interpolation lines gradient can be calculated. Gradient is hereby used to refer to the property possessed by a line or surface that departs from the horizontal.

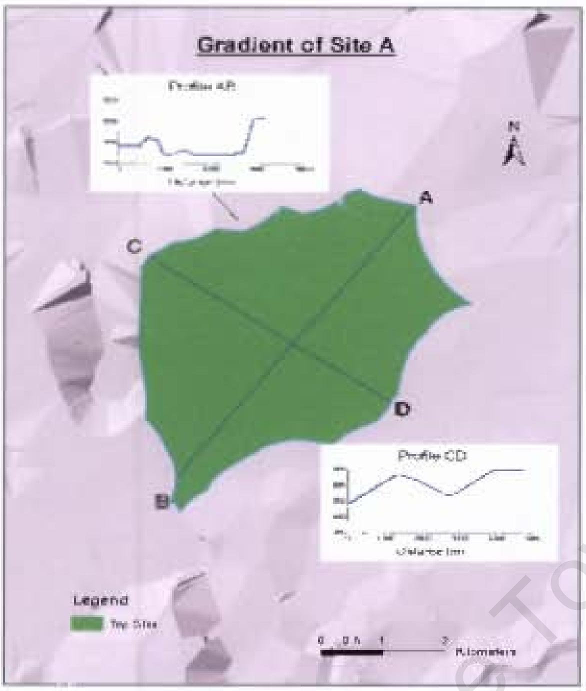

Figure 6.31(a) Gradient of Site A

From the figure above, the gradient of site A is approximately 1:62 (100/6200) when a profile is interpolated from point A to B and approximately 1:49 (100/4900) from point C to D.

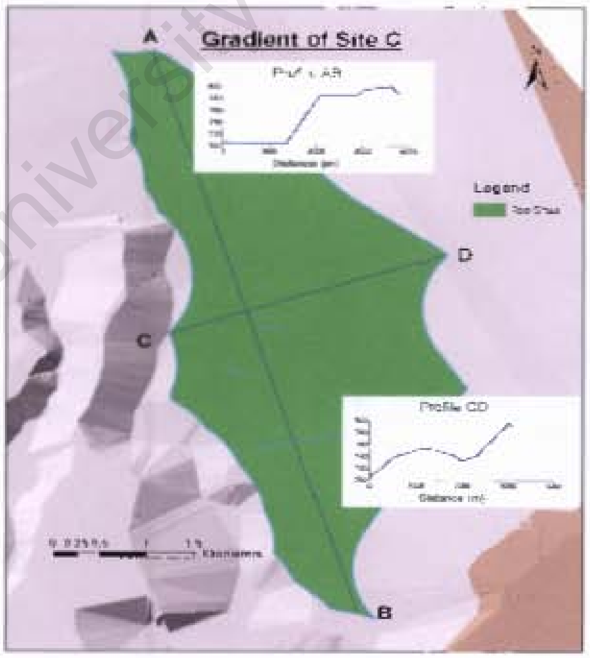

Figure 6.31(b) Gradient of Site C.

Figure 6.31(b) shows that the gradient of site C is approximately 1:75 (100/7500) when a profile is interpolated from point A to B. The figure also indicates that the gradient is approximately 1:32 (100/3200) when a profile is interpolated from point C to D.

This implies that the locations of both sites are relatively flat, which makes both sites suitable for landfilling on account of slope and gradient.

6.6.2 On account of visibility

Landfills are not visually appealing and as such constitute visual pollution. From the public acceptance point of view, exposed sites with high visibility are less desirable than secluded or naturally screened sites. To determine visibility of the two sites 3D analyst's line of sight capabilities were employed.

A lines of sight is a graphic line between two points on a surface that shows the parts of the surface along the line that are visible to or hidden from an observer. Visible segments are shown in green and the hidden segments are shown in red (ESRI, 2000). Several lines of sight for each site were drawn from the nearest incompatible land use and main roads as observation points as shown on the map in Figure 6.32.

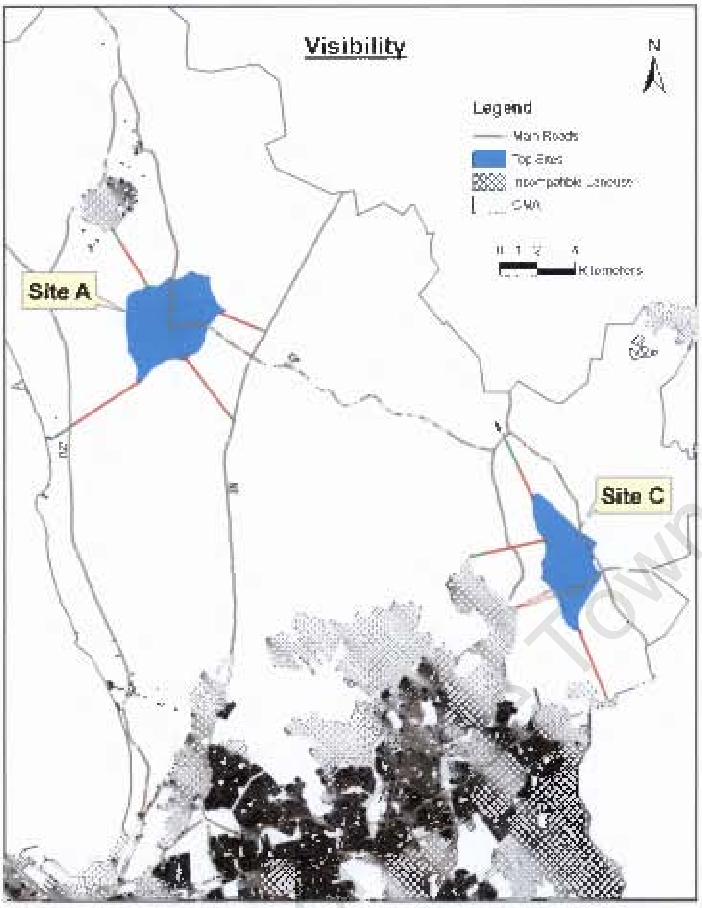

Figure 6.32 Visibility of sites

From incompatible land use and main roads, both sites are not visible as they are naturally screened by the landscape.

6.6.3 Distance from waste generation areas

Distance from waste generation areas is a controversial criterion. From public acceptance point of view, the greater the distance from residential areas the more desirable the site is. From economic viewpoint, the closer the site is from waste generating areas the less the transport costs. Since the sites are outside of buffered residential areas, the issue of public resistance to the development of a landfill would be minimized.

To determine distance from waste generation areas, Athlone waste transfer station[4] was used as a centroid point (Athlone is centrally located in relation to waste generation areas). Waste transfer station is a place where all waste generated is sorted out before being taken to landfill sites. The importance of a waste transfer station in waste management is emphasized by Figure 6.33.

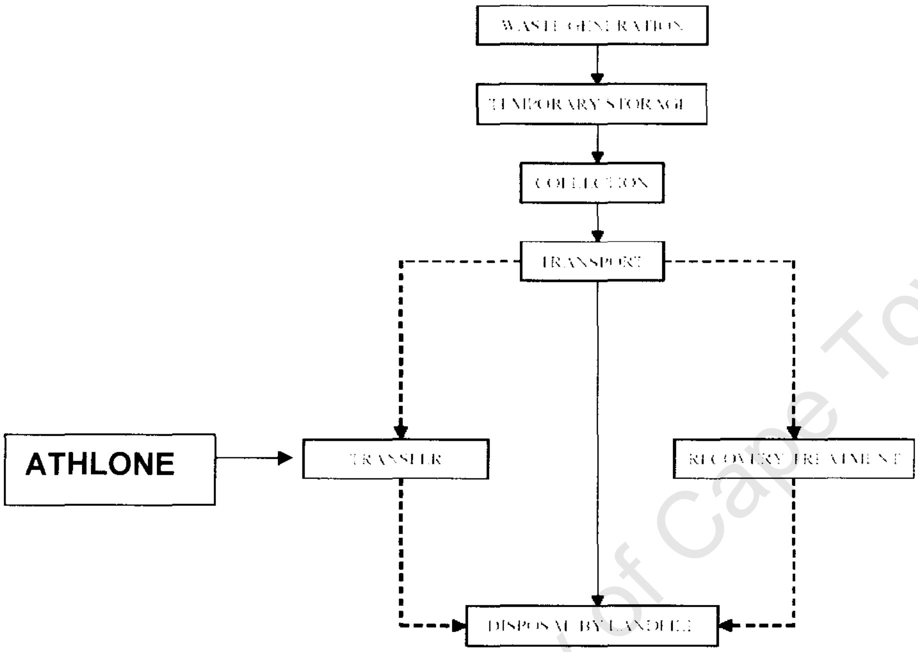

Figure 6.33 waste management systems
Source: DEAT (2005)

From special facilities layer, the Find tool was used to establish the location of Athlone and the draw toolbar was used to draw a point to denote Athlone. To show the relative distance, straight lines were drawn from Athlone to the two sites, hereby referred to as The Yes Clay final (as they are in the Go-Zone {Yes area} and have clayey soil) as shown in Figure 6.34. The ruler in the Tools toolbar was used to measure the distances from Athlone. It is worth mentioning that the actual distance, by road or railway, is longer due to avoidance of relief and drainage features among other obstacles.

[4] "As land for further development close to generation areas is difficult to find, transfer stations are used from which waste is transferred to more distant landfills" DWAF (2005).

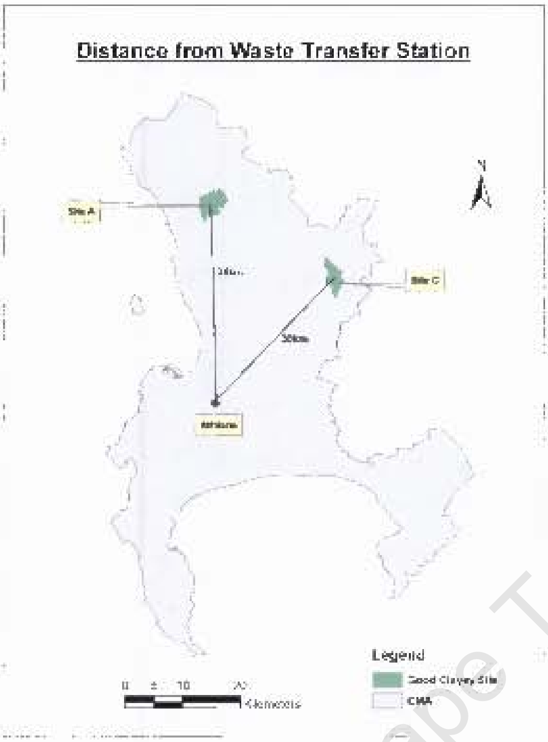

Figure 6.34 Distance from waste generation areas

For instance the distance of site A from Athlone by railway is approximately 40km and site C is approximately 35. Comparatively, the distance of site A and C from Athlone by road is approximately 38km and 30km respectively. Access to the two sites by road and railway is shown in Figure 6.36. The straight distance of site A is approximately 34km from Athlone and site C is approximately 30km as depicted in Figure 6.34. On account of distance from waste generation areas both sites are desirable.

6.6.4 Accessibility

Access to a landfill site is considered as an important factor from an economic viewpoint as it has cost and other implications. Huge costs could be incurred if a site is identified in inaccessible area where roads or railways have to be constructed. Due to convenience and environmental implications such as littering while enroute to a landfill, use of railway is highly desired (see Figure 6.35).

Figure 6.35 Waste containers delivery by rail

Source: CCA Environmental (2006).

Layers on main roads and railway were overlaid on the clayey Go Zones to establish accessibility to the two sites as shown on the map in Figure 6.36.

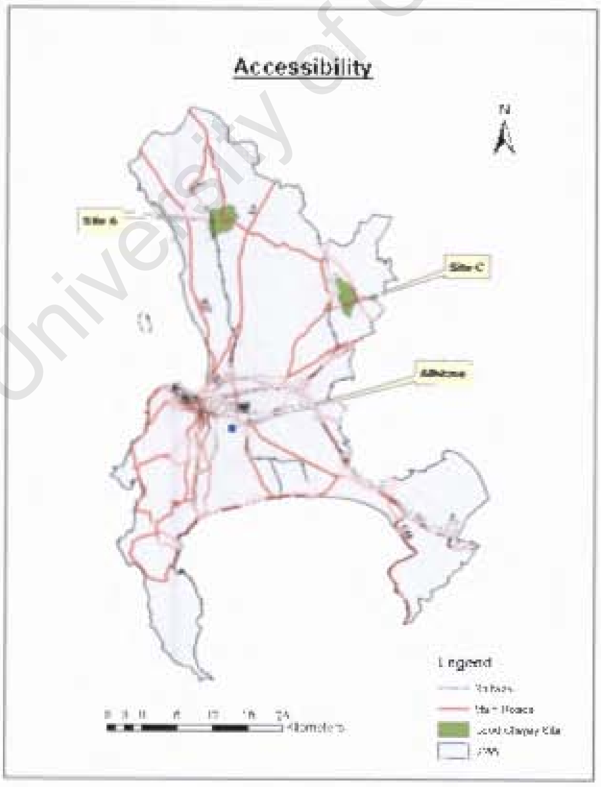

Figure 6.36 Accessibility to the sites

On account of road haul, both sites are conveniently located. Site A is more desirable if rail haul is considered. This is because of the presence of the railway that passes through the site. On the other hand, a short rail extension siding to serve site C would have to be constructed.

6.6.5 Size and buffer distance

Buffer zones are areas of land separating the registered surveyed boundaries of disposal sites from the registered surveyed boundaries of identified sensitive land use (DWAF, 2005). Size and buffer distance can be considered as important from both environmental points of view as well as from an economic perspective. A site is environmentally viable if adequate buffer zones from incompatible land use and other factors that constitute fatal flaws are possible.

It is economically sound to have a site that can cater for waste disposal over at least medium term to justify the capital expenditure. The aforementioned factors depend on size of the site; large areas are favoured. To establish the area, the attributes table of each site was used. To demonstrate the extent of buffer area, each site was buffered for a distance of 2000m as shown in Figure 6.37.

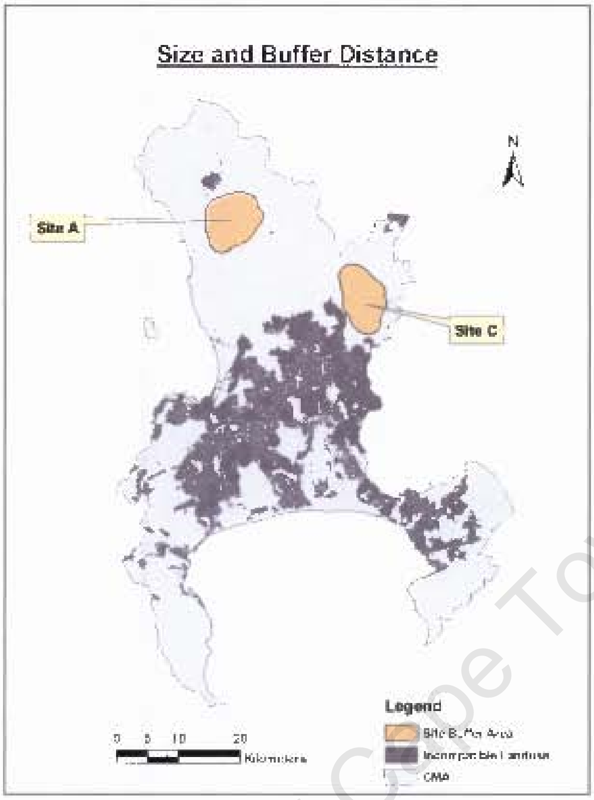

Figure 6.37 Size and buffer distance

On account of size, the unbuffered size of site A is 1886ha while the size of site C is 1324ha. From economies of scale point of view, site A is more attractive due to its large size. Based on proximity to incompatible land use site A has a large buffer area than that of site C. As opposed to site C, the buffer area of site A can further be increased to 4000m. Besides, most of the buffer areas of site A lies within areas characterized by clayey soils as shown in Figure 6.25, and on vacant land as depicted in Figure 6.27 and Figure 6.28. This makes site A the most suitable site.

6.7 Analysis results

The GIS analysis used the Department of Water Affairs and Forestry (DWAF) criteria for waste disposal by landfill to identify areas where the landfill site should be outside of (No Go Zone) as well as suitable areas for siting the landfill (Go Zones). Fatal flaw and environmental criteria were used to demarcate Go Zones and No Go Zones.

Two scenarios, once-off and derivative, were used to identify candidate sites. The derivative method which is more public friendly was used hand in hand with the ModelBuilder to identify good sites using compatible land use criteria. Additional requirements within the economic and public acceptance criteria were used to identify top sites; A and C. Additional criteria can be weighted in order to identify the most suitable site. Bearing in mind that both sites are suitable (good), the most suitable (best) site is assigned more weight as shown in Table 6.1.

Table 6.1 Best site decision table

CRITERIA	SITE A	SITE C
Slope and gradient	3	1
Visibility	3	3
Distance from Athlone	2	3
Accessibility	3	2
Size and buffer extent	3	2
SCORE	**14**	**11**

Rating

Good = 1

Better = 2

Best = 3

Based on the weights and final score, site A appears to be the best having scored 14 points while site C scored 11 points out of a possible 15.

Due to the emphasis laid on consideration of alternatives in the EIA process site visits to the two sites becomes necessary as advocated by Birkin et al (1996) who argues that such visits do not diminish even when more sophiscated techniques of site selection are used. Site visits can not be done unless the physical location is known. Figure 6.38 shows the location of the two sites among other details.

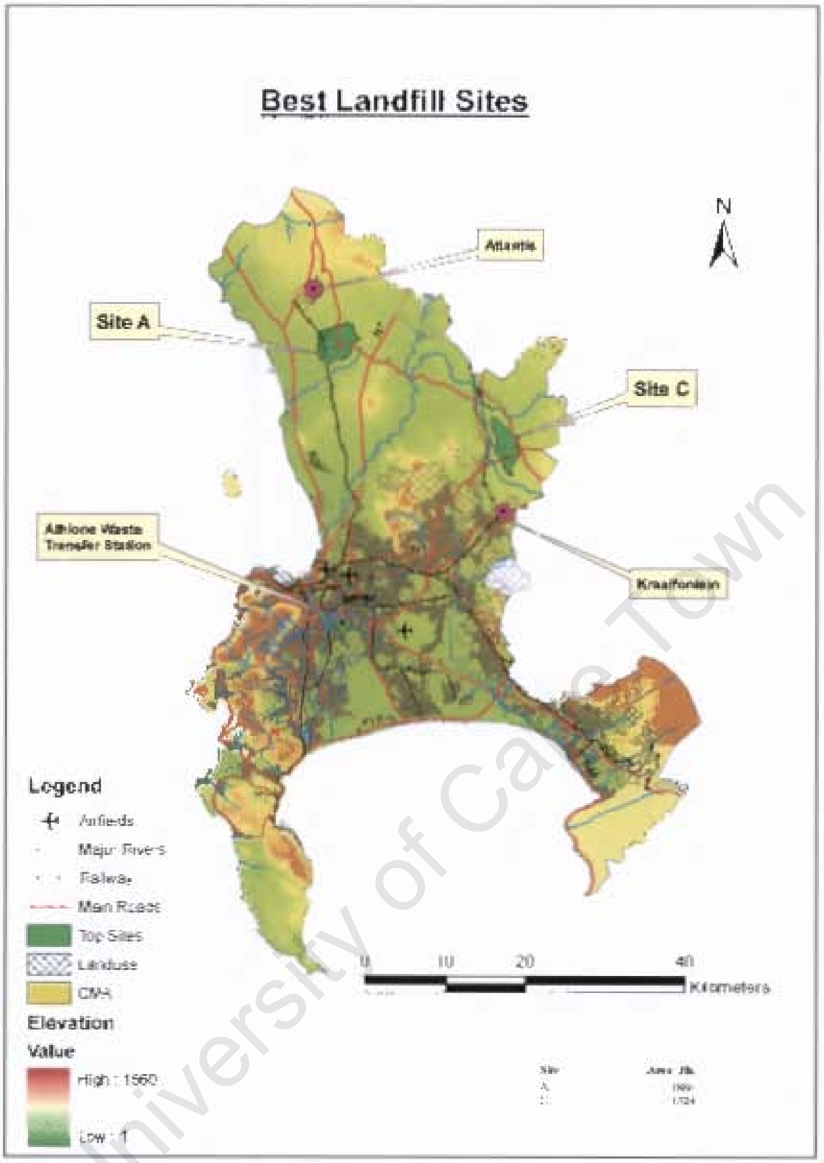

Figure 6.38 Best landfill site

The two sites that were identified are located to the northern region of the CCT. Site A is to the south of Atlantis and site C to the north of Kraaifontein as shown in Figure 6.38.

7 Conclusions, recommendations and future research

7.1 Conclusions

Studies have shown that other methods of waste minimization and other methods of waste disposal have proven to be inadequate, thus making waste disposal by landfill the last option. Based on their design capacity, all the existing landfill sites within the City of Cape Town (CCT) will have reached maximum capacity by 2015 or earlier due to increased waste generation. This creates an urgent need to construct a landfill site.

Technical consultants were appointed in April 2001 to identify potential sites within and around the CCT on which the landfill would be located. The search had to conform to the minimum requirements for waste disposal by landfill, as stipulated by the Department of Water affairs and Forestry (DWAF). Using DWAF's criteria, four sites were identified as indicated by the landfill site search report that was submitted in May 2004.

This research was motivated by the curiosity to know why it took that long to identify the site, the methods that were used and the sites that were identified. The research attempted to find out if GIS can be implemented in landfill site studies and in the process aid decision making. A GIS analysis was conducted in conformity to the minimum requirements stipulated by DWAF, where the identification of a regional landfill to serve the City of Cape Town (CCT) was used as the case study. The rationale behind it is to establish if the results of GIS analysis are similar to the previous study that used other methods. The research has led to the following conclusions:

- The minimum criteria for siting landfills showed that there is a geographic component to most requirements for waste disposal by landfill: - It is natural to expect that spatially oriented technologies such as GIS can help with decision making in such requirements.

- The EIA process and site studies in particular can benefit from application of GIS: - Conclusion of site studies does not imply beginning of construction of the development project. The selected site must still undergo screening phase in the EIA process.

In-depth screening that involves specialist studies on selected sites can make use of GIS if updated and accurate datasets are available. To tie with that, the EIA process can benefit from the GIS ability to provide map-based presentations of data relationships for decision makers.

- The techniques that were employed to identify the regional landfill site are time consuming: - A review of literature has shown that the technical committee took about four years to identify the four possible sites where the regional landfill can be located. Application of GIS that took the form of this master's thesis, that entail other procedures such as submission of proposal, literature review, data acquisition and analysis, lasted less than two years. It is however worth mentioning that the methods employed by the consultants included site visits as opposed to the desk-top-based GIS analysis.

- The techniques that were used by the technical consultants to identify potential sites are subjective: - Information gathered during the interview indicates that the consultants considered known areas such as abandoned mines and used methods that have always been used in other countries for many years. In support of Steinemann (2001) argument (Section 2.1.3.1) that agencies tend to prescribe alternatives and methods that they have used in the past with the premise that it offers them both the reduced effort of designing new ones and the comfort of familiarity. This limits the search for other potential sites as well as implementation of new technology such as GIS. Other sites and alternative technology may not receive favourable consideration making the site selection process subjective by limiting alternatives.

- Existing landfill sites do not meet the minimum requirements for waste disposal set out by DWAF: - Going by the existing criteria and GIS analysis results, all landfills within CCT are sited in inappropriate locations. Incongruence can be noted if the existing landfill sites in Figure 1.1 is imposed or overlaid onto Figure 6.18 that shows the Go and No Go Zones. The sites may however had met landfill requirements by the time they were established, but development projects have encroached into the landfill buffer areas, thus making the sites unsuitable under the current criteria.

- GIS can provide results that are similar to those emanating from use of other site selection techniques: - The GIS implementation yielded consistent results with the recommendations from previous study that used other techniques. The technical committee identified four top sites namely Kalbaskraal (rank1), Atlantis (rank 2), Vissershok (rank 3) and Eendekuil (rank4). Of the four top sites, only Atlantis lies within the CCT, and which the GIS analysis recommends as one of the most suitable.

  According to CCA Final Environmental Impact Report (2006), the extent of one of top sites, Atlantis site is 176ha and lies to the east of the railway and to the south of the brickworks. The GIS study shows the area of the top site (A) is 1886ha and lies to the south of Atlantis town and south east of the brickworks, and the railway passes through the western portion of the site. It can be inferred that a portion or the entire site that was identified by the technical consultants who used other techniques falls within the site that was identified using GIS. The study has therefore demonstrated that GIS can be used as a stand-alone technique to identify potential landfill sites.

7.2 Limitations in GIS implementation

The implementation of GIS in siting landfills has its limitations. A boundary defines the precincts of an area. The 'virtual face' of GIS can not venture into areas beyond polygon boundary, implying the area beyond is a vacuum. For argument sake, it would be misleading to assume that suitable areas near a polygon boundary may not have effects on areas beyond the map boundary. On the other hand, suitable sites that lie within the boundary and are small in size were disregarded. Such sites may be most ideal in terms of size if the area beyond the boundary meets all the requirements including huge buffer area. However, the study area must be delimited and considerations confined to areas within the CCT since the boundary is valid.

There have to be assumptions and generalizations when using GIS in site studies. For instance all vector datasets are represented by lines. It is assumed that all roads (access and national) or watercourses (seasonal streams and rivers) have the same width.

Spatial analysis operations such as buffering do not consider width of such vector datasets. Impact study results of vector features such as road construction may not be accurate although buffering can be based on attribute.

GIS data is not always available in usable format, may be outdated or inaccurate. Results derived from use of such data can be misleading. Most of the data used such as that from Chief Directorate: Surveys and Mapping (CDSM) had insufficient metadata. The purpose for which data was created and the level of detail may not be compatible with current projects.

7.3 Recommendations

Based on the research findings, the following can be recommended:

- A contentious issue in the EIA process has always involved public input to proposed development projects. Projects that are located near residential areas will arouse public resistance. As a mitigation measure for minimizing public resistance, large buffer distances from the location of proposed projects are necessary.

- In-depth specialist studies to determine impacts accruing from proposed projects can make use of GIS capabilities if detailed and accurate datasets are available. In-depth studies include ecological impacts and socio-economic impacts among others. Detailed, up-to-date and accurate data can be used in such studies, as well as in GIS analysis if data is sourced from credible sources. For instance ecological studies can make use of detailed data from Institute for Soil, Water and Climate (ISWC). It is worth noting that it would only be possible to use GIS for reviewing environmental reports if there is an agreed set of base data that applies to all projects of a certain type.

- There are two centers of power in terms of EIA decision making. Approval is done by DEAT (formerly by DWAF), and authorization by delegated authority, DEA & DP. It would be expensive to have GIS facilities and staff in both departments examining the same project. A single or centralized EIA decision making body, which is well equipped with GIS facilities and personnel would expedite decision making.

- Some of the criteria provided by DWAF are ambiguous. On the same note, most criteria brought forth by DWAF do not quantify or give specific distances to be considered when performing buffering operations, leaving quantification at the discretion of the analyst who may use short buffer distances to justify the objectives of the proponents. GIS implementation can be more objective if minimum requirements are clearly defined. An attempt to quantify the minimum requirements or provide optimum distances to act as guidelines should be made. Though prescriptive, such guidelines can lead to uniformity in terms of analysis results using different techniques. On the other hand, if all criteria are not met, leading to suitable sites being not identified, compromises can be made and mitigation measures implemented.

- Prospective sites that are ideal may have been eliminated due to large buffer distances or included due to small buffer distance. It is prudent to do field validation through site visits to the shortlisted sites as well as the most suitable sites before embarking on the screening and other phases of the EIA process. Site visits are both costly and time consuming, especially if prospective sites are in far flung areas and many consultants are involved. GIS is advantageous as only a few sites that had been identified by virtue of satisfying DWAF's minimum requirements would be visited, thus saving time and money, as opposed to other methods where all candidate sites, some of which do not meet the criteria, would be visited.

- One of the problems that GIS implementation faces is lack of updated and accurate data. The EIA regulating authorities should liaise with data miners so analysts who opt to use GIS can easily acquire the required data. It would also be easier to update data in one repository. On the same note, GIS vendors can be asked to tender supply of specific environmental data to be used in specific stages of the EIA process.

- The regulatory authority recommends use of the matrix and ranking method to determine landfill suitable sites (Section 2.2.4). DWAF should amend the section to incorporate new technology such as GIS. Incorporating GIS into existing methods would offer great flexibility by allowing alternatives to be generated thus expedite decision making.

- When performing analysis using GIS, the derivative method, though time consuming, is more convincing as each candidate site is weighted against each data set. The method can be hastened by use of tools such as the ModelBuilder.

- In case GIS analysis eliminates an entire region it would be appropriate to weight criteria. Criteria with serious environmental impacts that can not be mitigated should be given more weight and their scenarios run before criteria that have little or no impact.

- While this project was conducted using siting landfill to service the City of Cape Town as case study, the GIS data used and procedures followed are adaptable to other locations. It is recommended that GIS should be implemented in site selection for landfill sites and other site studies providing suitable search criteria is defined and has spatial component.

- Future implementation of GIS in EIA lies with environmental consultants who are GIS literate. This research advocates that environmental consultants to be equipped with GIS knowledge through training.

7.4 Future research

A brief historical perspective of GIS application was outlined in Section 4.2.1. Although GIS has been used in EIA as well as landfill site studies for many years, research output to show the fact is rare. This implies that GIS application in landfill site studies comprise research areas worth exploring.

The new National Environmental Management Act (NEMA) (Act No. 107 of 1998) EIA Regulations that took effect from 1st July 2006 laid emphasis on public involvement in proposed development projects. The Act provides guidelines on the public participation process and no project can be approved without carrying out a public participation process where Interested and Affected Parties (I&AP) can express their concerns and areas of perceived problems.

GIS experts should explore ways of taking GIS to the people, where they can interact with I&AP to create spatial inventories of potential environmental impacts and public comments thus enhancing consensus building. This evokes the need for future studies to look at the under-explored research area of Participatory GIS where the usefulness of the GIS technology can be appraised by the community.

A ModelBuilder was used to run scenarios during GIS analysis as discussed in Section 6.3. This GIS study proposes the development of a Spatial Decision Support System (SDSS) to be implemented in landfill site selection or other EIA site studies. Exploring this route for the future research efforts would significantly contribute to environmental management and decision making.

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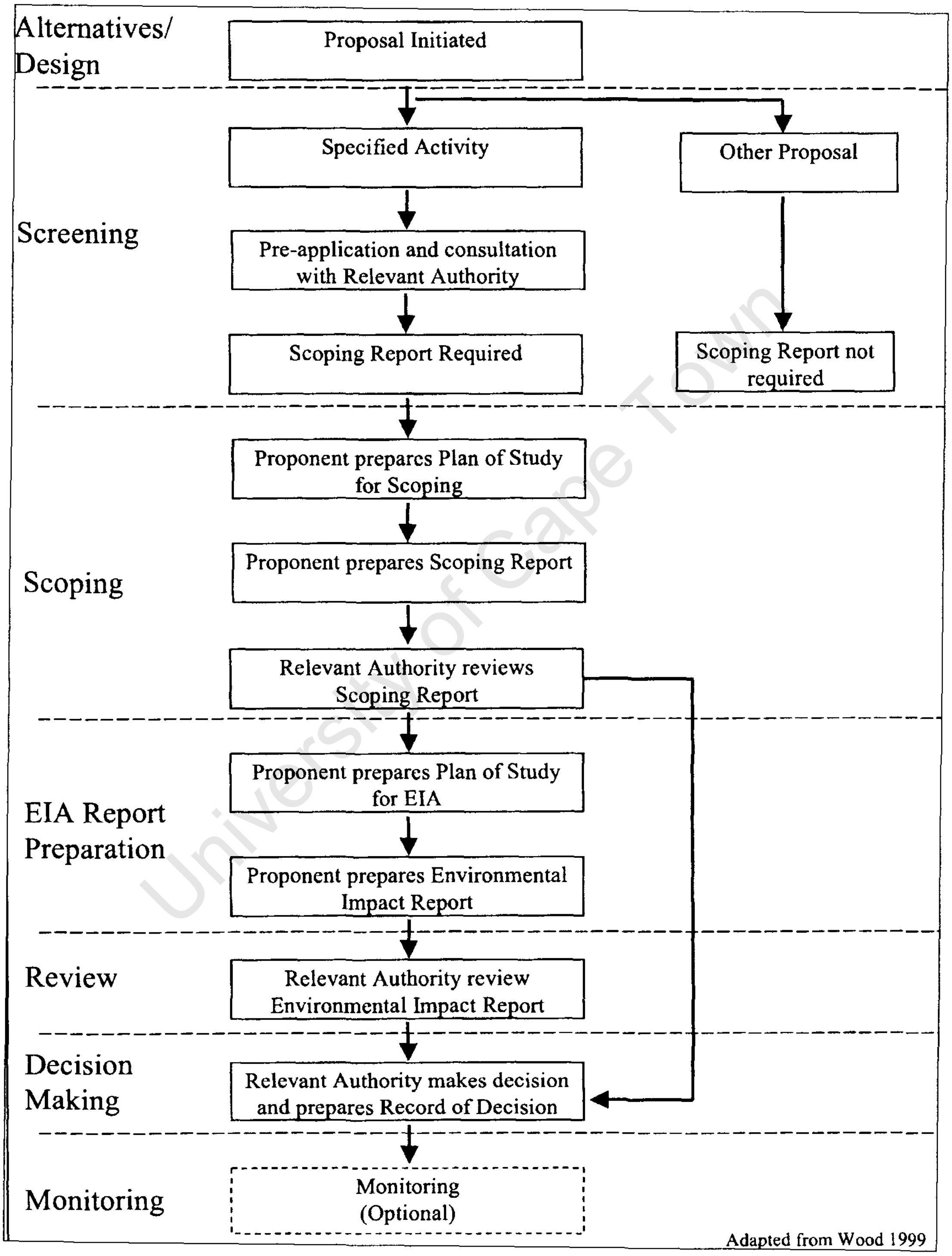
Appendices

Appendix A Main phases of the Scoping/EIA process



Source: http://www.ruc.dk/upload/application/pdf/9c4d310e/workingpaper1.pdf

Appendix B Minimum Requirements for site selection

Minimum Requirements for Site Selection

LEGEND	CLASSIFICATION SYSTEM									
B = No significant leachate produced B' = Significant leachate produced R = Requirement N = Not a requirement F = Flag: special consideration to be given by expert or representative(s) of the Competent Authority and/or the Department	G General Waste								H Hazardous Waste	
	C Communal Landfill		S Small Landfill		M Medium Landfill		L Large Landfill		H:h Hazard Rating 3 & 4	H:H Hazard Rating 1-4
MINIMUM REQUIREMENTS	B	B'	B	B'	B	B'	B	B'		
Consult *Figure 9* and apply as appropriate	R	R	R	R	R	R	R	R	R	R
Classify proposed site	R	R	R	R	R	R	R	R	R	R
Implement public participation process as set out in Appendix 11.1	F	F	F	F	F	F	R	R	R	R
Notify IAPs of the necessity and intention to develop a landfill	R	R	R	R	R	R	R	R	R	R
Liaise with IAPs	R	R	R	R	R	R	R	R	R	R
Eliminate areas with fatal flaws	R	R	R	R	R	R	R	R	R	R
Identify candidate landfill sites	R	R	R	R	R	R	R	R	R	R
Determine area of influence external to site boundary	N	N	F	F	R	R	R	R	R	R
Define buffer zone based on area of influence and related risk as assessed through air quality modelling	200 m	200 m	F	F	R	R	R	R	R	R

Source: DEAT (2005)

Appendix C Interview Questionnaire

Initial site selection

1. Were there pre-determined areas for siting landfills?
2. Who owns the land where candidate sites were selected?
3. Did you encounter cases where the most ideal site fell in privately owned land?
4. If so how did you address the problem?
5. Are there cases of expropriation of land on which selected landfill sites fall?

Project data and methods

6. What kind of spatial data is needed for siting landfills?
7. What baseline data was readily available for the project?
8. Where did you get baseline data from?
9. Was the available data adequate for the project?
10. If not, did you generate your own baseline data?
11. What methods did you use to generate your own data?
12. Did you encounter problems with data?
13. If yes, what problems did you encounter?
14. How did you address the problem associated with the data?
19. Which method(s) did you use to select candidate sites /final site?
20. Why did you prefer to use these methods for identifying a landfill site?

Problems and application of GIS.

21. Did you encounter problems with the methods you used to identify potential landfill sites?
22. If yes, what problems did you encounter with the method?
23. Did you use GIS in identifying candidate sites?
24. What reason can you provide for your answer?

25. What was the total number of prospective landfill sites?
26. What was the number of candidate/shortlisted sites?
27. What criteria did you use to eliminate shortlisted sites and subsequently got the best sites?
28. Are the current criteria compatible with GIS?
29. What are the strength and weaknesses of applying GIS?
30. Do you have other site selection projects/experience other than the current one?
31. Have you used GIS in other site selection projects?
32. If yes how did you apply GIS?

Appendix D EIA Listing Notice 2 No. R387

DEPARTMENT OF ENVIRONMENTAL AFFAIRS AND TOURISM

No. R. 387 **21 April 2006**

LIST OF ACTIVITIES AND COMPETENT AUTHORITIES IDENTIFIED IN TERMS OF SECTIONS 24 AND 24D OF THE NATIONAL ENVIRONMENTAL MANAGEMENT ACT, 1998

The Minister of Environmental Affairs and Tourism has in terms of sections 24 and 24D of the National Environmental Management Act. 1998 (Act No. 107 of 1998). listed the activities in the Schedule.

This Notice comes into effect on the date of commencement of the Environmental Impact Assessment Regulations. 2006. made under section 24(5) of the Act and published in Government Notice No. R. 385 of 2006.

SCHEDULE

ACTIVITIES IDENTIFIED IN TERMS OF SECTION 24(2)(a) AND (d) OF THE ACT, WHICH MAY NOT COMMENCE WITHOUT ENVIRONMENTAL AUTHORISATION FROM THE COMPETENT AUTHORITY AND IN RESPECT OF WHICH THE INVESTIGATION, ASSESSMENT AND COMMUNICATION OF POTENTIAL IMPACT OF ACTIVITIES MUST FOLLOW THE PROCEDURE AS DESCRIBED IN REGULATIONS 27 TO 36 OF THE ENVIRONMENTAL IMPACT ASSESSMENT REGULATIONS, 2006, PROMULGATED IN TERMS OF SECTION 24(5) OF THE ACT -

Activity number	Activity description	Identification of competent authority

1	The construction of facilities or infrastructure, including associated structures or infrastructure, for - (a) the generation of electricity where – (i) the electricity output is 20 megawatts or more; or (ii) the elements of the facility cover a combined area in excess of 1 hectare; (b) nuclear reaction including the production, enrichment, processing, reprocessing, storage or disposal of nuclear fuels, radioactive products and waste; (c) the above ground storage of a dangerous good, including petrol, diesel, liquid petroleum gas or paraffin, in containers with a combined capacity of 1 000 cubic metres or more at any one location or site including the storage of one or more dangerous goods, in a tank farm; (d) the refining of gas, oil and petroleum products; (e) any process or activity which requires a permit or license in terms of legislation governing the generation or release of emissions, pollution, effluent or waste and which is not identified in Government Notice No. R. 386 of 2006; (f) the recycling, re-use, handling, temporary storage or treatment of general	The competent authority in respect of the activities listed in this part of the schedule is the environmental authority in the province in which the activity is to be undertaken unless it is an application for an activity contemplated in section 24C(2) of the Act, in which case the competent authority is the Minister or an organ of state with delegated powers in terms of section 42(1) of the Act, as amended.

	waste with a throughput capacity of 50 tons or more daily average measured over a period of 30 days; (g) the use. recycling. handling. treatment. storage or final disposal of hazardous waste: (h) the manufacturing. storage or testing of explosives. including ammunition. but excluding licensed retail outlets and the legal end use of such explosives; (i) the extraction or processing of natural gas including gas from landfill sites: (j) the bulk transportation of dangerous goods using pipelines, funiculars or conveyors with a throughput capacity of 50 tons or 50 cubic metres or more per day; (k) the landing. parking and maintenance of aircraft. excluding unpaved landing strips shorter than 1.4 kilometres in length. but including - (i) airports: (ii) runways; (iii) waterways: or (iv) structures for engine testing: (l) the transmission and distribution of above ground electricity with a capacity of 120 kilovolts or more; (m) marine telecommunications; (n) the transfer of 20 000 cubic metres or more water between water catchments or impoundments per day; (o) the final disposal of general waste	

	covering an area of 100 square metres or more or 200 cubic metres or more of airspace; (p) the treatment of effluent. wastewater or sewage with an annual throughput capacity of 15 000 cubic metres or more; (q) the incineration. burning. evaporation. thermal treatment. roasting or heat sterilisation of waste or effluent. including the cremation of human or animal tissue: (r) the microbial deactivation. chemical sterilisation or non-thermal treatment of waste or effluent: (s) rail transportation. excluding railway lines and sidings in industrial areas and underground railway lines in mines. but including - (i) railway lines: (ii) stations; or (iii) shunting yards; (t) any purpose where lawns. playing fields or sports tracks covering an area of 10 hectares or more. will be established.	
2	Any development activity. including associated structures and infrastructure. where the total area of the developed area is. or is intended to be. 20 hectares or more.	
3	The construction of filling stations. including associated structures and infrastructure. or any other facility for the underground storage of a dangerous good. including petrol. diesel. liquid petroleum gas or paraffin.	
4	The extraction of peat.	

5	The route determination of roads and design of associated physical infrastructure. including roads that have not yet been built for which routes have been determined before the publication of this notice and which has not been authorised by a competent authority in terms of the Environmental Impact Assessment Regulations. 2006 made under section 24(5) of the Act and published in Government Notice No. R. 385 of 2006. where – (a) it is a national road as defined in section 40 of the South African National Roads Agency Limited and National Roads Act. 1998 (Act No. 7 of 1998); (b) it is a road administered by a provincial authority: (c) the road reserve is wider than 30 metres: or (d) the road will cater for more than one lane of traffic in both directions.	
6	The construction of a dam where the highest part of the dam wall, as measured from the outside toe of the wall to the highest part of the wall. is 5 metres or higher or where the high-water mark of the dam covers an area of 10 hectares or more.	
7	Reconnaissance, exploration. production and mining as provided for in the Mineral and Petroleum Resources Development Act. 2002 (Act No. 28 of 2002). as amended in respect of such permits and rights.	The competent authority for this part of the schedule is the Minister or an

8	In relation to permits and rights granted in terms of 7 above. or any other right granted in terms of previous mineral legislation, the undertaking of any reconnaissance exploration. production or mining related activity or operation within a exploration, production or mining area, as defined in terms of section of 1 of the Mineral and Petroleum Resources Development Act. 2002 (Act No. 28 of 2002).	Minister or an organ of state with delegated powers in terms of section 42(1) of the Act. as amended.
9	Construction or earth moving activities in the sea or within 100 metres inland of the high-water mark of the sea, excluding an activity listed in item 2 of Government Notice No. R. 386 of 2006 but including construction or earth moving activities in respect of – (a) facilities associated with the arrival and departure of vessels and the handling of cargo: (b) piers; (c) inter- and sub-tidal structures for entrapment of sand: (d) breakwater structures; (e) rock revetments and other stabilising structures: (f) coastal marinas; (g) coastal harbours: (h) structures for draining parts of the sea: (i) tunnels: or (j) underwater channels.	The competent authority in respect of the activities listed in this part of the schedule is the environmental authority in the province in which the activity is to be undertaken unless it is an application for an activity contemplated in section 24C(2) of the Act, in which case the competent authority is the Minister or an

10	Any process or activity identified in terms of section 53(1) of the National Environmental Management: Biodiversity Act, 2004 (Act No. 10 of 2004).	Minister or an organ of state with delegated powers in terms of section 42(1) of the Act. as amended.

Source: DEA & DP (2006)
Available: http://www.capegateway.gov.za/eng/yourgovernment/gsc/406/services/11537/10199

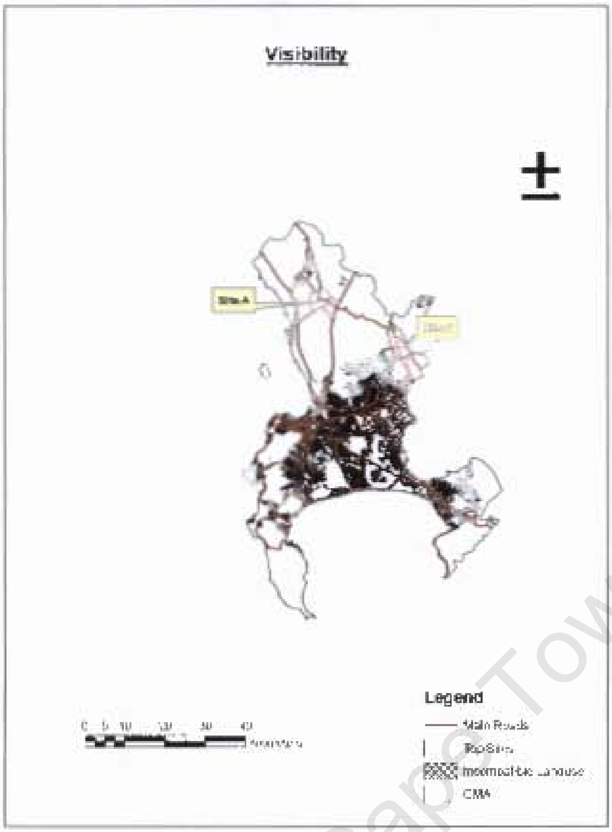


Figure 13 Visibility of sites

From incompatible land use and main roads, both sites are not visible as they are naturally screened by vegetation, localized terrain and undulations.

6.4.6 Distance from waste generation areas and accessibility