

**THE USE OF GEOGRAPHIC INFORMATION SYSTEMS  
IN THE INTEGRATED ENVIRONMENTAL  
MANAGEMENT PROCESS: A CASE STUDY OF THE  
EASTERN SHORES STATE FOREST**

by  
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## **DECLARATION**

The work described in this dissertation was carried out in the School of Environment and Development, University of Natal, Pietermaritzburg, from August 1998 to November 1999, under the supervision of Doctor Fethi Ahmed (Department of Geography).

These studies represent original work by the author and have not otherwise been submitted in any form for any degree or diploma to any University. Where use has been made of the work of others it is duly acknowledged in the text.

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## **ABSTRACT**

With the increasing demands that human beings place on the environment, a concerted effort needs to be made to ensure that the environment is conserved and utilised in a sustainable manner. Therefore, it is imperative that all development actions be carefully scrutinised. The Integrated Environmental Management process may be just the process to address such development problems. The IEM process aims not only to identify those activities that would have excessively negative impacts on the environment it also looks at proposing alternative development strategies that may reduce the environmental impact of development. A tool which is being well received as being able to assist in such decision making is a Geographic Information System (GIS).

The most suitable location for road networks that would have least environmental impact within the Eastern Shores State Forest, KwaZulu-Natal, were determined by implementing the Analytical Hierarchy Process (AHP) along with Multi-Criteria Evaluation (MCE) process within real-time GIS. The location of road networks is a fundamental aspect of development due to the many negative impacts they may have on the environment.

The AHP not only aided in identifying all the elements required to make a decision more accurately. It also allowed one to recognise the inter-relationship between the various elements. The biggest advantage however, of using this model is that it allowed for the establishment of relative mathematically-based weights for the criteria. This effectively aided in identifying which of the vegetation types (ie. wetlands, swamp forest, grasslands, wetlands and coastal forest and thicket) in view of environmental consultants and ecologists would be most conducive to development. In so doing minimising the impact of the development.

The MCE provided the ideal tool to incorporate these relative weights in order to combine them to arrive at an image that contained all the relative weights of all the various factors.

A spatial database was constructed and a number of relevant images developed, using various GIS techniques. From these images it was possible to determine the most suitable locations for road networks within the Eastern Shores State Forest.

Particular attention was focused on how GIS may be integrated within the IEM process. It was found that GIS could not only accurately determine where development should take place, but also established that it is an effective tool for aiding in the decision making process by providing accurate detailed maps of the area proposed for development. The success and overall simplicity of the procedure in this study suggests that GIS would be valuable to the IEM process.



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# LIST OF ABBREVIATIONS

AHP:	Analytical Hierarchy Process
asc.:	Ascii
DEM:	Digital Elevation Model
EIA:	Environmental Impact Assessment
ESSF:	Eastern Shores State Forest
gce:	grid cell equivalent
GIS:	Geographic Information System
GUI:	Geographical User Interface
IEM:	Integrated Environmental Management
IUCN:	International Union for the Conservation of Nature and National Resources
MCE:	Multi Criteria Evaluation
MS dos prompt:	Microsoft dos prompt
NCS:	Nature Conservation Services
NEPA:	National Environmental Policy Act
NPB:	Natal Parks Board
RMS:	Root Mean Square
SAFCOL:	South African Forestry Company Ltd.
SDI:	Spatial Development Initiative
TIN:	Triangulated Irregular Network
txt.:	text
UNEC :	United Nations Economic Commission
WCED	World Commission on Environment and Development
WLC:	Weighted Linear Combination

# **CHAPTER 1**

## **INTRODUCTION**

### **1.1. Preamble**

The primary aim of this study was to show how Geographic Information Systems (GIS) may be used in the Integrated Environmental Management (IEM) Process. This was achieved by conducting an extensive literature survey and undertaking a GIS project using the Eastern Shores State Forest, within KwaZulu-Natal as a case study. This chapter provides an overview of the IEM process whilst also highlighting the role of GIS within the IEM process. Leading from this the goals of the study are outlined and the limitations in the research explained.

### **1.2. Integrated Environmental Management**

The overriding goal of the IEM process is to ensure that South Africa's developing economy be redirected from that of historically environmentally unsustainable growth and utilisation towards that of environmental sustainability. The Integrated Environmental Management procedure has therefore been established in such a manner as to allow the environmental consequences of development to be fully recognised and considered early in the planning process. It also forms a framework whereby decision making is a factor throughout the duration of a project (Heydenrych and Claassen, 1998).

IEM is intended to give direction to project planning and implementation (Fuggle and Rabie, 1996). In order to achieve this, IEM has been designed to allow for a constructive and interactive approach to the

gathering and analysing of useful data. This is useful for decision making, in that the findings are presented in a manner which can be easily utilised for managing environmental problems during the life-cycle of a project (Glasson *et al.*, 1994). Thus, it enables the proponent and responsible authorities to identify actions that should be taken or that are in the best overall interest of society without jeopardising the project as a whole (Department of Environmental Affairs, 1992). Although one should not forget that there are times when a project should be terminated. This would occur when the impacts and actions of mitigation of a project could not be reduced enough to warrant the continuance of development (Mander, pers. comm., 1999). Therefore, IEM could be viewed as a participatory procedure, a mitigative and directional decision making support system in environmental management (Glasson *et al.*, 1994).

### **1.3. The Role of Geographic Information Systems within the IEM Process**

Mankind continues to make decisions relating to the development of 'natural areas' on a daily basis. These decisions determine how the land is utilised and therefore how it is to be managed in the future. Many of these development decisions cause irreparable damage to the environment, emphasising the need for a tool that has predictive capabilities, a requirement in conducting an environmental impact assessment. For a number of years it has been recognised that there is a need to establish predictive capabilities that will aid in ecosystem management. Despite this recognition very little headway has been made in incorporating 'decision support systems' such as GIS into this realm, even though they have proved their ability time and time again (Ventura, 1995).

Decision support systems have grown out of the need to provide succinct and reliable indices of performance to managers. Ventura (1995, p.461)

says that GIS "...has tremendous potential at this level both in allowing decision-making to be more objective and in elucidating the cumulative effects on incremental decisions." Therefore, even though decision support systems are in place their potential is still under-utilised.

GIS in South Africa has a very important role to play in determining and facilitating decisions relating to development issues. Although GIS has been developed for a number of years it is still a relatively new technology in South Africa. GIS is however increasingly being included in issues relating to environmental management. Despite this increased use by members within the environmental arena, many of them do not fully understand the capabilities of this tool. This lack of understanding has contributed to the misuse and misinterpretation of GIS. It is therefore imperative to identify how GIS may aid in the IEM process.

## **1.4. Goals and Objectives**

The overriding aim of this study was to investigate the implementation and use of GIS in an IEM process in South Africa. To date little use has been made of GIS in the IEM process within South Africa, hence there exists a paucity of literature relating specifically to the integration of IEM and GIS. However, a substantial amount of literature relating to the use of GIS and environmental matters, specifically the impacts that developments have on the environment was reviewed.

Literature directly related to the topic pertained mainly to foreign conditions, and although it could not be applied directly it did provide essential guidelines. It is the author's opinion that this may be attributed to South Africa's late arrival to both the GIS and the IEM process.

In meeting the overall aim of the study, numerous goals were set. The first was to provide overviews of the Integrated Environmental Management and the Environmental Impact Assessment Processes

currently in use within South Africa. This was achieved by carrying out an extensive literature survey on the topics as well as informal interviews with Environmental Consultants.

The second goal was to examine the use of GIS within the IEM process and establish practical examples of how GIS may be used to reduce/limit negative impacts on the environment due to development. This was also carried out in the form of a literature survey of all relevant literature pertaining to the topics in question.

The third goal, also carried out in the form of a literature survey was to identify some of the major impacts that a development such as roads could/would have on the environment. It also gives a brief overview of some of the legislation that relates to road development. <sup>ref</sup>

The fourth and final goal was to illustrate how GIS could be practically implemented and integrated in a holistic manner into the IEM process. This was achieved by carrying out a project within The Eastern Shores State Forest. The results of the case study show clearly how beneficial a tool such a GIS can be within the IEM process.

## **1.5. Limitations of Research**

The limitation and setbacks which were experienced whilst undertaking this project, pertained particularly to the nature of the research. With the time allocated for completing this research probably being the greatest limiting factor. Being part of a course work Masters, the initial time allocated for completion of this task was six months. However, due to the difficulty faced in acquiring the data for the topic and having other logistical problems with it, it was realised that more time would be required to complete the study. Logistical problems included such things as the distance between the study area and the area in which the author

was researching this project. This created difficulties in communication between the relevant authorities and the author. However, technology such as e-mail and faxes, allowed this problem to be partially overcome. The lack of finances was another major obstacle as the author could not visit the study area as often as he would have liked. Finances also posed a problem at the outset of the thesis whilst the author was gathering data, as many departments would not part with data unless the author paid for it. The sums requested were clearly out of the author's budget, the author was therefore not able to acquire all the information that he would like to have included in his research. However this data was not essential to the project and therefore did not alter the author's approach to the objectives set aside.

Before any analysis could be undertaken the data that the author had obtained from the Nature Conservation Services (NCS) needed to be 'cleaned'. Advice on how to clean the data was generously supplied, free of charge, by members of the same organisation.

Lastly the final limitation lay in the fact that the GIS package the author had originally decided to carry out his analysis with (IDRISI for WINDOWS) could not perform the final results for some unknown reason, although it has the functionality to do so. This meant that the author had to go back a few steps and convert the data so that the analysis could be undertaken using a different GIS package (ArcView).

# **CHAPTER 2**

## **INTEGRATED ENVIRONMENTAL MANAGEMENT (IEM) AND ENVIRONMENTAL IMPACT ASSESSMENT (EIA)**

### **2.1. Introduction**

Over the next five years it is hoped that IEM may have established the foundations for environmentally sustainable development (Fuggle and Rabie, 1996). In order to reach this goal the South African government has committed itself to ensuring that IEM procedures are implemented in such a manner that it is able to identify development impacts within both the private and public sectors. Government also wishes to ensure that public awareness and understanding of environmental issues are increased through better education, whilst also unifying it's approach to environmental management across all state departments. Lastly government wishes to conduct more research into understanding environmental impacts and developing and implementing new technology that may aid in minimising impacts (Hydrenrych and Claassen, 1998).

### **2.2. Underlying Principals of IEM**

The basic principles underpinning IEM are that there be (Department of Environmental Affairs, 1992, p. 5):

- informed decision-making;
- accountability for information on which decisions are taken;

- accountability for decisions taken;
- a broad meaning given to the term *environment* (i.e. one that includes physical, biological, social, economic, cultural, historical and political components);
- an open, participatory approach in the planning of proposals;
- consultation with interested and affected parties;
- due consideration of alternative options;
- an attempt to mitigate negative impacts and enhance positive aspects of proposals;
- an attempt to ensure that the 'social costs' of development proposals (those borne by society, rather than the developers) be outweighed by the 'social benefits' (benefits to society as a result of the actions of the developers);
- democratic regard for individual rights and obligations;
- compliance with these principles during all stages of the planning, implementation and decommissioning of proposals (i.e. from 'cradle to grave'); and
- the opportunity for public and specialist input in the decision-making process.

## 2.3. The IEM Process

The IEM process has been formulated in such a way that it allows the procedure to be regularly reviewed as experience is gained in this field. One should be aware that all projects, which could have significant negative environmental impacts, would more than likely be formally investigated in some manner. However, not all developments would be subject to full EIA's (Act No. 73 of 1989).

As a result of development activities having negative impacts on the environment, the Minister of Environmental Affairs and Tourism has,



under section 21 of the Environmental Conservation Act, 1989 (Act No.73 of 1989), identified a list of activities which may have a substantially detrimental effect on the environment (Appendix A). These activities are subjected to the IEM process (Act No. 73 of 1989). The process provides for decision making at different stages throughout the procedure. However, “in many cases, a brief investigation will convince the decision-taker that the proposed action will have no significant impacts, or that effective mitigatory measures may easily be implemented” (Fuggle and Rabie, 1996 p. 750).

Essentially, the IEM process may be separated into two major phases. Firstly, the scoping phase and secondly the impact assessment phase. Each of these phases in turn can be broken up into a number of smaller actions required by the new IEM process (Figure 2.1).

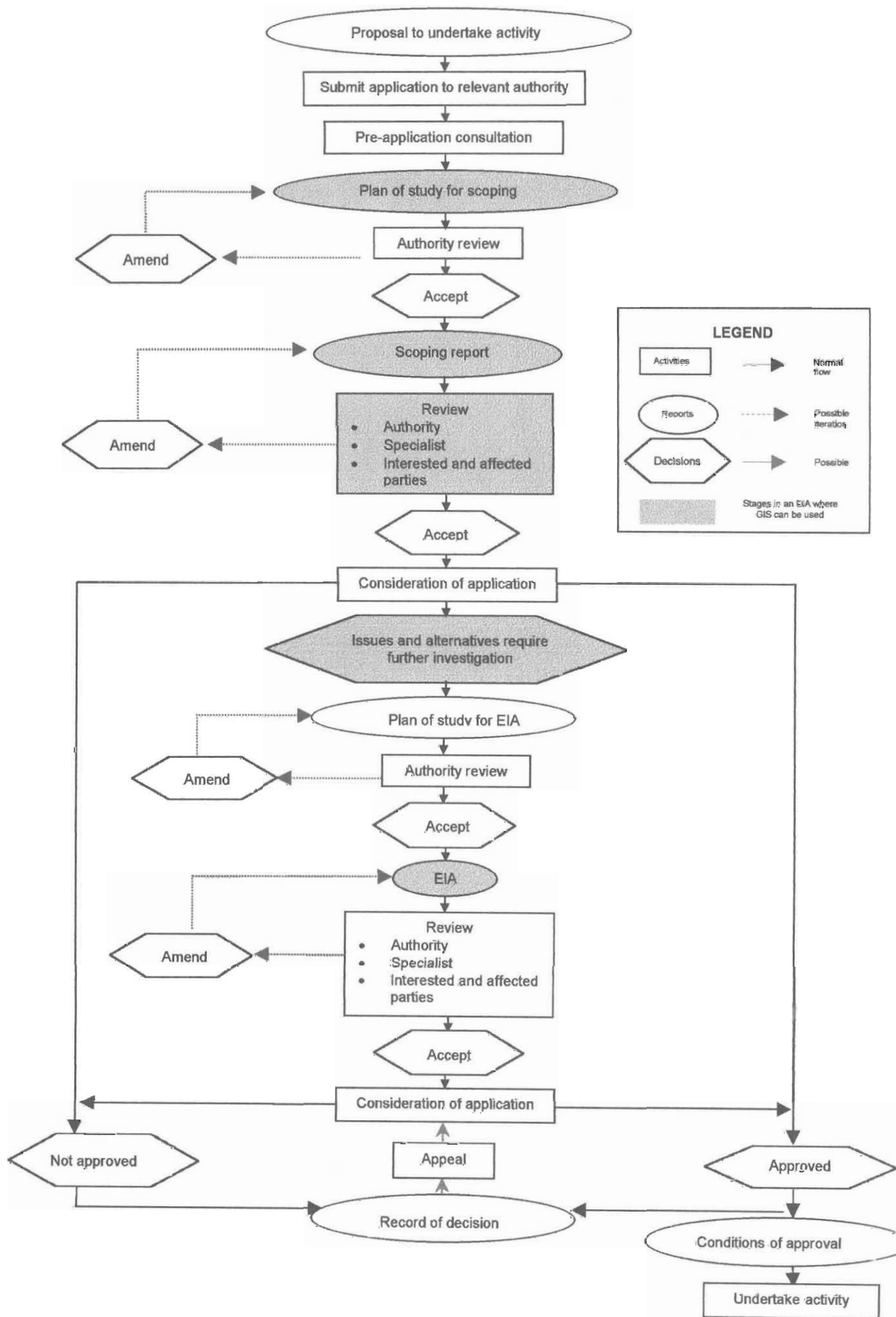
One needs to take cognizance of the fact that prior to scoping, an application to undertake such an activity needs to be submitted to the relevant authority<sup>1</sup>. This ensures that the proposal goes through the relevant channels in order for it to reach the stage where it is appropriate to begin a scoping report. If a decision is taken that the project meets the requirements, the applicant would then have to submit a scoping report to the relevant authority. Such a report would need to include: (Act No. 73 of 1989, p.4).

- i) a brief project description;
- ii) a brief description of how the environment may be affected;
- iii) a description of environmental issues identified;
- iv) a description of all alternatives identified; and
- v) an appendix containing a description of the public participation process followed, including a list of interested parties and their comments.

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<sup>1</sup>The relevant authority depends on who and where the application was made. It also determines the nature and scope of the investigation required.

Figure 2.1: The IEM Process (Lengoasa, 1997 p.4)



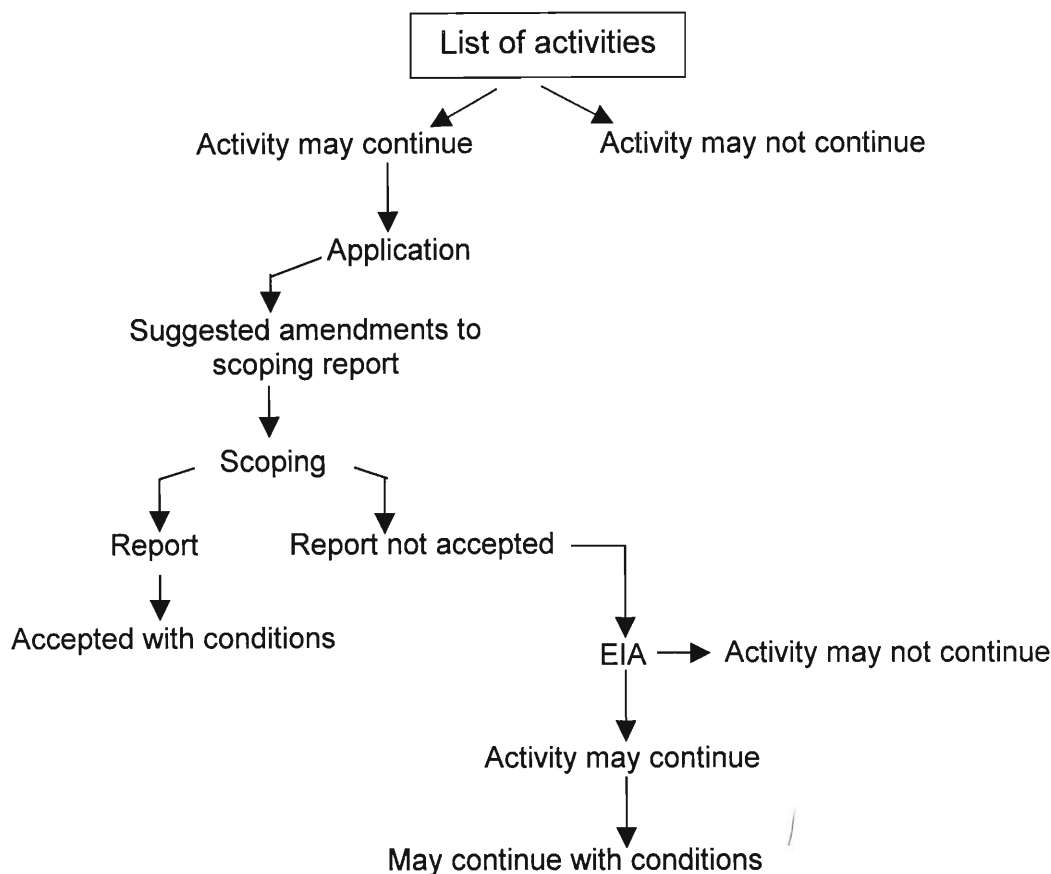
The relevant authority would then review the report and either accept it or suggest amendments that need to be made before such a project would be accepted, if at all. If the scoping report is accepted, the relevant authority must decide whether the information within the scoping report is adequate in order to consider the application without any further investigation or whether the information needs to be supplemented by an EIA. In the event that no further investigation is required the relevant authority would then consider the application and either grant authorisation with or without specified conditions, or the authority may refuse the application.

The relevant authority would then determine the period of validity of authorisation and it would make a record of the decision that was taken (Appendix B). Once the decision has been taken, and if the applicant wishes to appeal against the decision, an appeal to the Minister or provincial authority must be made in writing within 30 days from the date on which the record of the decision was issued to the applicant.

On the other hand if it was decided that the scoping report required an EIA, the applicant would have to submit a plan of study for an environmental impact assessment. This would have to include a number of factors as indicated in Appendix C. Once this has been undertaken and considered by the authority, the applicant would be requested to make amendments to the plan of study required by the relevant authority in order for the plan to be accepted. Only once all this has been completed may the applicant submit the relevant EIA incorporating a list of factors as set out in the regulations (Appendix D).

It is at this stage that the application will follow the same path as that of an application that did not require further investigation i.e. it would be considered and either refused or accepted with or without conditions (Figure 2.2. represents a simplification of the IEM process).

**FIGURE 2.2:** Simplification of the IEM Process (Mander, 1999).



## 2.4. Future developments within the IEM process

### *Monitoring*

At present the new regulations do not make provision for monitoring within the IEM process, however it is expected that such regulations will be brought into effect in the near future (Mander, 1999). The monitoring stage would regulate all proposals even if an environmental contract or management plan were in place. This would be undertaken to establish clear guidelines as to what should be done, by whom and how it would be financed. Furthermore, monitoring ensures that the project continues

along the guidelines set out by the conditions of approval if any were stipulated.

The Monitoring Process could include: (Fuggle and Rabie, 1996, p.753)

- A check that actions are in accordance with conditions of approval;
- A check that mitigation measures are being implemented during the construction phase;
- A check on the efficiency of those measures;
- Emissions monitoring; and
- Monitoring of selected environmental variables.

### *Auditing*

This stage, like monitoring, is not at present regulated, although it is hoped that it will be included in requirements in the near future. At this stage the project or policy proposal would be reassessed in the light of developments that occurred during the project's implementation. During this phase the positive and negative impacts of the development would be reviewed, providing feedback on how adequate the planning has been during the development proposal stage; on the accuracy of the investigations during the initial assessment and/or impact assessment stages; on the wisdom of the decisions at the authority review stage; and on the effectiveness of the conditions of approval at the implementation stage (Fuggle and Rabie, 1996).

The main aim of the IEM process is to establish whether or not an impact assessment is required. It is the intention of an IEM to ensure that, with the correct planning and by making use of the required stages of assessment, the decision making process will be greatly facilitated.

## 2.5. Environmental Impact Assessment (EIA)

Environmental Impact Assessments have been defined in many ways, for example, the narrow World Commission on Environment and Development (WCED) operational definition which states: "The term 'environmental assessment' describes a technique and a process by which information about the environmental effects of a project is collected, both by the developer and from other sources, and taken into account by the planning authority in forming their judgements on whether the development should go ahead". Then there is the very simple definition, put forward by the United Nations Economic Commission for Europe (1991): "An assessment of the impact of a planned activity on the environment " (Glasson *et al.*, 1994, p.3).

Over the past few years there has been a world wide increase in awareness of the importance of the world's natural resources, and the environment as a whole (Glasson *et al.*, 1994). There is a realisation that the preservation of these resources is of extreme importance, as not only does our economy depend on it, but so do our lives. Biodiversity<sup>2</sup> has often been termed the 'essence of life' as, without the different natural resources, humankind would not be able to sustain itself.

At present a substantial number of environmental issues are concerned with sustainable development and how we may optimally use the natural resources in ways that will ensure the resources exist for years to come (Heydenrych and Claassen, 1998). A major stumbling block is that the human population continues to grow exponentially which places greater pressure on the environment for development purposes. As a consequence the need to undertake EIA's, in order to minimise the effects of development before irreparable damage to the environment

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<sup>2</sup> Biodiversity is "the sum of the genetic, specific and ecosystem richness on the planet. It is the fundamental basis for the evolution and for continuing adaption to changing circumstances" (Krattiger *eds.*, 1994 p.8).

occurs, is of pressing concern. This growing awareness has led to the necessity to address these impacts during the planning stages of development (Mander, 1999).

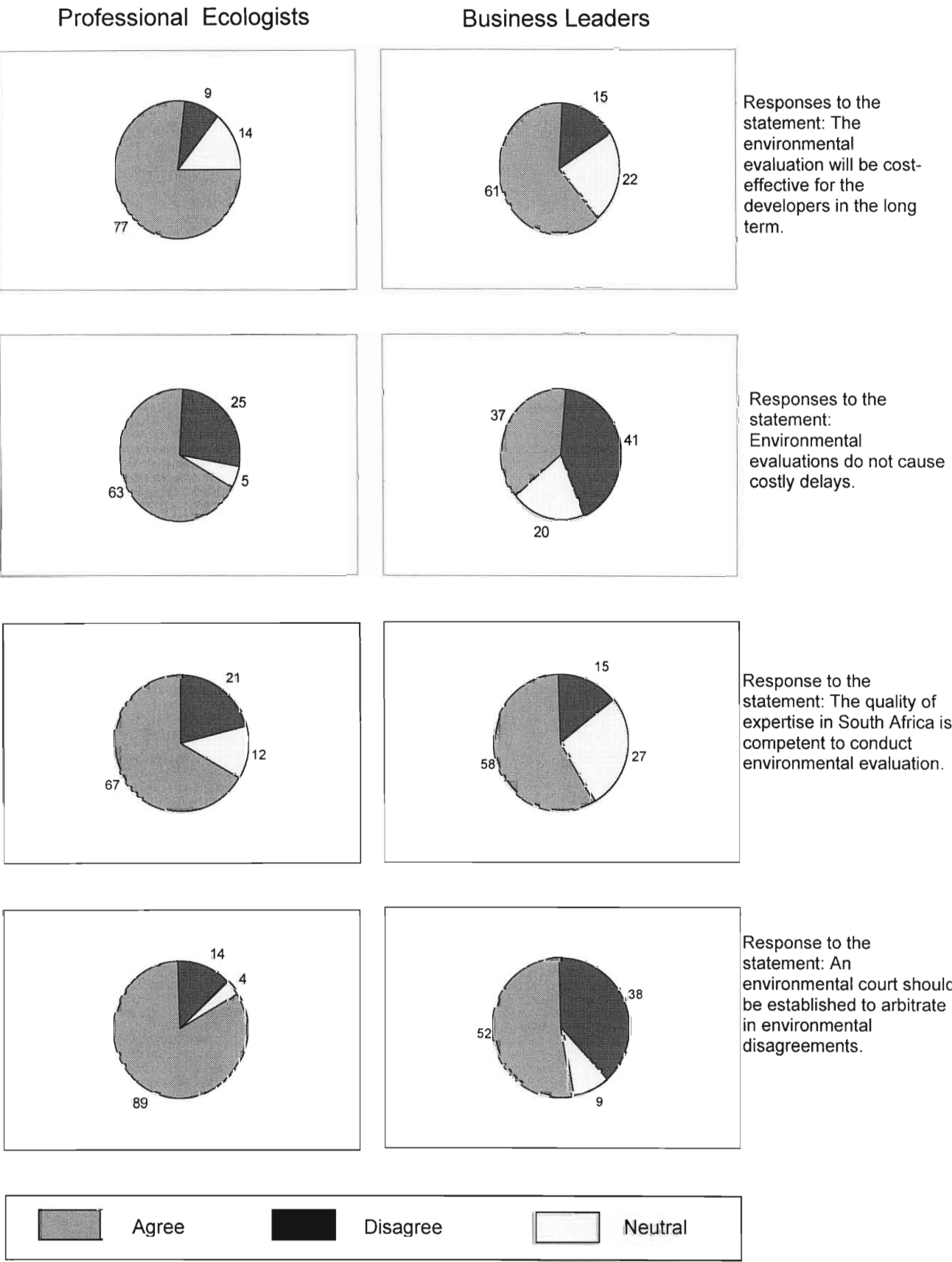
EIA's are essentially tools in the IEM process which examine the possible consequences of a proposed development before they actually take place. EIA's are thus focused on predictive and preventative techniques and not on remedying actions already in place. Although, to some extent, planners have started to address development issues and their impacts, they have failed to look at it in a 'systematic', holistic and multidisciplinary approach which is required in an EIA (Glasson *et al.*, 1994).

It is for this reason, of first having to assess what damage may be caused by a development, that the IEM process is often viewed by developers to be a procedural burden rather than an opportunity to improve the decision making process. What the developers fail to realise is that if one uses an EIA early in the planning process, environmentally sensitive development plans could be implemented with no added burden.

EIA's may also lead to improved relations between the developers, planning authorities and the local communities by ensuring interaction on a continual basis throughout the IEM process. In turn, this could lead to improved planning permission processes. All these measures, although previously neglected, could lead to a worthwhile financial return as against the extra expenditure incurred in the long term. This opinion is highlighted in Figure 2.3. where it is clearly set out that business leaders and professional ecologists alike, recognise that environmental evaluations will prove to be cost effective in the long term.

Although EIA's investigate primarily the impacts that development would have on the environment, they also, in many cases, suggest alternatives for the development, before any final decisions are made.

**Figure 2.3.** Graphs representing the perceptions of professional ecologists and business leaders towards the IEM Process (Preston et al, 1989, p.433).





However, an EIA is not supposed to act as a substitute in the decision making process, but rather, should aid in clarifying some of the trade-offs associated with the proposed development action. This could lead to a more rational and structured decision-making process.

Furthermore, EIA's may also act as a facilitation process between the developers, public interest groups and planning regulators. A framework for developers may also be provided through the use of an EIA. This may be achieved by integrating location and design issues with environmental issues. Lastly, EIA's aid in the formation of development actions by indicating sectors where the project can be modified to minimise or eliminate adverse impacts on the environment.

Increasingly, development has included evaluation methods so as to make it possible for one to place economic values on development impacts on the environment. These economic values are incorporated into cost-benefit appraisals (Heydenrych and Claassen, 1998). Moreover, the environment is often perceived as a set of resources, predominantly natural, that form an integral part of the nation's capital stock. As a consequence, all development depends either directly or indirectly "on the available supplies and quality of natural resources, stocks of natural capital should also be preserved, conserved, expanded, rehabilitated, restored or improved to support long term economic development. If natural capital is not properly managed, the prospects for long term economic development may be limited" (James, 1994, p.3). Thus further emphasising the importance in implementing EIA's in all development projects.

### **2.5.1. Why the need for EIA has emerged**

During the 1960's an awareness of the importance of the environment and how development could radically alter natural environments emerged. This was followed by the realisation that to reduce and try to

stop these impacts a policy on the environmental issues was required. The United States were the first to act , and by 1969 had formulated what was termed the National Environmental Policy Act (NEPA). This effectively introduced "environmental evaluations into the realm of public policy" (Fuggle and Rabie, 1996, p.748). A number of Western, industrial countries, soon followed.

South Africa as a developing country requires policies which are going to suit its political, social, cultural and physical environment (Fuggle and Rabie, 1996). With the backing of approximately 30 years of research which has been done, by other countries that already contain EIA's as part of their legislative processes, South Africa should be able to weigh up the pros and cons of instituting it's own criteria for environmental evaluation. This would, have the advantage of South Africa being able to establish a system that is well structured and regulated, should South Africa choose to use these countries as areas of references (Fuggle and Rabie, 1996).

To a large degree it seems as though the new regulations within South Africa have been carefully formulated and weighed up against other IEM processes around the world. Although one could argue that the process would be that much better if it made provision to regulate the monitoring and auditing processes. One should not forget that the IEM process in South Africa has been structured in such a manner that it allows for the process to be amended. This could add to the effectiveness of the process. Both monitoring and auditing are therefore expected to be regulated in the near future. On the other hand some countries have fallen into the trap of having an environmental evaluation structure that has been poorly structured and regulated. This has resulted in EIA's having become reactive, excessively negative, and the cause of great expense and delay to the development process.

On the whole, the "integration of environmental concerns into public policy depends on an open system of government, a wide disclosure of

information and an informed citizenry", (Fuggle and Rabie, 1996, p.748) which South Africa has historically lacked. Other exacerbating problems within South Africa include: the lack of scientific data, inadequate administrative structures and the insufficiency of trained personnel. "Furthermore, environmental assessment directs considerable attention at long term or inter-generational ecological criteria, aesthetic considerations and scientific/educational interests" (Fuggle and Rabie, 1996, p.748). As a result of the perception that less developed countries, including South Africa, regard scientific, educational and aesthetic requirements as luxury items, it is no wonder that environmental concerns carry little electoral weight in South Africa. Rather, people have historically been more concerned about their immediate needs such as food, shelter and security (Fuggle and Rabie, 1996). There is however, a growing demand amongst the South African public to have a greater say in issues that affect their daily lives and the environment in which they live. This shift has developed out of the realisation that the environment is an important asset and if not looked after it will soon be converted into a 'wasteland'.

## 2.6. Conclusion

It is clear that South Africa requires an approach to environmental evaluations that reflects the demand for a greater say in environmental matters. By so doing it will take into account the limitations and requirements of this country. Fuggle and Rabie (1996) argue that the new approach to IEM should not be a stop/go approach. They suggest that it be an approach that encourages decision-makers to formulate an appropriate compromise with the emphasis on identifying options and facilitating a choice between options, as opposed to detailing only the negative impacts of a development. On the other hand the author shares the opinion with many Environmental Consultants that having a stop/go approach is not necessarily a bad idea. The reason for this argument is

that at times there are development projects that, no matter what mitigatory measures are taken, the impacts of which on the environment (be it in the short term or long term), are going to be too substantial to allow the projects to go ahead. Thus, although it is essential for South Africa to pursue economic and social development, in order to meet the needs of society, it is equally important to ensure that development takes place on a sustainable basis. Too often in the past *ad hoc* development plans and projects have been destructive to the environment, and have thereby endangered the very basis on which continuity and sustainability of development depend. South Africa's new regulations have, to some degree, realised this and have made provision to stop projects that even with mitigatory measures would cause excessive environmental degradation (Mander, 1998).

# CHAPTER 3

## AN OVERVIEW OF GIS AND IT'S APPLICATION IN THE IEM PROCESS.

### 3.1. Introduction

This chapter provides an overview of GIS and its application within the IEM process. It also discusses practical examples in which GIS may be used to limit environmental impact.

#### 3.1.1. Defining GIS

A GIS may be defined as a computer-based system for spatial data handling, modelling and geographical representation (Clark *et al.*, 1993). Worral and Bond (1997, p.366) continue by adding that it is a "...toolkit for the modelling and analysis of complex research, management and planning problems; and, a system to support decision makers by enabling them to structure problems and identify potential solutions for evaluation."

Burrough (1986) states that GIS may act as a 'test bed' for studying environmental processes, while it may also allow managers to test the consequences which may arise if certain actions were to be taken, before any actual harm occurs. Franklin (1979) adds that environmental decisions are complex and thus require analysis of a number of different options, many of which involve considerable risk or uncertainty. It is for this reason that GIS is regarded as a 'general-purpose' technology for handling geographic data in digital form, and for satisfying the following specific needs: (Goodchild *et al.*, 1993)

- The ability to pre-process data from large stores into a form suitable for analysis, including such operations as reformatting, change of projection, resampling and generalisation;

- Direct support for analysis and modeling, such that forms of analysis, calibration of models, for casting, and prediction are all handled through instructions to the GIS; and
- Post-processing of results, including such operations as reformatting, tabulation, report generation, and mapping.

The full potential of a GIS still has to be realised (Beattie, 1998). At present, GIS does not contain any spatial reasoning capabilities about the data itself. This has led to many discussions on how one might be able to integrate Knowledge-Based Systems<sup>1</sup> and GIS. There remains uncertainty as to when and how such a process might take place (if at all), as the data representation techniques employed in GIS have not been directly compatible with the representations used by existing approaches to Spatio-Temporal reasoning<sup>2</sup> (Hayes, 1979, Kowalski and Sergot, 1986).

There is little doubt that this type of integration would provide support to an expert making decisions and predictions in the domain of dynamic spatial data (Beattie, 1998). Furthermore, the high quality graphics generated by GIS enhance the software's ability to communicate complex spatial problems and concepts to the public. This ensures that the public are included in the decision making process (Collinson, 1998).

## 3.2. The use of GIS in IEM

One may ask where incorporating GIS with IEM would be required? It is a widely accepted principle that our environment needs to be looked after and conserved so as to ensure its continuance for future generations

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<sup>1</sup> Knowledge –Based Systems are systems with artificial intelligence whose role it is to emulate the reasoning powers of human beings. Such systems therefore require all available knowledge pertaining to the subject in question. These systems are also supposed to fill the role of the expert (Smith *et. al.*, 1987).

<sup>2</sup>Such reasoning deals with geographical change of space over time.

(Beattie, *et al.*, 1995). Maintaining an environment that is healthy and that will ensure the diversity of species and the reproductive capacity of the eco-system remain a basic necessity for life. Large development projects can have adverse effects on the environment and many developers of these projects have conducted EIA's to try and limit these adverse effects. One of the most frequent categories of development for which EIA's are undertaken is in the construction of roads and highways (Beattie, *et al.*, 1995).

Due to the fact that the construction of roads may have such adverse effects on the environment it is important that the developers provide alternative routes and perform cost – benefit analyses. These costs may not only be monetary, but may also include the loss of environmental features, habitat and diversity. This is where GIS can be extremely helpful. It can graphically display where a road should or should not be placed taking into consideration a number of important factors such as wetlands, protected areas, important rivers, agricultural land and vegetation type.

There are a number of other advantages that Project Managers could benefit from, when using GIS to establish the most suitable routing of roads. Project Managers are often pressured for time while still having to produce high quality work, which is expected of them by their clients. GIS has proved it's ability to ease project schedules and their costs dramatically, provided they are put into operation during the development and planning stages. This has resulted in reducing stress experienced by Project Managers who have in the past been faced with projects containing multiple engineering and environmental challenges (Gesing, 1995).

Incorporating GIS in this way allows Project Managers to screen the various options and weigh them up against the detailed environmental information. This allows for a selection process, which enables the manager to select the most feasible corridors. As a result project

schedules can be greatly compressed and costs reduced without having to sacrifice the project quality or thoroughness. Ultimately therefore, a GIS speeds up the permitting and resource agencies' decisions on the project. It also reassures the public that all the information has been carefully and objectively evaluated and incorporated in a holistic manner which should be the overriding aim of the IEM process.

Furthermore, a GIS allows data to be continually updated as the project progresses. It allows the engineers to pursue the most feasible alignments from a design point of view as the project matures, while at the same time allowing the environmental scientists to examine and give weightings to the potential environmental effects. This is all brought about as GIS allows for a range of queries to be answered, enabling information to be sorted "...and numerous alignments considered without requiring manual computations" (Gesing, 1995, p 52).

### **3.3. Integrating IEM and GIS**

Most of the world, including South Africa, is faced with the daunting consequences of development and human overpopulation. The result of these two factors is an increasing concern regarding the negative impacts that man has on the environment and the very unsustainable manner in which he is going about the development processes. Sustainability<sup>3</sup> in the Twentieth Century has become a major driving force behind most development activities. To this end, IEM has been recognised as a process that incorporates the idea of sustainability into the decision-making processes. However, environmental practitioners require methods that optimise the array of requirements within the IEM process, with GIS being recognised as one of the methods that may aid in this process (Goodchild *et al.*, 1993). There is a growing perception amongst

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<sup>3</sup> "...development which meets the needs of the present generation without compromising the ability of future generations to meet their own needs" (Krattiger eds., 1994, p.6.).



environmentalists, planners and project managers, that EIA's are becoming one of the most efficient ways of determining the impacts of particular projects on the environment. As a result, since September 1997, some scheduled activities are required by legislation to have EIA's carried out ( Appendix A). A large majority of these EIA's have required the investigation into environmental factors, many of which have spatial components. A GIS enables the processing, integration, modeling and display of spatial data sets, therefore making it a tool that could be extremely useful in supporting the decision making process

However, there remains a perception amongst some developers and businessmen that the EIA process is time consuming, resulting in increased development costs. The use of GIS may provide innovative ways of optimising the EIA process while simultaneously speeding up the decision making process (Morris and Therivel, 1995). Canter in his book *Environmental Impact Assessment* (1997), emphasises that the liberal use of maps, photographs and drawings in EIA's added tremendous value to the reviewers as well as to the agency decision makers.

Maps such as topographic maps<sup>4</sup> that allow for the presentation of area features as well as surface – water drainage characteristics are generally used in EIA's. Another important map is the land-use map as it allows one to gain a broader perspective of what land-uses would be affected if the proposed activity was to be implemented.

Maps may also be used to display such factors as air and water quality levels, noise levels, plant and animal species distribution and historical and archeological sites. Maps may also be useful for illustrating socio-economic characteristics such as population distribution, housing, income levels and transportation systems (Canter, 1977). The above variables all

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<sup>4</sup> This type of map "may be defined as a map which shows all the information about natural and artificial objects, usually including the relief of the country, which can reasonably be shown at the scale employed" (Cheetham, 1965, p.3).

have spatial characteristics and would therefore be easy to analyse using GIS.

Using GIS maps within an EIA would be extremely useful. The added advantage of a GIS map is that it can incorporate those land use maps, the species distribution maps and perform simple GIS functions such as overlaying<sup>5</sup> in order to produce a map displaying all the collective factors on a single output. If, for example, one wanted to construct a road network within an area that was to have the least environmental impact on the surrounding environment, one could take these maps and use pre-determined criteria to produce a separate map showing alternative road routes with varying degrees of environmental impact. From this a further set of criteria may be used to narrow the choice down to a single road alignment with least impact. There can be no doubt that such maps would help decision-makers make better and more informed environmentally sustainable decisions.

Cognisance must be taken by those undertaking the EIA that the decision-makers are often not as familiar with the project area as they themselves may be. The use of maps, as mentioned earlier, will provide a better visual interpretation of the project, which could ultimately aid in improving the decision making process. Furthermore, one needs to bear in mind that the GIS is able to display the potentially impacted areas before they actually damage.

Therefore, the need for the integration of GIS in EIA is driven by our need to make environmental choices that will not only ensure sustainability but also provide for a rapid development process. Since the environmental regulations (Act 73 of 1989) EIA's have been carried out more regularly than ever before.

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<sup>5</sup> This module within Idrisi performs operations between two images, producing a single output image (Eastman, 1997, p. 5-8)

Environmental impacts require environmental problem solving. Ostensibly, the goal of environmental modeling, as well as environmental applications of GIS, require that the spatial aspects of environmental impacts and/or problems be examined explicitly resulting in solutions incorporating such knowledge. GIS excels in such tasks so long as it relies on its ability to map what is apparent within a predominately two dimensional macrocosm where all things are seen, assured, or equally unpredictable, and where change with time is, as a rule, not a restraining consideration (Goodchild *et al.*, 1993).

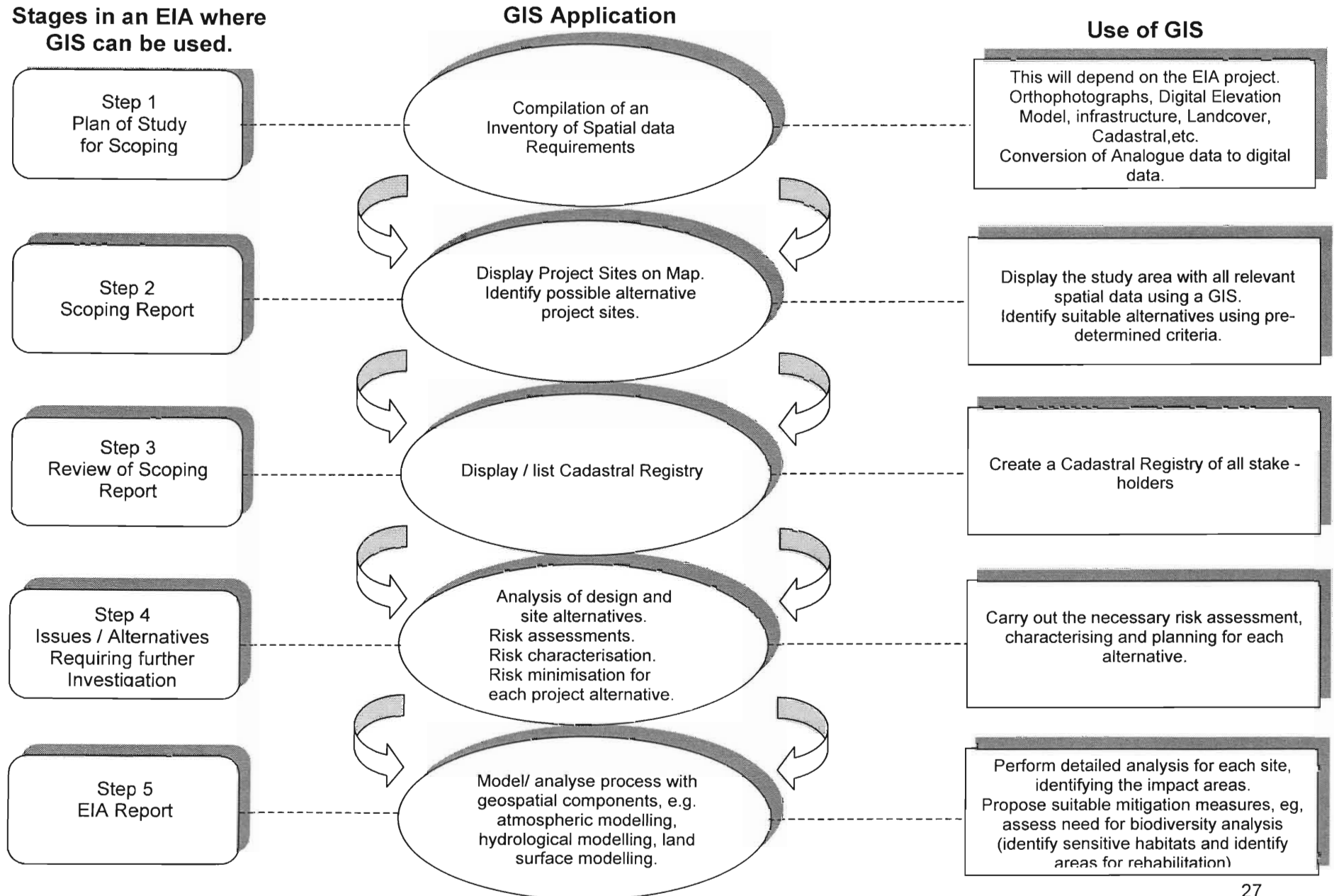
It must however be acknowledge that the growing concern regarding environmental impacts, and their immediate and long term consequences, has necessitated the need to bring about an Impact Assessment framework that is both efficient and financially viable. Figure 3.1. displays where and how a GIS may be used within the IEM process. Steps one (1) to five (5) correspond to those stages highlighted in the IEM process (Figure 2.1. p. 8).

It is therefore envisaged that with the aid of GIS, a more sound EIA process could be established, ensuring that optimal use of all resources is kept to a maximum whilst ensuring that minimal environmental degradation occurs.

### **3.4. Practical Examples of GIS in EIA**

It has already been established that all development activities have negative impacts on the environment (Fuggle and Rabie, 1996). The following section provides a broader understanding of how GIS may aid in mitigating some of these negative impacts. The answer as to how one may be able to mitigate these effects, lies in the ability of a GIS to be able to accurately show where different environmental factors are placed within the correct geographical space, whilst being able to carry out some

**Figure 3.1.** Framework for Using GIS in EIA's (Modified from Ramjatan and Ahmed, 1998)



basic GIS functionality to provide results. However, it also relies on having up-to-date databases.

### **3.4.1. GIS and Biological Diversity Density / Range**

#### **Mapping.**

The accelerating rate of extinction of fauna and flora, and the alarming rate of ecosystem destruction has prompted a call to the scientific community to provide a comprehensive assessment of the status and trends of biodiversity. It has also emphasised the need to establish strategies for conservation (Wilson, 1975). This has resulted in the proposal to create what has been termed biodiversity information systems.

A comprehensive data set for assessing the status, as well as for predicting trends in biological diversity, includes the distribution of taxa, ecological factors that influence their habitats as well as the human activities that affect these habitats. These data sets are inherently spatial attributes and thus can be stored as maps, tables or even as text files. GIS is a good tool to store and analyse such data sets. To determine which areas are occupied, field biologists collect specimens and record observations, noting geographical locations. From this collection of distribution points, a representative map may be generated indicating the species range and, the number of species within the specified area (Davis *et al.*, 1990). Such range maps are often stored in a database consisting of a published atlas for a specific taxonomic group with subsidiary maps of ecological factors. This type of format enables one to ask simple questions, in a GIS, as to the range of a particular species. However, it is not appropriate for identifying species density unless a separate database linked to the map has also been created (Marble, 1986).

The next step would be for the GIS user to isolate these occupied areas and either buffer them within a certain distance or to find areas or corridors between such sensitive areas that would have minimal impact

on the area were a road to be constructed through the area. These maps form part of what is referred to as biological diversity information systems.

One may therefore conclude that a biodiversity information system would be able to address questions such as: (Davis *et al.*, 1990)

- what is the range of a given species or community type?
- which species are at greatest risk?
- which sites have greatest species richness?
- which biologically important sites are at greatest risk (i.e. hot spots)?
- which ecosystems are adequately protected?
- what environmental factors are related to sites of greatest biodiversity? Can diversity be predicted on the basis of these factors?
- where can ecologically sustainable development occur with acceptable impacts on biodiversity?
- what are the trends over time in species and ecosystem diversity?

From the above, it is clear that a biodiversity information system would be important for the evaluation of the effects on biological diversity in the environmental impact assessment process and any subsequent attempts at mitigation. Thus, the information system can act as a point of contact for data on critical elements of diversity that may be affected by a given project. If one were to consider a transportation project using such an information system it would involve overlaying the project boundary with the data layers of observations of endangered species, species richness, communities and transportation infrastructure resulting in a map depicting the locations of critical elements of diversity which would be potentially affected (Davis *et al.*, 1990).

### **3.4.2. GIS and Slope Analysis**

GIS has the functionality to create what is termed a Digital Elevation Model (DEM). Using either point data or spot heights of an area or making use of digitised contour data, GIS is able to generate map

images. From these images a separate slope image may be created of a required area. The user is then able to carry out various analyses within the GIS in order to obtain the required results.

As an example, if one knew that the cost of developing land which has a slope of 'X' percent /degrees would not be financially viable, then the GIS user could instruct the computer to create an image of all those slopes that would be suitable as well as those that would be unsuitable. In the same way if it was a known fact that developing a road network on a slope of 'Y' percent/degrees would lead to excess soil erosion, then these areas could be masked out resulting in an image showing those areas favouring road development.

### **3.4.3. GIS and forest fragmentation**

The result of forest fragmentation is often a patchwork of small, isolated islands of habitat in a 'sea' of developed land. It is of great importance to try and maintain areas of significantly large habitat patches that will allow for the natural movement and processes of a habitat to continue in a natural state. This can be achieved by providing links or corridors between patches that allow both animal and plant species to travel along these corridors, promoting game flow and the re-colonisation of vacant habitat (Wilson, 1975; and Noss, 1987). In order to graphically generate possible forest or habitat corridor opportunities, GIS software may be used to incorporate thematic data layers of vegetation, communities, water features, municipal zoning maps and transportation routes. One may then carry out simple 'constraint overlay mapping operations' in order to construct a map that conveys significantly large contiguous forest patch polygons with other smaller interspersed forest patches (Sorrell, 1997).

The resultant map will be accompanied by a consolidated base-data layer with zoning categories that would have otherwise not been included.

These data layers may be reclassified and re-ordered, allowing for easy incorporation into future analyses.

Sorrell (1997) points out that the importance of such a GIS map is that it will facilitate park managers, conservation biologists, and planners working together to develop an ecological pattern that remains sensitive to cultural structures as well as natural features. This will ultimately lead to a proposed habitat network being constructed after much public consultation and inter-disciplinary efforts. "The concept of a coherent network, visualised in an effective map would be a stimulating and unifying product. It can convey effective messages in several ways to different audiences: (Sorrell, 1997 p.3)

- to politicians it can provide a clear, aggressive strategy with not only problems but with solutions that may be incorporated into other land-use projects;
- to scientists as a stimulus for criticism, co-operation and to present scientific information in a way that can be easily used in decision making;
- to local grass-root initiatives, increasing local awareness to conservation strategies allowing smaller efforts to become part of larger initiatives that transcend political boundaries; and
- to the public as a clear message the ecological network as a rallying point and social feedback mechanism for conservation policy".

Thus, the planning of such features, such as roads, would become more interactive and iterative among interested stakeholders. Furthermore, it establishes techniques making it easier to measure the costs of such planning against ecological, social and economic opportunities.



### **3.5. Conclusion**

This chapter has shown how GIS may effectively be used as a tool within the IEM process, in so doing the author has addressed the goal of identifying how GIS could be integrated into the IEM process. The practical examples give a clear indication as to where GIS has been used in natural resource management, and shows how such a tool would benefit environmental consultants. It is clear that such a tool would justifiably aid in the decision making process.

# CHAPTER 4

## IMPACTS OF ROADS ON THE ENVIRONMENT

### 4.1. INTRODUCTION

Experience has shown that roads inflict the single largest impact to healthy forests, wetlands, streams, fish and wildlife (Crupi, 1998). Furthermore, research also points to the fact that road construction poses irreparable damage to the sustainability of the world's biological diversity (Beattie *et al.*, 1995).

The ecological impacts associated with road building are broad and include such things as: habitat destruction, ecosystem fragmentation, edge effects, invasion of exotic species, increased pollution and overkill of wild life. 'Road Kills' may also show significant impacts on wildlife (Folkeson, 1996). Estimates from the United States show that approximately one million animals are killed daily on their roads. Thus, as the demand for roads increase, so the number of wildlife mortalities escalates (Crupi, 1998).

The direct effects of road building are more obvious in the loss and degradation of habitat (Beattie *et al.*, 1995). Throughout South Africa thousands of fragile acres of national forests and wetlands have been permanently lost in order to clear the way for public and private roads and to provide access for various industrial, commercial or private uses (Collinson, 1998).

## **4.2. DISRUPTION OF STREAM FLOWS AND WATER QUALITY**

Roads that bisect mountainous regions significantly degrade the natural hydrological cycle, making slopes more susceptible to land slides and erosion. Often this results in these eroded areas choking the aquatic habitats as the sediment enters the hydrological system (Folkeson, 1996). It can also affect the stream flow rate, raise water temperatures, reduce the presence of dissolved oxygen concentrations, as well as inhibit the reproduction patterns of fish and other aquatic species. The cumulative effects of degrading the aquatic watershed severely reduces the success of fish populations, which are a critical foundation to the ecosystem's food web. The end results are that the ecological balance is unstable, often causing those species that were reliant on the ecosystem process to reach the stage that their numbers are in perpetual decline (Folkeson, 1996).

## **4.3. HABITAT FRAGMENTATION**

Habitat fragmentation has been recognised as the greatest worldwide threat to forest wildlife and the primary cause of species extinction (Sorrell, 1997). It is a recognised fact that numerous wildlife species are averse to roads and the building of roads as not only does it cover natural vegetation, therefore impacting on wildlife habitats, but it also results in a physical barrier being established through a habitat (Sorrell, 1997). This results in dividing the population, its range and dispersal corridors (Sorrell, 1997). Furthermore, one has to consider the long term impacts of roads on the environment, because with road construction, come other developments, be they private, residential or commercial. This creates the necessity to build spur roads, which again sever the fauna and flora from their habitats and population (Anon, 1998a).

Fragmenting a population, creating small 'pockets or islands' of populations spread over a wide area without any contact with one another, effectively prevents the population from being a viable healthy genetic pool (Shafer, 1990). This isolation from a solid based gene pool reduces the competition between an animal and its rivals for reproduction, therefore the chances of producing offspring of the best blood line are greatly reduced. It also promotes interbreeding and could even cause a species to become rare or even extinct (Beattie *et al.*, 1995). The same impacts are apparent with those plant species that rely on animals for seed dispersal. Therefore, many plant species would also suffer the consequences brought about by a loss of genetic diversity, as many animals that in the past would have acted as seed dispersion agents would not be able to cross these physical barriers. Furthermore, species fragmentation profoundly affects wildlife by inhibiting not only its distribution, but also its behaviour and migration patterns (Shafer, 1990).

Other findings include the fact that it has been proven that competitively superior species may be the most susceptible to extinction, and that extinction events may take place many decades after habitat destruction (Tilmen *et al.*, 1994). A number of other negative impacts on the environment may be associated with the fragmentation of an ecosystem. For example, if a road is constructed in such a way that it passes through a forest, the likelihood of 'edge-effects' taking place are greatly increased, as the interior forest now becomes exposed to more fierce elements, increasing the rate at which large trees are damaged and blown down. This is as a direct result of vegetation being exposed to natural conditions to which it has not adapted itself. As a result many animals that seek refuge in this vegetation suffer. Birds nests are often blown out of trees, it also reduces the protection that used to exist for other nesting species. Nests that exist in these newly 'opened up' areas are now exposed to a higher risk of predation and parasitism as the vegetation offers less protection (Crupi, 1998). There is also a substantial decrease in the number of interior-dependent species as well as increased competition

between exotic and indigenous species as a result of fragmentation and edge effects.

#### **4.4. POLLUTION OF PRISTINE AREAS**

As already mentioned with the opening up of new roads, comes more development and with more development, come more roads so a ripple effect is often characteristic with these two factors, from the day that 'sod' turning occurs for a proposed project (Anon, 1998a). Therefore, a number of disturbances pollute the 'natural' environment. It is also acknowledged that noise travels vast distances and thus noise pollution may have substantial effects on wildlife behaviour and communication, often displacing it from its home range.

Vehicles also emit a number of other pollutants such as heavy metals, carbon dioxide, carbon monoxide, dust, motor oil, lead and petroleum all of which assault the road-side floral and faunal communities. These pollutants may also find their way into the water sources, which could also lead to dramatic negative impacts.

#### **4.5. INCREASED WILDLIFE MORTALITY**

Many fauna and flora species have also suffered the consequences of 'overkill', as a result of bag limits that just aren't realistic and secondly, as a result of illegal poaching, over-harvesting and harassment. These processes have all been facilitated by the offender's easy access to roads, therefore, these areas with roads show deteriorating signs of the above factors (Anon, 1998a). It has been said that the problem with over-hunting, harassment and illegal poaching "results from the absence of

human ethics and adequate law enforcement, but this opportunity solely exists because there was a road providing access” (Anon, 1998a, p.3.).

These views have started to raise the notion that construction of roads could soon lead to the depletion of a number of natural resources for which there is no substitute.

## **4.6. Mitigation measures to reduce ecological impact**

The following measures have been identified by the Department of Transport as measures that may be taken in order to lessen the effects of ecological impacts: (Department of Transport, 1990)

- Avoid sensitive ecological areas where possible;
- Avoid placing roads in close proximity to water courses;
- Ensure the maximum level of road safety at the most sensitive sites;
- Ensure rapid cleanup of spillages;
- Provide wind breaks for sensitive vegetation; and
- Endeavour not to dissect sensitive habitats.

It is hoped that by taking some of the above steps it would be possible to limit the impact on the environment by developing on land that has a lower biological diversity, thus ensuring that areas of high conservation significance are preserved.

## **4.7. ROAD DEVELOPMENT LEGISLATION**

There is a large array of acts, ordinances, local by-laws, as well as ministerial regulations relating to the planning, design and operation of roads within South Africa.

Firstly there is the embodying Environmental Conservation Act No. 73 of 1989. Schedule 1 1(d) of this Act states that the construction or upgrading of roads, railways, airfields and associated structures outside the borders of the town planning schemes, be identified as activities which may have a substantially detrimental effect on the environment, and as such would require an EIA. The act also makes provision for limited development areas to be declared, in which case roads in such areas would automatically be subjected to environmental evaluation (Appendix A).

The National Monuments Act No. 28 of 1969 affords protection to various cultural treasures above and below the ground, of which some do occur within the Eastern Shores. Therefore, when the roads are being planned these would have to be taken into account.

Other relevant legislation that exists is dealt with extensively in many literature sources of which one of the most recognised is the book by Fuggle and Rabie (1996) *Environmental Management in South Africa*. It is for this reason that the author has decided not to elaborate on the relevant legislation, however a list has been provided (Appendix E) with the most important legislation relating to transportation projects and environmental management being highlighted with an asterisk in parenthesis.

## **4.8. Conclusion**

It is a compelling point that in the future we will need to look in more detail at road site selection and ensure that sound management practices are put in place to ensure that the routes of least impact are taken and that all possible alternatives have been thoroughly studied and considered. This will ensure that our wilderness areas, which have the greatest biological diversity and complexity remain intact for the benefit of all society now

and in the future. This chapter has clearly stated the different impacts that road construction may have on the environment. It has set the scene for establishing why there is a need to integrate a predictive tool such as GIS into the environmental decision making process.



# CHAPTER 5

## STUDY AREA

### 5.1. Introduction

This chapter introduces the study area and establishes why it is of such importance to preserve the Eastern Shores State Forest (hereafter referred to as ESSF). The chapter highlights the need to develop road networks within the ESSF that will have the least environmental impact.

### 5.2. The Eastern Shores State Forest

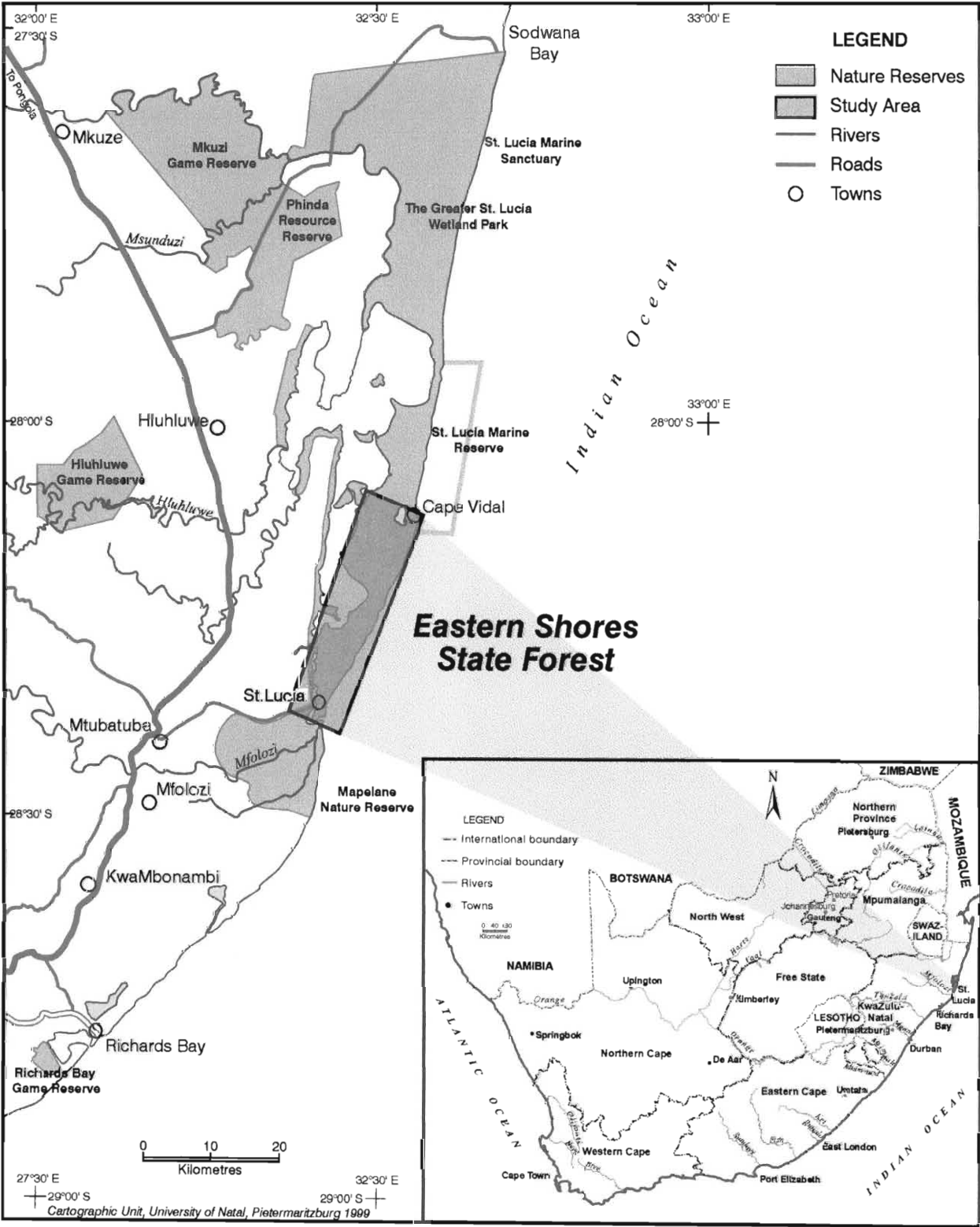
The Eastern Shores State Forest, along the east coast of Northern KwaZulu-Natal (Figure 5.1), comprises an area of 12 874ha (Summary Report, 1993). Approximately 2 622ha of this area is at present afforested with slash pine (*Pinus elliotti*), originally planted by the Department of Water Affairs and Forestry (DWAF). This area is currently under the management of the Nature Conservation Services (NCS)<sup>1</sup> however the South African Forestry Company Limited (SAFCOL), has a substantial portion of this area on lease from the state, reducing the area managed by the NCS.

Since the Ministerial decision to establish 'The Greater St Lucia Wetland Park', the forestry directorate has decided to phase out all afforestation within the ESSF. While there is to be no further planting of pines in the

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<sup>1</sup> Formally known as the Natal Parks Board (NPB).

Figure 5.1. Locality Map of Eastern Shores State Forest, KwaZulu-Natal



area, the agreement was that the present plantations would be left until a harvestable age of twenty years is reached. Effectively this means that the last of the pines will be clear felled by the year 2011.

New developments, however, indicate that this date should be substantially reduced partially as a result of public pressure to expand the conservation area, the new date that has now been set is 2005 (Blackmore, 1998).

The ESSF is recognised for its environmental and biological diversity, as it is the only area within South Africa where so many different environmental characteristics may be found in such close proximity to one another. These characteristics include coral reefs, turtle beaches, high-afforested dunes, freshwater swamps, grasslands, estuaries and wilderness.

“In comparison to conservation areas such as the Kruger National Park which is 2 million ha and the Okavango  $\pm$  2,2 million ha the St Lucia area is only a mere 250 000 ha. However, it is inhabited by such diverse fauna and flora that in some instances such as vertebrate and plant species significantly exceeds those of Kruger National Park and Okavango” (Review Panel Report, 1992, p.33). Moreover, the Eastern Shores are home to a number of rare and endangered species and provides a sanctuary for the breeding colonies of important populations.

Lake St Lucia and the Eastern Shores have for some time been a topic of debate. While both areas are considered to have some of the most attractive tourist destinations in South Africa, they are plagued by high levels of poverty and the resulting need to uplift local communities. As a consequence, the ESSF has been identified by the Spatial Development

Initiative<sup>2</sup> (SDI) as a potential area for eco-tourism. Numerous proposals for the development of specific areas have been identified, including the well known Cape Vidal area.

As the only access to the ESSF is via the NCS gate, the need for improved access to and from the area is self-evident. The present road leading to Cape Vidal is a gravel road. Due to the presence of heavy vehicle movement over its surfaces, the road has been badly corrugated and pot-holed. This is a direct result of the forestry activity occurring in the area. The problem of road damage will be largely remedied once SAFCOL have clear felled their timber plantations. (Collinson, 1998)

One needs to bear in mind that The Greater St. Lucia Wetland Park, which includes the Eastern Shores, could have been a mining area were it not for Justice Leon's decision to proclaim it a National Heritage Park. This landmark decision has led to conflict in the local communities regarding the continuance of mining in the area, as, in their minds, mining is synonymous with job creation (Collinson, 1998). The SDI now has the task of showing the communities that tourism is capable of generating more jobs than mining and that tourism's actions will be more sustainable. Another obstacle that has inhibited tourism development within the ESSF are land claims. The Mbuyazi Clan is an example of a community making just such a claim. However, a groundbreaking agreement has finally been reached on the land claims within this area, effectively making way for conservation, tourism and the reintroduction of elephant to the ESSF. This news was announced on Friday the tenth of September 1999 in Pietermaritzburg by the Commission for Restitution of Land Rights. All those families that were removed from the land they occupied "between 1956 and 1974 will get R30 000". The "total compensation for 26630 hectares from the village of St Lucia to Cape Vidal – is R16 680 000" (Gowens, 1999 p.1).

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<sup>2</sup> The SDI programme is a short term investment strategy that aims to unlock inherent economic potential in specific spatial locations in South Africa. It uses public resources to leverage private sector investment.

The question as to why all this development is being planned for the area has been asked on numerous occasions. The answer is simply that the present government wishes to bring about development to all those areas that are recognised or perceived as being impoverished and under-developed. St Lucia is seen as being an area that fits comfortably into such a description.

A number of obstacles will have to be considered when the development of the area is being planned. One of the major concerns is the impact of roads on the environment. The importation of high nutrient clay content soil often required for road construction into the area is undesirable as the ESSF is characterised by low nutrient soil (Avis, 1992). This would disturb the existing ecological balance in many areas. It is important to recognise that the construction of roads will always result in negative impacts on the environment, regardless of any mitigatory actions taken.

The key is to try and limit these impacts or to create as few impacts as is possible. In other words, location of the roads is of the utmost importance together with how they are constructed. The SDI has proposed that in order for the Eastern Shores to be viable, from a tourist market point of view, a minimum of 80km of road network must be developed, to carry the estimated number of tourists.

It is also important to establish what type of roads are going to be constructed through the natural vegetation. Should these roads be self-drives or guided trail drives? As yet, no decision has been made, but one must remember that even if guided trails are chosen, this does not necessarily mean that the roads will not have to be capped<sup>3</sup> (Collinson, 1998). Due to the nature of the soils in the area and their inability to resist movement, they too would have to be capped. Furthermore, there is still the problem that pathogens and alien vegetation will be introduced with road construction. In other words, whatever scenario is followed,

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<sup>3</sup> This refers to the process of placing some sort of layer over the existing material, for example covering the existing material with tar.

there is likely to be a degree of negative impact on the environment. The answer is to find a solution that will hopefully create the least impact, a goal that this thesis aims to achieve.

### **5.2.1. Locality**

The Eastern Shores State Forest is to be found along the east coast of Northern KwaZulu Natal, South Africa. It is bordered on the West by Lake St Lucia and on the East by the Indian Ocean. It falls between 28°06'30"S - 28°23'20"S, and 32°24'30"E - 32°33'40"E (Figure 5.1. p.41).

It ranges in altitude from 0m in the low-lying areas to 165m in the coastal dune system. The great difference in altitude is a direct result of the dunes along the eastern side of the ESSF.

## **5.3. Physical Environment**

### **5.3.1. Climate**

The Eastern Shores has a sub-tropical climate with warm, moist summers and mild, dry winters. The mean annual rainfall for the Eastern Shores is approximately 1200mm. The summer rainfall is usually greater than the winter rainfall, although on average there is a relatively uniform distribution of rainfall throughout the year. January and March are invariably the wettest months of the year (Kelbe & Rawlins, 1992) while it has been estimated that 61% of the rain falls between the months of November through to March. The months of May to September only contribute 23% of the mean annual rainfall (Avis, 1992). The area is, however, prone to fluctuations in rainfall from season to season and from year to year.

Mean daily minimum and maximum temperature ranges are within the region of 10,9°C and 22,6°C in June, to 20,6°C and 30°C in January

respectively. Frost has not posed any problem in the area, and accordingly no records have been made of frost being found (Avis, 1992). The mean Pan evaporation of the Eastern Shores area is approximately 1335mm annually and ranges from 160mm per month in January, to 60mm per month in June (Environmental Impact Report, 1992).

The winds of the Eastern Shores blow parallel to the coast, in almost equal proportion in both directions. Although in the past strong winds may have contributed to the formation of the impressive dune cordon these are thought to have little effect on sand movement at present due to the substantial vegetation cover (Tinley, 1985).

### **5.3.2. Geology, landforms and soils**

The landscape is dominated by the dune cordon, which runs parallel to the coastline. Inland from this cordon runs a low-lying inland plain, which extends to the shores of the lake. "The dunes have been modified to complex forms, with narrow, incised and almost linear depressions occurring in the seaward-facing slopes" (Davies, Lynn & Partners, 1992, p.177). "Linear interdune troughs occur at elevations of up to 70m above mean sea level in places. The shoreline dunes are largely protected against erosion by the sea, through the presence of carbonate-cemented sandstone reefs as the shoreline" (Davies, Lynn & Partners, 1992, p.177).

Coversands<sup>4</sup> occupy elevated portions of the dune cordon, and these form a mantle over the underlying formations. These coversands extend to depths exceeding 70m and decrease in thickness eastwards towards the shoreline and westwards over the coastal plain where they occur only as a superficial cover to older sediments. The heavy-minerals<sup>5</sup> that are present in minable quantities occur only within some areas of the coversands (Davies, Lynn & Partners, 1992).

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<sup>4</sup> Fine- and medium-grained, wind blown sands.

<sup>5</sup> Rutile, Illeminite and Zircon.

Several underlying geological formations form the Eastern Shores landscape. A thick mantle of wind-blown sands was deposited in the last 15,000 years form the dune cordon (Maud, 1968). Under this an older Tertiary Core of wind-blown sand is found, while beneath this, on the seaward half of the cordon, is a series of interlayered, uncemented sands and calcareous sandstone. Under these layers of sand lie the sediments of the Port Durnford Formation, approximately 20 to 40m deep, running along the coastline at below mean sea level and rising westwards (Davies, Lynn & Partners, 1992). Beneath the Port Durnford Sediments is cretaceous siltstone bedrock at approximately 35 to 70m below mean sea level at the coastline (Davies, Lynn & Partners, 1992).

The soils forming the dune cordon are generally young, well bleached soils with a poor nutrient status. "The frontal dunes have the youngest profiles. They are sandy and due to their high calcium content, have a high pH ( $\pm 7,4 - 8,5$ .) The majority of the remaining dune soils are acidic, with pH values of around 5,3 – 6,2." (Avis, 1992, p.177).

## **5.4. Biological Environment**

### **5.4.1. Terrestrial Flora**

The characteristic sub-tropical moist climate, the nutrient-poor soils and the disturbance regimes of the past such as shifting agriculture and fire on the Eastern Shores may be revealed in the vegetation of the area. Such practices have played a major part in maintaining grassland on the dune cordon. While in the low-lying plain, seasonal flooding and the periodic drought create a precarious mosaic of vegetation formations, where the dominant vegetation types are hygrophilous grassland<sup>6</sup>,

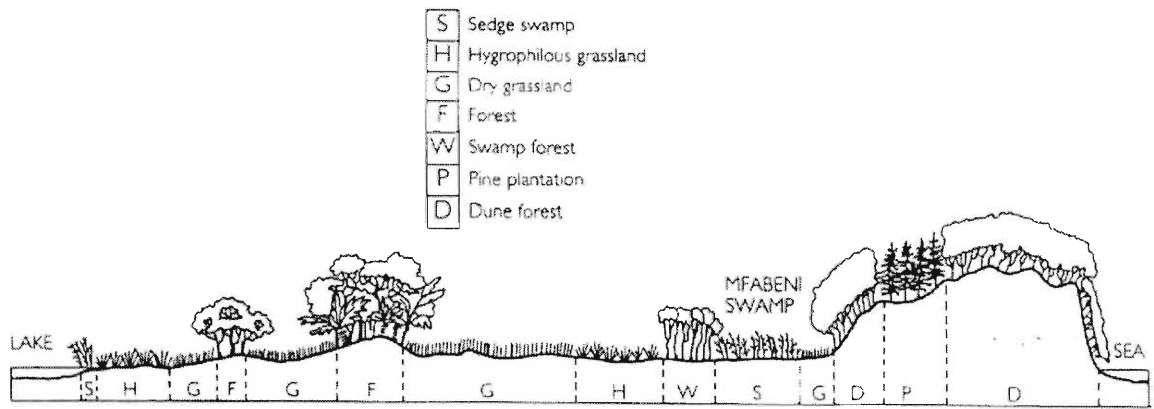
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<sup>6</sup> This type of grassland is found in depressions on the coastal plain west of the dune cordon, and is periodically flooded or has a water table close to the surface. Water loving species such as sedges predominate in these vlei grasslands even in the drier sections which are less frequently flooded. It is less diverse in species than the secondary grasslands (Lubke *et al.*, 1992).



swamp forests and various other aquatic plant species. Figure 5.2 shows a typical cross-section of the vegetation from the coast to the lakeshore.

**Figure 5.2:** A typical cross-section of the vegetation from the coast to the Lakeshore (Taylor, 1991, pp. 48).



The vegetation may be broken down into six major types and these have been identified by Lubke *et al.*, (1992, pp.202-206) as:

- Coastal thicket and forest<sup>7</sup>;
- Secondary dune scrub<sup>8</sup>;
- Secondary grasslands<sup>9</sup>;
- Swamp forest<sup>10</sup>;
- Vegetative pans and swamps<sup>11</sup> and
- Hygrophilous grasslands.

<sup>7</sup>Coastal thicket occurs on the steep seaward-facing slopes of the dune cordon while coastal forest occupies protected hollows on the landward side of the crest of the coastal dune. The coastal forest is taller than the coastal thicket (Lubke *et al.*, 1992).

<sup>8</sup>It occurs on the higher inland dunes, predominantly along margins of coastal forest. It represents a stage in the succession to the true forest, occurring where grassland previously dominated and where fire has been reduced (Lubke *et al.*, 1992).

<sup>9</sup>Found in the higher, dry areas of the dune cordon. It is diverse in terms of species and life forms (Lubke *et al.*, 1992).

<sup>10</sup>Found in areas of slow-flowing or stagnant water where the trees grow on water logged soils. This formation is rare in South Africa and of particular conservation value (Lubke *et al.*, 1992).

<sup>11</sup>These occur in the low-lying areas of the Eastern Shores, which are almost continually flooded (Lubke *et al.*, 1992).

However, these six vegetation types do not include the pine plantations and alien invasive plants that inhabit these plantations. It is estimated that there are approximately fifteen species of alien invasive species occurring within the ESSF (Lubke *et al.*, 1992).

### 5.4.2. Fauna

The diversity of habitats within the Eastern Shores area gives rise to a wide range of vertebrate fauna. Approximately 450 vertebrate species<sup>12</sup> have been recorded in terrestrial habitats (Berruti & Taylor, 1992). What makes the ESSF an even more important area to protect from the negative impacts of developments, such as road construction, is the fact that a large number of fauna within the confines of the ESSF appear in the ‘Red Data Book’ as indicated in Table 5.1(Review Panel Report, 1992, p.23).

**Table 5.1:** Red Data Book Species, occurring in the ESSF.

Class	Species	Red Data Book Category	Habitat
Mammal	Red duiker	Rare	Forest
	Red squirrel	Vulnerable	Forest
	Samango monkey	Rare	Forest
Reptiles	Forest cobra	Peripheral	Forest
	Gaboon adder	Vulnerable	Forest
	Setario’s dwarf chameleon	Restricted	Forest
Birds	Cuckoo hawk	Indeterminate	Forest
	Southern banded snake eagle	Rare	Forest
	Palmnut vulture	Rare	Forest
	Delegorgue’s pigion	Indeterminate	Forest
	African broadbill	Endangered	Forest
	Spotted thrush	Endangered	Forest
	Woodward’s batis	Indeterminate	Forest
	Wattle-eyed flycatcher	Indeterminate	Forest
	Yellow white-eye	Indeterminate	Forest
	Black-rumped button quail	Endangered	Mixed Thicket/Grassland
	Lesser black-winged plover	Rare	Grassland
	Natal nightjar	Endangered	Mixed Thicket/Grassland

<sup>12</sup> “65 Mammals, 286 Birds, 60 Reptiles and 39 Amphibians” (Berruti & Taylor, 1992).

### **5.4.3. ECO-TOURISM / CONSERVATION**

The NCS has adopted the following definition of eco-tourism-:

“...traveling to relatively undisturbed or uncontaminated natural areas with the specific objective of studying, admiring, and enjoying the scenery and it's wild plants and animals, as well as any existing cultural manifestations (both past and present) found in these areas....” (Ceballas-Lascurain 1987, quoted in Boo 1990).

Evidence has shown that the tourism industry generates a considerable amount of revenue for the South African economy. For instance in 1989 a sum of R2 billion in foreign exchange was earned through tourism, while the domestic earnings total a sum of R3 billion per annum (SATOUR, 1991).

It is therefore not surprising that tourism is viewed as the principal means of gaining economic returns from conservation areas. Therefore there is an absolute need to ensure that the wildlife of South Africa, especially in the conservation areas, are kept as natural as possible to preserve them for tourism in future generations.

The Eastern Shores of St Lucia have an important political and environmental history attached to them. There is evidence of some of the most significant events in South African history, dating back to over five hundred years, occurring in the region. These events include early settlement of indigenous people, the Portuguese navigators, the reign of Shaka, the Anglo-Zulu War, the Christian mission movement and, in more recent times, the Second World War. Finally, there are also the effects of the apartheid era and the legacy of forced removals (Review Panel Report, 1992).

The environmental history of the area is best described in a broad overview of the Greater St Lucia area. Lake St Lucia and its shores were proclaimed a game reserve in 1895. In 1905, extensions to this

area came in the form of the Hlabisa Game Reserve, and more land was included in 1927 when the lake and the entire Eastern Shores were proclaimed a bird sanctuary. In 1956, the Ozabeni Wilderness Area on the eastern shores was designated by the then NPB as the first Wilderness area in the country. However, afforestation continued to plague both the eastern and western shores despite a recommendation by the Kriel Commission<sup>13</sup> in 1966 for the increase in the size of the conservation area and a phasing out of the timber plantations. In fact, the opposite occurred with the timber production increasing its area of cover (Review Panel Report, 1992). Despite the above factors, the Greater St Lucia Park was proclaimed as a Ramsar<sup>14</sup> Site in 1986, effectively adding to the protection of this fragile ecosystem.

The Greater St Lucia Wetland Park is now by legislation a World Heritage Site<sup>15</sup>, one of only five successful nominations out of a total of twenty-two submissions processed by the IUCN during 1999 (Anon, 1999 p.1). This means that it has met the following criteria (Review Panel Report, 1992 p.33). It is:

- An outstanding example that represents major stages of the earth's evolutionary history.
- An outstanding example that represents ongoing geological processes, biological evolution and man's interaction with his natural environment. It also must contain unique, rare and superlative natural phenomena, formations or features or areas of exceptional natural beauty.
- An area with habitats where populations of rare or endangered fauna and flora exist.
- An area with National Heritage Sites which fulfil conditions of integrity.

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<sup>13</sup>Plans for the afforestation and for the construction of a dam on the Hluhluwe River provoked a public outcry in the 1960s. This led to the tabling in Parliament of a report by the Commission of Enquiry into the alleged threat to animal and plant life in St Lucia Lake. This was the Kriel Commission.

<sup>14</sup> International Convention listing wetlands of global importance.

<sup>15</sup> This is a site, which the International Union for the Conservation of Nature and Natural resources (IUCN) recognises as being of global importance.

It is therefore not surprising that the Eastern Shores of St Lucia is viewed as an important node for eco-tourism with its immense natural beauty and diversity of fauna and flora.

## **5.5. Eastern Shores State Forest Facilities**

### **5.5.1. Current Facilities**

The current facilities that exist within the Eastern Shores area are as follows:

(Environmental Design Partnership, 1992)

- Mziki hiking trail and overnight hut situated at Mt Tabor;
- facilities at Cape Vidal and Bhangazi (25 chalets and 50 camp sites);
- the only access road to Cape Vidal and Lake Bhangazi;
- the access to Mission Rocks, Pierrier's Rock and Bat Cave; and
- the Crocodile Centre and airstrip.

In a summary of the visitor's statistics as quoted in *Environment Design Partnership* (1992) an idea of the size of the sub regional tourist industry is provided. Annually, approximately 151 000-day visitors enter NCS facilities. The most popular sites to be visited are Cape Vidal, Charters Creek and Fanies Island (collectively) and the St Lucia Crocodile Farm which attracts approximately 50%, 12% and 24%, of the above mentioned figure, respectively. Just over 1% of the visitors use the trails in the Eastern Shores area, whilst 13% of the total is accounted for by people visiting the more distant Mapelane and False Bay nodes (in relation to the Eastern Shores areas).

"With reference to bed-nights (one bed-night defined as one occupied bed per night), approximately 255 000 places are filled annually in NCS hutted camps and caravan parks. Of the total, approximately 43% are accounted for by Cape Vidal, 14% by Charters Creek and Fanies Island,

25% by the NCS Caravan Park in St Lucia town and the balance of 18% by facilities at Mapelane and False Bay” (Environmental Design and Partnership, 1992, p.101).

At present, despite the extensive network of vehicular and non-vehicular access routes that traverse most of the Eastern Shores, there is very limited public access in the area. With the tourist nodes in the area being confined to wilderness trails, they account for approximately 75 000-day visitors and 109 bed-nights annually (Environmental and Design Partnerships, 1992).

According to the Environmental Design Partnership (1992), the main potential tourist attractions of the Eastern Shores area excluding Cape Vidal, include a landscape of relative high quality, an undeveloped coastline that provides access to Mission Rocks, and an extensive interface with Lake St Lucia. There is also the possibility of establishing tourist nodes south of Mission Rocks where a maximum of twenty to thirty cars are presently admitted on a daily basis. It is therefore noticeable that, with the exception of Cape Vidal, public access to the Eastern Shores is very limited.

### **5.5.2. Future Facilities**

In keeping with the idea of eco-tourism the Eastern Shores is limited as to what type of development may take place. It is for just such reasons that the former NPB established criteria for leisure use zones. These zones are described in Bainbridge *et al* (1991, p.43). The Eastern Shores have been designated as a moderate use zone in terms of the overall policy framework for the sub-region. The following elements as set out by Bainbridge *et al* (1991) in the EIA, are characteristic of such a zone:

- relatively easy access by vehicle or foot, feelings of independence and freedom will be fostered by the low level of interaction between users;

- an environment largely unmodified with the exceptions of roads and intermediate to low-order development nodes;
- motorised access on unsurfaced roads;
- medium and low-intensity self-catering facilities provided on a widely dispersed nodal basis, with restricted site modification to preserve the natural character;
- spatial intensity and sophistication of development that is graded from intensive use to low-intensive use; and
- self guided trails; with on-site representative facilities provided.

According to members of the NCS, a total of fourteen development nodes have been proposed for the Eastern Shores region. Although the areas in which these nodes will be located have not yet been finalised, members of the NCS have identified potential areas most suitable, in terms of fitting in with the whole concept of eco-tourism. However, it is an objective of this thesis to aid in the decision-making process by determining where the best location would be to site the required road networks for these proposed developments.

## **5.6. CONCLUSION**

With the ESSF forming part of the greater St Lucia Wetland Park that has just received World Heritage status, there can be no argument that the area needs to be developed in a manner that would not affect this status. This chapter has highlighted the effects that some development actions may have on the environment, especially those of road networks, the basic infrastructure for most development operations. This research now sets out how GIS may be used in order to minimise the impacts of development, by undertaking to establish a road network within the ESSF that would have the least environmental impact while still allowing all the proposed development nodes and tourist viewing sites to be developed.

Such a map could then be used during the IEM process to provide different alternatives, before the impact actually occurs.



# **CHAPTER 6**

## **MATERIALS AND METHODS - THEORY**

### **6.1. Introduction**

In order to make a decision one needs to identify clearly how one intends to reach the stage at which one may actually make that decision. This will clarify ones reasoning to others wishing to establish how the decision was reached, as it is often the case that there is more than one method to reach a single decision. Definitions taken from Eastman (1997) have been used in this thesis and are intended to minimise confusion about the way in which the methods for this thesis have been carried out (Appendix F).

### **6.2. The Analytical Hierarchy Process**

To solve a complex problem, such as the siting of road networks that will have least environmental impact, it requires that the problem be structured in a logical manner. The Analytical Hierarchy Process (AHP) provides a technique for such structuring. The AHP enhances the decision making process by providing a logical, easy-to-use framework in which all of the elements required for the decision may be defined, organised and carefully evaluated. Designed more than twenty years ago by Thomas Saaty this framework reflects the way in which ordinary people can make decisions on complex problems (Anon, 1998b).

The AHP ensures that one's objectives, alternatives and criteria are arranged in a hierarchical structure. Building such a structure not only helps to identify all the elements of a decision more accurately, it also allows one to recognise the interrelationship between these elements.

Among other factors that make the AHP the world's most popular decision support theory, is that it also permits one to "...derive relative, mathematically - based weights for your criteria, instead of having to guess or randomly assign weights to variables, as other decision analysis techniques do" (Anon, 1998b,up.).

The AHP is based on three principles:

- Decomposition of the decision problem;
- Comparative judgement of the elements; and
- Synthesis of the priorities.

Decomposition of the decision process is the first step to be undertaken. This step requires that the problem be structured in a hierarchical manner, with the most important aspect forming the apex of the pyramid. Therefore, the overall goal of the problem would be placed at the top level of the hierarchy, while the next level would be made up of the criteria required in order to reach the goal and the bottom level consisting of the alternatives to be evaluated.

The second step is to compare the alternatives and the criteria. This is done by comparing them in pairs with respect to each element of the next highest level. In order to carry out this comparison a table such as depicted in Table 6.1 is required. This allows one to express the comparison in verbal terms and then to translate these into the corresponding numerical value.

Finally the AHP requires that the comparisons be synthesised in order to arrive at the priorities of the alternatives with respect to each criterion and the weights of each criterion with respect to the goal. Once the priorities have been established they may then be multiplied by the weighting according to the respective criterion. It is these results that are summed up to calculate the overall priority of each alternative. This thesis has employed Idrisi's Multi-Criteria Evaluation (MCE) module to carry out this process. Idrisi is a geographic information and image processing software

system developed by the Graduate School of Geography at Clark University.

**Table 6.1:** Fundamental scale for pairwise comparisons

Verbal Weighting:	Numerical Weighting
Extremely preferred	9
Very strongly preferred	7
Strongly preferred	5
Moderately preferred	3
Equally preferred	1
Moderately less preferred	1/3
Less strongly preferred	1/5
Very less strongly preferred	1/7
Extremely less strongly preferred	1/9

### 6.3. Weighting of Factors

The procedure for weighting the factors, as described by Eastman (1997), is to compare each and every factor against every other factor, one at a time in a pairwise fashion giving a verbal weighting such as those in Table 6.1 as to how much/less preferred each factor is in relation to the others. If for example we take a set of N factors,  $(F_1; F_2; F_3; \dots; F_N)$ , then  $F_1$  may arguably be rated as being ‘extremely preferred’ to that of  $F_3$  and less strongly preferred to that of  $F_2$  in order to reach a required objective. Once these verbal weightings have been obtained their numerical equivalents from Table 6.1 may then be entered into a pairwise comparison matrix.

It is important to note that the matrix (Table 6.2) is designed in such a way that the main diagonal must be filled with the value of one, as this is the rating of the variable against itself. Another important aspect to note is that the upper right entries are the reciprocals of the lower-left entries. Effectively this means that only one side of the matrix needs to be completed.

**Table 6.2** Pairwise comparison matrix

	$F_1$	$F_2$	$F_3$	-	$F_N$
$F_1$	1	1/5	9	-	1/3
$F_2$	5	1	7	-	7
$F_3$	1/9	-	1	-	-
:	1/7	-	-	1	-
$F_N$	3	1/7	-	-	-

Once the weightings have been assigned to the various factors the logical consistency of these ratings needs to be examined. The programme Idrisi for Windows has a module called WEIGHT, which computes this consistency ratio. This value indicates the probability that the ratings have been randomly assigned. It also determines how individual ratings would need to be amended in order to obtain weightings that are perfectly consistent with the best-fit weightings.

If the consistency ratio is greater than 0.1 the matrix would have to be examined in order to identify which pairwise comparison has the largest deviation (i.e. the most inconsistent rating). One should bear in mind though that a high consistency ratio does not mean that the computer is indicating that the decision-makers are wrong but that their decision is inconsistent.

The weightings for this thesis were obtained in the above manner, as can be seen in Appendix (G), which is an example of the matrix that was completed by a select group of individuals that knew the vegetation within the study area as well as what sort of impacts road developments could/would have on the environment. The results of the questionnaire containing this matrix are described in more detail in Chapter 8.

## 6.4. Multi-Criteria Evaluation

In order to meet the specific objective of this study, namely the most suitable routes for a road network, a number of criteria needed to be evaluated. The process employed to address such a problem is referred to as the Multi-Criteria Evaluation (MCE) (Voogd, 1983, Carver, 1991 in Eastman 1997). In order to achieve MCE one of two processes is usually employed. The first is Boolean overlay which reduces all the criteria to logical operations such as intersection and union which in the Idrisi for windows OVERLAY module are the (AND) and (OR) operations.

The second process, which is the process that has been used in this thesis, is known as the Weighted Linear Combination (WLC). This process standardises the continuous criteria (factors) to a uniform numeric range (this process is described in more detail under the heading Standardisation of weights), and then combines them by means of a weighted average. This results in the continuous mapping of “suitability that may then be masked by one or more boolean constraints to accommodate qualitative criteria, and finally thresholded to yield a final decision”. (Eastman, 1997 p.9-5)

Boolean evaluation is an extreme form of decision making. This is emphasised by the fact that if the criteria are combined with logical (AND) operation, a location would have to meet every criterion in order for it to be included in the decision set. If a single criterion were not met then the location would not be accepted. It is therefore seen as being a procedure that is “risk-averse, and selects location based on the most pessimistic strategy possible”, (Eastman, 1997 p. 9-6) with the possibility of a location being chosen with it's worse qualities also passing the test.

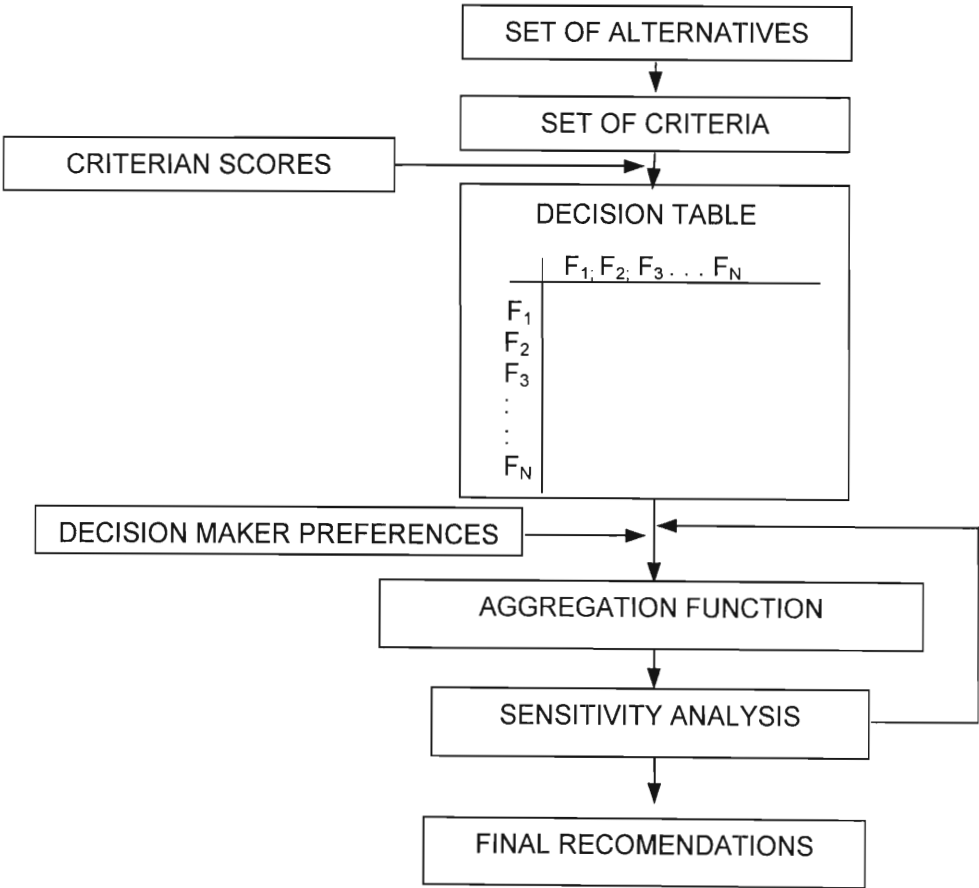
If on the other hand, a logical (OR) operation was chosen just the opposite would occur, with a location being included in the decision set

even if only a single criterion passed the test. This results in a strategy that is optimistic and bears substantial risk.

By comparison, the WLC allows criteria to “trade off their qualities”. (Eastman, 1997 p.9-6). This results in a situation where, if a number of poor qualities exist these are compensated for by some very strong qualities. This operation therefore represents neither the (AND) nor the (OR) operation, however lies somewhere between the two. It is therefore neither “risk averse nor risk taking”. (Eastman, 1997 p.9-6)

Due in part, to the ease at which these approaches may be implemented the Boolean strategy dominates vector solutions to MCE whilst WLC dominates solutions in a raster system. As the majority of data contained in this thesis is of a raster data type the WLC approach was employed. Figure 6.2. is a diagrammatic representation of the Multi-Criteria Decision making process.

**Figure 6.1.** Diagrammatic representation of the Multi-Criteria decision making process (Jankowski, 1995, pp.255)



## 6.5. Standardisation of factors

In order for the WLC of factors to have any significance it is essential that the factors all be standardised before the weighting takes place. In other words the factors are all converted in such a manner that they are 'stretched'<sup>1</sup> between the same range of values, indicating increasing preference with increasing value. The circumstance may arise where one may wish to stretch the values in such a manner that allows for decreasing preference with increasing values. If this is the case then the stretch should omit zero, as zero is often used by constraint maps to exclude an area. The data in this thesis that has required stretching has been stretched between the byte range of 0-255. Stretching was achieved by using Idrisi's Image Calculator<sup>2</sup> function, and the equation:

$$X_1 = (R_i - R_{\min}) / (R_{\max} - R_{\min}) * \text{standard range}$$

Where  $X_1$  = required image

$R_i$  = image to be stretched

$R_{\min}$  = minimum value of image to be stretched

$R_{\max}$  = maximum value of image to be stretched

Standard range = maximum range wanting to stretch to ie. 255

In the event that one wishes to reverse the values of a factor in order to ensure that it complies to the requirement of increasing preference with increasing value the factor is stretched in the same way as all the others and then SCALAR<sup>3</sup> is used to 'reverse score' the factor in order to ensure

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<sup>1</sup> Stretch may refer to both an expansion and a contraction of data values. If one refers to a 'byte stretch' it means that a conversion has taken place from a specific data type(byte, real, integer) to the full byte range (0-255)

<sup>2</sup> Image Calculator is an interactive expression-building module that encapsulates the functionality found in various modules within Idrisi.

<sup>3</sup> SCALAR does scalar arithmetic on images by adding, subtracting, multiplying, dividing or exponentiating the pixels in the input image by a constant value.

it complies. To do this the user would need to subtract the maximum value of the image from the image, which in the case of an image stretched from 0-255 would be 255. This would result in an image with negative values. In order to convert these negative values to positive ones the whole image would have to be multiplied by negative one. The resultant images would therefore conform to the requirement of increasing preference with increasing value.

## **6.6. Conclusion**

This chapter has highlighted the necessity to explain how one intends to reach the stage at which one may make a decision and as to how the results are going to be obtained. This is an important process as it allows others wishing to carry out projects of a similar nature to be able to do so without having to search through the literature. It also gives other people confidence to see that the methods that have been employed produce good results.



# **CHAPTER 7**

## **MATERIALS AND METHODS -**

### **PRACTICAL**

#### **7.1. Introduction**

The previous chapters have undertaken comprehensive theoretical reviews of GIS and the IEM process, whilst also addressing the impacts that road networks have on the environment. Chapter 7 takes the important step of illustrating how GIS can be practically integrated into the IEM process, to ensure that EIA's are carried out in a more effective and efficient manner. The objective was to establish a road network within the Eastern Shores State Forest that would have the least environmental impact. This was done using landcover types as the determining factors and slope as the constraint. It was anticipated that the results would show how the existing road structure had been incorrectly placed. In order to identify those areas most suitable for development the following preliminary steps were required:

- Sites with natural features of conservation significance were identified; (Sensitive areas)
- Criteria were identified that contribute to conservation significance; (Wetlands and Swamp forests, bio-diversity )
- Sites were analyzed in terms of these criteria for conservation significance; and
- Potentially affected sites were ranked according to their relative conservation significance (the AHP Process).

In order to rank the different landcover types the environmental consultants and ecologists had to determine the conservation significance of each vegetation type. This would ensure that those areas with the least environmental importance would be selected for development before areas of higher importance. Totman *et al.* (1994, p.23) set out commonly used criteria in order to establish this, these criteria are as follows:

- amount of biodiversity within the site;
- conservation status of the affected biodiversity;
- degree of dependency of species on the site;
- uniqueness of ecological processes associated with the site;
- uniqueness of physical features associated with the site;
- relative size of the natural area;
- proximity of other natural areas;
- conservation status of similar vegetation associates;
- conservation status of the affected site;
- naturalness of the area; and
- the habitat's sensitivity to disturbance.

## **7.2. Research Constraints**

### *Ecological Constraints*

Ecological processes within an area determine the variety and distribution of fauna and flora within that area. As such different habitats within an area may have less or more conservation value than others. Given this the following ecological constraints were addressed in this thesis:

- given the relative scarcity of grasslands, within the dune system, the alignment should favour forest over grasslands; this was addressed by the weighting of the factors ensuring that grasslands were placed high on the weighting scale;
- the alignment must be no closer than 30m from wetlands. This option was invoked to reduce nutrient, fine sand fraction and run-off loading within the wetland;
- the alignment should also be no closer than 30m from Swamp Forests, this parameter was included as a result of the factor weighting carried out by the author. This resulted in environmental consultants giving the same weighting to both wetlands and swamp forests. Thus the author has treated them as being equal by applying the same parameters to both;
- the width of the road should be sufficiently narrow as to allow the large tree canopy to remain intact (this project does not deal with road width, however it has been taken into consideration by allowing for the 30m buffer) ; and
- the road networks should not disturb sensitive areas. Here the 30m buffer was applied, ensuring no development would take place within thirty meters, thereby reducing the impact on these areas.

### *Engineering Constraints*

In any development project, engineering constraints exist due to a number of environmental, social and political factors. Although the author recognises this fact this study has focused on the physical (environmental constraints). Thus the engineering constraints applied in this research are:

- The alignment should allow for a maximum gradient of ten percent. However, a twenty-percent gradient is permissible when alignments traverse the slope (Blackmore,1998.).
- The alignment should follow the shortest possible route. (A function of the cost path function).

### *Tourism Constraints*

It is a recognised fact that tourists visit an area in order to have the advantage of being able to view as many of the different facets of that area as is possible. In order to do this the services within the area must meet their requirements. In a Game reserve (such as the ESSF) therefore they would want to have the advantage of being able to see as much game as possible, as well as a wide variety of different species. With this in mind the following two constraints were adopted:

- the alignment of the roads should function as a service or access arterial for other dedicated tourists or game-viewing roads; and
- the road network should cater for a number of vantage or vista points, or lay-byes.

## **7.3. Parameters Used in Order to Achieve Alternatives**

- the wetlands, sensitive areas and swamp forests along with their buffers were considered as absolute physical barriers;
- slopes with a gradient greater than 20% were also considered as

physical barriers (this gradient was chosen so as to reduce the cost of excavation, as the steeper the gradient the higher the cost);

- for those options where the existing roads and the proposed roads were overlapping, the current roads have been preferred to that of developing new roads; and
- very few grassland areas were identified within the dune system. The impacts, therefore, on the dune vegetation were viewed as uniform throughout.

## **7.4. Data Collection**

The data collection consisted of both vector layers and raster images. The first data obtained was the broad land cover image classified by Mr. A. Blackmore of the NCS (based on a landsat satellite image). Other important data collected included:

- current road networks within the ESSF;
- contour data;
- wetlands;
- sensitive areas; and
- future development nodes and tourist view sites.

It is imperative that one understands the difference between vector layers and raster images, thus the following definitions have been provided: "With vector representation, the boundaries or the course of the features are defined by a series of points that, when joined with straight lines, form the graphic representation of that feature. The points themselves are encoded with a pair of numbers giving the (X) and (Y) co-ordinates in systems such as latitude/longitude or Universal Transverse Mercator grid coordinates. The attributes of the features are

then stored with a traditional database management (DBMS) software program” (Eastman, 1997, p.2-5).

On the other hand with raster systems, “... the graphical representation of features and the attributes they possess are merged into unified data files. The study area is subdivided into a fine mesh of grid cells in which we record the condition or attribute of the earth’s surface at that point. Each cell is given a numeric value, which may then represent a feature identifier, a qualitative attribute code or a quantitative attribute value” (Eastman, 1997, p.2-5).

## **7.5. Cleaning and Converting Data**

The land cover image, that was to form the backbone of the thesis, was obtained from the NCS. This satellite image unfortunately required a lot of attention, as it had not been correctly geo-referenced. After creating a substantial correspondence file<sup>1</sup>, by using points extracted from 1:10 000 orthophotos as correct reference points, and the Idrisi module RESAMPLE<sup>2</sup>, it was discovered that the land cover image still did not fall within the correct latitudes and longitudes.

Subsequent to checking with the NCS that the road vector file had been properly captured and that it was geo-referenced and after being reassured that the road vector layer met the required criteria, the author

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<sup>1</sup> A file that contains the co-ordinates of specific points termed control points, in two different reference systems. Normally the first set of co-ordinates corresponds to the locations in an arbitrary plane reference system (non-geographic), while the second set of co-ordinates corresponds to the same locations in the same location in the desired georeferencing system.

<sup>2</sup> RESAMPLE registers the data in one grid system to a different grid system covering the same area.

attempted to create the correspondence file again. Once this file, which contained 25 points, was produced the land cover image 'sat' in the correct geographical position with a Root Mean Square (RMS) error of 0.0015. This means that there is very little difference between the original control points and the new control points location, ensuring that the highest accuracy of the geographical data is maintained (Figure 7.1.).

Other difficulties experienced by the author are mentioned hereafter. Using the contour data that had also been captured by the NCS by the process of digitizing from 1:10 000 orthophoto's and saving it as a vector file, the author tried to create a Digital Elevation Model<sup>3</sup> (DEM) within Idrisi. In doing so, it was found that a significant amount of starring had occurred, and for this to be eliminated the author had to import the contours into Cartalinx<sup>4</sup> (Idrisi,1998). Investigation of this large vector file enabled the author to identify a number of errors.

These errors included contours overlapping each other, nodes that had not been snapped together, a number of dangling arcs<sup>5</sup> as well as values which had been assigned to contours differing within the different arcs that formed a single contour. Once the author was satisfied that the data had been 'cleaned', it was decided to recreate a DEM. After trying to run a filter, the starring was still profound. Running a filter on the data reduces the accuracy thereof and so whilst the author appreciates that this process could reduce the starring he was reluctant to do so.

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<sup>3</sup> A data model used to represent a topographic surface, often based on a grid with a height value for each cell.

<sup>4</sup> Cartalinx is a Spatial Data Builder – a digital map development tool that serves as a companion to a variety of popular Geographic Information Systems and Desktop Mapping software products.

<sup>5</sup> These are arcs which have at least one node not attached to another arcs node.

Figure 7.1.

Landcover classification of study area





The author then elected to take the contour data into ArcView (ESRI, 1996) GIS. However, for reasons unbeknown to the author, Idrisi would not export the contour file as a shapefile in order to export it into ArcView. Therefore, the contour image was saved as an Idrisi vector file and imported into ARC/INFO (ESRI, 1995) GIS as a coverage. Here Arc-info clean operation was used to 'clean' the data. This then allowed the author to export the file as a shapefile to ArcView. This shapefile was then used to create a Triangular Irregular Network or TIN<sup>6</sup>, which in turn was converted to a grid, creating the DEM (Figure 7.2).

In order to get this grid data source back into Idrisi the header file had to be changed from that of an ArcView header to that of an Idrisi header file (this process is described in more detail later in this chapter).

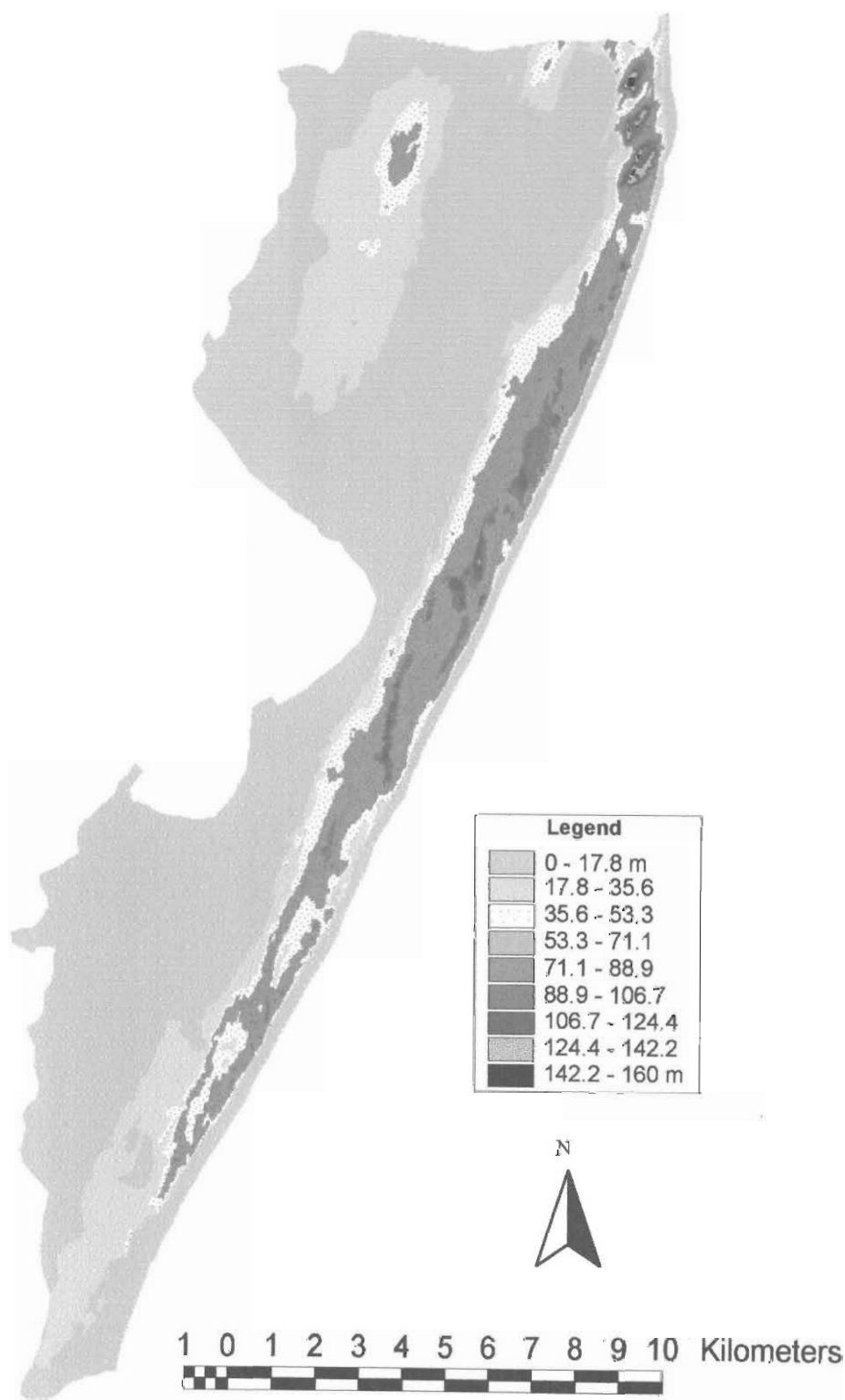
Once the DEM was back in Idrisi, SURFACE was used on the DEM to create a slope image. SURFACE determines the steepest slope between a pixel and its four neighbours (i.e. those directly above, below and to either side of it) and assigns this value to the corresponding pixel in the slope image. Diagonal neighbours are however not considered in this procedure. From this image two boolean images of slope were created. The first image was of slopes with a gradient of 20% and above. This image would later be incorporated into the project as a constraint. The second slope image, included all slopes between 10.1% and 19.9%. These slopes would not act as constraints, rather they would act as a guide to indicate where the cost of road construction would be greater due to the extra construction needed to meet the required maximum allowable slope of 10%.

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<sup>6</sup> A method of creating a surface from a point data in the vector data model. The TIN is created from an arbitrary distribution of points joined to form triangles. (The essential to GIS – Jargon Buster, undated.)

Figure 7.2.

Digital Elevation Model



Other problems that the author faced were that of projection and dealing with raster data within Idrisi. When the data was received from the various sections within the NCS not all of it was in the same projection which made it impossible to carry out any analysis. Thus the author had to decide which projection would be used. It was determined that LO33 would be used as the author felt it better to do the analysis in meters instead of degrees. Once this was decided the entire data set was converted within Idrisi to LO33 by using the module PROJECT (the functionality of this module is described under the heading Projection). The problem of not being able to rasterise all the data within Idrisi was overcome by exporting the data into ArcView and creating grids.

## **7.6. Projection**

Projection refers to the representation of one surface onto another. In the mapping sciences it refers to the representation of a spherical earth onto a flat medium such as paper or a computer screen (i.e 3D to 2D). Since it is physically impossible to flatten a globe without distortion, scale will vary across the projection surface with consequent distortions in distance, area, and angular relationships. Fortunately, it is possible to engineer this distortion so that specific properties, such as the preservation of aerial or angular relationships, are maintained within certain constraints.

The Idrisi module PROJECT transforms either raster images or vector files from one referencing system to another. The module carries this operation out by using “ellipsoidal formulas and datum transformations” (Idrisi, 1998, p.8-11).

## 7.7. Cell size

Cell size is always a problem when using a GIS that is based on a raster system. The reason for is that one needs to weigh up the advantages and disadvantages of either using large or small cell sizes. Large cells may give a more realistic interpretation of the overall resolution and reduce the time required for processing, however they also typically lose resolution when trying to display images with high spatial frequency. Also, large cell sizes do not display point or line features well. The dilemma of choosing the cell size on which to base the images for this thesis was overcome by using a 30 X 30m-cell size. This cell size was chosen as a result of the Satellite land cover classification image being at this particular cell size. Therefore due to the fact that one's results can only be as accurate as one's least accurate data, there was no apparent reason for making the other images any different in cell size.

## 7.8. Boundary Image (Mask of Study Area)

In order to accurately create the images required for this thesis, the author required a boolean mask<sup>7</sup> of the ESSF. This image was created by using the geo-referenced landcover image to on-screen digitize the boundaries of the study area from. POLYRAS<sup>8</sup> was then used to convert the resultant vector image into a raster. The resultant boolean image would later be used as a mask to exclude all areas not contained in the study area. Thus ensuring only those areas within the study area, be included in the analysis.

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<sup>7</sup> A boolean mask is an image that excludes all those areas, other than those contained within the required area i.e. the study area.

<sup>8</sup> POLYRAS converts vector polygon data to raster data

## 7.9. Factor Images

To create these images the land cover classification image was used along with Idrisi's RECLASS<sup>9</sup> module. Each vegetation type within the landcover image had already been assigned an individual numerical identifier by the NCS. This allowed the author to identify the vegetation type of his choice and assign a new value of one to the vegetation type in question and a value of zero to all other values, resulting in boolean images of all the respective vegetation classes.

This process was not used to identify the wetlands, as the wetland data set captured by the NCS would provide more accurate results, due to better resolution. The disadvantage of this approach was that it meant that the wetland data sets would not overlay precisely, resulting in areas on the landcover image which had been classed as wetlands not been considered as such during the analysis (such problematic areas have been highlighted in chapter 8). This vector polygon data source then had to be rasterised. To be able to do this the data was exported to ArcView as a vector file format. This could not be done in Idrisi as the file contained too many features for the sixteen-bit version of Idrisi to handle. Once rasterised<sup>10</sup> the polygons were clipped to the study area extents and exported back into Idrisi.

## 7.10. Constraints Image

Figure 7.3. represents all those areas that should be excluded from development, and therefore are considered as absolute barriers. The

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<sup>9</sup> RECLASS classifies the data stored in images or attribute value files into integer categories. Classification or reclassification is by equal intervals division of the data range, or by the application of user-defined limits.

<sup>10</sup> In ArcView the creation of raster files are termed grids.

image is composed of sensitive areas, swamp forest, wetlands, (all including the specified thirty meter buffer, as well as the slope constraint of twenty percent). It is this image that would be used as the constraints in order to complete the friction surface.

The grey boundary image (mask) acting as a backdrop in this image has been included to provide easy identification of those areas that did form part of the study area, however, due to the constraints having been excluded, it ensures that no development takes place on these areas.

## **7.11. Friction Surface**

A number of steps were followed in creating this image. Firstly DISTANCE<sup>11</sup> was run on each of the factor images separately. The resultant images were then masked accordingly with the boolean mask of the study area, before byte stretching to the common numeric range of 0-255.

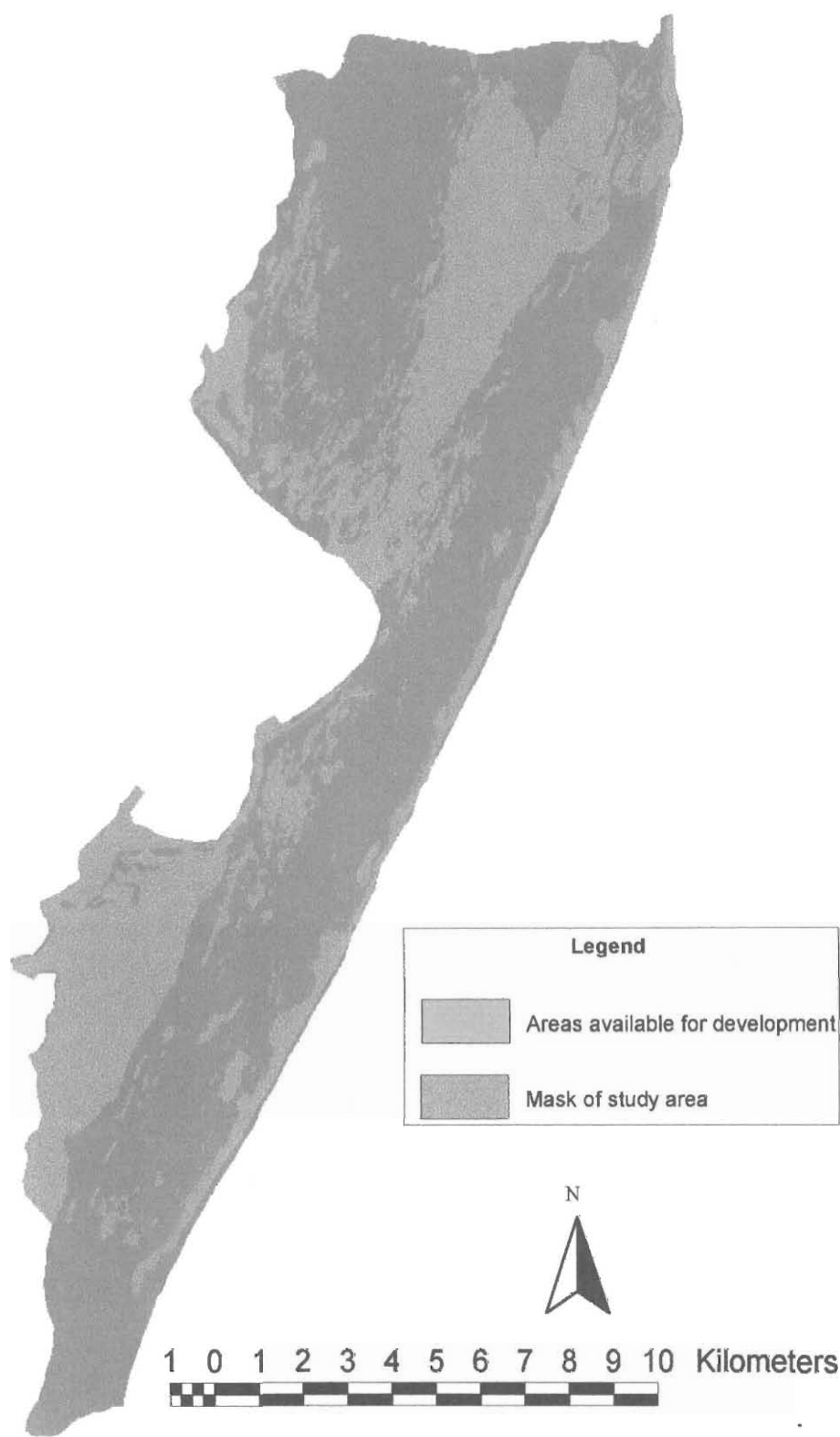
The result was images depicting decreasing preference for road construction with increasing distance away from each individual factor. This effectively meant that as the images stood, the best areas for development would be closest to each vegetation type, and in actual fact just the opposite was what was required. These images, except that of pine, were therefore reversed scored. Due to the precedence of developing on land already disturbed (i.e. that of exotic pine), this vegetation type did not need to be reverse scored to ensure that it complied with the other factors.

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<sup>11</sup> DISTANCE measures the Euclidean, 'as the crow flies', distance between each cell and the nearest of a set of target features. Distances are output in reference system units. Distances derived from images with rectangular cells are correctly calculated.

**Figure 7.3.**

**Constraints overlayed on the Mask of the Study Area**



These images now effectively represented relative suitability images. These distance / relative suitability images (Figures 7.4 and 7.5) were then used by the MCE module to combine all the criteria to produce a single composite basis.

All the factors and constraints were combined in the MCE module by controlling the different levels of trade-off between factors and the level of risk assigned in the combination procedure. It is for this reason (of taking into account the trade-off between the various factors and constraints) that the swamp forest and wetlands factors were used as both factors and constraints. While they would usually be treated as absolute barriers or constraints.

Trade-off reflects the degree to which one factor may compensate for another and the manner in which it compensates is governed by a set of factor weights (trade-off weights). Factor weights are given for each factor such that all factor weights, for a set of factors, sum to one; this indicates the relative importance of each factor to the item under consideration. The resultant image (Figure 7.6.) depicts which areas would have the least friction (i.e. most preferred to develop) or which areas would have the highest friction (those areas least preferred for development).

## **7.12. Cost Surface within Idrisi**

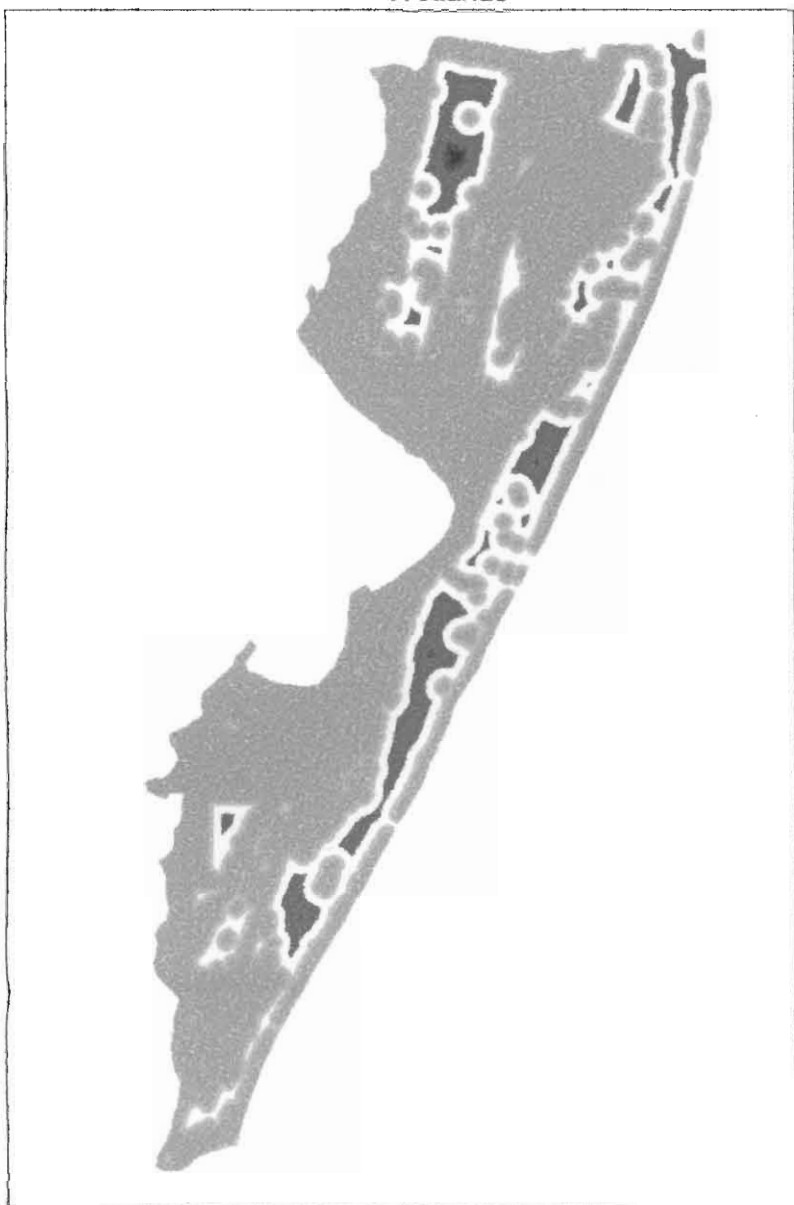
Once the friction surface had been created the module COST was used to generate a distance/proximity surface (cost surface), where the distance is measured as the least effort in moving over a friction



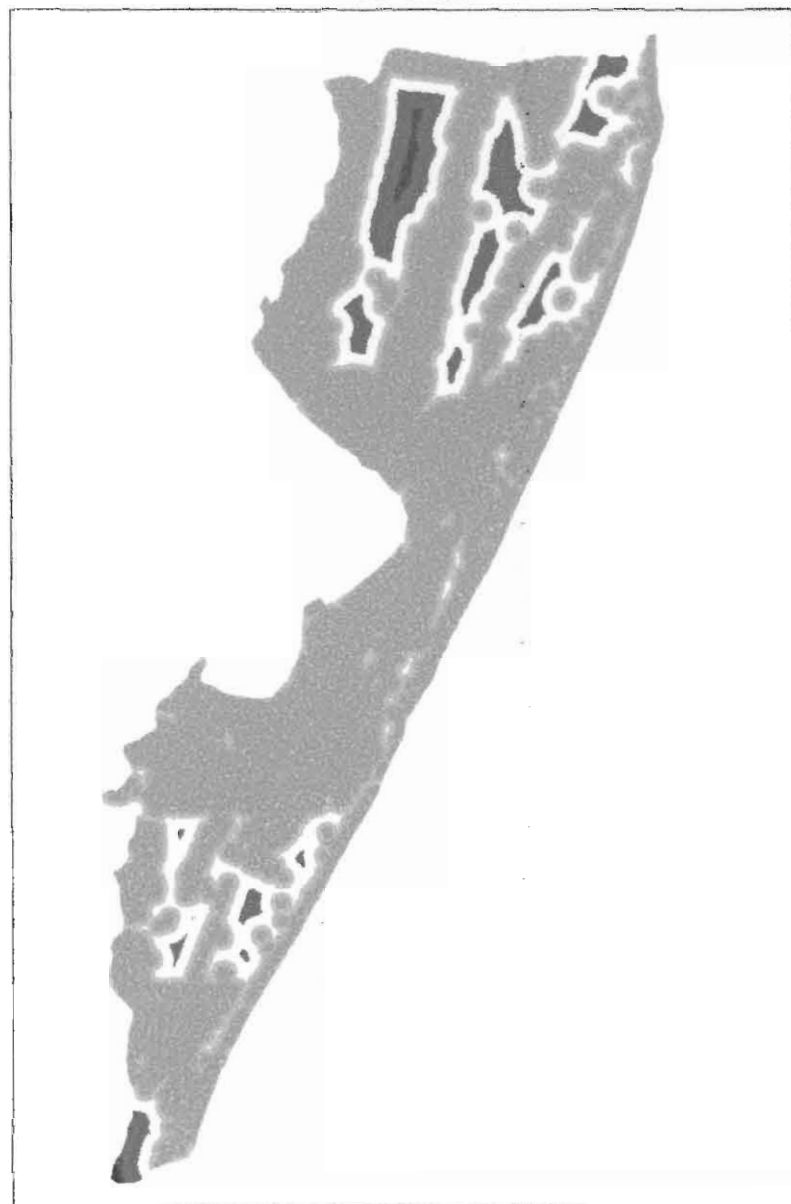
Figure 7.4.

Distance / Relative Suitability

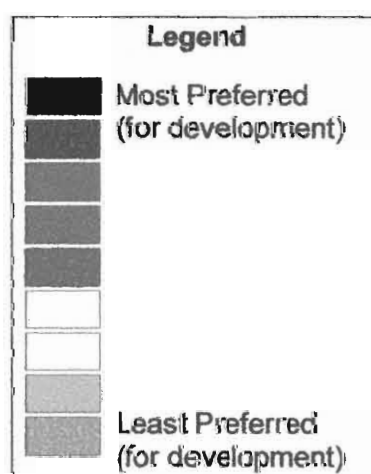
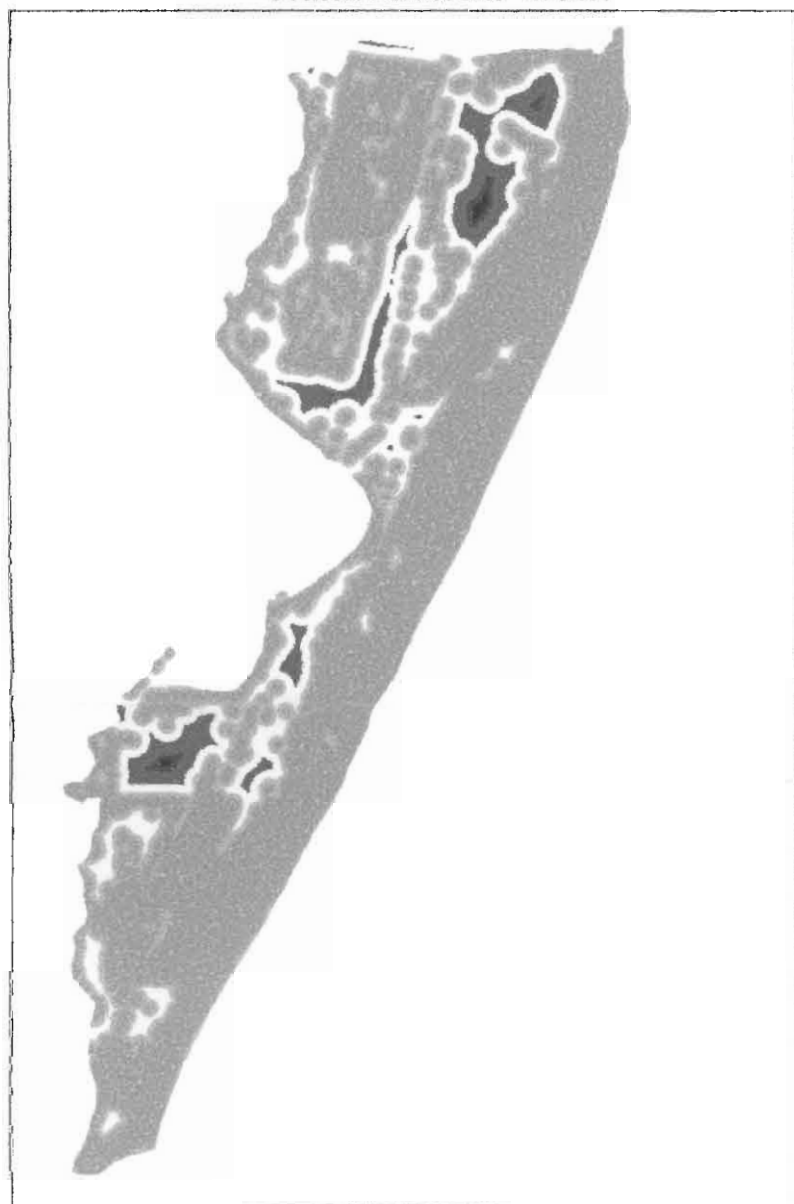
Wetlands



Grasslands



Coastal Forest and Thicket



1 0 1 2 3 4 5 6 7 8 9 10 Kilometers

A scale bar with alternating black and white segments, representing distances from 0 to 10 kilometers.

Figure 7.5.

Distance / Relative Suitability

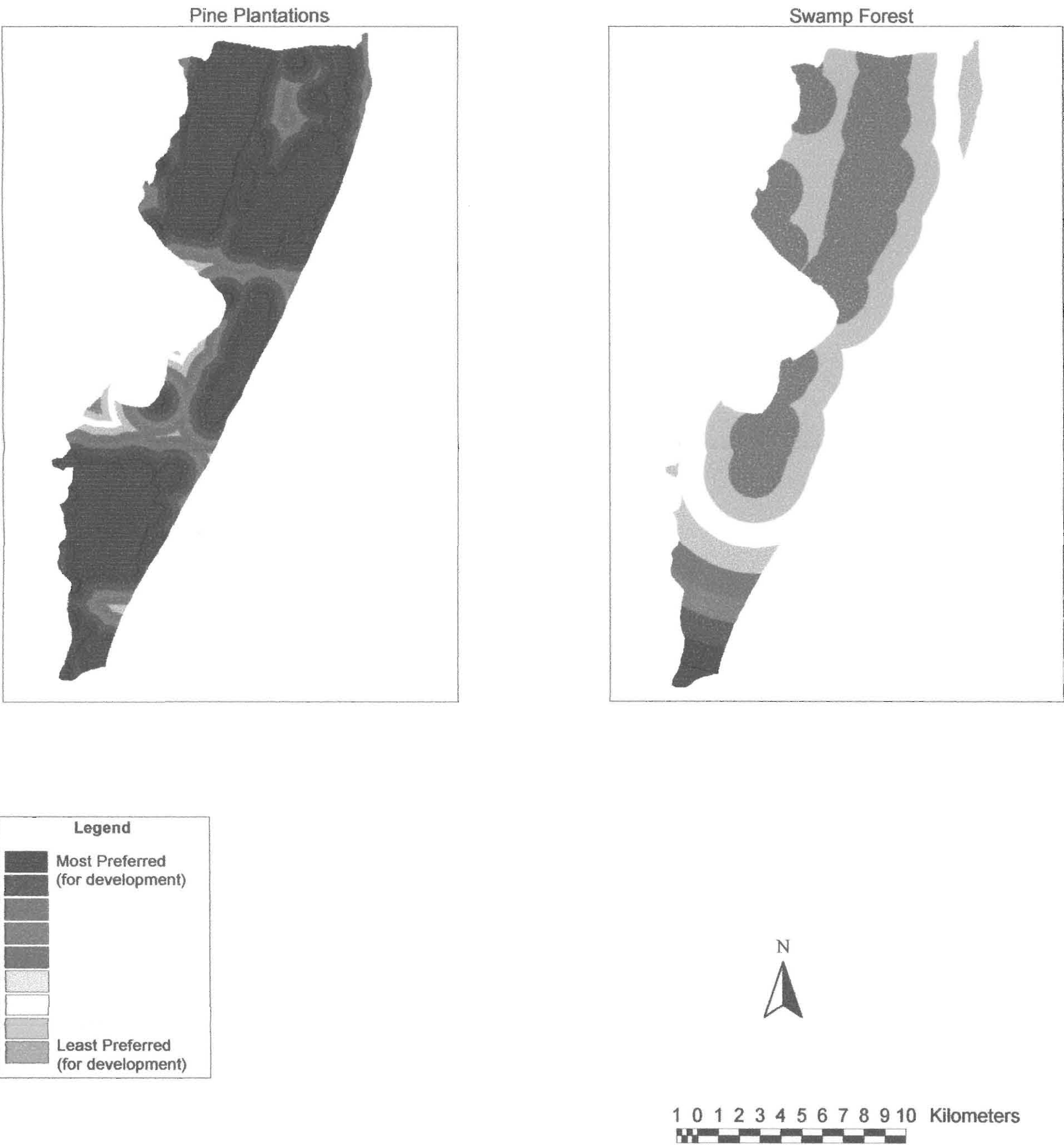
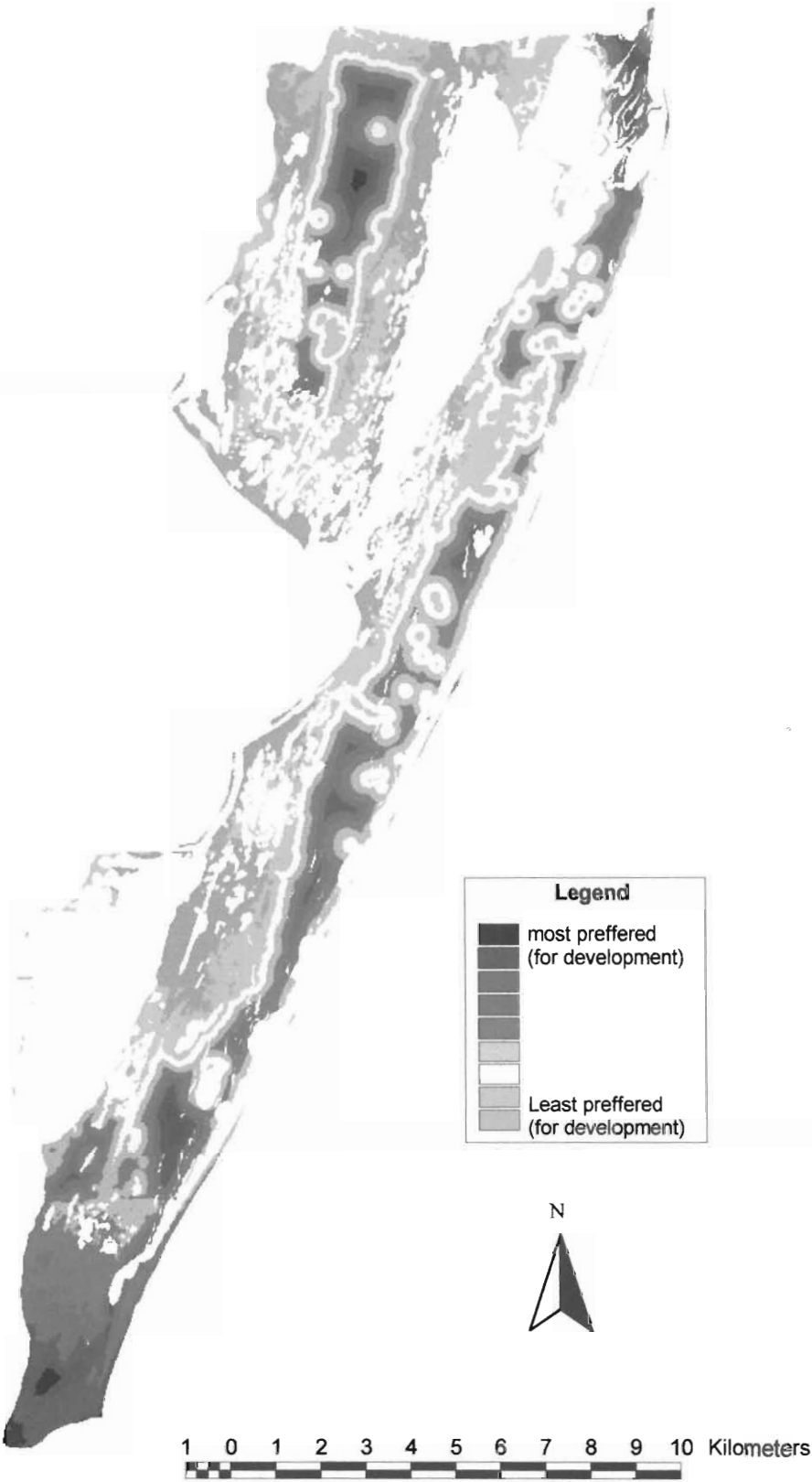


Figure 7.6.

Friction Surface



surface. The unit of measure required for this operation is the 'grid cell equivalent' (gce). For example a gce of one (1) indicates the cost of moving through a grid cell with a friction value of one (1). Therefore one may have a cost of five gce's if one was required to move through five grid cells with a friction of one (1) or one cell with a friction of five in order to reach a required destination (Idrisi, 1998).

Distances are measured according to the minimum number of cells that are required to be traversed in order to move to the nearest source target from a specific cell. From any cell, movements are in eight directions, with diagonal movements producing a cost, which is 1,41 times the friction value destination (Idrisi, 1998).

Under the COST module, one of two cost functions may be chosen: The Cost Push Function (Pushbroom) or the Cost Grow Function. The Cost Push Function is the faster of the two functions, however it is limited in its capability to deal with complex barrier patterns, such as those of streets. Barriers are thus specified as high relative frictions and not as absolute barriers. The Cost Grow Function allows one to stipulate absolute (true) barriers by assigning them a negative friction value, whilst also allowing one to specify relative frictions. Lastly it may output buffer zones directly and therefore deal with complex barrier patterns destination (Idrisi, 1998).

In order to achieve the necessary results, the data for this thesis required that buffers and absolute barriers be included in the data set. It is for these above mentioned reasons that the Cost Grow Function was preferred to that of the Cost Push Function, despite the extra time required to complete the process.

### **7.13. Future Development Nodes and Tourist Sites**

This image was created in two separate stages. Firstly co-ordinates were obtained of those areas within the ESSF that have been 'earmarked' for future development. These co-ordinates were then on-screen digitized in order to form a vector file of the fourteen nodes being considered for development. The module POINTRAS<sup>12</sup> was then used to create a raster image of these nodes. Secondly the tourist sites were obtained as an Idrisi vector file from the NCS.

### **7.14. Pathway in Idrisi**

Once the cost image had been produced, the author attempted to use the module PATHWAY to determine the least cost route between one or more target cells (proposed development nodes) and one or more lower terminal cells (proposed tourist view sites).

PATHWAY creates the minimal cost route by targeting the lowest point on the cost surface and following the steepest downhill route, until no further movement is possible. It is important to note that no false minima may exist on the cost surface and that the lowest point or points have a value of zero. This is automatically done by the output from the cost module destination (Idrisi, 1998).

When the author applied this module to the data, an error message consistently appeared ("Local minimum found. No possible solution-saving intermediate results") (Idrisi, 1998). This error message meant

that the computer had located the terminal point, but, it was not the lowest on the cost surface however. The author decided to check

whether the same message would be given if a portion of the data was selected (windowed) along with the nodes also being windowed to the same extent. PATHWAY was again used, but the same result was obtained.

Finally the only option left was to e-mail Clark University's customer support labs (the creators of Idrisi for windows), and ask for assistance as to what might be causing such a problem. Feedback came from a Mr. G. Votour whose response was "it sounds as though there is a 'pit' in your data which is causing this error. As the algorithm searches for the least cost pathway, it can become 'stuck' in areas that have lower values." His solution was to advise the author to try and locate any pits in the data and fill them in. He suggested that in order to do this he suggested the author try and detect any large areas of low or zero values, and once they were located, to onscreen digitize in order to create vector polygons with the aid of the module POLYRAS of the potentially problematic areas. This would allow the author to selectively raise the values of these specific areas. In order to locate these pits ORTHO<sup>13</sup> was used.

The author was reluctant to continue with this step as it essentially meant that one was manipulating the data source, making it less accurate. PATHWAY was again used on the manipulated data set however and the same error message appeared. It was at this stage, after hearing that ArcView had the ability to perform the PATHWAY operation, that the author made the crucial decision to convert his entire data set to ArcView format.

The problem now faced was that of trying to export Idrisi image files to

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<sup>12</sup> POINTRAS converts point vector data to a raster representation. In this conversion process an image file is updated with vector point attribute values in overlapping areas of the image and vector files.

ArcView grids. The difficulty lay in there being no export function within Idrisi that would do this direct conversion despite the program's ability to convert Idrisi vector layers to ArcView. This meant that the author had to find an alternative means of exporting Idrisi images to ArcView as grids. In order to do this, the author changed the Idrisi's image header to that of an ArcView header and then took the Idrisi image file and opened it in word-perfect as an ASCII text file. The 'find and replace' option was then used to retrieve all the Hard Returns, and replace them with spaces. Finally all the zero's had to be found and replaced with negative nine thousand nine hundred and ninty nine (-9999 is the no data value for an ArcView header, while 0 is the no data value for an Idrisi header). This was then saved as a .txt file which was then changed to an asc. file in Windows Explorer.

Unfortunately, this conversion process failed to work as it did when the DEM was converted from an ArcView grid to an Idrisi image. As a last resort the author accessed the internet and located a program called IDR2GRID written on the 2/5/1999, this program was then downloaded and set up on the computer.

It requires that the computer be opened up in MS DOS prompt mode, and that the user specify which directory he/she wishes to access followed by the following command: IDR2GRID [Source Image] [Destination Grid]. The source image is the Idrisi image and the destination grid the directory under which one would save the new grid data source. This process proved to be very successful, enabling the author to convert his entire data set into ArcView format. Once the author was satisfied that all the data had successfully been transferred he again accessed the internet to download an extension for ArcView that would enable the cost distance image and cost path function to be repeated in ArcView.

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<sup>13</sup> ORTHO displays and prints three-dimensional orthographic perspective displays of IDRISI for Windows images. Normally the images displayed are surfaces, although any IDRISI for Windows image may be viewed with this routine.

## **7.15. Cost distance modelling in ArcView**

This function, instead of measuring the actual distance from one point to another (Euclidean distance), measures or determines the least cost distance (accumulated travel cost) from each cell to the nearest cell in a set of source cells. Furthermore, it applies distance in cost units not as geographical units as is the case when measuring Euclidean distance.

In order to carry out any cost distance function's a Source Grid and a Cost Grid are required. The Source Grid may contain a single zone or multiple zones, which do not necessarily have to be connected. Source cells include all those cells that contain a value including zero. All those cells that are to be exclude should be assigned as No Data on the Source Grid.

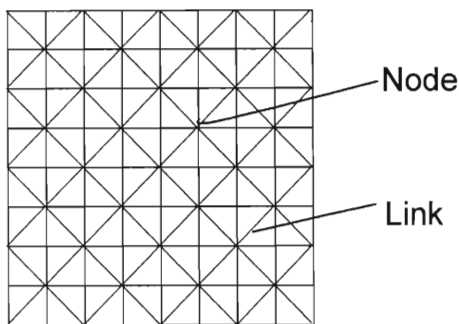
The Cost Grid interprets an impedance value in some uniform – unit of measure allowing for a cost to be assigned to each and every pixel (cell). These values associated with each cell in the Cost Grid represent the cost-per-unit distance of passing through any specific cell, where the unit distance corresponds directly to the cell width. Those costs, as with the Cost Surface in Idrisi, do not necessarily calculate the monetary costs. The Cost Grid could represent travel time or even preference (the latter of which applies to this thesis).

## **7.16. Calculating Cost**

The Cost Distance function produces an output Grid that assigns an accumulative cost to each cell closest to the source cell. "The algorithm utilizes the node / link cell representation". (ArcView on line help,



1999,up) This means that each center of a cell is recognised as a node, and every node is joined by links to its adjacent nodes.



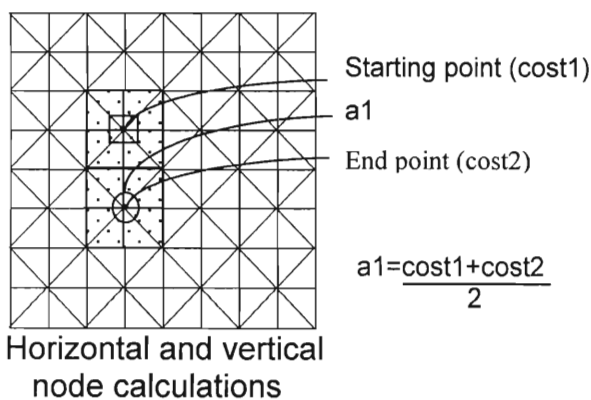
With every link having an impedance value associated with it. This impedance is calculated from the various costs “associated with the cells at each end of the link (from the cost surface) and from the direction of movement” (ArcView on line help,1999,up).

The cost of moving from one cell across the links to one of its four directly connected neighbours is one times the cost of Cell 1 plus the cost of the Cell 2 divided by two.

Thus the equation would be

$$a1 = \text{Cost } 1 + \text{Cost } 2 / 2$$

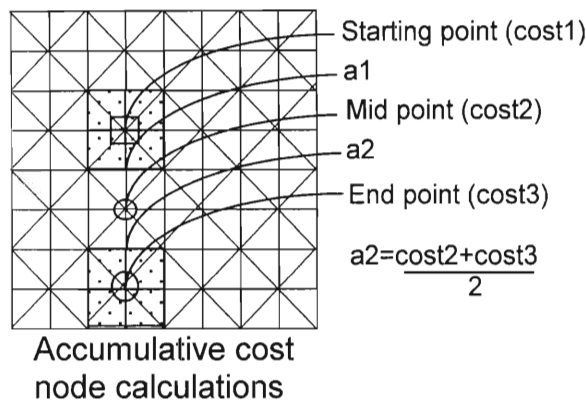
Where Cost 1 is the cost of Cell 1, Cost 2 is the cost of Cell 2 and a1 is the length of the link from Cell 1 to Cell 2



The accumulative cost is determined by the following formula.

$$\text{Accum\_cost} = a1 + (\text{cost2} + \text{cost3}) / 2$$

Where cost2 is the cost of cell 2, cost3 is the cost of cell 3 and accum\_cost is the accumulative cost to move into cell 3 and cell 1.

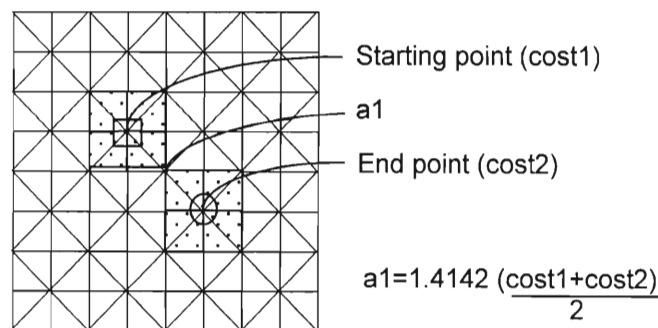


If the movement is diagonal, the cost to travel over the link is 1.41216 (or the square root of 2), times the cost of cell 1 plus the cost of cell 2 divided by 2.

$$a1 = 1.414216(\text{cost1} + \text{cost2}) / 2$$

But when determining the accumulative cost for diagonal movement the following formula must be used.

$$\text{Accum\_cost} = a1 + 1.414216(\text{cost2} + \text{cost3}) / 2$$



### Diagonal node calculations

The above procedures ensure that the module assigns the lowest accumulative cost to each cell. This is important when it comes to calculating the path of least cost.

#### **7.16.1. Application of Cost Distance**

Cost Distance requires that the user enter the source theme (in this case the proposed development nodes and tourist view sites of which the author had to assign numerical values to each using ArcView, (Figure 7.7.) one at a time, and the cost theme (Friction Surface), which for this thesis was created in Idrisi by the MCE module. This Idrisi image was converted to an ArcView Grid file and then entered as the cost theme. Lastly it required that the user specify: Create direction Grid. This resulted in the production of two shapefiles, one for Cost distance and one for Cost direction.

These shapefiles were then converted to Grid by selecting the 'Convert to Grid' function in the Theme drop down properties menu. With these Grids still visible on the view, albeit not active, Path was chosen from the view GUI<sup>14</sup>.

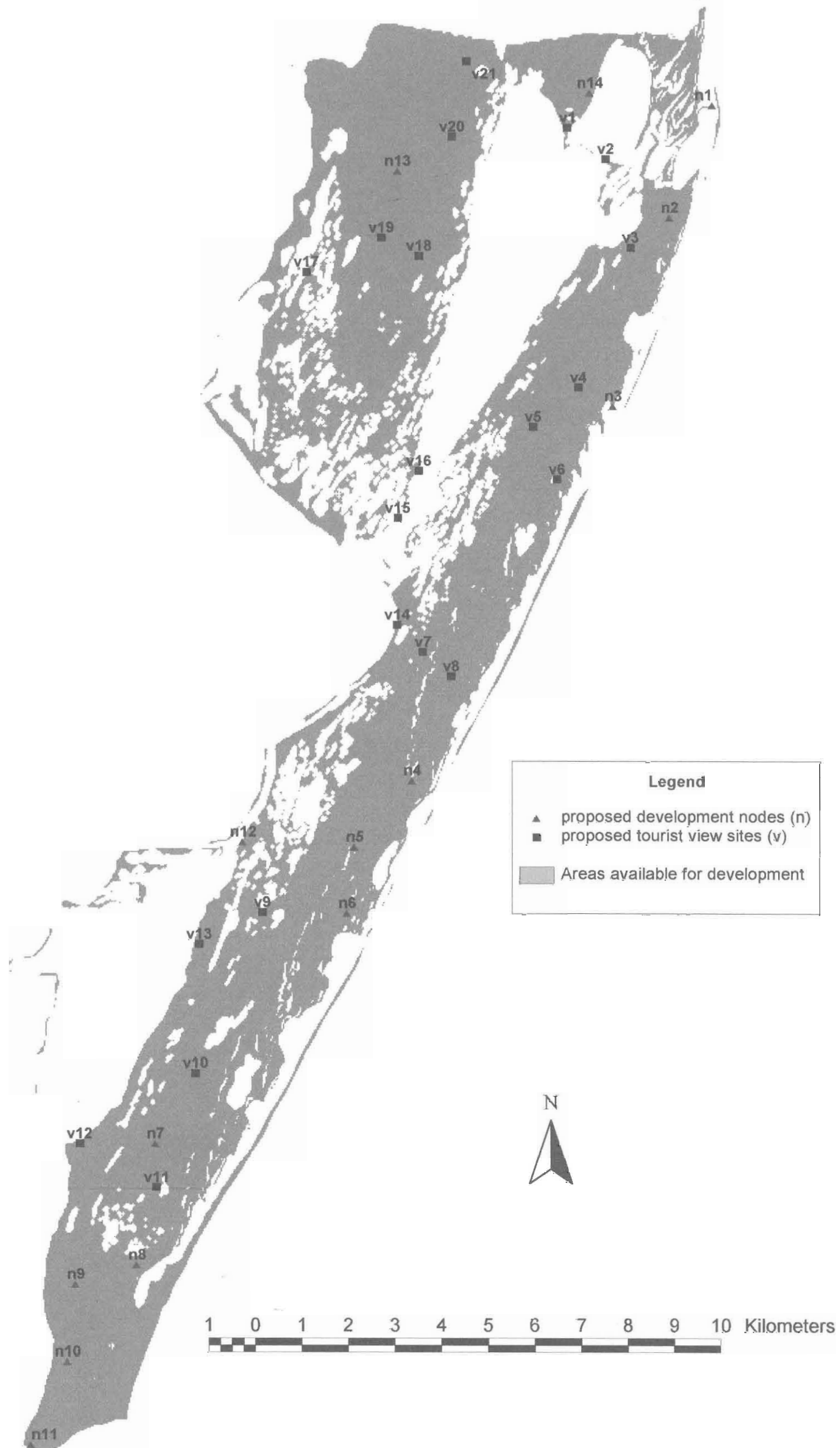
These procedures were conducted on all the development nodes and tourist sites barring (n10) and (n11) due to the fact that these two nodes are situated in the town St Lucia itself and therefore already have a well established road network. This resulted in Cost distance and Cost direction images for every node and site. As a result of having to create both Cost distance and Cost direction images of every node and site it was not practical to include images of all of these.

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<sup>14</sup> Graphical User Interface (GUI) is a method of interaction with a computer that uses pictorial buttons (icons) and command lists controlled by a mouse (GIS Jargon Buster, undated).

Figure 7.7.

Proposed development nodes and tourist view sites overlayed on constraints



However, four examples, Figures 7.8.; 7.9. and 7.10. demonstrate how the Cost function has operated.

Figure 7.8. represents both the Cost direction and Cost distance of the proposed development node (n5). Whilst Figure 7.9. represents the Cost direction and Cost distance of proposed tourist view site (v8). These images depict how the Cost function has separated the study area into two sections (Northern and Southern). The Northern and Southern sections were separated due to the constraints ensuring that at the transition between the North and South no pixels existed for the module to continue calculating (i.e. they have been assigned a value of No Data). For these reasons the author has also included two examples (n13 and v18) of the Cost function in the Northern part of the study area (Figure 7.10.). The Cost direction images enable the module to follow the correct direction whilst searching for the route of least cost. On the other hand the Cost distance images enable the module to calculate the least cost route in terms of distance.

## **7.17. Cost Path**

Cost Path creates the least cost path output either as a shapefile or as a grid. This least cost path is calculated from both the Cost distance and Cost direction themes. With the themes containing the friction surface, nodes and sites active in the view, a node or site was selected. Once this had been done the function cost path is then chosen from the GUI. Cost path requires that one enters the destination theme (target cell), the cost distance theme and the cost direction theme and lastly one should enter whether the output should be a grid or a shapefile. For this thesis the output file type selected was a shapefile.

Figure 7.8. Cost direction and Cost distance of the proposed development node (n5)

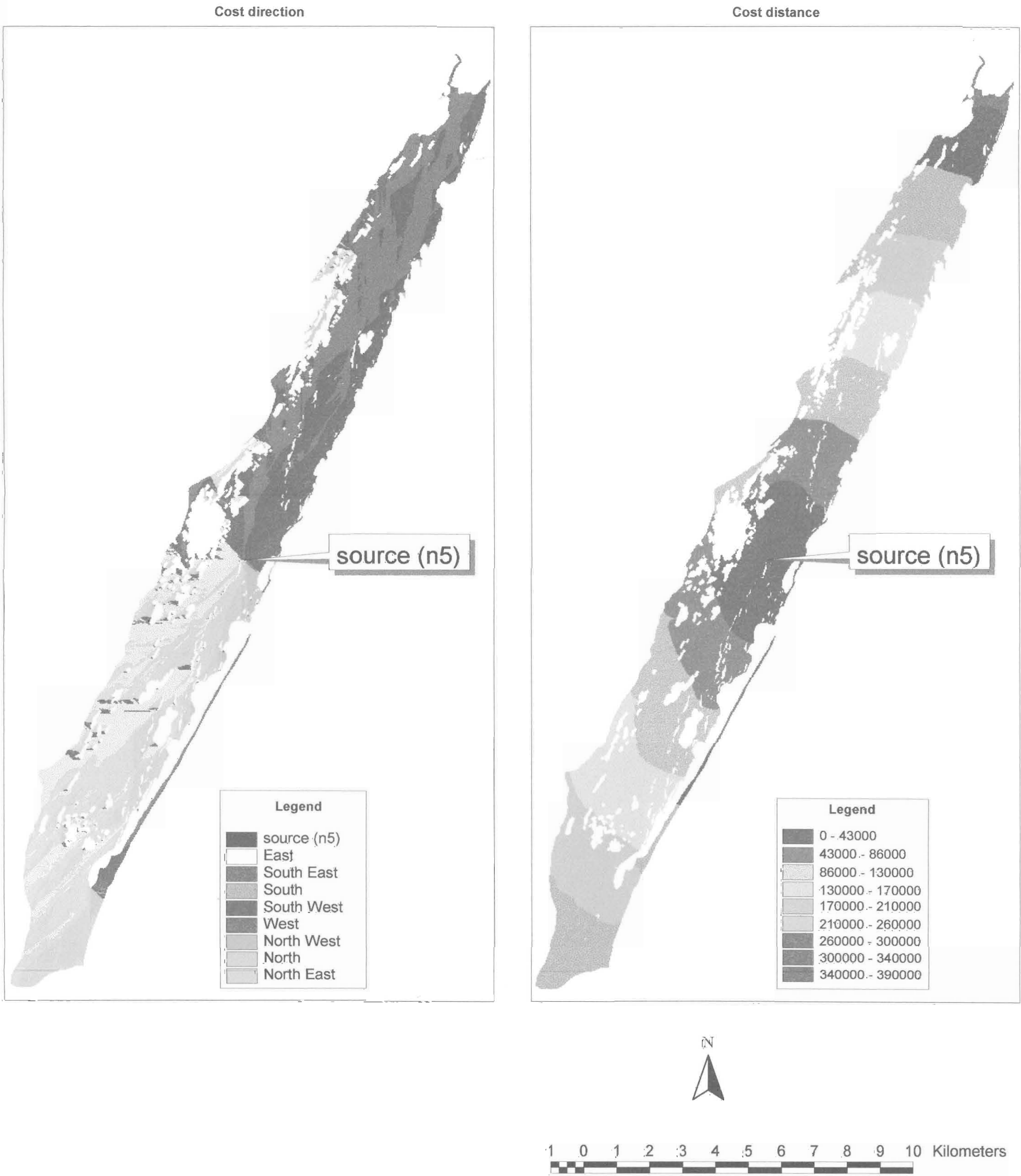
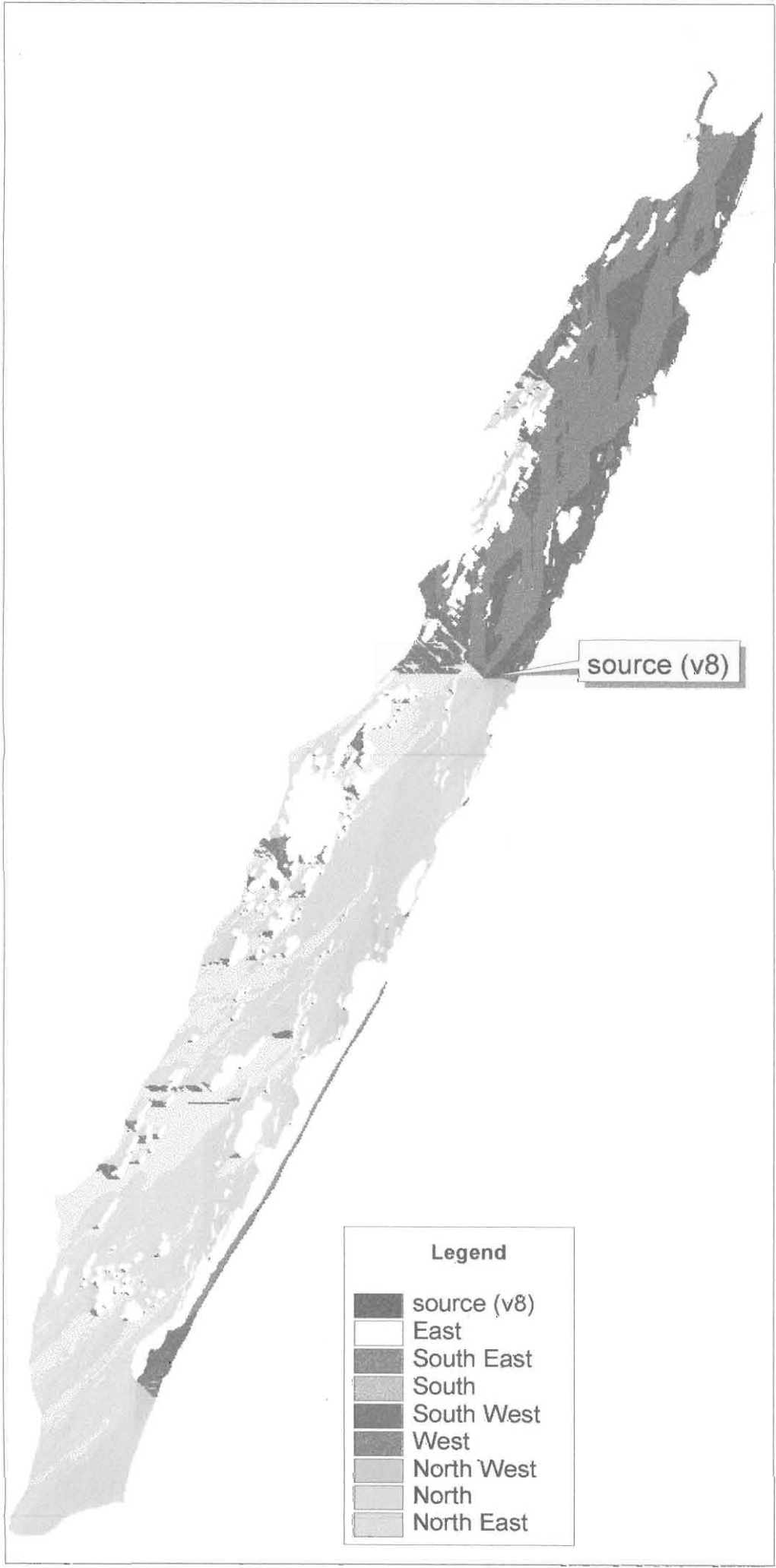


Figure 7.9.

Cost direction and Cost distance for proposed tourist view site (v8)

Cost direction



Cost distance

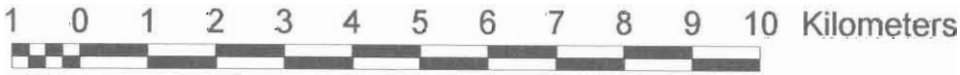
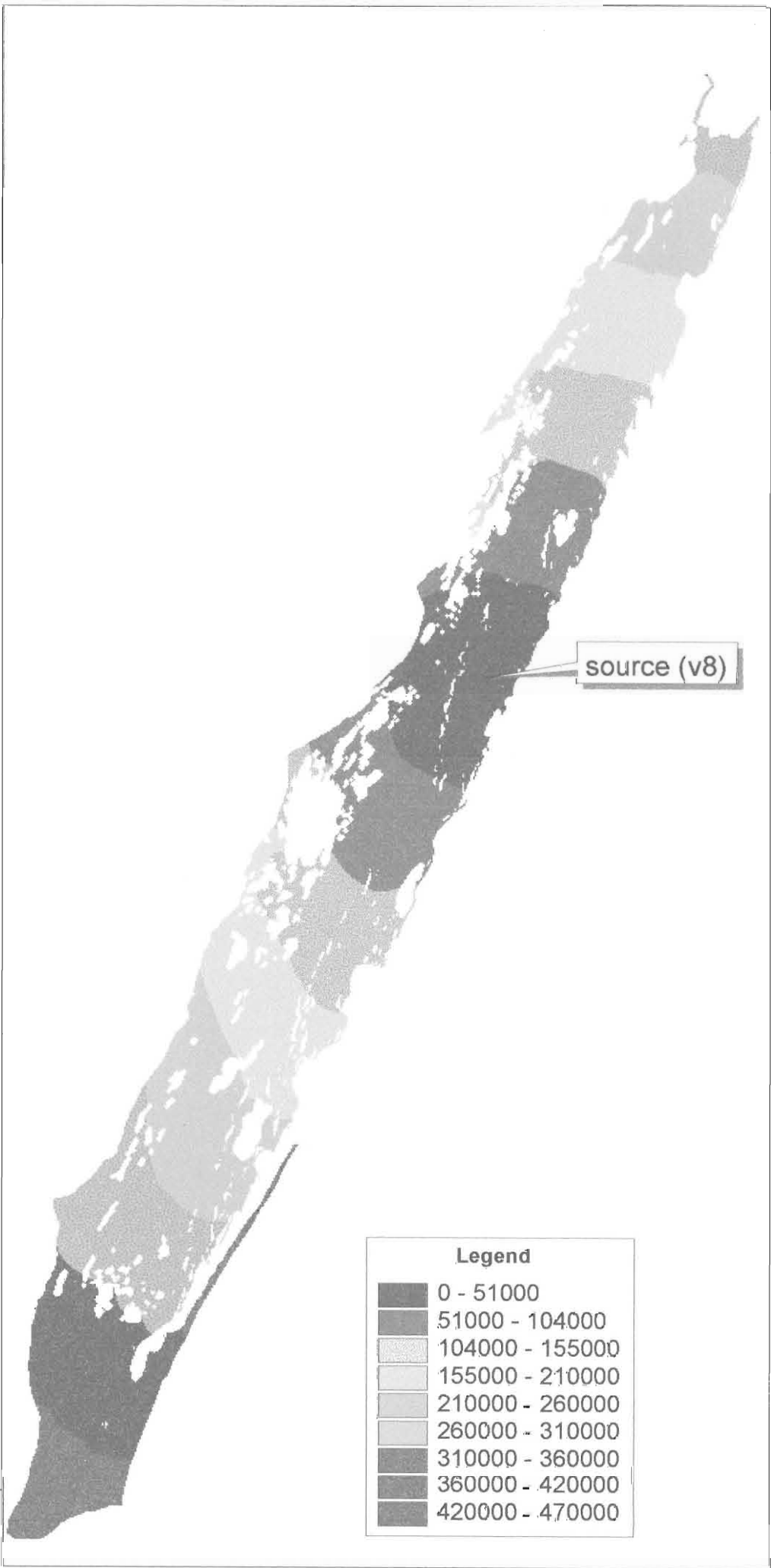
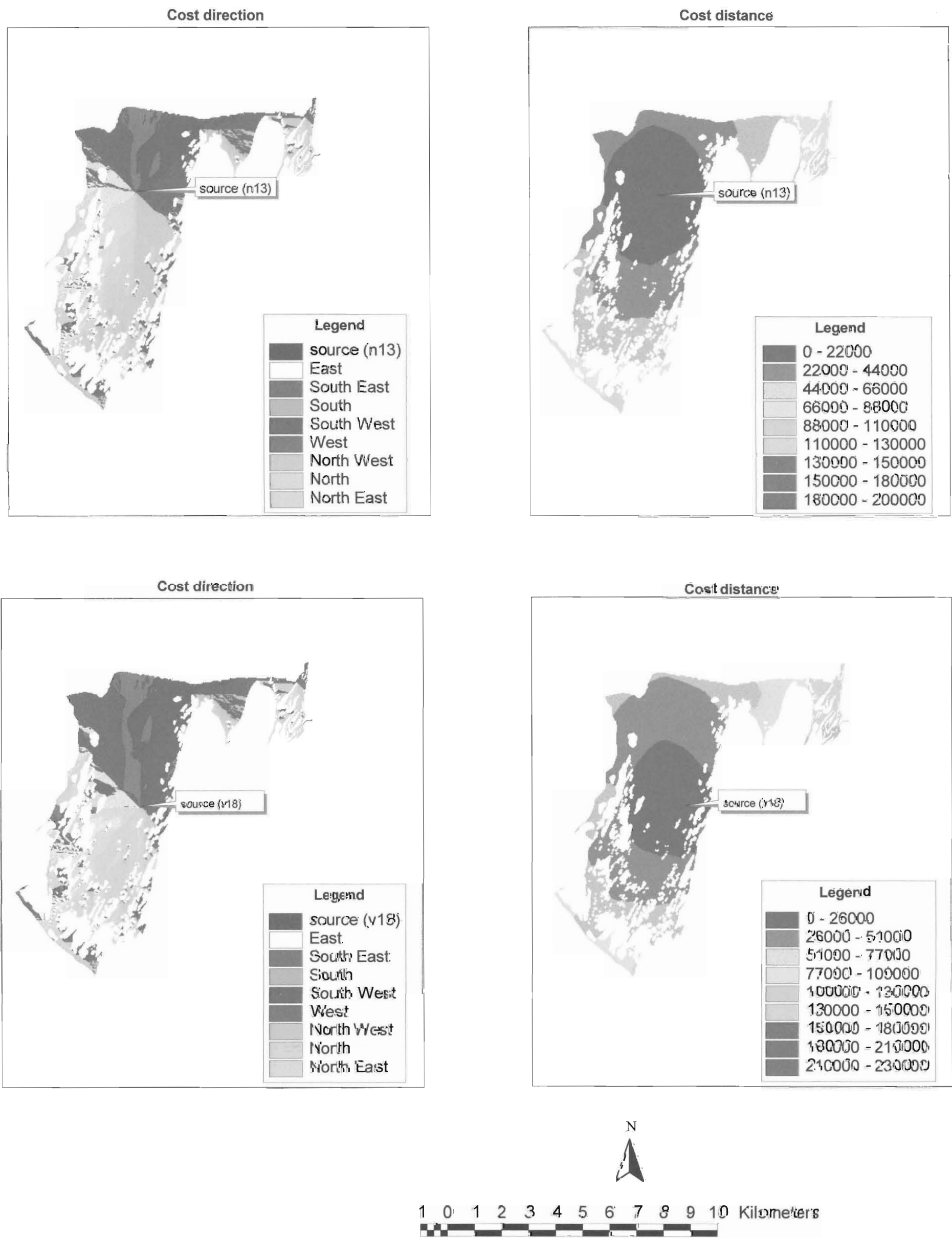


Figure 7.10.

Cost direction and Cost distance for proposed development site (n13) and proposed tourist view site (v18)





The Cost path procedure is as follows. Cost path uses the Cost distance Grid to identify the accumulative cost for each cell to return to the closest cell in a set of source cells. It does however not indicate which source cell to return to or how to get there, rather what has been termed a Cost back link returns a Grid with a value range from zero (0) to eight (8) that may be used in order to establish a route to the source. It is at this point that the Cost direction Grid becomes important, the reason being that it plots the direction using the Cost back link that would follow the route of least cost. For example a value of (0) acts as the source cell (i.e. where one wishes to establish the path/road network to), while one (1) indicates that the path must move to the immediate right (i.e. in an easterly direction), two (2) to the lower right diagonal (South Easterly direction), three (3) to the cell directly below (Southerly direction), four (4) to the lower left diagonal (South Westerly direction), five (5) to the cell on its immediate left (Westerly), six (6) to the upper left diagonal (North Westerly), seven (7) to the cell directly above (Northerly) and lastly eight (8) to its immediate upper right diagonal (North Easterly).

The Cost path request uses these directions as well as the Cost distance to retrace the destination cells through the back link Grid to the source. This enabled the Cost path to create a path (road) that followed the path of least cost (those areas most preferred for development) on the Friction Surface.

## **7.18. Conclusion**

This chapter has not only described the practical method in which the images required to achieve the results were carried out, but has emphasised the different GIS techniques that were required in order to

achieve these results. It proves that GIS has the functionality to carry out complex analyses of environmental problems.

One of the most important factors to take note of is that, by carrying out an exercise such as this one, has enabled the identification of areas that should not be developed before any development actually takes place. Such predictive techniques would prove to be very valuable during EIA's, where it is fundamental to identify possible negative impacts, siting of proposed development activities as well as mitigative measures that may reduce environmental degradation.

# CHAPTER 8

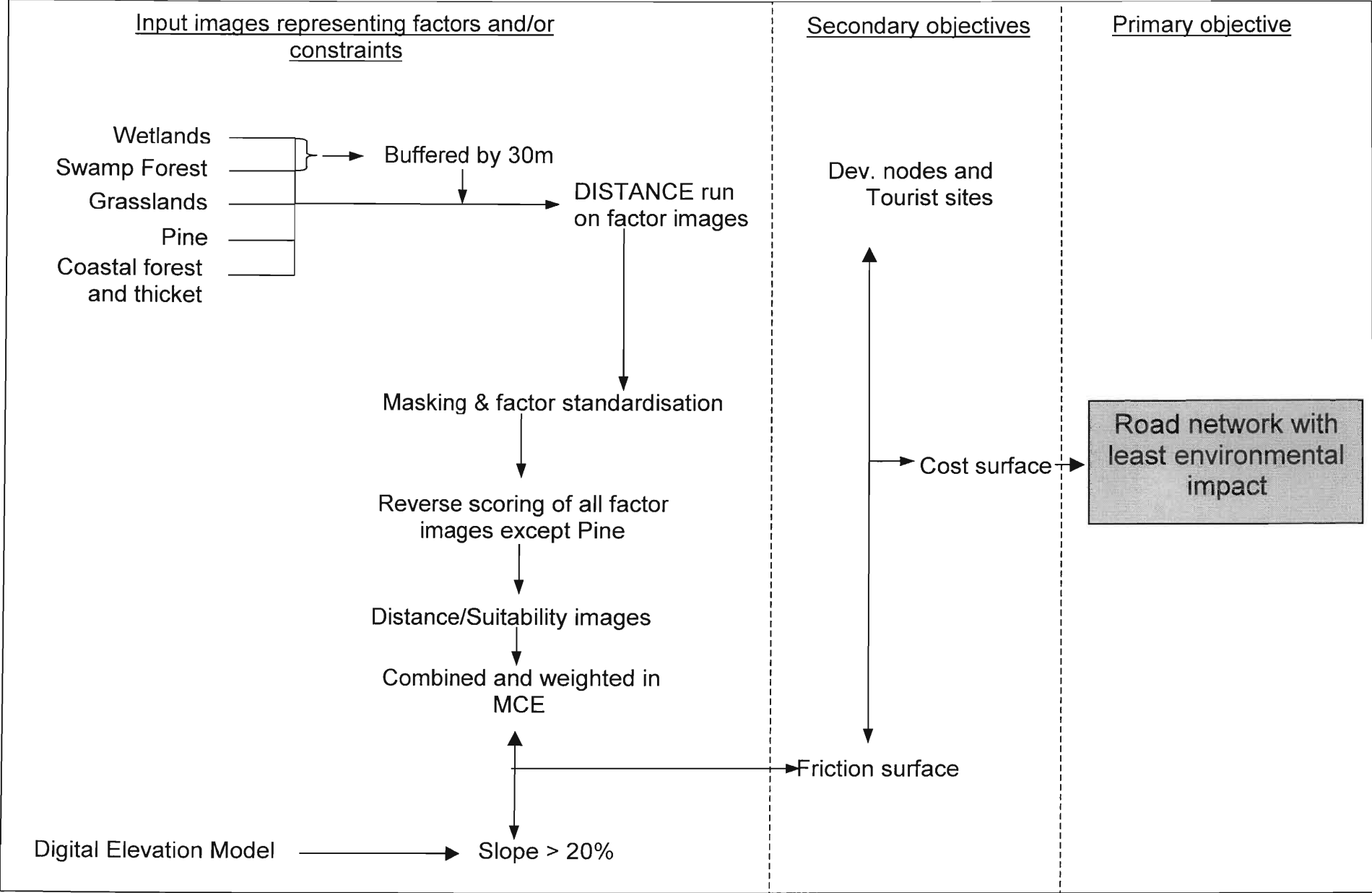
## RESULTS AND DISCUSSION

### 8.1. Introduction

To show how effectively GIS may be incorporated into the IEM process a case study of the ESSF was carried out. In so doing both the Spatial analytical capability and graphical output of a GIS were employed. The flowchart (Figure 8.1) shows how the various criteria were combined in order to achieve the results. The results show how effective GIS was in determining a road network within the ESSF that would have minimal environmental impact. The images that follow (Figures 8.2. – 8.7.) represent these findings.

The questionnaire (Appendix G) that was answered by a team of twelve environmental consultants and ecologists supplied the relevant weights required during the methods leading up to this point. Unanimously all the questionnaires were returned with the same weighting. When these weights were incorporated into the MCE in Idrisi the consistency ratio obtained was lower than 0.1 which meant that the weightings were relatively consistent. Had the ratio been greater than 0.1, a value considered by the WEIGHT module in Idrisi to be unacceptably high, the factors would have had to be re-evaluated to achieve an acceptable consistency ratio. In order to ensure accurate results, professionals who are familiar with the problems being dealt with were identified, and requested to complete the questionnaire. Had the questionnaire being answered by individuals that do not understand the importance or methodology of such an exercise, the results (Table 8.1) could have proved to be dramatically different.

**Figure 8.1.** Flowchart showing how the criteria were combined.



**Table: 8.1.** Pairwise comparison of the respective criteria along with relative factor weights.

	Maximise road network in Pine plantations	Minimise road network in Wetland	Minimise road network in Swamp Forest	Minimise road network in Grasslands	Maximise road network in Coastal Forest and Thicket	Factor Weights
Maximise road network in Pine Plantations	1	---	---	---	---	0.0287
Minimise road network in Wetland	9	1	---	---	---	0.4149
Minimise road network in Swamp Forest	9	1	1	---	---	0.4149
Minimise road network in Grasslands	5	1/9	1/9	1	---	0.0888
Maximise road network in Coastal Forest and Thicket	3	1/9	1/9	1/7	1	0.0528

The factor weights represented in Table 8.1. indicate which landcover types were more or less favoured for development. With pine having the lowest value (0.0287) ensuring that it received a low friction value, while at the other end of the scale wetlands and swamp forests were given the same weighting emphasising the importance of these areas. The MCE combined the factor weights and respective distance/relative suitability images in order to establish the different trade-off values described in section 7.11. The image that resulted from this was the friction surface. The friction surface was required to produce the Cost Distance and Cost direction images which in turn were used by the Cost Path to produce the road network. Once the proposed road network had been created, the first step was to compare the proposed road network (that of least environmental impact) to that of the existing road network. To achieve this both networks were overlayed onto an image containing all the constraints (Figure 8.2), that is the wetlands, swamp forests and their respective buffers, sensitive areas and those areas with slopes greater than 20%. These constraints were identified to reduce the environmental

Figure 8.2.

Existing and Proposed road networks overlayed on Constraints



impact of development. Environmental consultants and ecologists identified these areas as requiring special consideration, and thus, should not be developed. Therefore, when comparing the proposed road network to that of the existing network, as well as the necessary constraints (Figure 8.2), it is clear that the existing network is incorrectly placed if one wishes to have a network that creates as little environmental damage as possible. This may be deduced by viewing these roads and taking note as to how they pass through a number of those areas not available for development (i.e. they pass through a number of areas masked out due to the constraints).

Furthermore, if one considers the proposed road network, there are very few constraint areas through which this road network passes. This is again emphasised when comparing the road networks against the friction surface (Figure 8.3.), as the proposed network favours those areas most preferred for development and therefore those areas with low friction values.

In the event that the proposed road network does pass through areas masked out, as a result of having no other alternative means of reaching a required destination, the author has opted to follow the existing route (examples of such areas are highlighted in Figure 8.4. (A; B and C). In so doing, new land would not be disturbed. However, during the scoping stages of the development, the decision-makers could decide that an alternate alignment should be followed due to long-term impacts that the current alignment could have on the environment. Such impacts could include the deterioration of the hydrological cycle, or result in the loss of an important species. On the other hand decision-makers may conclude, in such problematic areas, although a number of negative attributes do exist in establishing a road through these areas, the re-routing of the road would not warrant such measures and thus recommend that the existing alignment be kept. However, stringent mitigative measures would have to be introduced (as recommended in section 4.6 p. 36).

### Existing and Proposed road networks overlaid on the Friction Surface





Figure 8.4.

Existing and Proposed roads overlayed with Landcover classification of study area



From the friction surface (Figure 8.3.) it is clear that those areas favoured for development would be pine, then coastal forest and thicket, then grassland and lastly swamp forest and wetlands.

The friction surface emphasises the road alignment that would have least environmental impact. It also provides a clear indication as to why the road network has been aligned in the manner in which it has in order to create the network ensuring that it joins all the proposed future development nodes and tourist sites following the path of least friction (cost). Therefore, there is little doubt that such a road network would lead to a much more 'sound' development approach.

In comparing the existing road network against the friction surface it is clear that it bisects areas with high friction values and therefore areas that would not be recommended for development by the decision makers. In addition the friction surface would allow environmental consultants and engineers to identify other preferred areas that could be proposed for development. This would be possible as the friction surface indicates those areas most conducive to development, not just for that of road construction. If during the EIA the identification of alternative sites are required, consultants and engineers alike may revert to this image in order to identify all those areas more suited to development and environmental sustainability. Once these have been decided upon (i.e. areas with low friction values) the model may be extended to create a new road to these areas and the old road deleted from the data set. This ensures that the data may be continually updated during the process.

The landcover image (Figure 8.4.) provides the decision makers with the opportunity to view the road alignments and consider how they traverse the different vegetation types, taking into account the different weightings established. From this image it is clear that the road alignment continuously sways towards those areas currently planted to pine, while it attempts to stay away from those areas that contain higher weightings (eg. wetlands, swamp forest, sensitive areas and slopes greater than

20%). The proposed road network may be seen to be favouring a path that would cause the least environmental impact. When comparing the number of 'pockets' or 'islands' into which the existing road network fragments the habitats, to that of the proposed network there is no doubt that the proposed network would have less negative environmental impact. For example on examination of the road networks (Figure 8.4), the existing network fragments the study area into twenty different 'pockets' or 'islands' while that of the proposed network creates only thirteen.

Both road networks (existing and proposed) were taken into ARC/INFO as shape files, while the landcover image had to be converted to a polygon data type in ArcView before opening it in ARC/INFO. It was then possible to carry out a classical line on polygon identity overlay. This effectively identified the different 'arcs' forming the road network and assigned the identification value corresponding to the various landcover types to the respective 'arcs'. In performing this operation Table 8.2. was produced. Figures 8.5 and 8.6 emphasise these results.

The results in Table 8.2 illustrate that the proposed road network has a total length of 106 340m while the existing road network has 173 283m a difference of 66 943m between the two networks. This reduction in length would have a positive impact on the environment, by reducing habitat fragmentation and exposing greater areas for rehabilitation.

If one considers that the proposed road network has 66 943m less length than that of the existing road network the argument may arise that due to this there will be less network within each landcover type. However, if one considers proportionally the difference between the two networks it is clear that despite the reduced distance the proposed road network is located in areas that would ensure that this difference is still substantial. For example in those areas considered as constraints or with high friction values within the study area (i.e. wetlands, swamp forest and grassland), the actual difference in road length in metres may be expressed as a

percent by subtracting the difference in length passing through each landcover type and multiplying by a hundred over one (as illustrated in highlighted boxes in Figure 8.5) i.e. 69.3%; 98.5% and 67.0% respectively. While landcover types such as coastal forest and thicket and pine have values of 15.2% and 20.7% respectively and have also decreased in proportion though not to the same degree as these areas due to the fact that these areas were more preferred for development by the environmental consultants and ecologists who answered the questionnaire (Appendix G).

The results shown in both Figures 8.5 and 8.6 combined with Table 8.2 seem to indicate that coastal forest and thicket was the most preferred area to develop, this was not the case, as the most preferred due to the weightings obtained in Table 8.1 was pine. The reason for there being more of the proposed network within the coastal forest and thicket is due to the greater proportion of this landcover type in the study area, as well as the fact that many of the proposed tourist view sites and development nodes being placed within this landcover type. This ensures that a substantial portion of the road network falls within these areas.

The conclusion that may be derived from Table 8.2 and Figures 8.5 and 8.6 is that although as a proportion of the overall length the proposed road has increased the network within coastal forest and thicket and pine but in terms of the actual length it has decreased.

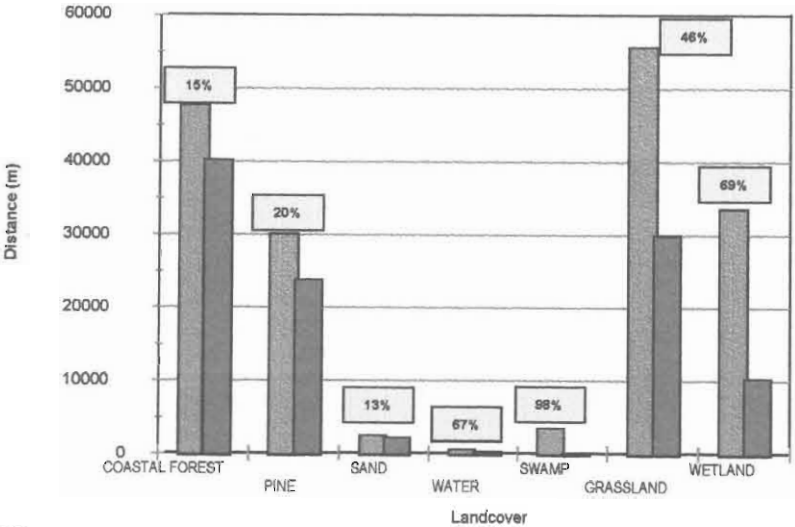
In terms of the proposed network length, by using these methods, it has decreased the use of the sensitive landcover types (water, swamp, grassland and wetlands) using the other landcover types (coastal forest and thicket) more efficiently, thus making it possible to shorten the overall network.

It is reassuring to note that over half of the network falls within pine and coastal forest and thicket (63 883m), stressing the great potential that GIS has for identifying the most suitable areas prior to development.

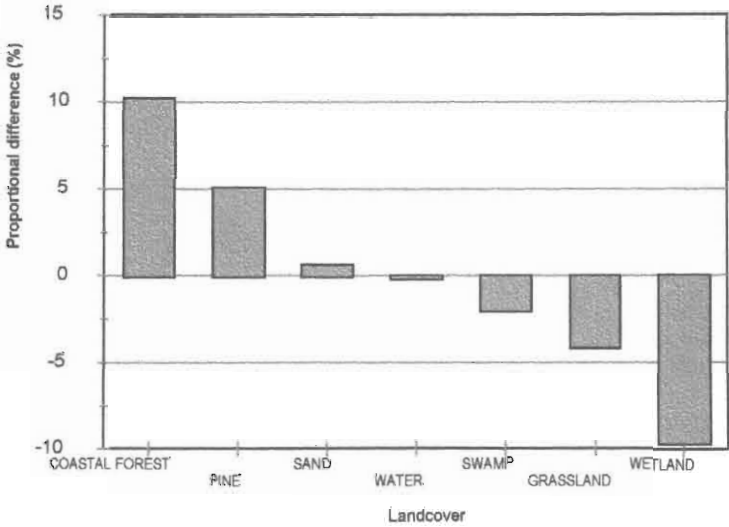
**Table 8.2.** Comparison between existing and proposed road networks passing through each landcover type.

LANDCOVER	ACTUAL DISTANCE IN METRES OF EXISTING ROAD NETWORK (m)	%	ACTUAL DISTANCE IN METRES OF PROPOSED ROAD NETWORK (m)	%	PROPORTIONAL DIFFERENCE BETWEEN PROPOSED & EXISTING ROADS AS A %	DECREASE IN DISTANCE BETWEEN PROPOSED & EXISTING ROADS (m)	ACTUAL DIFFERENCE IN DISTANCE BETWEEN PROPOSED AND EXISTING ROADS AS A %
Coastal forest & thicket	47681	27.5	40106	37.7	10.20	7575	15.89
Pine	29984	17.3	23777	22.4	5.06	6207	20.70
Sand	2458	1.4	2139	2.0	0.59	319	12.98
Water	570	0.3	188	0.2	-0.15	382	67.04
Swamp	3470	2.0	51	0.0	-1.95	3419	98.52
Grassland	55613	32.1	29796	28.0	-4.07	25817	46.42
Wetland	33507	19.3	10283	9.7	-9.67	23224	69.31
<b>Total</b>	<b>173283</b>	<b>100.0</b>	<b>106340</b>	<b>100.0</b>		<b>66943</b>	<b>38.63</b>

**Figure 8.5.** Graph representing the actual difference in (m) between the proposed and existing road networks.



**Figure 8.6.** Graph representing the proportional difference in percentage between the proposed and existing road networks.



Key

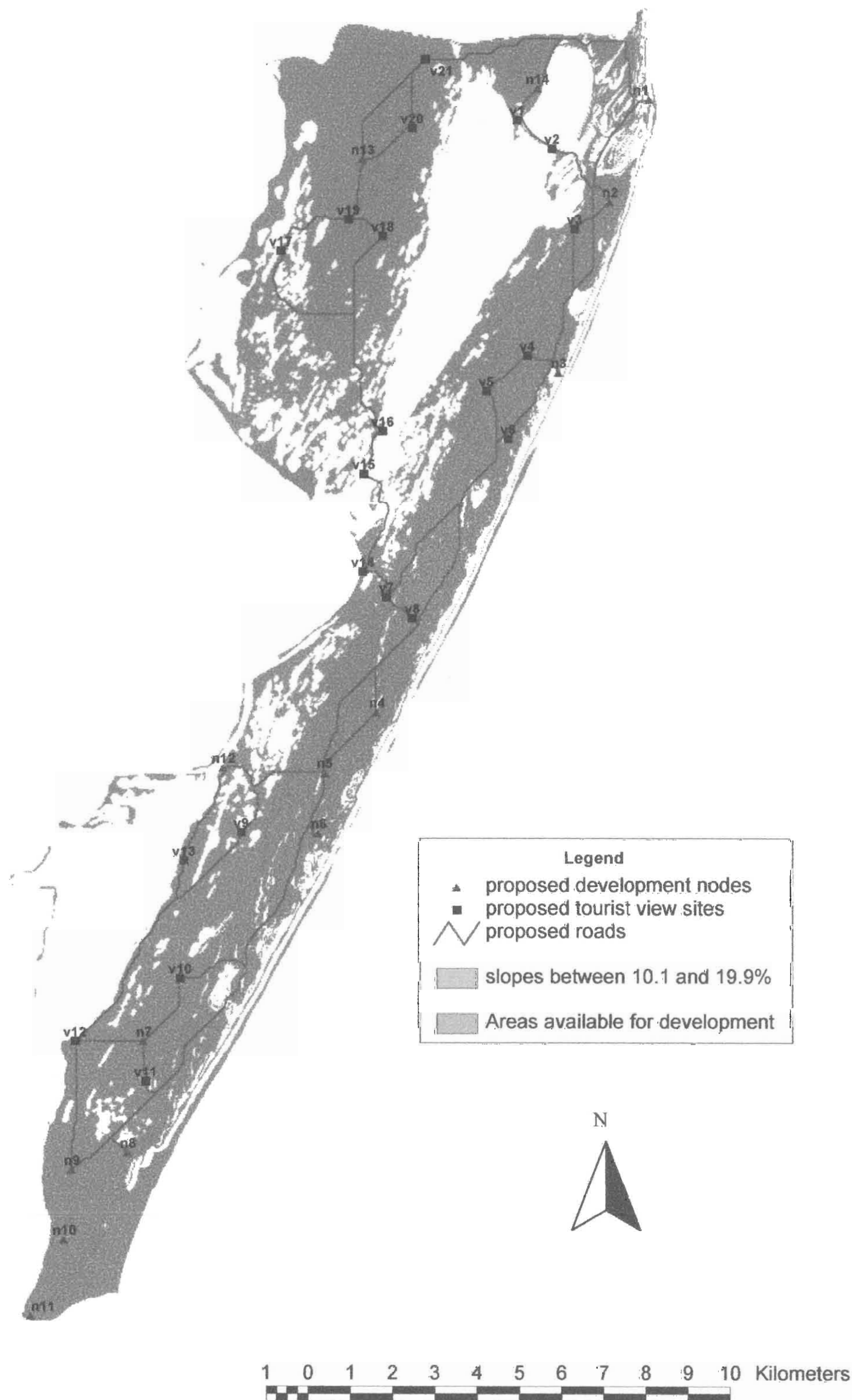
Existing network Proposed network Actual difference in metres as a (%)

Another image that would prove useful for those conducting the EIA would be an image of those areas where slope could pose a problem. As such Figure 8.7 represents all those slopes within the study area that fall between the range 10.1% and 19.9%. They indicate which areas are going to have to be cut away in order for the road network to maintain an alignment that is no steeper than 10%. Such an image may also play an important role in identifying mitigative measures in those areas that would require large amounts of earth works due to the steepness of the land.

In order to place these results in the context of the study area, aerial photos were obtained in digital format, from the Office of the Surveyor General (1996), allowing the road networks to be overlayed. This image acts as an excellent visual medium, enabling decision makers to view the road networks as they would appear in reality. Aiding the decision making process by enabling those involved in the IEM process to view the area and the road networks before actually visiting the area. Effectively permitting them to identify problem areas or areas that require more attention than others. From this a list of priorities can be compiled. This would ensure that little time would be lost once actually on-site. It also affords them the opportunity to compare the friction surface and constraints map against what is actually on the ground. In so doing, they can satisfy themselves that the correct decisions will be made before visiting the area.

Figure 8.7.

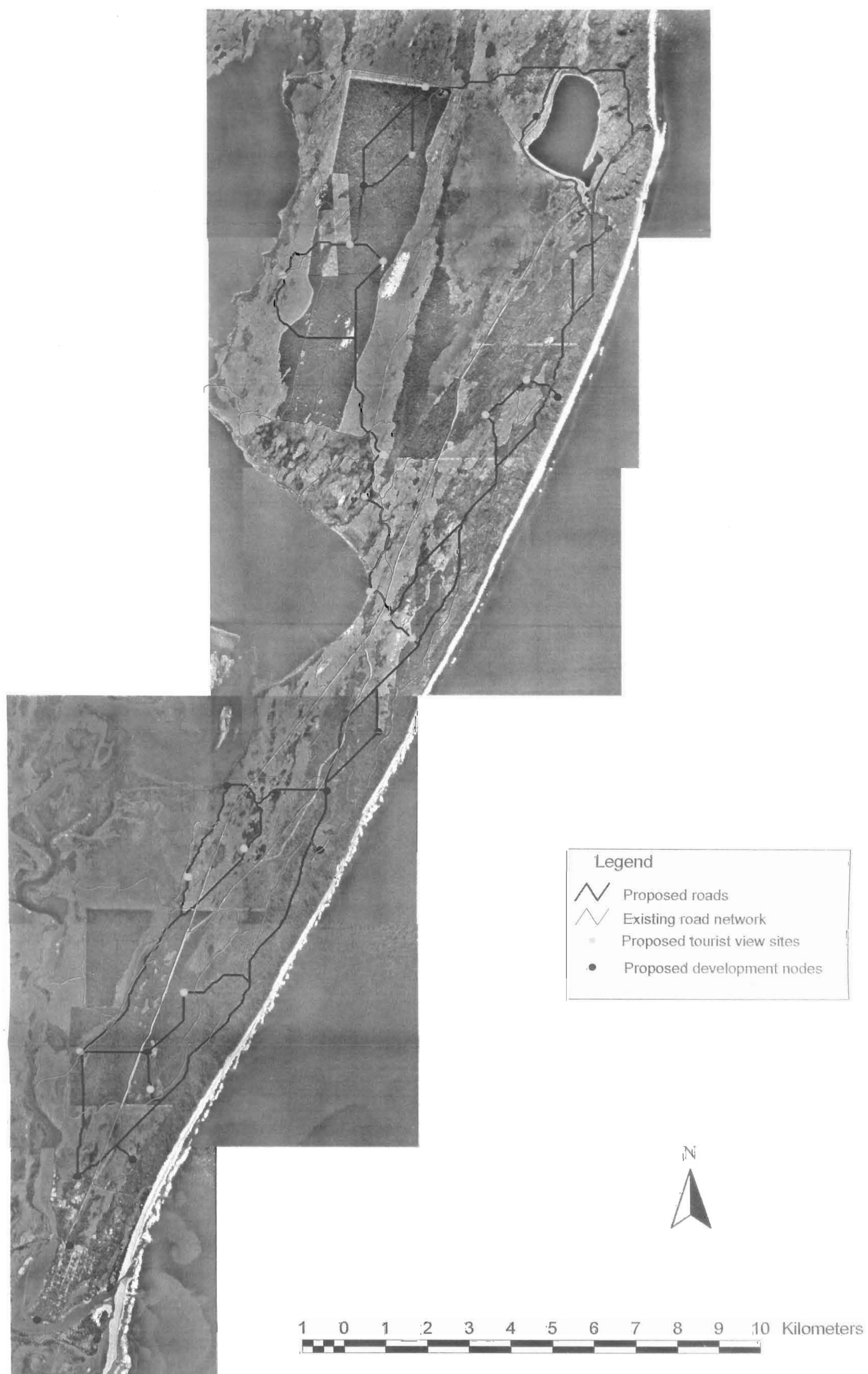
Slopes of between 10.1% and 19.9% overlayed with proposed roads and constraints





**Figure8.8.**

Proposed and existing road networks overlayed on aerial photos of Eastern Shores State Forest





# **CHAPTER 9**

## **CONCLUSIONS AND RECOMMENDATIONS**

The results of this study emphasise how GIS may be used as an analytical tool within the IEM process. The proposed new road network has not only taken into account those areas of differing sensitivity, but it has also not allowed development to take place within thirty metres of those areas viewed as being most important to conserve and preserve. However, whilst achieving this it has also established the road network in such a manner that tourists visiting the area would be able view all the different habitat types along with the wildlife that may be found in these various regions. This ensures that tourists get to see as much of the area as possible with as little impact or disturbance to the environment as is possible. Furthermore, it has identified those areas currently considered as important tourist sites as well as being able to reach all the proposed future development nodes whilst following a path that causes the least environmental impact.

In order to achieve the overall aim of this study a number of goals were set at the outset that required extensive literature surveys to be conducted. For example, the first goal of providing an overview of both the IEM and EIA processes was established by carrying out a literature review. The second component of the literature survey examined the role of GIS within the IEM process. This was supported by a number of examples, showing how useful GIS may be with respect to environmental management and identifying areas that should be restricted from development. Thus the second goal of the study was achieved.

The third goal of the study was met by examining the impacts that roads have on the environment. This was established by identifying a number of practical problems that have been experienced in the past. Lastly, and probably the most important goal was met by undertaking a practical project within the Eastern Shores State Forest that required, the author to identify real life problems and apply them in an integrated and holistic manner in order to show GIS's effectiveness within the IEM process.

Multi-Criteria Evaluation, although seldom used in the past, has for this thesis proved to be both an efficient and effective method within the GIS process. It has enabled the author to weigh up the various environmental factors controlling the placement of roads, and subsequently to use the GIS as a tool to extract or identify all those areas most conducive to development, whilst applying the constraints in the same process. The greatest challenge within the MCE process, that of having to make the multicriterion choice i.e. having to identify those choice alternatives that satisfied the objectives of the author, was overcome by extracting each vegetation type as classified by members of the NCS individually and applying the respective weights to these.

From this it could be established, by using the Analytical Hierarchical Process, which vegetation type was weighted as being more important than the others. In so doing a rational method of decision making was developed. This allowed the GIS to establish the most feasible sites/routes for the road network in the study area. In the past these areas would have been selected by using manual map overlays as a part of the suitability analysis. This is a considerably more labour intensive and time consuming process, not to mention its greater susceptibility to error.

Quinn et al (1993 p.3.) have stated that it is their "...belief that the adoption of a decision support approach to ecosystem management is a necessary

and appropriate response to the requirements of environmental management in the 1990's". They continue by adding that "...society is becoming increasingly complex. The number and characteristics of the interactions which occur between social, economic, environmental and political issues, and the non-linear dynamic nature of responses which are difficult to predict, create uncertainty. Under these circumstances decisions are difficult to make, difficult to explain and difficult to defend. A consequence is debilitating, unproductive debate which stifles progress and wastes resources". The advances that technologies, such as GIS, have made in the area of environmental decision making have opened up new opportunities for supporting such decisions, and are therefore, not only aiding in speeding up the decision making process but are also ensuring that more informed decisions are made.

Therefore, the benefits of implementing and using GIS to assist environmental consultants within the IEM process was clearly illustrated in the results. The adoption of GIS as part of the IEM process will not only improve the quality of the process but it has the potential to speed up the entire process. Thus the study has shown that incorporating GIS into the IEM process will not only provide for more efficient and effective process, but will also allow for greater participation, comprehensiveness and flexibility.

With the 1990's drawing to a close substantial technological advances ( such as GIS, AHP, Decision Support Systems and Expert Systems to name a few) have been made, which despite their proven capability are still not widely used. The author hopes that with the beginning of the new millennium, more positive steps towards integrating these powerful decision-aiding technologies with environmental approaches will be made. There is no doubt, as the author hopes he has shown with this thesis, that technology such as GIS could play an important role in aiding future decisions about crucial environmental problems.

From the results it is recommended that those areas where the proposed road network and the existing network are in close proximity to each other i.e. within a threshold of 30 meters (Ahmed, 1999) that the proposed alignment be discarded and the existing used as a cost saving. In other words in determining which network should be utilised and which should be discarded three strategies should be employed. Firstly, if the existing and proposed networks are exactly aligned, then the existing network may be kept. Secondly if the networks are in close proximity to each other environmental consultants would have to establish the impacts of moving the proposed alignment to meet that of the existing one, and implement any mitigative measures that may be required. On the other hand they may insist that the existing alignment be changed to meet that of the proposed network. Thirdly, if the existing network does not fall within close proximity i.e. in the order of 100 meters or more to the proposed network, and therefore in areas recognised by the study as being more important to conserve, then it should be abandoned and rehabilitation measures put into place.

This study was based on the physical constraints within the study area and focuses little attention on social and political constraints that may exist in the study area. Thus, to further the study it would be important to identify such constraints. For example, had the NCS not resolved the problem of land claims the study would have had to include other areas within the study area as absolute barriers. The reason being is that if these people did not wish to relocate, the land on which they lived would not be available for development and thus any proposed development would have to take this into account as well as factors such as noise pollution, that could effect their quality of life.

If the finances had been available to obtain other data sets such as geology and lithology maps the author would have been able to perform a soil

erosivity potential analysis. This would allow one to identify those areas most susceptible to soil erosion and thus special attention would be required when developing on or near such areas.

The author has shown that this has been a profitable exercise and feels that it is most certainly an approach that can be applied elsewhere in South Africa and abroad.

In conclusion, society is beginning to take cognisance that the argument of being able to develop a country first and then attempt to rectify the environmental disruptions at a later stage is neither scientific nor rational. This realisation stems from the identification that not only is the above argument unethical but it is also incorrect from an economic view-point (Tolba 1987, after Biswas *et. al.*) Tolba (1987, quoted in Biswas *et. al.*, p.xi) adds to this by saying “ ‘The get rich quick’ syndrome generally produces short term benefits at long term costs which often could far exceed the initial gains.” Thus, it is not only desirable to pursue the short and long term development goals while simultaneously ensuring sound environmental management, it is also essential. With the above in mind one realises that the use of GIS within the IEM process can prove to be a useful and successful exercise for reaching the desired objective of identifying/managing both short and long term environmental impacts.

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# APPENDICES

## List of Activities in Schedule 1

1. The construction or upgrading of –
  - (a) facilities for commercial electricity generation and supply;
  - (b) nuclear reactors and installations for the production, enrichment, reprocessing and disposal of nuclear fuels and wastes;
  - (c) transportation routes and structures, and manufacturing, storage, handling or processing facilities for any substance which is dangerous or hazardous and is controlled by national legislation;
  - (d) roads, railways, airfields and associated structures outside the borders of town-planning schemes;
  - (e) marinas, harbours and all structures below the high-water mark of the sea;
  - (f) cableways and associated structures;
  - (g) structures associated with communication networks, other than telecommunication lines and cables, as well as access roads leading to these structures;
  - (h) racing tracks for motor-powered vehicles and horse racing, excluding indoor tracks;
  - (i) canals and channels, including diversions of normal flow of water in a river bed and water transfer schemes between water catchments and impoundments;
  - (j) dams, levees or weirs affecting the flow of a river;
  - (k) reservoirs for public water supply;
  - (l) schemes for the abstraction or utilisation of ground or surface water for bulk supply purposes;
  - (m) public and private resorts and associated infrastructure;
  - (n) sewage treatment plants and associated infrastructure;

- (o) buildings and structures for industrial and military manufacturing and storage of explosives or ammunition or for testing disposal of such explosives or ammunition.
2. The change of land use from –
    - (a) residential use to industrial or commercial use;
    - (b) light industrial use to heavy industrial use;
    - (c) agricultural or undetermined use to any other land use;
    - (d) use for grazing to any other form of agricultural use; and
    - (e) use for nature conservation or zoned open space to any other land use.
  3. The concentration of livestock in a confined structure for the purpose of mass commercial production.
  4. The intensive husbandry of, or importation of, any plant or animal that has been declared a weed or an invasive alien species.
  5. The release of any organism outside its natural area of distribution that is to be used for biological pest control.
  6. The genetic modification of any organism with the purpose of fundamentally changing the inherent characteristics of that organism.
  7. The reclamation of land below the high-water mark of the sea and in inland water including wetlands.
  8. The disposal of waste in terms of section 20 of the Environment Conservation Act, 1989.



9. Scheduled processes listed in the Second Schedule to the Atmospheric Pollution Prevention Act, 1965 (Act No. 45 of 1965).

### Record of Decision

1. The relevant authority must issue a record of the decision that was taken under regulation 9 (1) to applicant, and on request to any other interested party.
2. The record of the decision must include –
  - (a) a brief description of the proposed activity, the extent or quantities and the surface areas involved, the infrastructural requirements and the implementation programme for which the authorisation is issued;
  - (b) the specific place where the activity is to be undertaken;
  - (c) the name, address and telephone number of the applicant;
  - (d) the name, address and telephone number of any consultant involved;
  - (e) the date of, and persons present at, site visits, if any;
  - (f) the decision of the relevant authority;
  - (g) the conditions of the authorisation (if any), including measures to mitigate, control or manage environmental impacts or to rehabilitate the environment;
  - (h) the key factors that led to the decision;
  - (i) the date of expiry or the duration of authorisation;
  - (j) the name of the person to whom an appeal may be directed as contemplated in regulation 11;

- (k) the signature of a person who represents the relevant authority;  
and
- (l) the date of the decision.

### **Plan of Study for Environmental Impact Assessment**

1. In the event of a decision contemplated in regulation 6 (3) (b), the applicant must submit a plan of study for an environmental impact assessment, which must include –
  - (a) a description of the environmental issues identified during scoping that may require further investigation and assessment;
  - (b) a description of feasible alternatives identified during scoping that may be further investigated;
  - (c) an indication of additional information required to determine the potential impacts of the proposed activity on the environment;
  - (d) a description of the proposed method of identifying these impacts; and
  - (e) a description of the proposed method of assessing the significance of these impacts.
2. The relevant authority may, after receiving the plan of study referred to in subregulation (1) and after considering it, request the applicant to make the amendments to the plan of study that the relevant authority requires to accept the plan.

### Submission of Environmental Impact Report

1. After the plan of study for the environmental impact assessment has been accepted, the applicant must submit an environmental impact report to the relevant authority, which must contain –
  - (a) a description of each alternative, including particulars on –
    - (i) the extent and significance of each identified environmental impact;  
and
    - (ii) the possibility for mitigation of each identified impact;
  - (b) a comparative assessment of all the alternatives; and
  - (c) appendices containing descriptions of –
    - (i) the environment concerned;
    - (ii) the activity to be undertaken;
    - (iii) the public participation process followed, including a list of the interested parties and the comments;
    - (iv) any media coverage given to the proposed activity; and
    - (v) any other information included in the accepted plan of study.

## Legislation with Relevance to Road Construction

(Taken from Transportation Environmental Management Manual vol.2:  
supplementary Background information 1994)

### *Acts*

- i. Land Survey Act, 9 of 1927
- ii. Sea-Shore Act, 21 of 1935 (\*)
- iii. Advertising on Roads and Ribbon Development Act, 21 of 1940
- iv. Explosives Act, 26 of 1956 (Regulations) (\*)
- v. Water Act, 54 of 1956 (\*)
- vi. Atmospheric Pollution Prevention Act, 45 of 1965 (\*)
- vii. Physical Planning Act, 88 of 1967
- viii. National Monuments Act, 28 of 1969 (\*)
- ix. Mountain Catchment Areas Act, 63 of 1970 (\*)
- x. Subdivision of Agricultural Land Act, 70 of 1970
- xi. Water Research Act, 34 of 1971
- xii. National Roads Act, 54 of 1971 (\*)
- xiii. Hazardous Substances Act, 15 of 1973 (\*)
- xiv. Sea Birds and Seals Protection Act, 46 of 1973
- xv. Internal Health Regulations Act, 28 of 1974
- xvi. Lake Areas Development Act, 39 of 1975 (\*)
- xvii. National Parks Act, 57 of 1976

- xviii. Health Act, 63 of 1977
- xix. Dumping at Sea Control Act, 73 of 1980
- xx. South African Transport Services Act, 65 of 1981 (Regulations)
- xxi. Machinery and Occupation Safety Act, 6 of 1983 to be replaced shortly. Refer presently to the Draft Bill on Occupational Safety and Health (Government Gazette 13978, 11 May 1992)
- xxii. Agricultural Pests Act, 36 of 1983
- xxiii. Conservation of Agricultural Resources Act, 43 of 1983
- xxiv. Forest Act, 122 of 1984 (\*)
- xxv. Sea Fishery Act, 12 of 1988
- xxvi. Road Traffic Act, 29 of 1989 (\*)
- xxvii. Environment Conservation Act, 73 of 1989 (\*)
- xxviii. Minerals Act, 50 of 1991 (and Regulations)
- xxix. Physical Planning Act, 125 of 1991 (\*)

## *ORDINANCES*

### *Natal*

- i. Town Planning Ordinance, 27 of 1949 (\*)
- ii. Nature Conservation Ordinance, 15 of 1974 (\*)
- iii. Prevention of Environmental Pollution Ordinance, 21 of 1981 (\*)

## Definitions

### **Decision**

A decision is a choice between alternatives. The alternatives may represent different courses of action, different hypotheses about the character of a feature, different classifications, and so on. We call this set of alternatives the *decision frame*.

### **Criterion**

A criterion is some basis for a decision that can be measured and evaluated. It is evidence upon which an individual can be assigned to a decision set. Criteria can be of two kinds: factors and constraints, and can pertain either to attributes of the individual or to an entire decision set.

### **Factors**

A factor is a criterion that enhances or detracts from the suitability of a specific alternative for the activity under consideration. It is therefore most commonly measured on a continuous scale.

### **Constraints**

A constraint serves to limit the alternatives under consideration. A good example of a constraint would be the exclusion from development of areas designated as wildlife reserves. Another might be the stipulation that no development may proceed on slopes exceeding a 30% gradient. In many cases, constraints will be expressed in the form of Boolean (logical) maps: areas excluded from consideration being coded with a 0 and those open for consideration being coded with a 1.



**Decision Rule**

The procedure by which criteria are selected and combined to arrive at a particular evaluation, and by which evaluations are compared and acted upon, is known as a decision rule. A decision rule might be as simple as a threshold applied to a single criterion (such as, all regions with slopes less than 35% will be zoned as suitable for development) or it may be as complex as one involving the comparison of several multi-criteria evaluations.

Decision rules typically contain procedures for combining criteria into a single composite index and a statement of how alternatives are to be compared using this index.

***Choice Function***

Choice functions provide a mathematical means of comparing alternatives. Since they involve some form of optimisation (such as maximising or minimising some measurable characteristic), they theoretically require that each alternative be evaluated in turn. However, in some instances, techniques do exist to limit the evaluation only to likely alternatives.

***Choice Heuristic***

Choice heuristics specify a procedure to be followed rather than a function to be evaluated. In some cases, they will produce an identical result to a choice function, while in other cases they may simply provide a close approximation. Choice heuristics are commonly used because they are often simpler to understand and easier to implement.

## Objective

Decision rules are structured in the context of a specific objective. The nature of that objective, and how it is viewed by the decision makers (i.e., their motives) will serve as a strong guiding force in the development of a specific decision rule. An objective is thus a *perspective* that serves to guide the structuring of decision rules.”

QUESTIONNAIRE

To whom it may concern,

The following questions and table, relate to a proposed tourist road network within the Eastern shores State Forest. My aim is to use GIS as a tool to propose a network that will have least environmental impact on the environment. I would appreciate it if you could answer the questions and fill in the table provided.

Yours faithfully

Timothy Mark Liversage

- Q4. Minimising the Road network within Grasslands is \_\_\_\_\_  
to that of minimising the Road network in the Pine plantations.
- Q5. Minimising the Road network within Grasslands is \_\_\_\_\_  
to that of minimising the Road network in the Wetlands.
- Q6. Minimising the Road network within Wetlands is \_\_\_\_\_  
to that of minimising the Road network in the Swamp forest.
- Q7. Minimising the Road network within Coastal Forest / Thicket is  
\_\_\_\_\_ to that of minimising the Road network in the Pine  
plantations.
- Q8. Minimising the Road network within Coastal Forest / Thicket is  
\_\_\_\_\_ to that of minimising the Road network in the Pine  
Wetlands.
- Q9. Minimising the Road network within Coastal Forest / Thicket is  
\_\_\_\_\_ to that of minimising the Road network in the  
Swamp forest.

Q10. Minimising the Road network within Coastal Forest / Thicket is \_\_\_\_\_ to that of minimising the Road network in the Grasslands.

	Maximise road network in Pine plantations	Minimise road network in Wetland	Minimise road network in Swamp Forest	Minimise road network in Grasslands	Maximise road network in Forest and Thicket
Maximise road network in Pine Plantations	1	---	---	---	---
Minimise road network in Wetland	9	1	---	---	---
Minimise road network in Swamp Forest	9	1	1	---	---
Minimise road network in Grasslands	5	1/9	1/9	1	---
Maximise road network in Forest and Thicket	3	1/9	1/9	1/7	1