Using Multi-Criteria Decision Making in Developing a Decision Support System for Land Suitability with Regard to Natural Resource Management

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Abstract

This research explores decision making in land suitability with regard to natural resource management, as it is practised in South Africa and internationally. The complexity of the problem leads to the need to use stakeholder analysis and Multi-Criteria Decision Analysis which are researched further in the dissertation. A framework for decision making on land suitability is suggested. It is applied experimentally in several case studies on decision making in land suitability with regard to natural resource management. A land suitability analysis provides a typical scenario whereby a hard factual approach such as a GIS with data on soils, climate, rainfall, topography, ecosystems, etc. is combined with socio-economic activities such as agriculture, forestry and nature conservation. Most land suitability analysis is carried out with the aid of a GIS. However, a GIS is limited to largely objective, spatial data. It is here that multi-criteria decision analysis plays an important role by combining the different stakeholder perspectives with socio-economic and scientific data in a comprehensive Decision Support System. In this research, the Analytic Hierarchy Process is used to produce an experimental model on decision making in land suitability and this model is then tested against real life case studies which proves the model to be a valid decision making technique.

Preface

This work was carried out in 1999 at the Centre for Environment and Development, University of Natal (Pietermaritzburg) under the supervision of Professors D. Petkov ánd D. Archer. The results in the dissertation represent original work that has not been previously submitted to any university in requirement for any degree.

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Chapter 1: Introduction

As the human population increases and people demand a higher standard of living, there is an increase in demand for and pressure on land for food, water, living space, recreation, raw material and nature conservation. Due to the limited area of high potential land in South Africa, there is competition among different land uses such as agriculture, forestry, nature conservation, water resource management and many others. Therefore, efficient decision making with regard to the use of an area of land becomes important.

Usually different departments/organisations perform decision making for their own discipline, eg. the provincial and national departments of agriculture and nature conservation are in charge of agriculture and nature conservation respectively. Forestry and water resource management also have their own government departments, para-statals and commercial companies. A decision making process involving all these organisations is highly complex. A model that would be able to bridge the gap between these different departments, would be a useful tool in providing the conditions for a balanced decision. Building such a model is a complex task which needs a computerised decision support system (DSS).

A decision support system may be described as any system that supports the decision making process (Farthing and Mengerson, 1999). However a more detailed definition is given by Rhodes (1993), as follows.

> " A methodology, embodied in an organised group of people and machines, which is designed to assist, but only in a secondary role, one or more members of the organisation to express a preference for one action amongst the many which could be taken where at least one of these actions involves embarking on a sequence of events whose outcome cannot be precisely determined. The preferred action is deemed to be related to the person's job within the organisation and is deemed to influence and be influenced by the others within the organisation."

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The above definition reveals that a decision support system is used to complement human decision makers and not to replace them.

There is a strong need for more natural resource decision support systems (DSS) in South Africa. Decisions regarding land suitability, for example, are usually made by experts in a particular discipline with respect to their discipline. What is needed is a trans-disciplinary approach to decision making regarding land suitability in natural resource management.

Traditionally decisions were based on technical natural resources data and hard systems such as geographical information systems (GIS). The authorities that undertook natural resource decision making usually assumed control of the process with minimum consultation with stakeholders. These decisions were the property of the relevant authority regardless of the social and economic consequences of these decisions. In this case DSS tools merely assist the authority in making the decision. This top down method is referred to as the rational approach to decision making. The rational / technocratic approach serves the needs of the relevant authority and a few key stakeholders and it does not capture the complexity of decision making regarding land suitability in natural resource management (Dale *et al*, 1999).

The more modern trend in decision support, which is used in this research, uses a systems approach to problem solving. This involves integrating hard, technical systems with expert judgements and local knowledge in a comprehensive decision making process.

As illustrated in Figure 1 a comprehensive natural resources decision support system combines both hard systems such as GISs and databases, with soft systems such as local knowledge and expert judgements. Human ethical and moral values, relative to the situation, are also accounted for when local knowledge and expert judgement is used. This model captures the complexity in decision making and addresses the needs of a broad range of stakeholders. The model also enables a transparent decision making process since it brings all the factors relevant to the process into the open. The technique used to model this process is called the Analytic Hierarchy Process (AHP), a methodology of the multi-criteria decision analysis/making (MCDA/M) process.
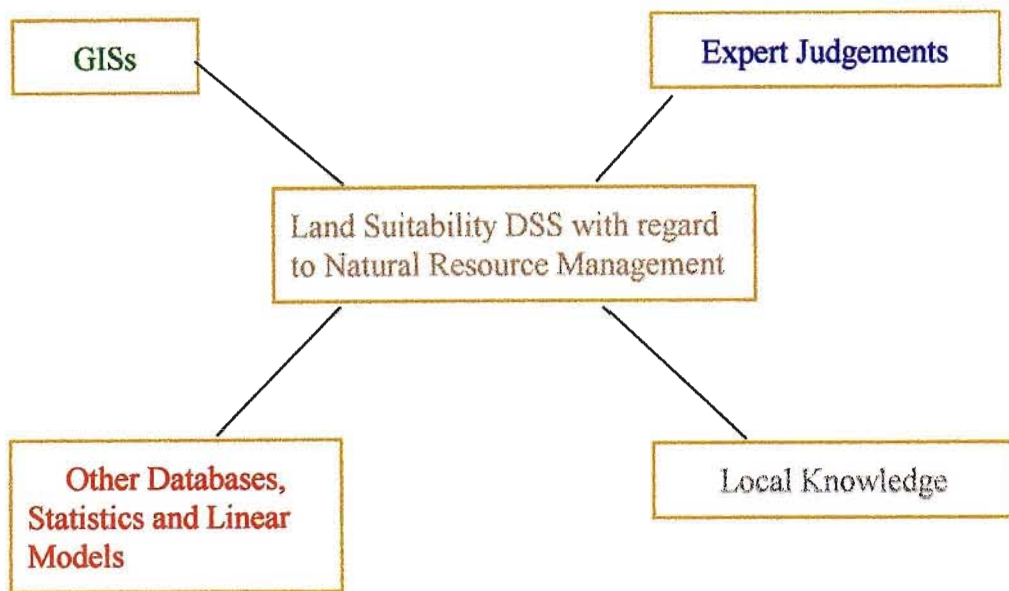
Figure 1.1: A systems approach to natural resource management. The decision support system would involve hard and soft systems.

With a systems approach to natural resource decision support, some common problems such as the lack of hard data from a GIS or database can be overcome to a certain extent with the integration of local knowledge and expert opinion into the model. The MCDA model has the added advantage of including a wider range of data than a GIS which is restricted to objective, spatial data. Therefore a paradigm shift towards a systems approach in decision making enables a more transparent, accountable and effective decision to be made.

1.1 Goals of the Research

The aim of this project is to create a model which would allow people to efficiently make a decision on the utilization of a piece of land in terms of agriculture, forestry, nature conservation or water resource conservation /management, and to propose a process for the creation of such a model.

The sub-goals of the project can be defined as follows:
- Investigate current practices in decision making in land suitability in South Africa, especially the province of KwaZulu-Natal.
- Research literature sources on the application of formal decision making approaches in

land suitability with regard to natural resource management.

- Investigate the appropriate multi-criteria methods for making decisions on land suitability.
- Formulating a framework for making decisions using MCDA/M in land suitability.
- Testing the framework.

1.2 Scope and Delimitations of the Research

The research concentrates on developing a process to produce an MCDA model on the utilization of an area of land. The activities that are available for that land are cropping, grazing, forestry, nature conservation and water resource management/conservation. A model and illustrative example are first developed to test the use of MCDA and the AHP in producing a suitable DSS for this situation. Then the resultant model is tested with the use of case studies involving three areas of land that have been well researched by other systems.

This project is part of much larger project called the SA-ISIS (South African Integrated Spatial Information System) 2000 project which aims to provide web-accessible information and decision support tools to assist decision making in natural resource management. This programme involves several organisations each with their own team of researchers. The model developed in this project would be included, as an illustrative example, in a world-wide-web based tutorial on DSSs involving the Analytic Hierarchy Process.

1.3 Research Methodology

An extensive literature survey on the application of MCDM to land management was conducted. It was supplemented by research in the field on how decision making is performed in the area of land suitability determination. Both the practical and theoretical work on this project underlined the importance of stakeholder analysis for its success, which became part of the work on the project. The multi-criteria decision model was built through prototyping. It allowed the successive refinement of the requirements towards such a model. The latter were extracted through interviews with prominent experts on the issue of land suitability, coming from various backgrounds.

There are certain steps (Mengersen and Farthing, 1999) to be followed when developing a decision support system, these are:

- Identification of the problem

    In this step, the problem situation is identified. The stakeholders, objectives, criteria and a general approach to the problem are also identified.

- Development of alternatives

    The alternatives can be a number of proposed solutions, ideas or recommendations.

- Choosing an alternative

    In this step the most suitable alternative is chosen from the alternatives identified in the previous step. This can be accomplished by deriving weights for each alternative. The alternatives can also be ranked to provide a range of options.

- Implementing the chosen alternative

    This demonstrates the use of the chosen alternative to all the interested and affected parties.

- Monitoring the impact of the chosen alternative

    This is carried out to ensure that the problem is addressed to the satisfaction of all the interested and affected parties.

- Feedback / Reiteration

    If the chosen alternative provides an unsuitable solution to the problem, then some or all of the above steps have to be re-iterated in order to better structure the problem. The solution to one problem may also identify other problems which would then need to be structured according to the above steps.

Multi-Criteria Decision Analysis (MCDA) is an approach whereby all the above steps can be accomplished. The AHP component of MCDA is used to derive the weights for each alternative.

Stakeholder analysis is used to identify the stakeholders and assessed their position regarding the problem situation.

Computers and information technology (IT) play an important role in decision support systems. The mathematical calculations involved in producing a DSS model can be undertaken by a computer leaving the stakeholders free to engage in the decision making process. Dale *et al.* (1999) describe the following roles for IT in DSSs:

- Synthesising information and knowledge.
- Recognising and managing uncertainty.
- Facilitating the learning process.
- Supporting the argumentation and negotiation processes.

However, in South Africa, decision makers should guard against using IT to intimidate and exclude stakeholders who are not computer literate. The Analytic Hierarchy Process relies heavily on computer technology for its implementation. The software used is called Expert Choice[R]. This is combined with a spreadsheet and a word processing software to form the DSS. Information for the proposed DSS also comes from computer based GISs, databases and linear models.

1.4 Importance of this Research

The practical implementation of such a project can result in the following:

- It takes advantage of existing information by systematically integrating it into a system that allows a wide range of users to interpret the data using a set of tools developed by experts.

- It captures the expertise of natural resource specialists and makes this expertise available across a wide range of decision making contexts.

- It provides an explicit method for integrating ecological, social and economic criteria into the decision making process.

- It provides a set of "best practice" decision making tools to planners and managers.

- It provides a framework for improving decision-making processes statewide and regionally.

- It provides a mechanism for identifying information shortfalls.

- It helps identify research needs where information is deficient or relationships between factors need to be defined.

In addition to the above benefits described by Itami *et al.* (1999), a decision support system on land suitability would benefit South Africa in other ways, such as:

- Facilitating communication between the different organisations and stakeholders in the decision making process.

- Empowering the relevant stakeholders in the decision-making process.

- Allowing for a transparent decision making process.

1.5 Overview of the Dissertation Structure

Chapter two gives an overview of MCDA, AHP, stakeholder analysis and other techniques that can be used in a natural resource DSS. This information was obtained from a review of the literature on systems thinking and problem structuring techniques. Chapter 3 illustrates some of the current practices in decision making regarding land suitability in natural resource management. This chapter compares and contrasts the rational approach to decision making in South Africa versus the systems approach that is used in other countries. Chapter 4 contains the process for developing the DSS with illustrative examples on how the model is used. This model is then tested using case studies presented in Chapter 5. Chapter 6 contains the conclusion as well as recommendations for future research.

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Chapter 2: Survey of Current Research Methodology in Systems Thinking, Stakeholder Analysis and MCDA

The purpose of this review is to provide an analysis of the current state of research on the application of multi-criteria decision making/analysis (MCDM/A) and systems thinking to land suitability. This is a broad, complex issue; hence, a need for such techniques. "Land Suitability is defined as the fitness of a particular area for a given use. However, land suitability is relative to the needs and possibilities of interests groups"(Malczewski *et al*, 1997). The review also provides information on other systems techniques that can be used, in appropriate situations, to address the issue of land suitability in natural resource management.

Several researchers (Bawden and Packham, 1998; Brouwer and Jansen, 1989; and Bawden *et al*, 1985) have identified the need to have a systems approach to agricultural research. This is evident in the farming systems research (FSR) paradigm. FSR methods integrate the farming production unit, scientific agricultural research and the surrounding socio-economic factors. This is a multi-disciplinary approach involving crop production, animal husbandry, agroforestry, ecology, watershed management, biodiversity conservation, economics, politics, sociology and many others. This approach can lead to conflicts among stakeholders who have various interests, goals and objectives. Thus a natural resource land suitability decision support system, involving FSR, should be able to reconcile the human need for food and the need to conserve the environment.

Palonen and Mattila (1992) identified a need for and produced a farmer friendly "decision support system for field crop cultivation" in Finland. This system provides the farmer with information on the species and variety of crop to produce as well as crop cultivation practises. The programme provides farmers with the latest research results and this assists the farmer in reducing costs while also protecting the environment.

Conway (1985a and b) described a simple decision tree which summarises the decision making processes to establish the best crop to grow on farms in Northeast Thailand and East Java. Typically, decision trees show the different relationships between objectives, criteria and

alternatives. They may be regarded as simplified decision support systems. However, this system is a hard system governed by "yes" versus "no" and "more" versus "less". This system makes limited use of the multiple criteria in the decision making process, since there are no relative weights between the different criteria and the different objectives. There is also little stakeholder representation in these systems. In the past, decision making was governed by techniques such as the Multi-Attribute Utility Theory (MAUT). In this theory alternatives were ranked one at a time, subject to forceful axioms about lottery comparisons, transitivity of choices and rationality as defined by the experts (Saaty, unpublished); i.e. it was largely a top down approach and difficult to understand by the users. It appeared that a more holistic participative technique is needed with regard to decision support in land suitability.

Currently there are numerous better techniques that are available to identify and analyse a land suitability problem situation. These techniques involve stakeholder identification and analysis; identification of goals, objectives, criteria and sub-criteria; and ranking these into a hierarchy with weights attached to each alternative. Some of these techniques are illustrated in the following sections.

2.1 Stakeholder Involvement in Decision Support Systems

There are certain crucial steps to follow in order to ensure an effective, natural resource management, decision making process (Dale *et al.*, 1999). This a would include the:

1.   Application of a sound social, economic and environmental assessment.
2.   Establishment of appropriate institutional arrangements which support equitable negotiations among stakeholder interests and
3.   Operation of clear mechanisms to build the capacity of stakeholder groups involved in the use and management of resources.

The above three points demonstrate the integration of stakeholders and technical data into the decision making process. This shows that current rational decision making systems can be built upon with stakeholder input rather than being replaced with totally new systems. Thus, in order to achieve consensus in this largely political issue of natural resource management, the

collective understanding of all the different stakeholders would have to be taken into account.

To empower the different stakeholders to enable them to participate effectively in the decision making process, the following points should be considered (Dale *et al.*, 1999):

- Improving the stakeholders understanding of the technical nature of the decision making process.
    - Educating the stakeholders on the techniques used in structured problem solving and systems thinking.
    - Informing the stakeholders of the technical data available for natural resource management such as GISs.
    - Informing the stakeholders of the biological, socio-economic and political nature of the problem.

- Reforming the institutional arrangements for decision making.
    - Improving the internal institutional arrangements of key authorities such as government departments
    - Improving institutional arrangements to encourage equitable negotiations
    - Organising the stakeholders into working groups such as farmers associations and conservation associations.

- Building the capacity of key regional stakeholders.
    - Raising the level of understanding of the constituents of major stakeholder groups regarding the significant resource use and sustainability issues at hand
    - Increasing the access that stakeholder groups have to information of importance to natural resource management
    - Ensuring that appropriate technical, skills and financial resources are made available to plan, and/or ensuring that existing resources are used more efficiently
    - Ensuring that stakeholder groups build a clear mandate from their constituents, and establish and maintain effective mechanisms for consulting and representing

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them.

- Improving the negotiation capacity of key stakeholder groups in the arena.

There is a contrast in the systems approach to decision making and the top down system of decision making which involves inflexible statutory processes, structures with limited adaptability and the lack of institutional arrangements to encourage equitable negotiations between stakeholders. Traditionally decision support systems were "overused by centralised authorities for spatial representation and data management and underused for interpretive analysis, stakeholder capacity building and as tools to assist, structure and manage negotiation" (Dale *et al.*, 1999). To make optimum use of stakeholders in a DSS, the inputs from these stakeholders need to be analysed. The next section illustrates techniques on how stakeholder analyses are performed.

2.2 Stakeholder Analysis

Stakeholder analysis is one of the earlier approaches in soft systems thinking which can be integrated with other problem solving techniques. There are many different forms of stakeholder analysis available for particular situations.

A stakeholder (Banville *et al*, 1998)is said to have a vested interest in a problem by:
- mainly affecting it
- being mainly affected by it
- both affecting it and being affected by it.

In most cases the stakeholders are visible but in some cases the stakeholders might be invisible. This usually means that it may be undesirable for them to be included or it may have been impossible to include them eg. future generations. However, these silent stakeholders may still be affected by the decision making process and may be capable of negatively retaliating if they are adversely affected by the decision making process. For a MCDA to adequately cater for the different types of stakeholders, it is important that they be classified. Figures 2.1, 2.2 and 2.3 illustrate systems for classifying stakeholders.

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Stakeholder's potential
for threat to the organization

	High	Low
High Stakeholder's potential for cooperation with the organization **Low**	**Type 4** MIXED BLESSING Strategy: COLLABORATE Strategy: DEFEND NONSUPPORTIVE Type 3	**Type 1** SUPPORTIVE Strategy: INVOLVE Strategy: MONITOR MARGINAL Type 2

Figure 2.1: A typology of stakeholders (Savage *et al.*, 1991) used to determine stakeholders potential for threat to the organisation.

Savage *et al.*,1991 use two strategic dimensions to classify stakeholders namely the potential for threat to the organisation and the potential for collaboration with the organisation. Derived from these two classifications are four different classes namely supportive, marginal, non-supportive and mixed blessing. A management system for each of these four classes is proposed namely involve, monitor, defend and collaborate.

This strategic approach proposed in Figure 2.1 is a valuable tool for analysing stakeholders involved in land suitability decision making. There are often competing interests for the land and the proposed issue would thus be subject to opposition. This classification allows for the classification of stakeholders for and against the issue.
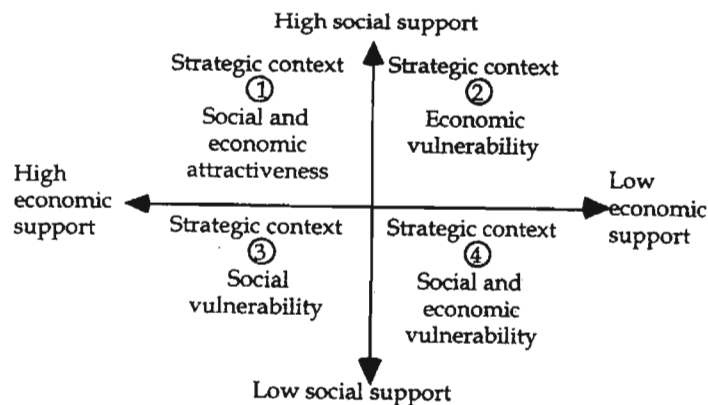
Figure 2.2: Classification of Stakeholders according to Whitehead *et al.*, (1989).

The stakeholder classification proposed by Whitehead *et al.*, 1989 assesses the vulnerability of a particular issue or proposed action. For instance a proposed use of an area of land may have high economic support from one set of stakeholders but low social support from another. These stakeholders would have to be weighted against each another to determine wether the proposed land use is feasible.
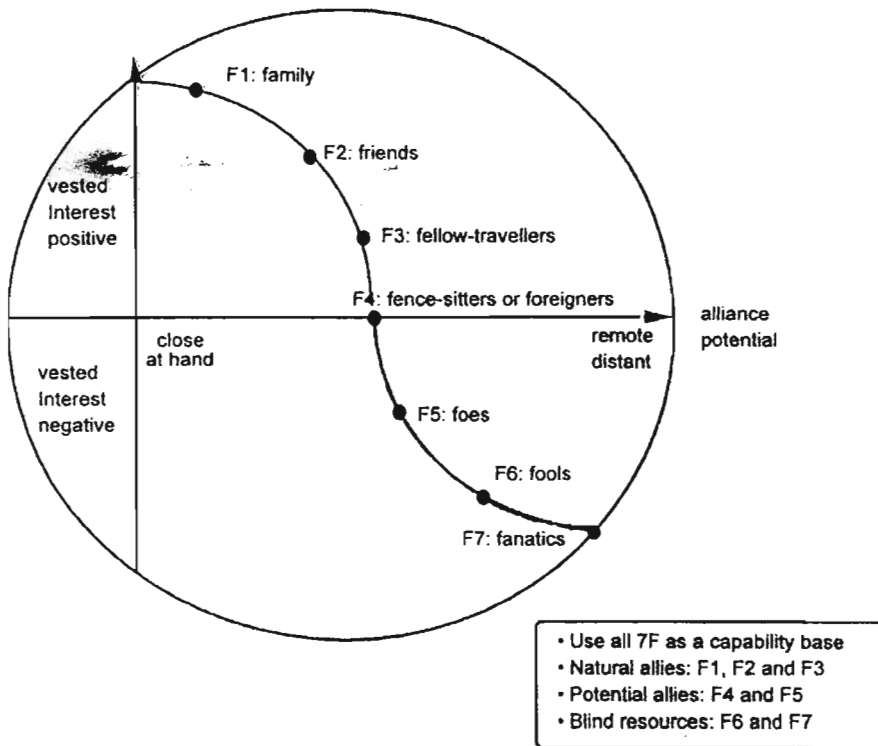
Figure 2.3: Classification of stakeholders according to Martin, (1985).

In this analysis, Martin (1985, cited in Banville *et al.*, 1998) has grouped stakeholders in seven groups according to the following:

F1 = Family: This includes the people who see the issue as essential to their survival.

F2 = Friends: See the issue as important but not essential to their survival.

F3 = Fellow-travellers: see the issue as desirable but neither essential or important.

F4 = Fence Sitters: are neutral but could easily switch between factions.

F5 = Foes: are clever adversaries but can be opened to collaboration or even ephemeral coalitions on issues of mutual interest.

F6 = Fools: includes people with erroneous perceptions, inconsistent behaviour or fragile loyalty, who often unknowingly act against their own interest and are more dangerous by

accident than by design.

F7 = Fanatics: will do anything including self destruction to oppose the actions considered.

This model is particularly useful for assessing the potential support for a certain action. This makes it useful for thinking about the implementation stage of a decision (Banville *et al.*, 1998). This model captures the richness of the stakeholders that may be relevant to determining land suitability, in natural resources, decision making process. These stakeholders would, again, have to be weighted and their impact on the proposed activity be assessed before action is taken.

The seven classes of stakeholders that is illustrated in Figure 2.3 makes this stakeholder classification model the one that is most appropriate to the situation that the project faces.

There may be issues that have so extremely polarised views from different stakeholders that consensus becomes difficult. In land suitability, this might occur when conservationists and developers are stakeholders involved in making a decision on what to do with a piece of land. The next section provides a technique to deal with such a situation.

2.1.1 Strategic Assumptions Surfacing and Testing (SAST)

Strategic Assumptions Surfacing and Testing (Mason and Mitroff, 1981 and Flood, 1995) is used when testing polarised viewpoints (TPV) over a particular issue. This technique involves allocating the debating stakeholders into various groups. These groups are then asked to list their key assumptions. These assumptions are then numbered and tested in an assumption rating chart, such as depicted in Figure 2.4. This is carried out for each group.
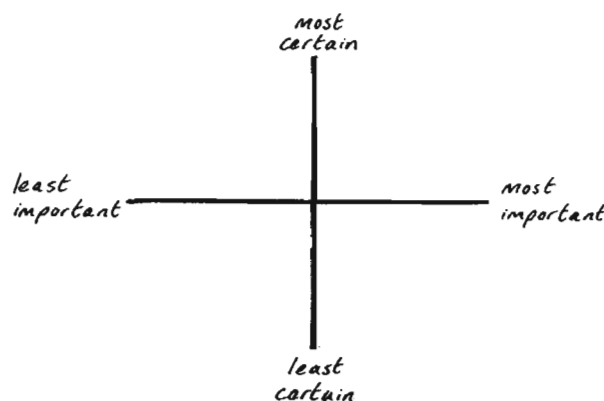
Figure 2.4: An assumption rating chart

The number allocated to each assumption is then plotted on the graph according to the importance of the assumption relative to the success or failure of the groups viewpoint and the degree of certainty of the assumption. The assumptions that are positioned on the top right hand side of the chart are the important ones. The assumptions positioned in the lower right hand quartile is the problematic planning region. It is this region that may lead to failure of any viewpoint.

After the points have been plotted, adversarial discussion and debate should be allowed to proceed. This exposes more stakeholders which may have been initially omitted as well as exposing more assumptions and possibly placing more assumptions in the problematic zone. This technique aims to provide an understanding of the problem. It exposes stakeholders perceptions of the issue. This may lead to some stakeholders changing their views and accepting others or it may lead to a compromise. Strategic assumptions surfacing and testing (SAST) can play an important role in land suitability regarding natural resource management. The many stakeholders involved often have conflicting, polarised viewpoints, which SAST is designed to address.

2.2.2 The Stakeholder Analysis Module

This tool is used mostly by commercial concerns and has significance for the more commercial aspects of land suitability such as agriculture and forestry. The stakeholder analysis module (SAM) is used for effective issues management as a methodical strategy for determining the possible stakeholders in an issue (Weiner and Brown, 1986). This analysis could determine how the different stakeholders react to the organisations decisions, what consequence could their reaction carry and how they might interact with each another, to determine the probability for success of a contemplated scheme.

To conduct a SAM, the issue has to be clearly defined. Then, important underlying criteria such as social, economic, political and technological factors have to be identified. After this has been accomplished, all the stakeholder groups have to be listed. To identify the stakeholders, the reasons why a group might respond to a particular point such as economic gain / loss and safety or health of a particular group have to be considered.

After listing, the stakeholders must be grouped to avoid any duplication. Then each stakeholder should be given a weight for each of the classes / categories as shown in Figure 2.5.

Category	Weight				
	Slight, if any		Moderate	Pronounced	
	1	2	3	4	5
A. Access to media.					
B. Access to government.					
C. Importance to success (survival, profits, etc.) of your organization.					
D. Authority to determine decisions made by your organization.					
E. History of successful court challenges on this or similar issues.					
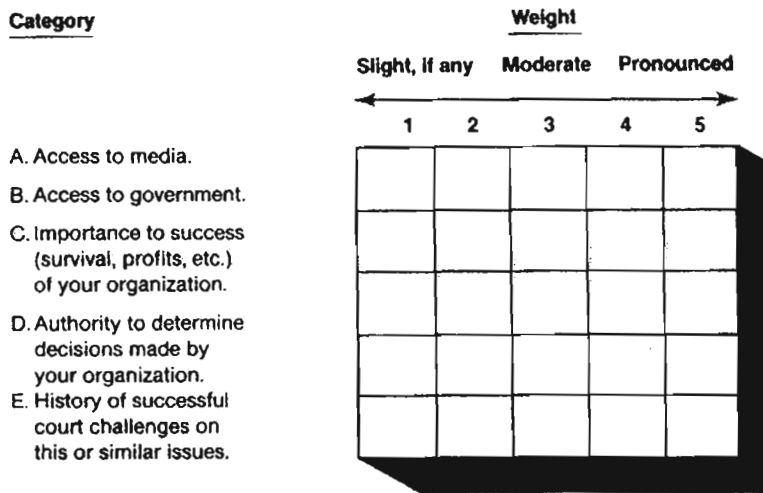
Figure 2.5: Categories by which to weight the impacts of the different stakeholder groups. For instance customers may have a weight of 5 for category C but academics may have a 1, etc (Weiner and Brown, 1986).

Influence Position Chart

Stakeholders	Access to Media	Access to Government	Importance to Business Success	Authority to Determine Organization's Decisions	History of Successful Challenges	Total Weight	Likely Position
Politicians	5	5	1	1	3	15	N
Corporate Community	2	3	1	1	3	10	P
Academia/Teachers	2	2	1	1	1	7	U
Management	1	1	5	5	3	15	P
Employees	3	2	5	2	3	14	N
Stockholders	1	1	3	3	1	9	P
Unions	3	2	4	3	3	15	N
Civil Rights Groups	4	3	1	1	4	13	N
Social Service Agencies	2	4	1	1	1	9	N
Minority Interest Groups	2	5	2	1	3	11	N
Middle-Class Voters	2	5	3	1	1	12	U
EEOC	4	5	2	3	3	17	N
Customers/Clients	1	2	5	3	4	15	P
Competitors	1	2	5	1	2	11	U
Creditors	1	3	3	2	1	10	P
Consumer Activists	5	5	2	2	5	19	P
Vendors/Suppliers	1	2	4	1	1	9	P
Local Community/City	5	5	3	1	2	16	N

Total N (Negative) =119
P (Positive) = 87
U (Neutral) = 30

Figure 2.6: An influence / position chart showing all stakeholder groups, their appraised weights and their possible dispensation towards the issue (Weiner and Brown, 1986).

The weights for each stakeholder then have to be totalled to provide an assessment of the total impact on the issue. Then the impacts of each stakeholder group have to be judged as either positive (P), neutral (U) or negative (N). Figure 2.6 gives the totals of the weights for a particular corporate example. These figures can then be grouped as in Figure 2.7 to yield information on which stakeholder groups can combine and side with or against your issue.

Category Matrix

	POSITIVE	NEGATIVE	NEUTRAL
HEAVY (Total Weight= 15 & over)	Management Customers/Clients Consumer Activists	Politicians Unions EEOC Local Community/City	
MEDIUM (Total Weight= 10-14	Corporate Community Creditors	Employees Civil Rights Groups Minority Interest Groups	Middle-Class Voters Competitors
LIGHT (Total Weight= 9 & under)	Stockholders Vendors/Suppliers	Social Service Agencies Poor/Minority Voters	Academia/Teachers

Figure 2.7: A category matrix grouping the stakeholders according to their weights and dispensation towards the issue (Weiner and Brown, 1986).

This approach can serve to assist decision makers in land suitability by identifying stakeholders and their potential impacts on the outcomes of the decision making process. It then leads to a decision on whether to implement a particular issue or not. This technique may be useful when analysing a contentious issue such as environmental preservation versus development.

It is evident that different approaches to stakeholder analysis may be relevant to different situations. When confronted with an issue involving land suitability, it is highly probable that there would be conflicting viewpoints and political agendas. A combination of these stakeholder analysis techniques can be used to analyse these power games. However, problem structuring does not only involve stakeholders but also the issues that stakeholders identify. Some of the techniques used in identifying issues and structuring problems are illustrated in the next sections.

2.3 A Brief Overview of Soft Systems Methodology in Identifying the Nature of Decision Problems

2.3.1 The Process of Soft Systems Methodology

Soft systems methodology was developed by Checkland in the 1980s (Flood, 1995; Atkinson, 1989; and Checkland and Scholes, 1993). It represents a cyclical process for realising a problematical real world situation and taking action over it. Figure 2.8 illustrates the cyclical nature of SSM in problem solving (Atkinson, 1989) in its original from developed by Checkland in 1981 and known now as SSM - Mode One.
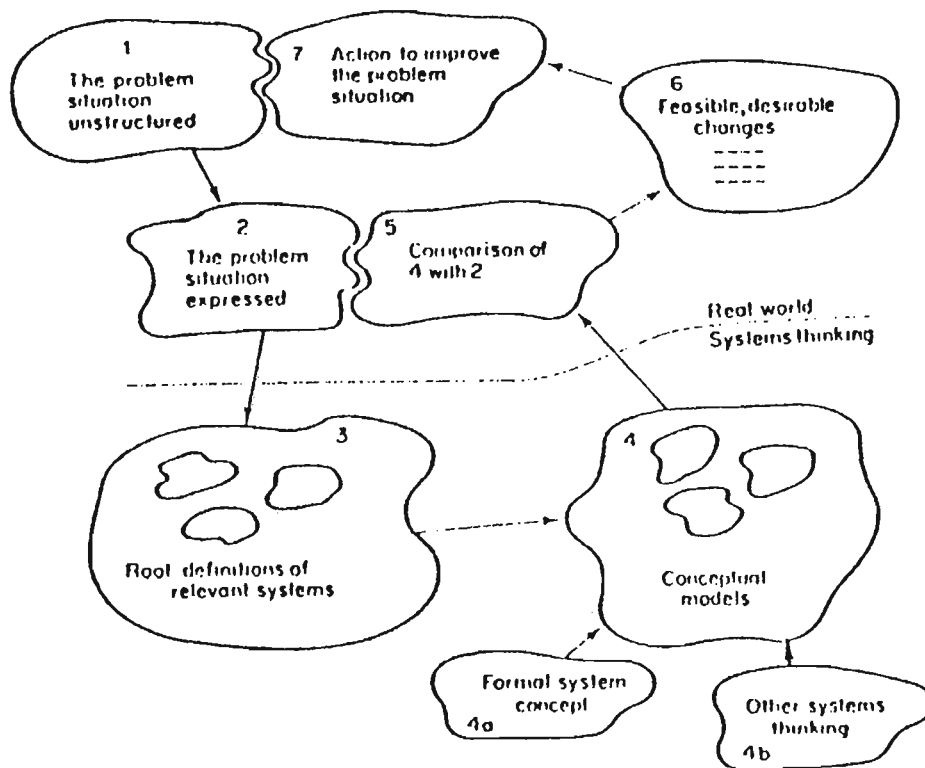
Figure 2.8: The cyclical nature of SSM (mode one) used to identify the problem situation (Atkinson, 1989).

At stages 1 and 2, the problem situation is still unstructured. Themes within this problem situation can be identified with the aid of 'rich pictures'. Root definitions (stage 3) are then used to express the problem. The CATWOE analysis is often used to check certain features of a root definition. These are the:

- Customers - victims or beneficiaries of the system
- Actors - those who carry out the systems activities
- Transformation process - What are the inputs and outputs of the system and what is the

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transformation process that turns inputs into outputs

- **W**eltanshauung - What is the world view expressed by this system
- **O**wners - Who owns the system or who has the capacity to stop the activity
- **E**nvironmental Constraints - What are the factors that are neither controlled or influenced by this system but are a constraint in the environment in which this system operates.

A conceptual model is built in stage 4 for each root definition. A conceptual model is a flow chart depicting numerous interrelated activities which are expressed by the root definition. The formal systems model depicted in stage 4a is used to check the consistency of the conceptual model. Soft systems methodology is not the only systems thinking available, however SSM caters for the influence of other systems thinking at stage 4b.

In Stage 5 a comparison is made between stages 2 and 4. This promotes a debate to generate a series of strategies to deal with the problem situation. In turn, this leads to an itinerary of possible changes (stage 6) and then action is taken to implement these changes (stage 7). The advantage of the cyclical nature of SSM is that it is a learning process which, while attempting to solve one problem, may identify others. These new problems can then be re-iterated into the SSM cycle. The above SSM theory is only a part of the entire problem. Figure 2.9 illustrates how the methodology given in Figure 2.8 is integrated into a larger problem solving system.

Figures 2.8 and 2.9 illustrate mode 1 of SSM. In this mode, SSM is used as a prescriptive set of steps to follow to structure a problem situation. The more recent mode 2 (Checkland and Scholes, 1993) is used as a sense making device which aims to understand the organisational culture of the institution concerned with the problem. With the use of mode 2 SSM, the problem situation is facilitated through a cyclical process with each cycle providing more information and more accurate models of the problem situation.

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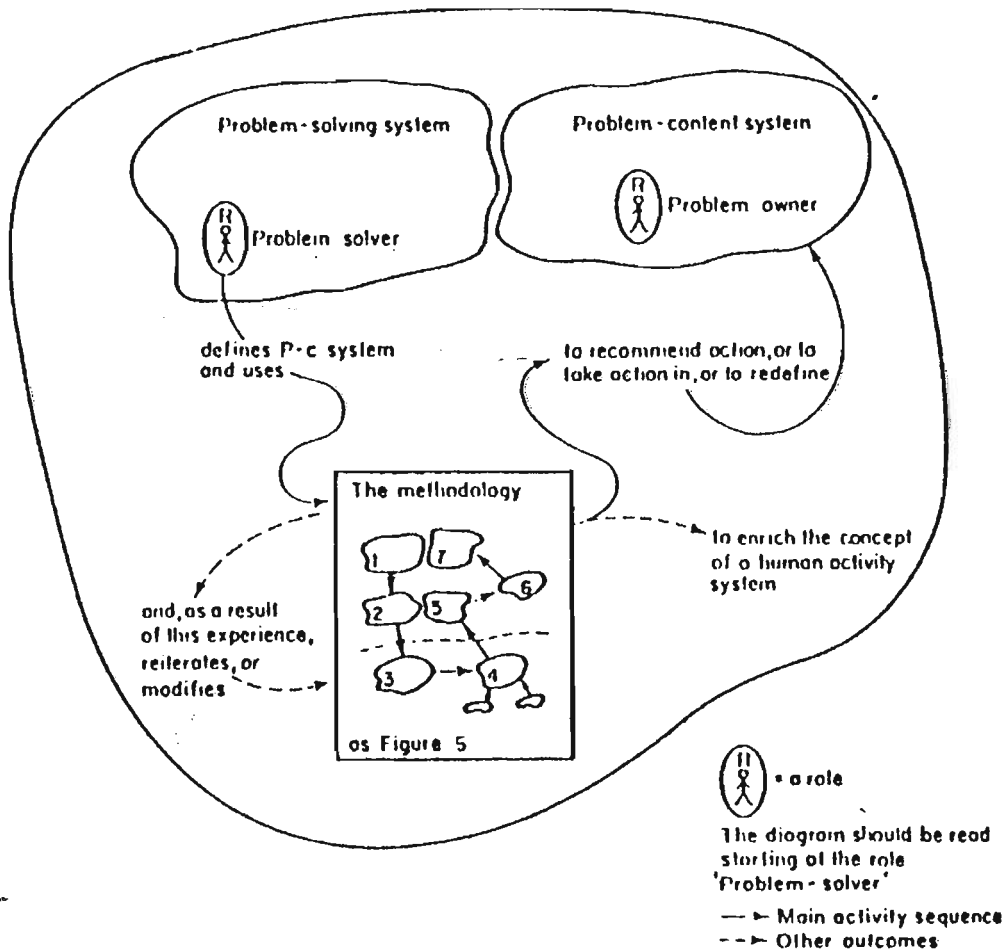
Figure 2.9: An outline of a system to use the SSM theory (Atkinson, 1989).

Soft Systems Methodology provides an understanding of the problem situation rather than providing a solution. This is because SSM is used in situations that do not contain well defined / technical problems such as engineering systems. Soft systems methodology is used for messy problems where the situation is poorly understood such as social or socio-economic problems. However this is often seen as a weakness of SSM. Managers require a decision to be made and the mere understanding of the problem may not be enough. However, understanding of the problem does give a decision making process structure to it compared to approaching a problem in an unstructured fashion. More on SSM can be found in Checkland and Scholes (1993).

2.3.2 Soft Systems Methodology Used in Developing a Research Paradigm for Agriculture and Natural Resource Management Systems

At the Hawkesbury Agricultural College in Australia in the late 1970s, a multidisciplinary team of researchers and educators realised that the students were ill-equipped to handle the socio-economic aspects of farming (Bawden *et al.*, 1985). The agricultural education that they

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possessed failed to handle the key interface between the environment and its human component.

Figure 2.10 illustrates the Hawkesbury Approach to solving problems in systems agriculture. This approach can be modified to solve problems in natural resource systems. It shows SSM as the starting point to identify the problem situation. All other systems follow. This methodology is an example of action research and represents a bottom up approach (i.e. serving the client first, rather than the traditional top down approach) and provides for evaluation of the cultural and political convictions of the farmers. The problem situations that this systemic approach raises cannot be solved unconditionally and these problems never disappear entirely. Hence SSM cannot, on all occasions, be used to solve problems but rather to improve the problem situation.

Another product of using soft systems methodology (SSM) in agriculture is a conceptual model that illustrates the complex interaction which agriculture plays as an interaction between social systems and natural systems (Figure 2.11). This interaction holds true for all other natural resource systems such as forestry, nature conservation and water resource conservation.

	PROBLEM FOCUS	CLASSIFICATION	OUTCOMES
SITUATION IMPROVING / SOFT SYSTEMS RESEARCH	1. Given this complex problem situation, how can I improve the situation?	Soft Systems Research	Client (Learner) Satisfaction
SITUATION OPTIMISING / HARD SYSTEMS RESEARCH	2. Given this system, how can I optimise its performance?	Hard Systems Research	Performance Optimisation
PROBLEM SOLVING / APPLIED RESEARCH	3. Given this component, how can I improve its effectiveness?	Applied Research	Problem Resolution
PUZZLE SOLVING / BASIC RESEARCH	4. Given this phenomenon, why is it so?	Basic Research	Puzzle Resolution

Figure 2.10: The Hawkesbury approach to structured problem solving (Bawden *et al.*, 1985).

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NATURAL ECOSYSTEMS

Marine Systems

Dry Forest Systems

Desert Systems

Estuarine Systems

Grassland Systems

Conserving Systems

Resource Providing Systems

Information Generating Systems

Leisure Systems

Moist Forest Systems

Storage Systems

Syndication Systems

Cultural Systems

Farmer Organisation Systems

Savanna Systems

Integrated Pest Management Systems

Information Systems

Marketing Systems

Political Systems

Farming Systems

Wet Forest Systems

AGRICULTURAL SYSTEMS

Law Enforcing Systems

Consuming Systems

Transporting Systems

Lobbying Systems

Output Processing Systems

Credit Providing Systems

Resource Providing Systems

Satisficing Systems

Ideological Systems

SOCIAL SYSTEMS

Figure 2.11: A conceptual diagram depicting agricultural systems as an interaction between social and natural systems (Bawden *et al.*, 1985).

Figures 2.10 and 2.11 provide a guideline for deciding priorities for research. The initial stage is a thorough holistic analysis of the situation using soft systems methodology. This provides a base and direction for future action research (Bawden *et al.*,1985). Thus by utilising the Hawkesbury hierarchy a feedback mechanism is set up whereby SSM identifies the research needs in order to conduct basic (research stations, colleges and universities) and applied research (on farm research). The results and implementation of this research now identify more problems, again utilising SSM to identify and structure these problems and eventually providing scope for the more hard systems, applied and basic research.

Pure SSM was not used in this study since SSM serves to provide a better understanding of the problem situation rather than provide an answer on "what to do with a piece of land". However, SSM can be used when a messy situation arises in order to determine the issues and stakeholders involved in a decision making process. The next section illustrates the technique that is used in this study and how to apply it.

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2.4 Multi-Criteria Decision Making

Traditionally, decisions were made by one person at one time in one place. Recently, however, decision support has become more complex: involving more criteria and stakeholders, with the decision making process occurring in different places at different times. Multicriteria decision making / analysis (MCDM-/A) attempts to address these issues (Banville *et al.*, 1998). Multicriteria decision making involves a number of different problem identification and evaluation processes: stakeholder analysis, SSM, multi-attribute utility theory and the analytical hierarchy process. Figure 2.12 shows the MCDA processes:
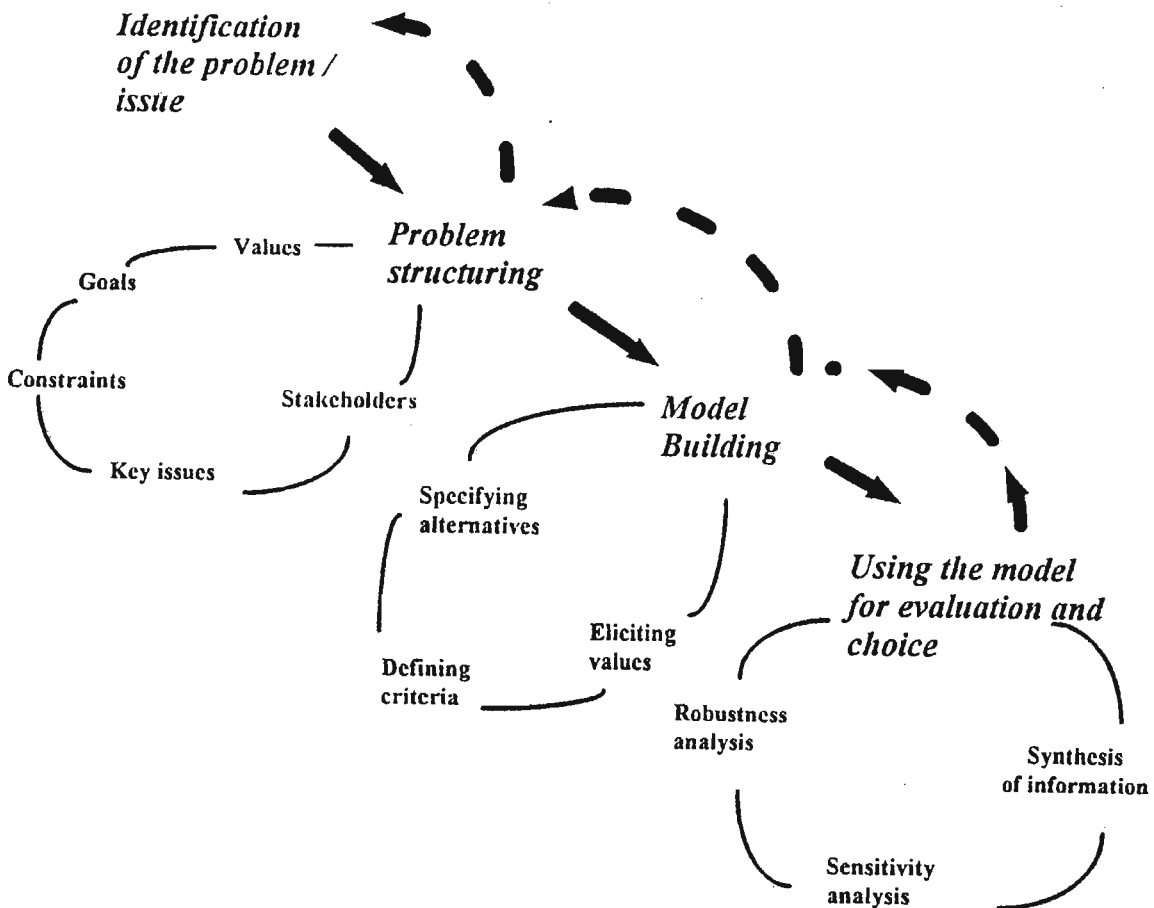
Figure 2.12: Belton's (1999) representation of the MCDA process.

In Figure 2.12 cyclical systems of reiteration are illustrated. These are important in determining the problem structure, model building and in evaluating the model. The cycles represent the feedback mechanisms to identify the stakeholders, issues, criteria and alternatives. There is a strong flow of information from problem identification to problem structuring to model building to evaluating and using the model. There is also a feedback/reiteration mechanism between these

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steps. Feedback is necessary in order to enhance the understanding of the problem. Also when one issue is resolved other problems get identified resulting in a reiteration of the process. The cyclical system represented in Figure 2.12 is designed to be never ending; however, in reality there are usually time constraints in problem solving.

An important feature of MCDA is the value tree, which shows the structure of the problem situation. The value tree can represent the characteristics of a problem in the following fashion (Keeny and Raiffa, 1976; Keeny, 1992 and Belton, 1999):

- "Complete - all important aspects of the problem are captured
- Operational - it can be used with reasonable effort
- Decomposable - allowing different parts of the tree to be analysed separately
- Nonredundant - to avoid double counting of impacts
- Minimal or concise - keeping the level of detail to the minimum required
- Measurable - possible to specify in a precise way the degree to which objectives are achieved through the association of appropriate attributes
- Understandable - to facilitate generation and communication of insights "

An example of a value tree is shown in Figure 2.13.
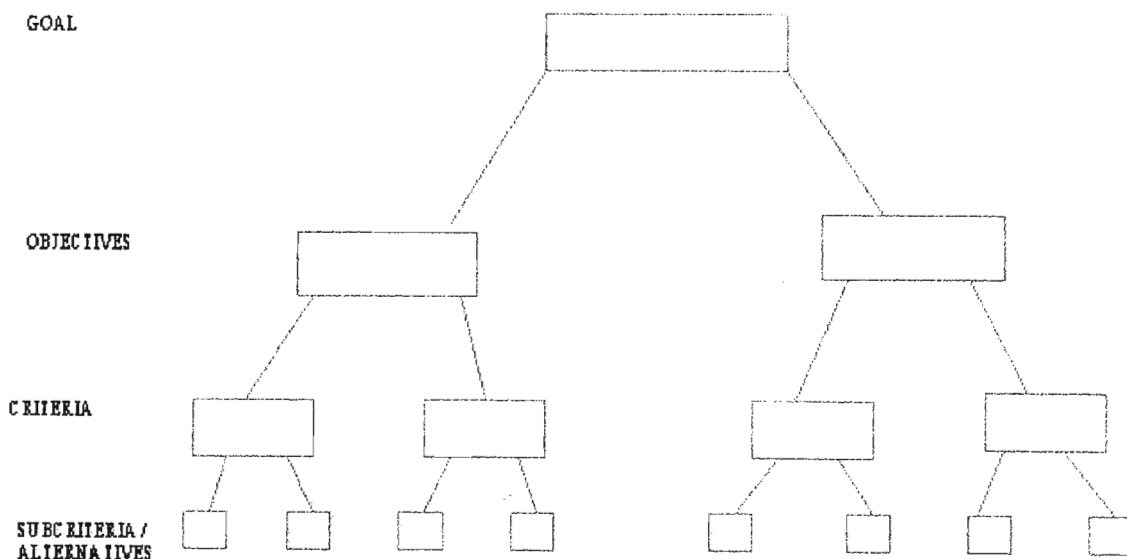
Figure 2.13: An example of a value tree.

2.4.1 Multi-Attribute Value Theory

The multi-attribute value theory (MAVT) (Belton, 1999) is an approach within MCDA which is used in practice in decision support systems. The fundamental requirement of value theory is to represent a stakeholders choice in a defined context by a value function. This value function is represented by $V(\ )$ such that if alternative A is preferred to alternative B then $V(A) > V(B)$. Multi-attribute value theory can be used to evaluate different strategies, scenarios and alternate futures. However, for this to happen, the individuals choices must satisfy two properties namely transitivity and comparability.

Transitivity works, basically, by comparing three alternatives; A, B and C. If a decision maker likes A more than B and B more than C then A is preferred to C. Thus, in value theory, the preferences in a static situation should be transitive.

The second property or comparability is were there are two alternatives, A and B, such that a decision maker must be able to indicate whether they like A more than B, B more than A or is indifferent between the two. This is termed the ordinal value function, which gives the order of preferences. This function is used to determine increasing functions (IF) i.e. if $V_1(\ )$ and $V_2(\ )$ are two ordinary value functions which describes an individuals preferences then there exists an increasing function such that: $V_1(\ ) = IF(\ V_2(\ )\ )$. Another value function pertaining to the comparability property is called the measurable value function. This function is used to determine the value of a change in preference such eg. if $V(A) - V(B) > V(B) - V(C)$. This means that there is a greater preference for changing B for A than exchanging B for C. This can be represented as: $V_1(\ ) = \alpha + \beta V_2(\ )$, where $\beta > 0$. The ordinal and measurable value functions are used in determining numerical weights for a preference in multi-criteria decision support.

The results of comparing the different alternatives and criteria is a value tree. Figure 2.14 depicts a value tree for choosing a suitable site for an MCDA conference. The DSS can be integrated with certain computer programmes which, for instance, could bring up pictures of the various alternatives for conference centres in order to provide more information to the decision makers. The MAVT analysis is simple and user friendly; however, it has its limitations in that it does not capture the richness of a problem situation as efficiently as the analytical hierarchy process as described in the next section.
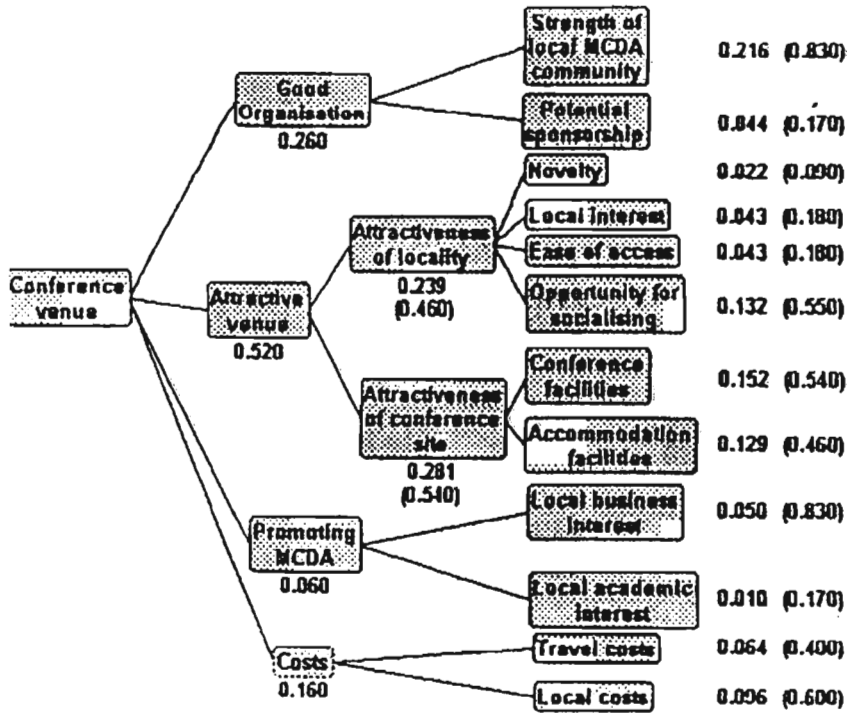
2.14: The conference venue value tree. This value tree has numerical weights but the weighting factors could be graphs, etc (Belton, 1999).

2.4.2 The Analytic Hierarchy Process (AHP)

The AHP was developed by Thomas L. Saaty in 1971 while he was working on contingency planning in the Department of Defense, US military (Saaty, 1990). The theory relies on grouping a number of elements, which can or cannot be controlled by the decision maker, into aggregates sharing common properties. These aggregates share one level of the hierarchy and then may be grouped again according to another set of common properties into the next level of the hierarchy. This process is repeated until a single "top" element of the hierarchy is reached. A typical hierarchy takes the form of a value tree as described in Figure 2.13. The effectiveness of the hierarchy as an analytical tool comes about by determining the effect that each element of each level of the hierarchy has on the final outcome (goal) of the decision making process.

Petkov (1995) illustrates the steps in building an AHP model derived from Saaty (1979 and 1990).

- ▸ Establish a hierarchical structure to represent the problem. The overall goal is at the top of the hierarchy. The lower levels contain the criteria guiding the decision and the factors affecting them.

- ▸ Provide pairwise comparisons between elements within the structure. Saaty (1979) has

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suggested a 1 to 9 scale to measure the importance or preference of one factor in a cluster of the hierarchy over another with respect to the root of that cluster. The scale is defined as follows: 1 - the two factors are equally important; 3 - móderate importance of one factor over another; 5 - strong importance; 7 - very strong importance; 9 - absolute importance. The intermediate values in the above scale are 2,4,6 and 8 respectively. When the second alternative is more important than the first, the reciprocal value of the measure from the above scale is considered. The comparisons form the reciprocal matrices and therefore it is necessary only to provide judgements that must be placed in cells above the main diagonal of the matrix of comparisons.

- Calculate the relative local priorities of those factors, describing their contribution towards the factor which is at the root of that cluster. Inconsistencies in judgement are detected through a measure called a consistency ratio, which helps control any biases and indicates when the comparisons should be repeated to improve their consistency.

- Calculate the overall global priorities of each element in the hierarchy towards the main goal of the problem. These priorities show the contribution of a given factor from a particular level of the hierarchy towards the main goal. The ranking of the factors according to their priorities or the priorities themselves can be used for proportional distribution of resources.

The above steps can be accomplished using a software package called Expert Choice[R]. This programme performs the computation whereby eigenvectors are derived from the matrices of judgements, in order to synthesize the local and global priorities or weights of the individual factors in each level.

The absolute mode of comparison in the AHP can be used at the last level. For the other levels, the relative comparison mode is used to generate the local priorities. The absolute mode of AHP is used when there are numerous alternatives (more than 7) to choose from. Rather than a pairwise comparison between alternatives, the alternatives are compared against a standard. This allows for the evaluation of a very large number of alternatives.

The merits of the AHP is that it structures a problem in a way that:

- When people participate in the process of structuring and prioritizing a hierarchy, they engage naturally in successive grouping of items within levels and in distinguishing

among levels of complexity.

▸ Individuals informed about a particular problem may structure it hierarchically somewhat differently but, if their judgements are similar, their overall answers tend to be similar. The process is robust: fine distinctions within the hierarchy tend in practise not to be decisive.

▸ In the course of developing the theory, a mathematically reasonable way to handle judgements was found (Saaty, 1990).

The aim of the AHP is to model problems incorporating knowledge and judgements by clearly articulating, debating and prioritizing the issues. These judgements are then refined through a feedback mechanism leading to **an** answer and not **the** answer i.e. it helps improve the problem situation. The eventual outcome is to derive weights for alternatives with respect to criteria and for criteria with respect to objectives. These weights have to be useful for allocating resources to a particular alternative that most strongly fulfils the entire set of objectives (Saaty, 1990).

To determine the weights of objectives, criteria, sub-criteria and alternatives, a matrix of pairwise comparisons must be set up (Table 2.1). These objectives, criteria, etc. are represented as A_1 to A_n and their weights as W_1 to W_n. The judgements are made according to the intensity of importance scale given in Table 2.2 (Saaty and Vargas, 1991). The weights are obtained as the normalised elements of the eigenvector corresponding to the largest eigenvector of the matrix of comparisons (Saaty, 1990). These are called local priorities, showing the importance towards the root of the cluster. Once the weights for the elements within one level of the hierarchy have been computed, the global priorities giving the contribution of an element in the hierarchy towards the overall goal are calculated. This allows ranking of the alternatives. The final outcome is an alternative(s) with the highest weight. The outcome of this process is illustrated in Figure 2.15 (Liao, 1998).

Table 2.1: A matrix of pairwise comparisons.

$$A = \begin{array}{c|cccc} & A_1 & A_2 & \cdots & A_n \\ \hline A_1 & \dfrac{w_1}{w_1} & \dfrac{w_1}{w_2} & \cdots & \dfrac{w_1}{w_n} \\ A_2 & \dfrac{w_2}{w_1} & \dfrac{w_2}{w_2} & \cdots & \dfrac{w_2}{w_n} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ A_n & \dfrac{w_n}{w_1} & \dfrac{w_n}{w_2} & \cdots & \dfrac{w_n}{w_n} \end{array}$$

The comparative scale, illustrated in Table 2.2, is used to measure the intensities of the comparisons in a pairwise pattern. These intensities are entered into a software package such as Expert Choice[R] which performs the matrix algebra and provides the weights/priorities of the factors for each level of the hierarchy. These weights are defined as the local priorities of the hierarchy. They are used to calculate the global priorities of the elements in the hierarchy towards the main goal: i.e. global priorities takes into account comparisons between the different levels of a hierarchy.

There are further variations in the AHP, for instance when there are not more than seven alternatives at the lowest level of the hierarchy, the relative pairwise comparison mode of AHP is applied: i.e. the method described above where the ratings for each alternative are derived from a pairwise comparison with the criteria in the level above. When there are more than seven alternatives in the lowest level of the hierarchy, the absolute comparison mode of AHP would have to be applied. In the absolute mode of AHP the intensities of the elements, in the upper levels of the hierarchy, are still compared in a pairwise fashion. The total rating of each alternative, at the lowest level, is the sum of the values of all the individual ratings according to all criteria (Petkov and Gialerakis, 1997).

As a measure to control possible errors in judgement due to non compliance with the transitivity rule when making pairwise comparisons, a measure of inconsistency is introduced called the consistency ratio (CR). For the results to be acceptable, it is recommended that the value of this ratio should not exceed 0.1 (Saaty, 1990).

Table 2.2: The intensity of importance scale.

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance of one over another	Experience and judgement slightly favour one activity over another
5	Essential or strong importance	Experience and judgement strongly favour one activity over another
7	Demonstrated importance	An activity is strongly favoured and its dominance demonstrated in practice
9	Absolute importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values between the two adjacent judgements	When compromise is needed
Reciprocals of above nonzero numbers	If activity i has one of the above nonzero numbers assigned to it when compared with activity j, the j has the reciprocal value when compared with i.	
Rationals	Ratios arising from the scale	If consistency were to be forced by obtaining n numerical values to span the matrix.
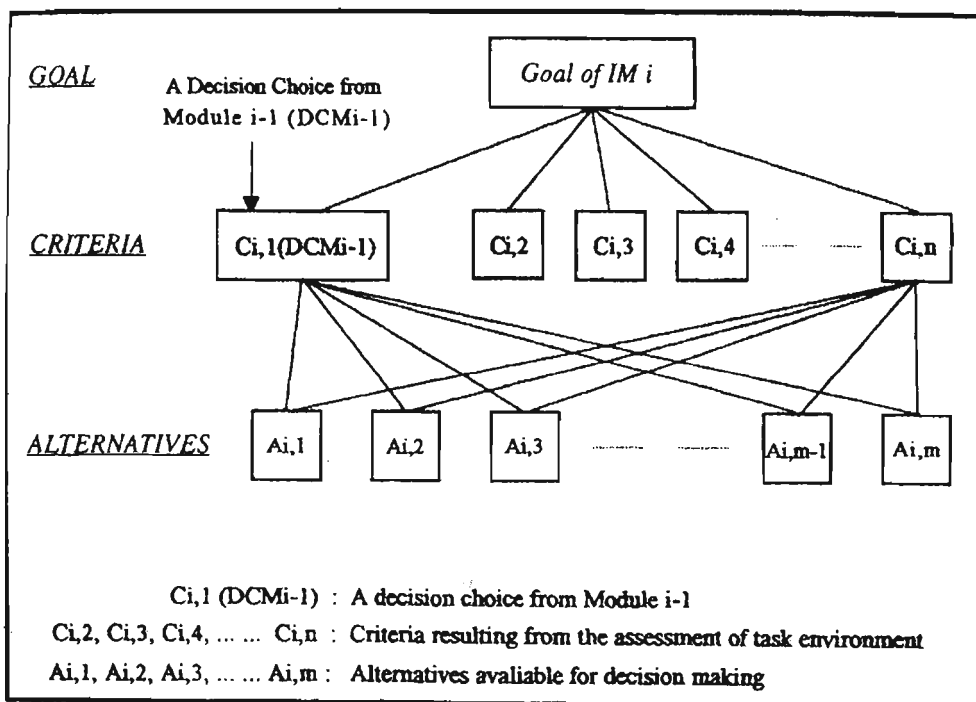
Figure 2.15: A hierarchy depicting the interaction between a goal, criteria and alternatives (Liao, 1998).

Multi-criteria decision analysis can be combined with stakeholder analysis to give a better representation of the problem. According to Banville *et al.*, 1998, there is nothing new about the concept of stakeholders in MCDA; however, the representation of stakeholders in MCDA has been, to a certain extent, neglected. The stakeholders contribution can be incorporated into MCDA; firstly, by assessing the stakeholders as explained in section 2.1 and incorporating their interests, issues and judgements into an AHP model.

As already demonstrated, multi-criteria decision making incorporates numerous decision making tools both from soft systems thinking and hard systems. Stakeholder analysis, Soft Systems Methodology, Multi-Attribute Utility Theory and the Analytic Hierarchy Process are combined to form a system whereby the richness of a problem situation is exposed hence leading to a more accurate analysis of the problem.

A land suitability analysis is a typical scenario whereby hard factual systems such as a GIS with soils, climate, rainfall, topography, ecosystems, etc. is combined with socio-economic activities, such as agriculture, forestry and nature conservation. Most land suitability analysis is carried out with the aid of a GIS. However, the GIS cannot make a decision. It only provides objective, spatial information for human decision makers. It is here that multi-criteria decision making/analysis plays an important role in combining the different stakeholder perspectives with socio-economic and scientific data.

The AHP has many wide and varied uses (Saaty, 1990) among which are personnel selection, corporate planning and benefit/cost analysis by government agencies for resource allocation purposes. At an international scale, the AHP is used for planning infrastructure in developing countries and evaluating natural resources for investment. The following are some key concepts (Saaty, 1990) on which the AHP is based:

- Hierarchic representation and decomposition, which is called hierarchic structuring: breaking down the problem into separate elements.
- Priority discrimination and synthesis: which we call priority setting; that is ranking the elements by relative importance.
- Logical consistency: ensuring that elements are grouped logically and ranked consistently according to logical criteria.
- Measurement cannot be made without a scale but traditional scales such as time and

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money limit the nature of ideas which can be dealt with. Thus a new scale for measuring intangible quantities is needed.

• The AHP is a flexible model that allows decisions to be made by combining judgement and personal values in a logical way.

Figure 2.16 illustrates the advantages of using the AHP. However, models that are created using the AHP have similar disadvantages as most models in that they are merely representations of reality.

Unity:
The AHP provides a single, easily understood, flexible model for a wide range of unstructured problems

Process Repetition:
The AHP enables people to refine their definition of a problem and to improve their judgment and understanding through repetition

Complexity:
The AHP integrates deductive and systems approaches in solving complex problems

Judgment and Consensus:
The AHP does not insist on consensus but synthesizes a representative outcome from diverse judgments

Interdependence:
The AHP can deal with the interdependence of elements in a system and does not insist on linear thinking

AHP

Tradeoffs:
The AHP takes into consideration the relative priorities of factors in a system and enables people to select the best alternative based on their goals

Hierarchic Structuring:
The AHP reflects the natural tendency of the mind to sort elements of a system into different levels and to group like elements in each level

Synthesis:
The AHP leads to an overall estimate of the desirability of each alternative

Measurement:
The AHP provides a scale for measuring intangibles and a method for establishing priorities

Consistency:
The AHP tracks the logical consistency of judgments used in determining priorities

Figure 2.16: The advantages of the Analytic Hierarchy Process (Saaty, 1990).

To aid decision making, a structure is needed. This is addressed by the Analytic Hierarchy Process which involves pairwise comparisons with alternatives, criteria and objectives, within and between different levels of the hierarchy. This gives a mathematical and transparent method of finding the alternative with the highest weight. Due to its cyclical nature, multi-criteria decision analysis does not always provide an answer to a problem but, rather, improves the problem situation. It is this cyclical nature that also leads researchers to identify scope for basic and applied research hence making research more participatory and action oriented.

South Africa does not have a comprehensive decision support system for land suitability assessment. Each department, such as agriculture and nature conservation has its own GIS and database on criteria for land suitability analysis but there is no system integrating land suitability for the entire natural resource complex. So MCDM/A can play an important role in providing a decision making platform for all the models, databases, personal knowledge, stakeholders and legislation concerning land suitability and natural resource management to be integrated into a holistic system.

The AHP provides such a platform for a transparent decision support process in natural resource management. Subjective criteria can be integrated with hard data to substitute for gaps in the knowledge in natural resource management to yield a reliable decision. The robust nature of the AHP may become a disadvantage in situations were finer gradations (i.e. when there is not much difference in preferences) are needed to separate criteria but in natural resource management, this is usually not the case.

The next chapter illustrates the current decision making processes that occur in a land suitability analysis. It also gives examples of the use of MCDA and the AHP combined with other systems in the decision making process. Some practical examples of the use of AHP in agriculture are provided in Chapter 3 which also contrasts the difference in the paradigm of the current decision making process in South Africa compared to multi-criteria decision making in other countries.

Chapter 3: Overview of Current Practises in Decision Making in Land Suitability and Natural Resource Management

This section describes the decision making processes used to assess land suitability with regard to natural resource management, in South Africa and internationally.

3.1 South African Examples of Decision Making in Land Suitability

Generally in South Africa, decision making rests in the hands of the experts. Rational methods are used which rely heavily on hard problem solving approaches using GISs, statistics, linear programmes and databases, with limited stakeholder participation. The following sections illustrate some of these approaches:

3.1.1 The Bioresource Programme

The Bioresource Programme is the property of the Natural Resource Section, Technology, Development and Training Directorate, KwaZulu-Natal Department of Agriculture and Environmental Affairs based at Cedara. This section is from the work of Camp (1999).

The Bioresource Programme has two main functions:

- Mapping of natural resources
- Appraising land use.

The programme is used to produce maps of the natural resources and the land use potential of the Province of KwaZulu-Natal, or for any particular area within the Province. Land use potential can include the crops that can be grown and the levels of production that can be achieved for each of 30 crops for which crop production models exist. The information is regarded as a first appraisal and, under certain circumstances, it is necessary to do a field inspection or a survey.

KwaZulu-Natal (KZN) has been mapped and described at three levels under the Bioresource Programme. The three levels, which are described from the largest to the smallest unit, are the Bioresource Group (BRG), Bioresource Unit (BRU) and Ecotopes, (crop and veld). A brief

definition of each unit, and other elements of the programme, are defined below:

- Bioresource Group (BRG)

  A BRG consists of a single vegetation type. It is formed by the grouping of BRUs of the same vegetation type. The BRG is used for extensive planning and veld management norms are defined for each BRG. There are 23 BRGs in KZN.

- Bioresource Unit (BRU)

  A BRU is an area within which the environmental factors such as climate, soil type, vegetation and terrain type have a degree of homogeneity such that land use practices, farming enterprises, production and production techniques, can be clearly defined and will differ from adjacent BRUs. The BRUs can be used for farm or site planning purposes and, using a GIS, a wide variety of maps can be produced illustrating information such as the suitability of areas for particular crops and the levels of production that can be achieved. There are 590 (continuously updated) BRUs in KZN.

- Ecotopes

  An ecotope is a class of land defined in terms soil form, texture and depth which has a narrow range in terms of the farming enterprises it can support, the potential yield for each enterprise and the production technique for each enterprise. These soil factors will differ significantly from adjoining ecotopes and there will be no significant advantage in further subdivision within the ecotopes. The ecotopes are used to define land use for particular sites when farm planning. Both crop and veld ecotopes have been defined and, being listed for each BRU, are subject to the climate of the BRU in which they are found.

While the three units defined above can provide information on the natural resources of an area, the crop production models of Smith (1996) add invaluable quantitative agricultural production information to the value of the Bioresource Programme.

- Crop Models

  The crop production models developed by Smith (1996) use the climate and soil information contained in the inventory of each BRU to predict the potential production for 29 crops.

The large data base of the Bioresource Programme is manipulated by a Geographic Information System and other computer programmes. Figure 3.1 shows a map of KwaZulu-Natal depicting the Bioresource Groups.

- The Computer Support Programmes

  The Bioresource Programme information is captured in a Geographical Information System (GIS) and other programmes to produce inventories and maps of KZN depicting the natural resources and many forms of agricultural potential.

This system is run by experts in their particular field. It provides an important source of information. However, it allows for limited stakeholder participation in the decision making process; even farmers are merely regarded as inputs into the model, hence limiting its potential as a DSS. Also the crop models (that are used to make recommendations on what crop to plant in an area) follows a rigid formula and does not account for the unique situation faced by each farmer. These problems can be overcome if this programme is used in conjunction with expert opinions and local knowledge and built into a DSS. In fact combining a comprehensive database, like the Bioresource Programme with expert opinion and local knowledge, would create a very accurate DSS compared to using only subjective criteria such as local knowledge and expert judgement only. This forms the basis for this research project.
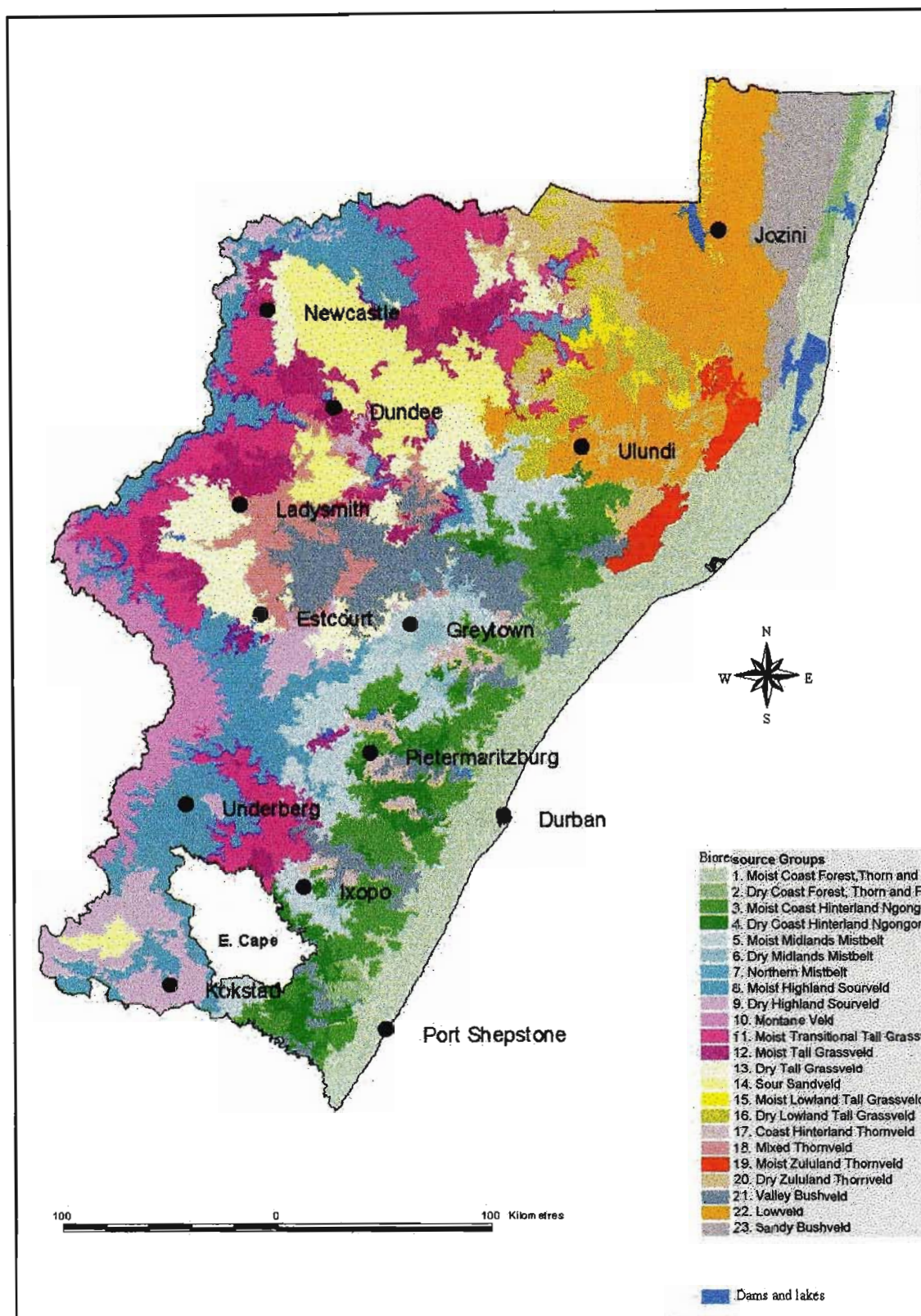
Figure 3.1: The Bioresource groups of KwaZulu-Natal, South Africa.

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3.1.2 The ACRU Model

The ACRU model is the work of Prof R. E. Schulze, Department of Agricultural Engineering, University of Natal. The following are extracts from Schulze (1995):

The ACRU model is an agrohydrological model, the concepts which are illustrated in Figure 3.2. The inputs into the model are illustrated at the top of the diagram; these are then analysed according to the operational modes as well as simulations to provide outputs that are relevant to the specific objects of the query such as stormflow, crop demand, etc.

Some applications of the ACRU model include:

- Water resources assessments
- Design flood estimation
- Irrigation water demand and supply
- Crop yield and primary production modelling
- Assessments of impact of land used changes on water resources
- Assessments of hydrological impacts of wetlands
- Groundwater modelling.

3.1.3 Decision Making in Nature Conservation

The KwaZulu-Natal Nature Conservation Service (KZNNCS) utilises a mixture of GIS, databases and statistical tools to aid their decision making processes. The Bioresource Programme is also used as required. Use is made of the Analytic Hierarchy Process by the Biodiversity Research Programme. This is illustrated in Figure 3.3 which shows a hierarchy, without the weights, for choosing sites of conservation importance (Goodman, 1999-Pers comm).

| INPUTS | LOCATIONAL | CATCHMENT | CLIMATIC | HYDROLOGICAL | LAND CHANGE | AGRONOMIC |
| | SOILS | RESERVOIR | LAND USE | IRRIGATION SUPPLY | IRRIGATION DEMAND | |

| MODEL | **ACRU MODEL** |

| OPERATIONAL MODES | SOIL WATER BUDGETING/ TOTAL EVAPORATION MODELLING → | POINT or LUMPED or DISTRIBUTED MODES or G.I.S. LINKED | ← DYNAMIC TIME or ANNUAL CYCLIC CHANGE |

| SIMULATION OPTIONS / COMBINATIONS | RUNOFF COMPONENTS | RESERVOIR STATUS | SEDIMENT YIELD | IRRIGATION DEMAND | IRRIGATION SUPPLY | LAND USE IMPACTS | CLIMATE CHANGE | CROP YIELD |

OUT- / PUT		RUNOFF COMPONENTS	RESERVOIR STATUS	SEDIMENT YIELD	IRRIGATION DEMAND	IRRIGATION SUPPLY	LAND USE IMPACTS	CLIMATE CHANGE	CROP YIELD
Daily		✓	✓	✓	✓	✓	✓	✓	✓
Monthly		✓	✓	✓	✓	✓	✓	✓	✓
Annual		✓	✓	✓	✓	✓	✓	✓	✓
Risk Analyses		✓	✓	✓	✓	✓	✓	✓	✓

| SPECIFIC OBJECTIVES / COMPONENTS | Stormflow Baseflow Peak Discharge Hydrograph : - generation - routing EV analyses | Outflows: - overflow - normal flow - seepage - abstractions Interbasin transfers Off-channel storage | Sediment - generation Reservoir - siltation | Crop Demand Application: - on demand - fixed cycle - fixed amount - deficit | From : - reservoir - river - river and reservoir - off channel storage Return flows | Gradual change Abrupt change Total evaporation Tillage practices Wetlands | ΔCO_2 ΔT ΔE ΔP | Maize Winter Wheat Sugarcane Primary productivity - dryland - irrigated - profit / loss |

Figure 3.2: Concepts of the ACRU agrohydrological modelling system (Schulze, 1995).
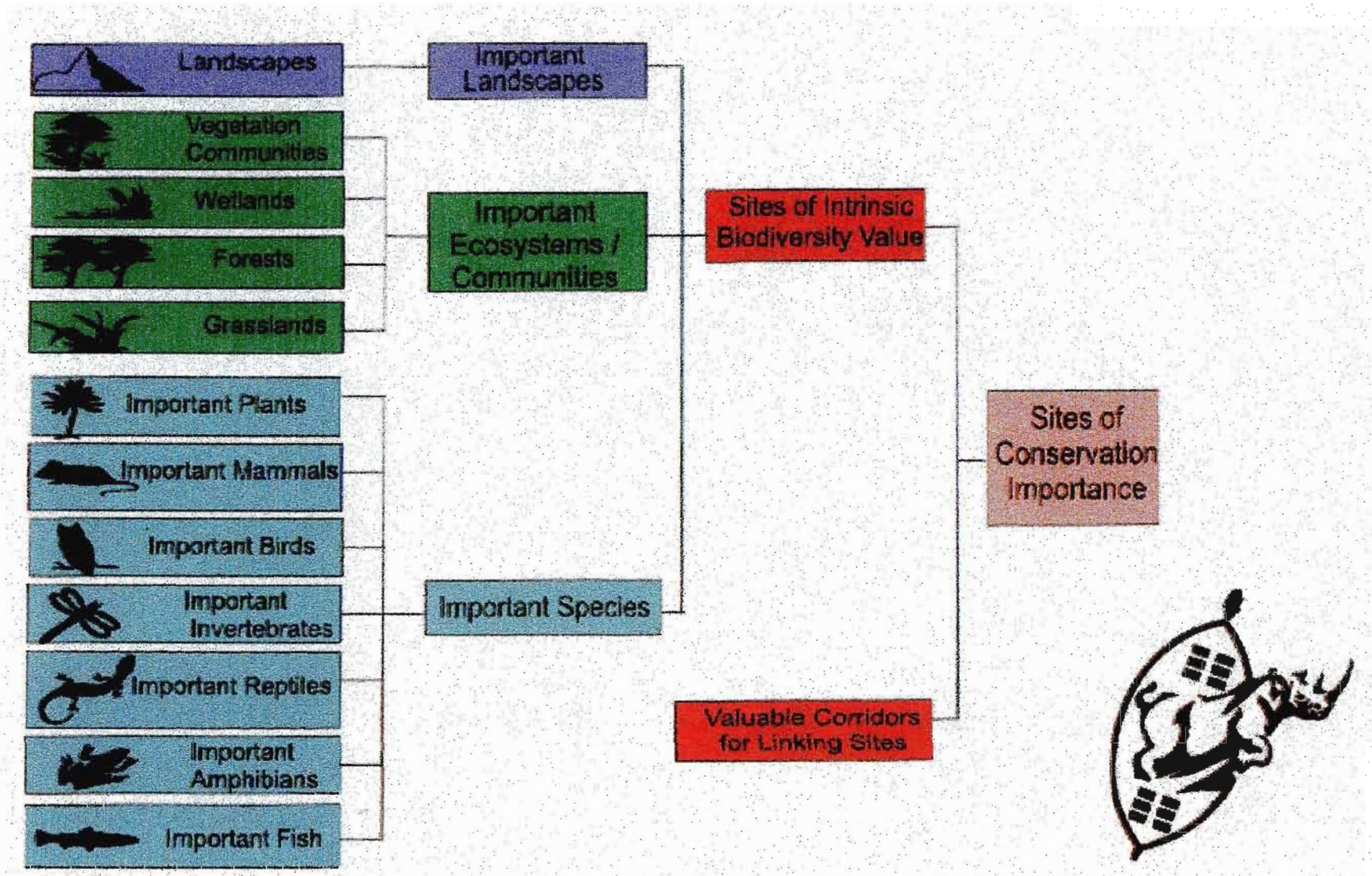
Figure 3.3: A hierarchy depicting the criteria for a decision making process for sites of conservation importance (Goodman, 1999).

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3.1.4 Decision Making in Farm Planning

This section is based on a paper delivered at the recently held "Multiple Objective Decision Support Systems (MODSS'99)" conference in Brisbane, Australia. This conference dealt largely with decision making in natural resource management. There was only one paper from South Africa presented at this conference, this paper was by Van der Weshuizen and Viljoen (1999). Most of the papers dealt with the systems approach to decision making in natural resource management. However, the paper presented by the South Africans involved the classical, rational method of decision making. This paper gives a detailed account of the rational approach as well as identifying some of the shortcomings of this approach.

Farm planning involves decision making in land suitability at a local level. It specifically deals with planning for optimum profit. The recommended procedure for a farm plan as given by Van der Westhuizen and Viljoen (1992) is:

Step 1   Collect background information of the farm, e.g. information on soil classification, climate, grazing potential of veld/pastures and distance from towns, cities and markets.

Step 2   Draw up a farm map to indicate the location of the various cultivated lands, camps and fixed improvements.

Step 3   Compile an inventory of the present fixed improvements, implements, tractors and livestock as well as all other assets and debts of the farm. Do an evaluation of the labour situation - permanent as well as casual labour.

Step 4   Describe the present land utilization pattern as well as the different livestock enterprises on the farm.

Step 5   Diagnose the present farming situation. This includes the calculation of net farm income and various efficiency measures. Draw up a balance sheet and calculate ratios. Interpret all ratios and other figures.

Step 6   After completion of the soil classification and the determination of the potential of the veld, a new set of maps is prepared. The soil scientist, together with the farmer, determines the new boundaries of the cultivated lands based on the soil classification information. The farmer and a grazing expert determine a new division of camps, based on the classification of the veld. This process is called the physical-biological planning.

Step 7   In consultation with the farmer and relevant agriculturists all crop enterprises that must be considered for inclusion in the new plan are identified. A description of the production practices to be followed for each crop enterprise and activity budget is compiled.

Step 8   The same exercise (as in step 7) is repeated for livestock enterprises.

Step 9   All restrictions, whether physical, technical, biological, financial, personal or institutional that must be taken into account during planning, are determined.

Step 10   Feed-flow planning is carried out with the aid of a computer for each of the livestock enterprises to be considered.

Step 11   The initial linear programming matrix to be used in the planning is considered.

Step 12   The linear programming planning solution is determined - the so-called optimal plan. This is done by means of an interactive process and also involves consultation between the planners and the farmer until a solution is found that suits the farmer. A sensitivity analysis as well as a break-even analysis must also be carried out. Due consideration must also be given to the possibility of applying other planning techniques, i.e. dynamic linear programming and risk programming.

Step 13   The mechanization system of the farm is replanned to fit the requirements of the

new farm plan.

Step 14   An assessment is done of additional investment in fixed improvements, implements, tractors and livestock that are needed to put the new plan into effect.

Step 15   The phasing-in of the new plan is described. This includes the drawing up of cash-flow budgets and projected balance sheets for each phase/year. All outstanding debts, interest and principal payments are specified. A marketing plan must be set up.

Step 16   A detailed description of the farming activities of the first year of implementation is drawn up for each month of the year.

Step 17   Write a coherent planning report and discuss it with the full planning team. The farmer must be satisfied with all recommendations.

Step 18   Visit the farmer periodically during the implementation phase (especially during the first year) and give advice on the implementation of the plan.

Step 19   Evaluate the degree of implementation after each year, make necessary adjustments to the plan and draw up a new short-term plan for the following year.

Step 20   If significant changes are considered for the farm a full replanning must be carried out.

Van der Westhuizen and Viljoen (1999) have mentioned that not all farmers implement their farm plan. Several reasons were given for this: that the above steps were not implemented properly, that suggestions were not taken into account thoroughly and that personal preferences of the farmers were not taken into account. Another interesting revelation was that implementation of the farm plans almost came to a standstill when the agricultural economist co-ordinating the efforts left his job.

The above shortcomings emphasise the, already discussed, limitations of the rational approach to decision making. It seems that the farmer is treated as an input into the decision making process rather than a stakeholder either making a meaningful contribution to it or as the focus of the decision making process. When the agricultural economist left, the farmers stopped implementing their farm plans. This shows that the farmers did not have ownership of the decision making process and were merely responsible for technical duties on their farm while the agricultural economist did the managing. This exercise revealed that such a top down approach is not sustainable. Again, this situation could have been improved if the hard technical details of the farm plan was incorporated into a DSS with expert opinion and the farmers local knowledge.

There are thus many decision support systems regarding land suitability in natural resource management in the country. These systems may operate at a provincial or national level. However most of them are top down, rational systems. They mainly deal with hard data with limited stakeholder inputs. This is a limiting factor in their usefulness in making a decision on land suitability since land suitability has socio-economic and political components to it. The next sections shows land suitability decision making in other countries, contrast these approaches with the ones used in South Africa.

3.2 Decision Making in Land Suitability in Other Countries

The paradigm shift towards the systems approach to decision making in land suitability, has been successfully accomplished in other parts of the world. This section presents some cases where the AHP and MCDA has been effectively used in decision making involving land suitability and natural resource managment. Even though the cases illustrated largely involve the systems approach, the rational approach is not neglected in other countries.

3.2.1 MCDA in Agriculture

Alphonce (1997) used the Analytic Hierarchy Process to determine the portions of a farm that a farmer should allocate to different crops such as maize, millet and cassava. The criteria that were considered included:

- Production Cost
- Risk of crop failure (reliability)
- Palatability
- Availability of market for surplus production (market availability).

These criteria were then graphically represented as a hierarchy as shown in Figure 3.4.
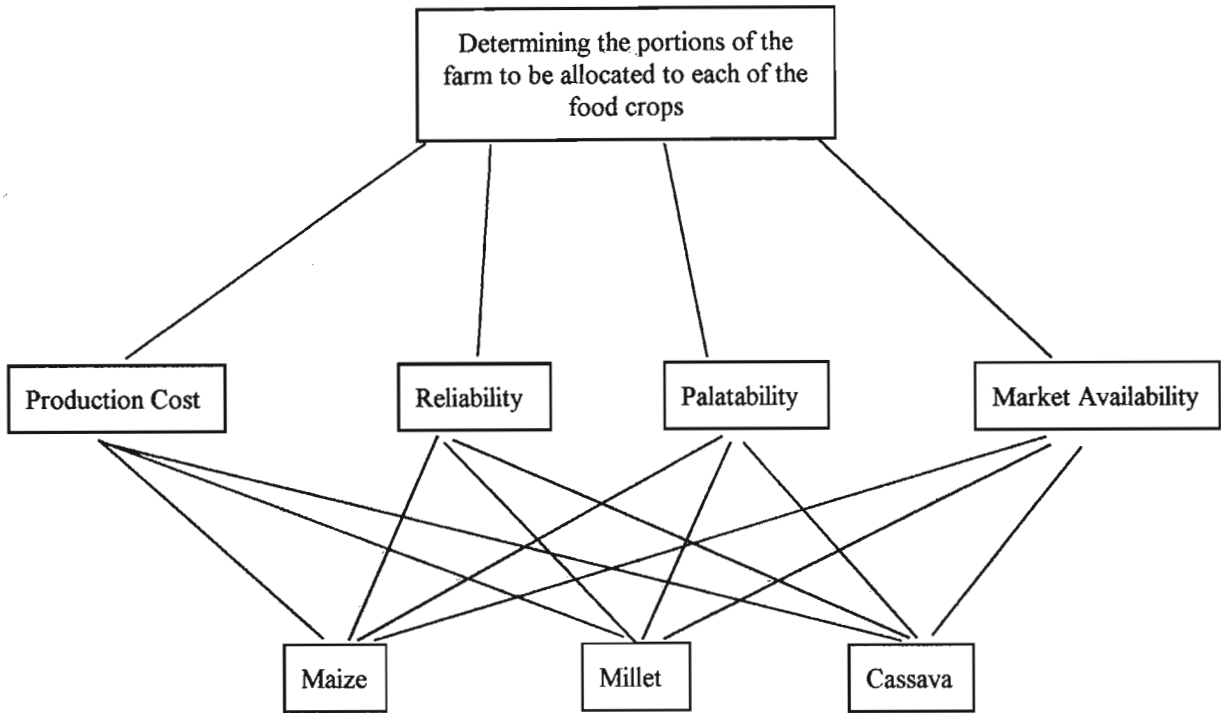
Figure 3.4: A hierarchical representation of allocating a portion of a farm to different crops (Alphonce, 1997).

The farmer was then asked to compare in a pairwise fashion the importance of the criteria of the first level according to the 1-9 scale (table2, chapter2). The resultant matrix, the weights / local priority and the corresponding consistency ratio (CR) is smaller than 0.10 (or 10%), the results are acceptable.

	Cost	Reliability	Palatability	Markets	Local Priority
Cost	1	½*	3	4	0.274
Reliability	2	1	6	9	0.564
Palatability	1/3	1/6	1	2	0.102
Markets	½	1/9	½	1	0.060

* Note the first ½ means that reliability is slightly more important than cost i.e. reliability has a value of 2.
CR=0.006

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The next step was a pairwise comparison of each crop alternative with respect to each of the criteria. The following matrix is the comparison for the reliability attribute i.e. which crop is the most reliable. Note this comparison needs to be undertaken with respect to each of the other criteria as well.

	Maize	Millet	Cassava	Local Priority
Maize	1	1/3	1/6	0.096
Millet	3	1	1/3	0.251
Cassava	6	3	1	0.653

CR = 0.016

The next step was to compare the local priorities of each of the alternatives to each of the criteria. Then the portions of the farm to be allocated to each crop were determined by the product of the criteria priorities and the crop local priorities, giving thus the global priority for each crop. Thus the global priority for millet is obtained as follows:

$0.274 \times 0.660 + 0.564 \times 0.251 + 0.102 \times 0.340 + 0.060 \times 0.170 = 0.458$

	Cost (0.274)	Reliability (0.564)	Palatability (0.102)	Markets (0.060)	Global Priority
Maize	0.130	0.096	0.400	0.770	0.177
Millet	0.660	0.251	0.340	0.170	0.458
Cassava	0.210	0.653	0.260	0.060	0.456

This means that 17.7% of the farm should be planted to maize, 45.8% of the farm should be planted to millet and 45.6% of the farm to cassava. The farmer can at this stage explore how changes in the weights of the criteria can influence his/her decision on what to plant. This is known as sensitivity analysis in AHP (Saaty, 1990).

The above example illustrates how the AHP can be used to structure a farmer's problem according to the needs of the farmer, by using the farmers own inputs. This gives the farmer

ownership of the problem and hence the farmer is more likely to implement the solution. Another example of the use of the AHP in agriculture is given by Alphonce (1997) which shows how agricultural activities can be chosen on the basis of the benefits that they provide (Figure 3.5). In this hierarchy the farmer has a choice between horticulture, dairy, food crops or cash crops with the sub-criteria and criteria for these choices are given in the levels above.
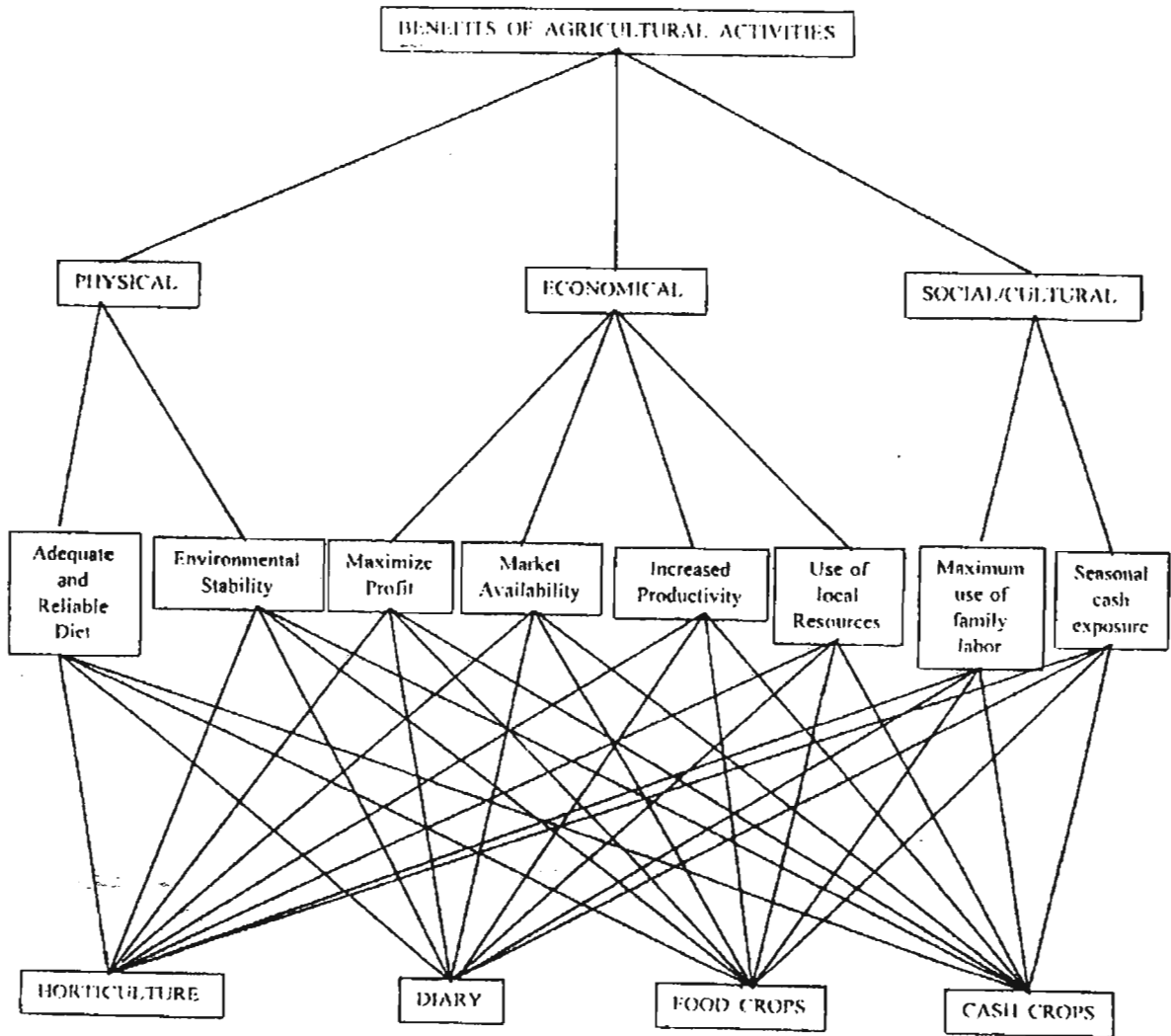
Figure 3.5: A hierarchy to determine the benefits of agricultural activities (Alphonce, 1997).

Another application of the AHP in agriculture is to choose between different farming systems. Figure 3.6 (from Mawapanga and Debertin, 1996) illustrates the structure of this problem:

THE FARMER'S DECISION CHOICE
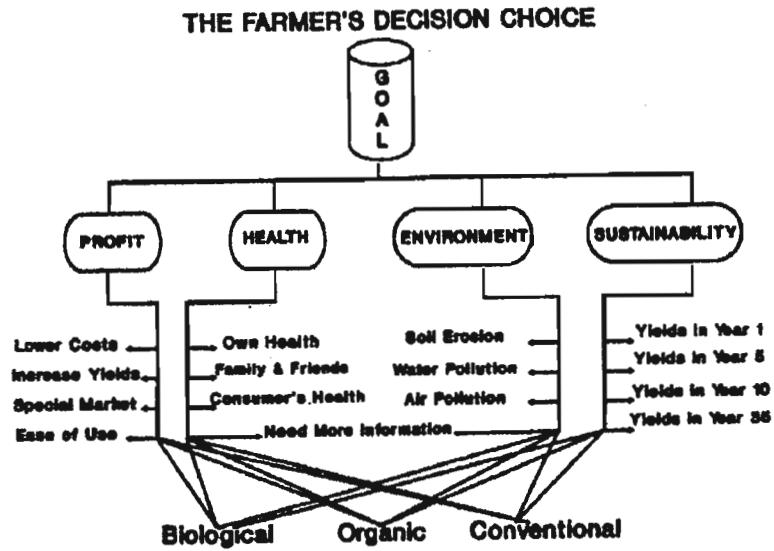
Figure 3.6: A hierarchy representing a choice of farming systems available to a farmer (Mawapanga and Debertin, 1996).

In Figure 3.6 the farmer has a choice of biological, organic or conventional farming systems. The issues, criteria and eventually weights are provided by the farmer. Again this gives ownership of the process to the stakeholders.

The three hierarchies (or similar ones) presented above can provide adequate decision support for drawing up a farm plan. Figure 3.6 can help the farmer make a decision on what farming system to use, Figure 3.5 can help the farmer in choosing the best farming activity and if cropping is chosen, Figure3.4 can help the farmer allocate land to each crop. Contrast this to the rational system of 20 steps to drawing up a farm plan provided in section 3.1.4 and it becomes evident how prescriptive the rational system is and how little stakeholder participation is used.

In the above examples, decisions are based on local knowledge provided for by the stakeholders (farmers). However, a more reliable decision can be made when combining local knowledge and judgements with expert judgements and a hard system like a GIS. This is evident in the next section.

3.2.2 Combining MCDA and GIS in Land Suitability Analysis

This example is based on the work undertaken by Malczewski *et al.* (1997) in Mexico. These researchers utilized stakeholder analysis and AHP in a multi-criteria group decision making model for the Cape Region of Mexico (Figure 16). Numerous interest groups (stakeholders), socio-economic activities, objectives and attributes were collected and then incorporated into an AHP and the relative weights calculated by allowing the relevant stakeholders to compare the objectives, in pairwise fashion, relative the the 1 to 9 intensity table (table 2.2). These weights were then used to allocate and prioritise land use activities for each geographical region of this area (table 3.1).

An important aspect of the use of MCDA in this sort of analysis is the integration of a geographical information system (GIS) with socio-economic activities such as agriculture, tourism, etc. MCDA combined with GIS seems to be a common combination for land use suitability analysis. Whitley *et al.*, 1993 used a GIS "Melting Pot" in order to perform a general land suitability analysis for the USA on agriculture, office, retail/service, industrial, forest, high density residential and low density residential. The term melting pot was used because the researchers enlisted the aid of experienced and knowledgeable stakeholders in order to compile an AHP model on land suitability which was then integrated into the GIS in order to determine classes of highly, moderately, least suitable and unsuitable areas for general land usage.
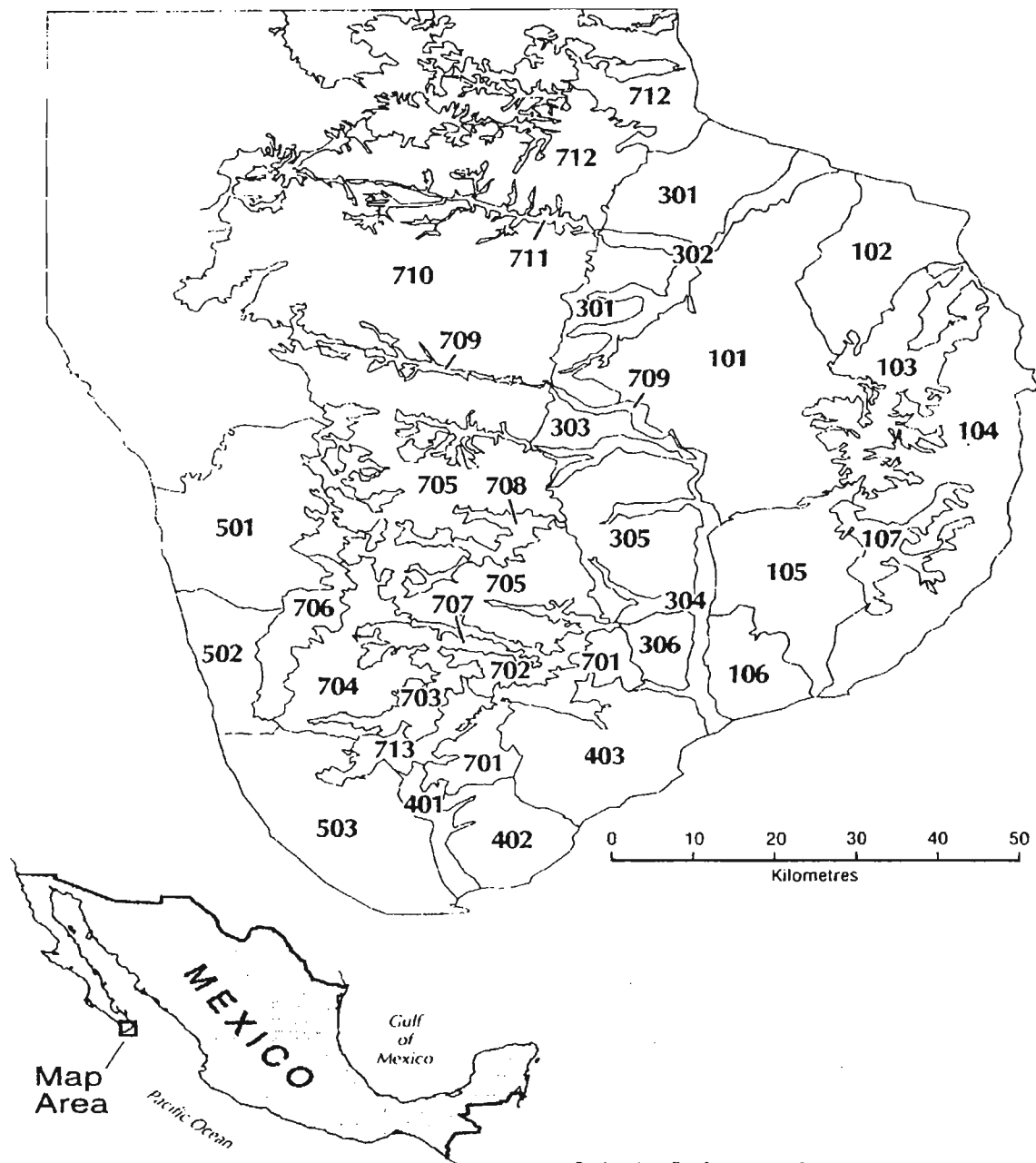
Figure 3.7: A map of the study area of the Cape Region, Mexico (Malczewski *et al*, 1997).

Table 3.1 illustrates how a MCDM model has identified and ranked the socio-economic activities to be undertaken on a geographical unit. It has given the most important / beneficial activity as strategy A. It then provides alternates incorporating the strategy from activity A with secondary and tertiary activities.

Table 3.1: Land suitability strategies for allocating activities to geographical units in the Cape Region, Mexico (Malczewski *et al*, 1997).

Geo-units	Strategy A	Strategy B	Strategy C
101	CAR	CAR,TSF,AGR	CAR,AGR,HUN
102	TSF	TSF,CAR,IND	TSF,UDE,WCA
103	FOR	FOR,AGR,HUN	FOR,WCA,BCO
104	BCO	BCO,CAR,IND	BCO,CAR,FOR
105	CAR	CAR,WCA,IND	CAR,WCA,AGR
106	UDE	UDE,TSF,HUN	UDE,TSF,HUN
107	FOR	FOR,AGR,IND	FOR,IND,UDE
301	TSF	TSF,CAR,IND	TSF,UDE,WCA
302	CAR	CAR,FOR,WCA	CAR,FOR,WCA
303	CAR	CAR,FOR,WCA	CAR,FOR,WCA
304	UDE	UDE,TSF,CAR	UDE,TSF,FOR
305	UDE	UDE,CAR,FOR	UDE,FOR,IND
306	TSF	TSF,CAR,FOR	TSF,FOR,UDE
401	UDE	UDE,TSF,FOR	UDE,TSF,FOR
402	TSF	TSF,UDE,CAR	TSF,UDE,HUN
403	UDE	UDE,TSF,CAR	UDE,TSF,HUN
501	CAR	CAR,AGR,WCA	CAR,AGR,WCA
502	CAR	CAR,WCA,AGR	CAR,WCA,AGR
503	UDE	UDE,TSF,CAR	UDE,TSF,IND
701	HUN	HUN,FOR,WCA	HUN,FOR,WCA
702	BCO	BCO,HUN,WCA	BCO,WCA,FOR
703	BCO	BCO,HUN,WCA	BCO,WCA,FOR
704	BCO	BCO,HUN,WCA	BCO,WCA,FOR
705	BCO	BCO,HUN,WCA	BCO,WCA,FOR
706	HUN	HUN,FOR,BCO	HUN,FOR,WCA
707	BCO	BCO,HUN,WCA	BCO,WCA,FOR
708	BCO	BCO,HUN,WCA	BCO,WCA,FOR
709	BCO	BCO,HUN,WCA	BCO,WCA,FOR
710	BCO	BCO,HUN,WCA	BCO,WCA,FOR
711	BCO	BCO,HUN,CAR	BCO,WCA,FOR
712	FOR	FOR,WCA,TSF	FOR,WCA,TSF
713	FOR	FOR,HUN,BCO	FOR,HUN,WCA

Notes: AGR = agriculture; CAR = cattle ranching; BCO = bioconservation; HUN = hunting; FOR = forestry; TSF = tourism/sport fishing; IND = industry; UDE = urban development; WCA = water catchment.

What is evident from the Mexican example is that MCDM/A is useful for decision making on what to do with a particular piece of land and what other alternatives are available once the objectives of the first strategy have been accomplished. This would allow for multiple land uses and hence this model is applicable to the situation in KwaZulu-Natal where the province has been divided into bioresource groups consisting of an area of a single vegetation type and bioresource units consisting of an area which has a certain degree of environmental (climatic,

terain, soil) homogeneity (Camp, 1999). Each of these bioresource groups and units would have to be evaluated for suitable land use alternatives.

A DSS in natural resource management is not an easy task. The field is a broad one incorporating many disciplines and sub-disciplines such as agriculture, forestry, nature conservation, water resource management, *etc*. Hence it is difficult to find an expert in natural resource management except experts in the various disciplines. There are also gaps in the knowledge on natural resource management, as well as certain misconceptions that some stakeholders may have. The next section deals with the difficulties involved in developing a natural resource DSS.

3.3 Problems Related to Developing a Natural Resource Decision Support System

Walker *et al.* (1999) describe certain challenges facing the production of a natural resource DSS such as:

* Limited Predictive Power

  Natural resource management is characterised by complex interactions which are only partially understood and for which limited data are available. This leads to limited predictive capabilities of a natural resource decision support system.

* Uncertain Objectives

  When dealing with a diversity of multiple stakeholders, their objectives are sometimes different and may also be unclear. This now poses a challenge to the decision making process.

* Appropriate Use of Outputs

  A significant level of interpretation and expertise is required in order to make effective use of the outputs from a DSS. In some cases, assumptions and uncertainties may limit the reliability of the output from a DSS. But this may reveal to the decision maker where there is a shortfall in the information.

3.4 Concluding Remarks on Chapter 3.

As illustrated in this section, each government department and each organisation has its own decision support system pertaining to its own activities e.g. agriculture, nature conservation, forestry and water resource management. Most of the information is kept within these organisations. Even if organisations did want to communicate there would be difficulties due to different formats, resolutions and scales of the data that exists in each organisation. This difficulty can be addressed using a DSS based on the process developed in this project.

This chapter illustrated the differences between the rational approach to decision making in land suitability and the systems approach. In South Africa the rational approach is mostly used, with the exception of a few organisations. The systems approach is better capable of taking into account the more human qualities in a decision making process. However, the rational approach should not be neglected, if combined with the more subjective human qualities it can lead to more effective decision making than human qualities alone.

Due to the lack of transparency there is an impression that decisions regarding land suitability in natural resource management are made by trial-and-error. The use of MCDA and AHP gives the decision making process more transparency hence more credibility. Also with transparency comes accountability and this may enhance the sustainability of the outcome of the decision making process.

The next chapter shows how MCDA can be used to create a decision support systems to answer the simple question of "what to do with a piece of land" with regards to agriculture, forestry, nature conservation and water resource conservation/management.

Chapter 4: A Model for Determining the Land Use Suitability of a Particular Area of Land with Regard to Natural Resource Management

4.1 A Framework for building a Model for Determining the Land Use Suitability of a Particular Area of Land with Regard to Natural Resource Management

This chapter describes the developing and testing of a systems approach to assist in the determination of a piece of land in regard to agriculture, forestry, nature conservation and water resource management/conservation. As illustrated in chapter 3, the current method of land suitability analysis is to use the traditional rational method.

The current approach is departmental based with various government departments and non-governmental organisations involved in each of the above activities. The aim of this research is to facilitate communication between these organisations to ensure effective decision making in natural resource management. Figure 4.1 shows the framework for decision making that is suggested
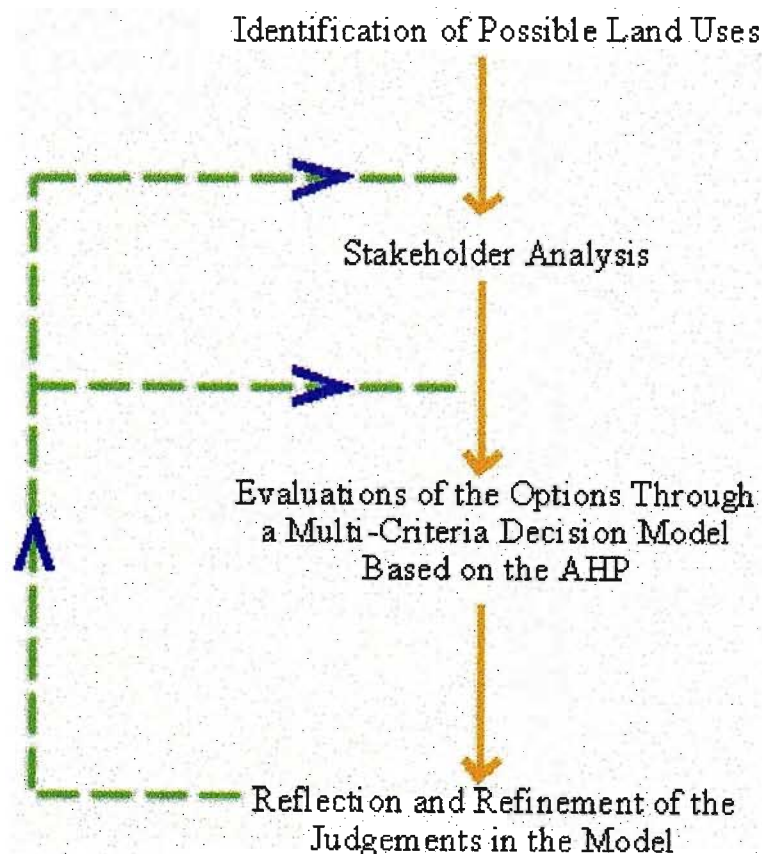
Figure 4.1: A framework for decision making on land suitability.

The framework combines stakeholder analysis, a Multi-criteria Decision Making Approach with the Analytic Hierarchy Process. This allows to combine their strengths in a complementary manner.

The identification of possible land uses in the framework is performed on the basis of the needs of the potential user and the existing knowledge in agriculture, nature conservation, forestry and water resource management; it is not discussed here in detail. The stakeholder analysis is further elaborated in the next section.

4.1.1 Stakeholder Analysis

In MCDA there is a need to somehow quantify all data relevant to the process, be it soft or hard, hence MCDA is integrated with stakeholder analysis.

Before the model is attempted, it is advisable to conduct a stakeholder analysis in order to determine the influence each stakeholder has on the process. This model used stakeholders from the KwaZulu-Natal (KZN) Department of Agriculture, Mondi Forests, ATI Consulting, KZN Nature Conservation Service (KZNNCS) and the Wilderness Action Group (Figure 4.2). Other organisations were approached but had limited participation, due to lack of time and money or interest. Generally the people from the organisations that participated were enthusiastic and were pleased to be part of the decision making process. Their enthusiasm was reflected by the highly consistent judgements that they provided for the model. They felt a need for this sort of model as a natural resource DSS.

Due to time and budgetary constraints, only a few of the stakeholders involved in land suitability analysis were incorporated into the model. However, this is adequate since at this stage of the project the objective was only to test a process to produce a model for land suitability.
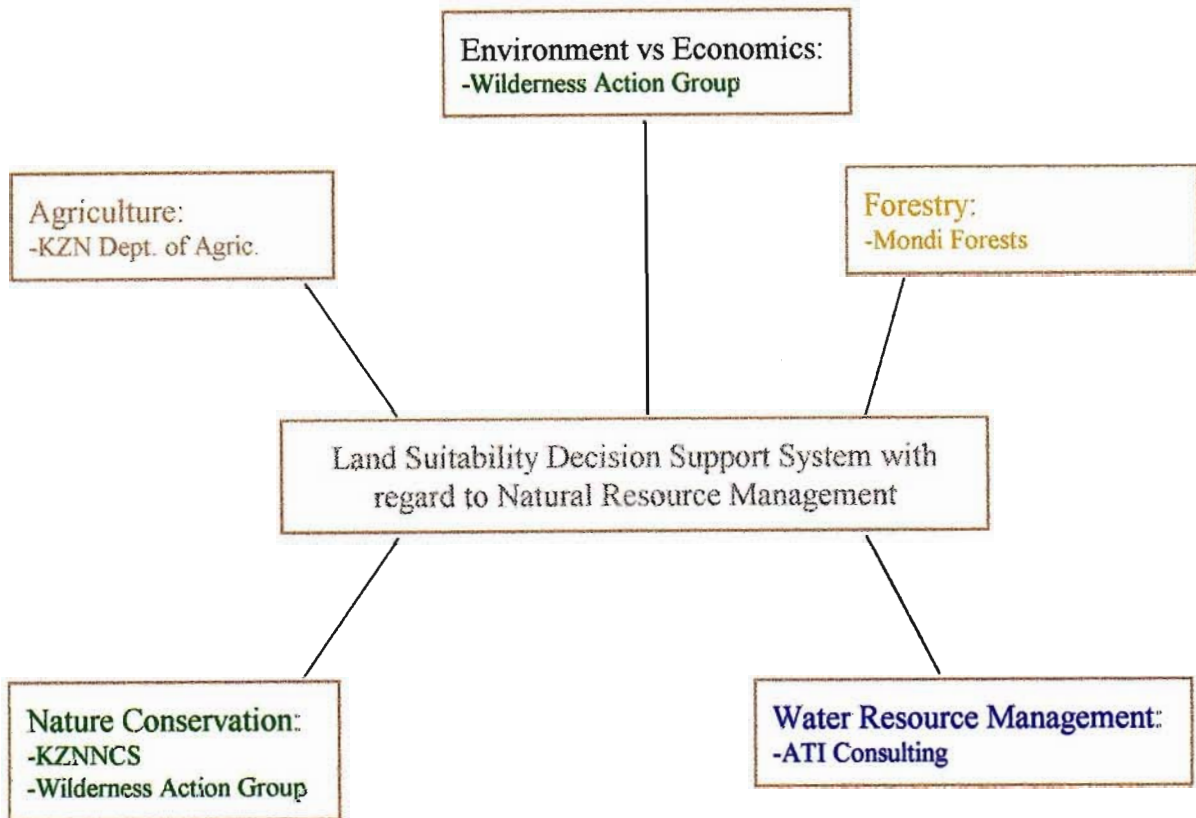
Figure 4.2: Stakeholder involvement in producing a DSS for land suitability in natural resource management.

The model used to classify the stakeholders was developed by Martin (1985), as illustrated in Chapter 2, Figure 2.3. This model was chosen as it most appropriately represented the reality of the situation when developing the DSS. According to Martin (1985), the stakeholders in this project are classified as follows (where appropriate names would not be given):

F1: Family

The SA-ISIS 2000 consortium falls into this classification since this project is part of the ISIS programme.

F2: Friends

Organisations mentioned in Figure 4.2 fall into this category. They realise the benefits of the systems approach to natural resource management and provided input into the process of developing a DSS. The individuals that provided their inputs were senior officers, experienced in natural resource management. They also were experienced in using rational approaches such as GIS, but realised the limitations of these approaches and the need for MCDA.

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F3: Fellow Travellers

These were people and organisations who realised the benefits of the process to produce a natural resource DSS but it is not part of their job or company objective. These are the organisations and individuals that usually do hard data capturing but are usually not involved in the decision making process.

F4: Fence Sitters

These are individuals and organisations who have not encountered MCDA but they are curious to see how it is used.

F5: Foes

The process of using MCDA in natural resource management did not have any foes *per se*. However, there were people who did not understand the process and hence were critical of it. These are people who believe that rational systems especially GIS are the "be all and end all" of decision making in natural resource management (NRM). These people tended to be not very experienced in GIS or NRM and hence did not realise the limitations of the use of GIS in NRM. These tend to be junior people in the organisation and hence may not play a significant role in NRM. Also refer to F6 for more details.

F6: Fools and F7 Fanatics

Generally there is a problem with the ethical nature of Martin's classification and these last two categories were not considered specifically in this project. However they may be relevant, sometimes, in other situations.

Due to time and financial constraints only stakeholders classified as "friends" were used in this study eg. Banville *et al.* (1998), found 600 stakeholders divided into 65 groups in an area of 100km². However, in a real life situation all the relevant stakeholders should be included.

In this case stakeholder analysis is used to evaluate the stakeholders involved in testing the process of using MCDA in NRM. This is a slight deviation from the norm because stakeholder analysis is usually used to evaluate the stakeholders over a specific problem / issue. It is just that

in this case, the issue is on using MCDA to produce a NRM decision support system. The next section illustrates the process used in combining MCDA, stakeholder analysis and the AHP into a comprehensive DSS.

4.2 The Process of Building the Model for Decision Making with Regard to Land Suitability

This model is based on the assumption that the decision maker knows what is available in terms of the natural resources in the particular area(s) of land. The actual decision making process is relative to what natural resources are available on the land, as well as the location of the land. This would then lead to a decision on what best to do on the land in terms of its potential. The source of data for this decision making process can be of a "hard" nature such as that found in a GIS, or it can be of a soft nature such as local knowledge from people who are familiar with the piece of land.

During the initial development of this project it was proposed that a comprehensive DSS for land suitability be developed. However, it was realised that this was impractical considering the complex nature of the problem and the time frame and budget of the project. It is also not desirable to have one model since it may not capture the richness of the problem. It was then decided that a land suitability DSS is more suitable for individual situations. However, no framework was found for using MCDA in developing such a DSS. It was then decided this research should focus on developing such a framework

4.2.1 An Overview of the Model

The model aims to identify and compare areas of land according to how well they are endowed with natural resources in terms of cropping, grazing, forestry, nature conservation and water resource conservation. An AHP model is provided as Figure 4.11 and Appendix A (which contains a detailed Expert Choice printout on the AHP model).

Suitable experts from various organisations (Figure 4.2) were approached and their input sought to include into a land suitability in natural resource management DSS. Their judgements were then entered and the resultant hierarchy was derived. This hierarchy (Figure 4.11) contains six levels as explained below:

1. The first level of the hierarchy contains the goal (Land Suitability), which is to assess which activity is most suited to a particular area of land, in terms of its natural resource potential.

2. The second level of the hierarchy contains a comparison between the importance of economic and environmental needs of the particular area of land. If relevant, these needs are determined using techniques like Soft Systems Methodology and MCDA, which would involve various stakeholders such as local communities, government departments, businesses, conservation organisations, etc. These needs would be specific to a certain area. For this project, they are considered equally important; hence the equal weight allocated to the criteria "economic" and "environmental". However, this would change in a real life situation.

3. The third level of the hierarchy contains the activities that can be undertaken on a piece of land such as "cropping", "grazing", "forestry", "nature conservation" and "water resource conservation/management". These activities are compared in relation to their economic worth: i.e. which, generally, brings in the most economic returns and their environmental worth, i.e. which activity is the most environmentally friendly.

4. The fourth level of the hierarchy involves comparing the characteristics of the land with the different activities. This is to ensure that the activities in the third level are feasible in relation to the soil, climate, vegetation, topography, etc of the area of land.

5. The fifth level contains the intensities for the factors from the fourth level, needed for the absolute mode of the AHP. They are used to determine the extent of the resources in the fourth level i.e. whether the resources are outstanding, good, average, fair or poor.

6. Finally, the last level contains the pieces of land that are to be evaluated. In Figure 4.11 this is area1, area2, area3, area4 and area5.

4.2.2 Explanation of the Criteria

The criteria used is sourced from hard systems such as GISs and databases, as well as expert and local knowledge on the subject. The aim is to find out if a certain activity (such as cropping) can be undertaken on that piece of land. This means breaking down the activity into its basic components such as soil, water, climate, topography and then assessing the land in relation to these criteria. The relevant factors affecting each activity (potential land use) are identified below.

Is the Land Suitable for Cropping Agriculture (Cropping)?

How suitable is the soil, physical and chemical properties, for cropping (soil)?

How suitable is the climate, excluding rainfall, for cropping (climate)?

How suitable is the topography for cropping (topography)?

How adequate is the quantity and quality of water, i.e. rainfall and irrigation, for cropping (water)?
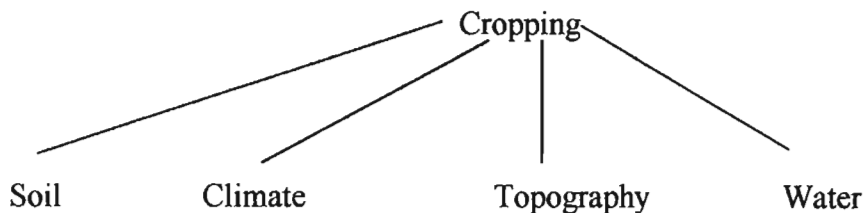
Figure 4.3: Hierarchy for cropping agriculture.

Is the Land Suitable for Grazing (Grazing)?

How suitable is the vegetation for grazing (vegetation)?

What is the potential carrying capacity of the land (capacity)?

How suitable is the water for grazing agriculture (water)?

How suitable is the topography for grazing agriculture (topography)?

How disease free is the area (diseases)?
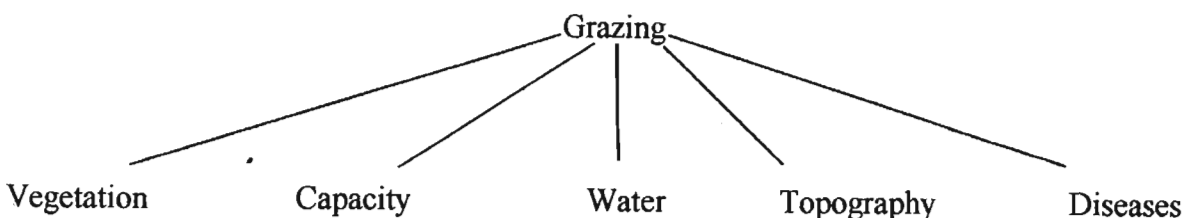
Figure 4.4: Hierarchy for grazing.

Is the Land Suitable for Forestry (Forestry)?

How suitable is the soil for forestry (soil)?

How suitable is the climate, including rainfall, for forestry (climate)?

How suitable is the topography for forestry (topography)?

How adequate is the infrastructure for water eg dams (water)?

How close is the area to the market for wood (market distance)?
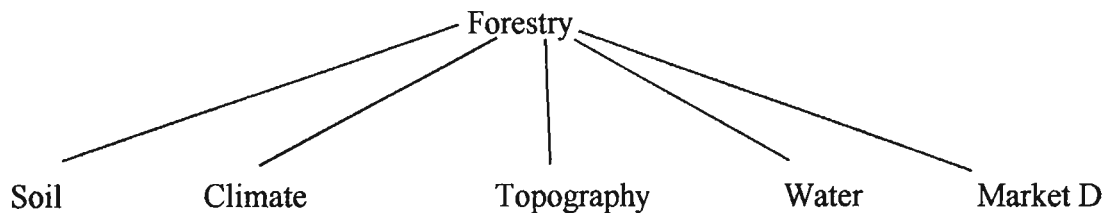
Figure 4.5: Hierarchy for forestry.

Is the Land Suitable a Priority for Nature Conservation?

How important is the area for rare or endemic species (endemics)?

What is the level of the aesthetic scenery / unique landscapes in that area (landscape)?

What is the level of any unique ecosystems in that area (ecosystems)?

How important is that area as a corridor for migration (corridors)?

The IUCN (international conservation union) guidelines is that 10% of the habitats and ecosystems found in that area should be conserved. Is enough of that ecosystem already conserved or is there less than 10% conserved (legislation)?
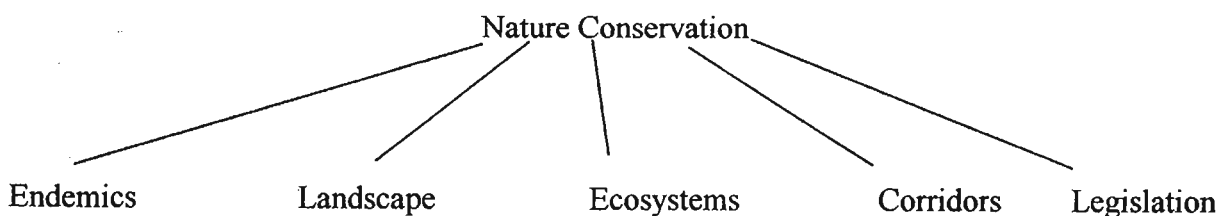
Figure 4.6: Hierarchy for nature conservation.

Is the Land Suitable for Water Resource Management?

What is the condition of vegetative cover, in the area, and its relevance to water resource management (Veg Cover)?

How relevant is the soil type to water resource management (soils)?

What is the rainfall of that area (rainfall)?

How relevant is the topography in the area to water resource management (topography)?

Are there any relevant rivers, wetlands, dams and lakes in that area (waterbodies)?

How important is the climate, excluding rainfall, of the area, to water resource management (climate)?
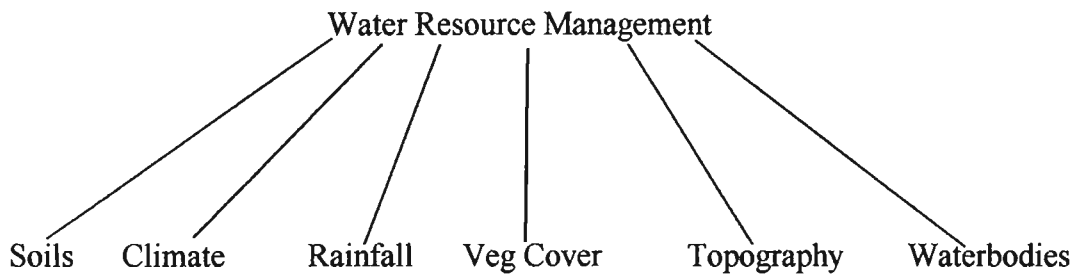
Figure 4.7: Hierarchy for water resource management/conservation.

Which Activity Yields the Greatest Economic Returns / Development (Economic)?

Cropping

Grazing

Forestry

Nature Conservation

Water Resource Management
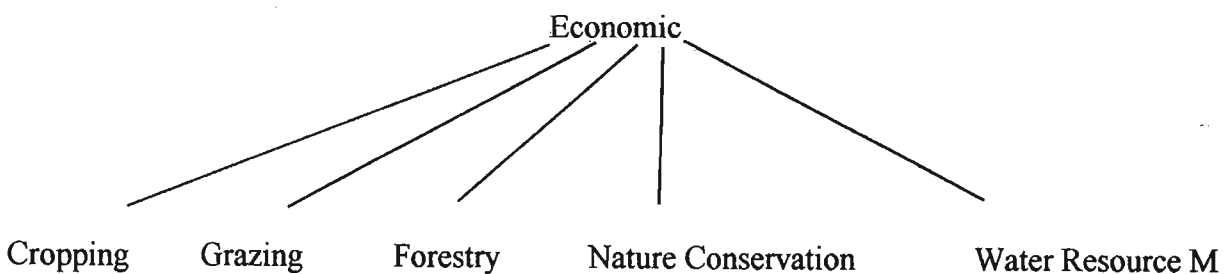
Figure 4.8: Hierarchy of economic worth of the activities.

Which Activity is the Most Environmentally Friendly* (Environment)?

Cropping

Grazing

Forestry

Nature Conservation

Water Resource Management

* Environmentally friendly means which activity does the least harm or the most good to the environment.
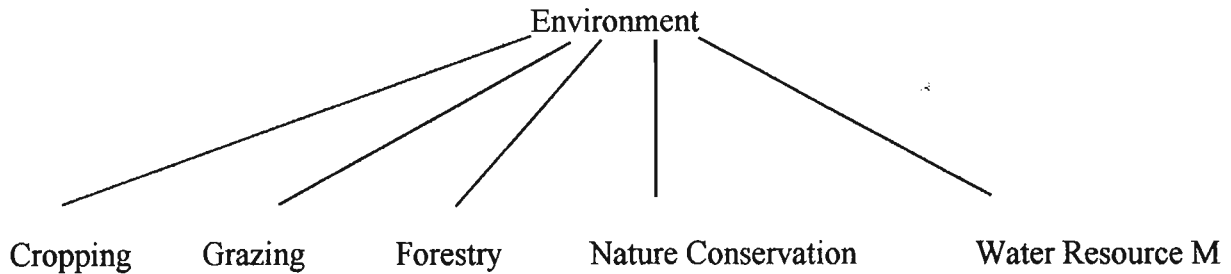
Figure 4.9: Hierarchy of environmental friendliness of the activities.

4.2.3 Explanation of the Evaluation of the Criteria and the Potential Uses of Areas of Land

Each of the criteria and factors of the model is evaluated by an expert(s) in that particular field. These judgements are entered into a matrix, such as Table 4.1, which illustrates the matrix of judgements for, "which activity is the most environmentally friendly". The values for the judgements are obtained from the intensity scale provided at the bottom of Table 4.1 eg. moderately more important is equal to a value of 3. The judgements entered in this matrix mean that:

- Grazing is **moderately** more environmentally friendly than cropping; hence grazing is given a value of **3**

- Forestry is **equally to moderately** more environmentally friendly than cropping; hence the value of **2**

- Nature conservation is **extremely** more environmentally friendly than cropping; hence a value of **9**

- Water resource management/conservation is **extremely** more environmentally friendly than cropping; hence a value of **9**

- Grazing is **strongly to very strongly** more environmentally friendly than forestry; hence a value of **6**

- Nature conservation is **very strongly** more environmentally friendly than grazing; hence a value of **7**

- Water resource management/conservation is **very strongly** more environmentally friendly than grazing; hence a value of **7**

- Nature conservation is **extremely** more environmentally friendly than forestry; hence a value of **9**

- Water resource management/conservation is **extremely** more environmentally friendly than forestry; hence a value of **9**

- Nature conservation is **equally** as environmentally friendly as water resource conservation; hence a value of **1**

Note: the diagonal of the matrix consists of 1s and that the bottom left half of the matrix is merely the inverse of the top right half of the matrix. Appendix A, Tables A1 to A8 contain matrices of judgements and the derived priorities for all the levels of the hierarchy.

Table 4.1: A matrix of judgements with respect to which activity is the most environmentally friendly.

	Cropping	Grazing	Forestry	Nature Cons.	Water Res. Man.
Cropping	1	1/3	½	1/9	1/9
Grazing		1	6/1	1/7	1/7
Forestry			1	1/9	1/9
Nature Cons.				1	1/1
Water Res. Man.					1

Matrix entry indicates that the row element is:
1 = equally   3 = moderately   5 = Strongly 7 = Very Strongly   9 = Extremely
more environmentally friendly than the column element

The matrix of judgements is then used to derive priorities (weights) of each criteria (Figure 4.10). Note that these priorities sum to 1.000. They are the local priorities of the possible land uses with respect to the environment criterion. The global priorities with respect to the overall goal, taking into account the priorities at higher levels are shown in Figure 4.11. Thus in the complete hierarchy (Figure 4.11) the global priorities of possible land uses sum to 0.500. This is due to the re-scaling of the values so that the sum of the priorities of each of the elements is equal to the priority of their parent node in the level above. The judgements can be checked for consistency against the consistency ratio (Figure 4.10). Ideally the consistency ratio should be below 0.1 or 10%, if not then the judgements should be rechecked.

The priorities of the levels of intensities for each factor (i.e. outstanding, good, average, fair and poor) are calculated in a similar fashion. Hence the intensities are constant for each of the factors affecting the criteria in the fourth level; this simplifies the model. If desired other scales can be used to rate the criteria such as high, medium and low or numerical classes like 100-200mm, 201-300mm, 301-400mm. This scale need not be constant for all the criteria since it is permissible for different criteria to have different rating scales.

```
0.033
CROPPING
0.104
GRAZING
0.040
FORESTRY
0.411
NATURE C
0.411
WATER RE
```

INCONSISTENCY RATIO = 0.086.

Figure 4.10: The priorities of each criterion (possible land uses) derived from the matrix of judgements for the most environmentally friendly land use.

Table 4.2: A Sample of the printout showing the ratings of five areas. Note this is only a sample of the ratings. (Appendix A, Table A9 contains the full printout. Table 4.3 gives the numeric equivalent of these ratings.)

	Economic				Environment	
	Cropping				Water Res. Man.	
	Soil	Climate	Topography	Water	Climate	
Alternatives	0.0604	0.0248	0.1162	0.0557	0.0331	Total
Area4	Outstand	Outstand	Outstand	Outstanding	Outstanding	1
Area1	Good	Good	Poor	Good	Good	0.532
Area5	Outstand	Good	Good	Good	Good	0.395
Area3	Average	Average	Average	Average	Average	0.279
Area2	Poor	Poor	Poor	Poor	Poor	0.092

Table 4.2 shows how the absolute ratings for the different land areas are entered. Note: these land areas are not real areas but are merely used here for illustrative purposes. The ratings from Table 4.2 are expressed numerically in Table 4.3. The sums of these numerical value are used to determine what activity is most suitable for that particular area of land as illustrated in tables 4.4 and 4.5 with further explanations given with the tables. However before this model can be tested on real areas of land, the mathematical structure of the model would need to be validated.

4.3 Experimental Validation of the Mathematical Framework of the Model

Figure 4.11 illustrates the structure of the model. Before the costly and time consuming phase of field testing this model is implemented, it is important to judge whether this mathematical framework would provide a reasonable output for decision making. In order to achieve this, five hypothetical areas of land were invented and included as an illustrative example in this project. These areas are known simply as Area1 to Area5 (Figures 4.10 and 4.11). It should be noted that these areas are not delimited hence do not have the limitations that a defined area would have. The addition of these five areas of land to the model made the model much easier to explain to the relevant stakeholders in order to engage their opinions.

These areas of land were then allocated absolute ratings. Area1 and Area5 were allocated ratings at random while Area2 was given a rating of "Poor" for all the sub-criteria, Area3 was given a rating of "Average" for all the sub-criteria and Area4 was given a rating of "Outstanding" for all the sub-criteria. The areas of land with single ratings of all the sub-criteria were incorporated into the model to assess whether the model is stable enough to give a constant output.

The main reason for the theoretical test of the model is to ensure that it is capable of assisting the decision maker in deciding on the use of a particular area of land in terms of its natural resources. How to use the model to achieve this is explained in the following sections.

The top level of the hierarchy contains the overall goal of finding the best land use. The second level comprises two broad criteria: economic and environment which are rated equally. The third level contains a set of potential natural resource activities/uses that can be carried out on a piece of land. The fourth level contains the characteristics of the land which are compared to the activities (more information can be found in section 4.2). The fifth level contains the intensities / ratings by which the characteristics are rated (weighted). The sixth level contains a list of alternative areas which are to be assessed.

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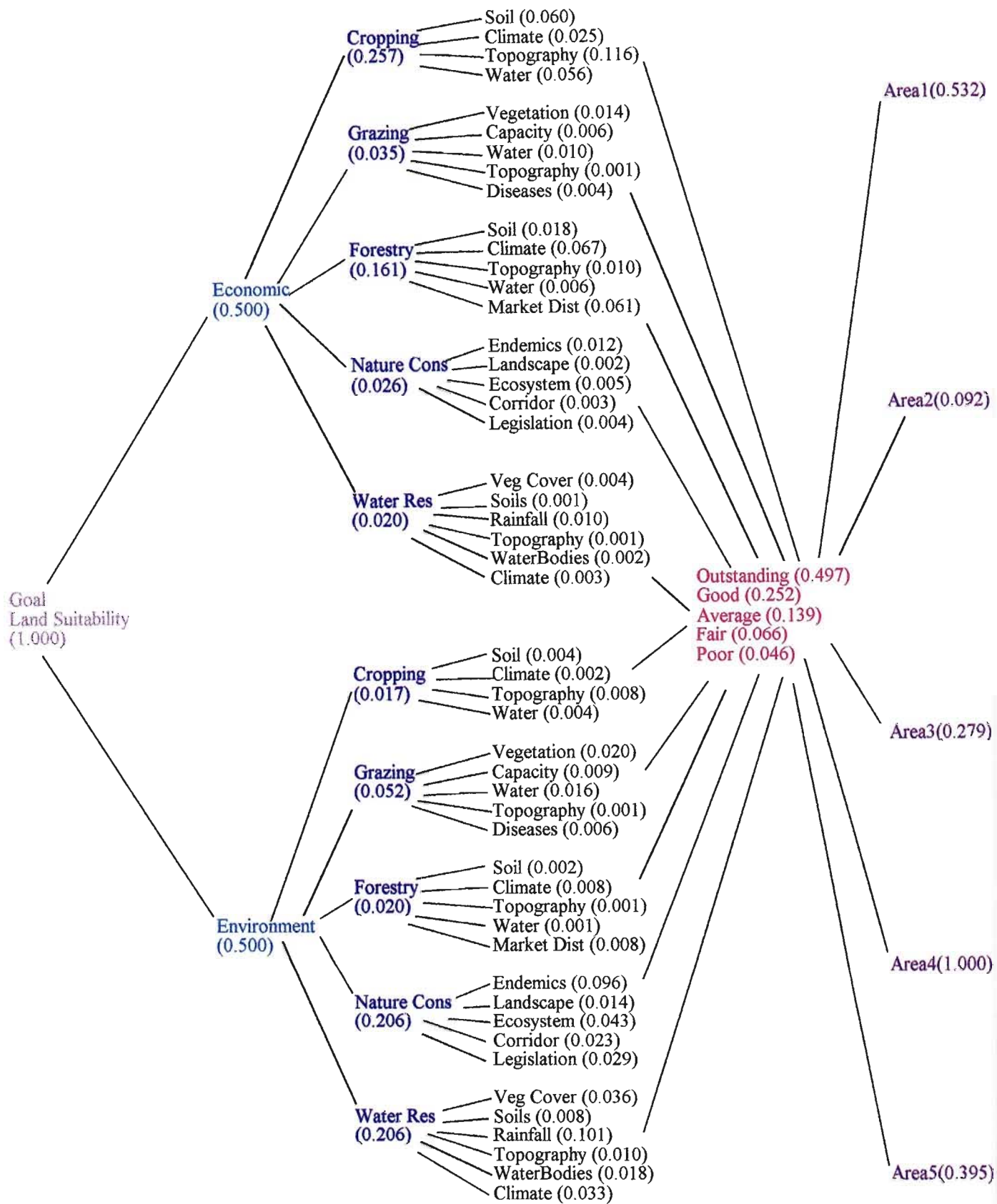
Figure 4.11: Hierarchical representation of the problem of prioritization of the criteria and activities towards the overall goal of finding the best use of land from a natural resources perspective.

Table 4.3: Ratings of each specific land area considering relevant sub-criteria for each of the potential land uses, done separately for the economic and environmental criteria. (The Appendix, Table A9 gives the verbal equivalent of this table.)

Economic

	Cropping				Grazing				
Area	Soil	Climate	Topography	Water	Vegetation	Capacity	Water	Topography	Diseases
Area4	0.0604	0.0248	0.1162	0.0557	0.0136	0.0057	0.0105	0.001	0.0042
Area1	0.0307	0.0126	0.0107	0.0283	0.0136	0.0057	0.0053	0.0001	0.0004
Area5	0.0604	0.0126	0.059	0.0283	0.0018	0.0008	0.0053	0.0005	0.0021
Area3	0.0169	0.0069	0.0324	0.0155	0.0038	0.0016	0.0029	0.0003	0.0012
Area2	0.0055	0.0023	0.0107	0.0051	0.0012	0.0005	0.001	0.0001	0.0004

	Forestry				Nature C					
	Soil	Climate	Topography	Water	Market Dist	Endemics	Landscape	Ecosystem	Corridor	Legislation
Area4	0.0181	0.0674	0.0095	0.0057	0.0606	0.0123	0.0018	0.0055	0.003	0.0038
Area1	0.0092	0.0342	0.0009	0.0029	0.0308	0.0123	0.0005	0.0028	0.0015	0.0011
Area5	0.0092	0.0342	0.0048	0.0029	0.0056	0.0011	0.0005	0.0015	0.0008	0.0005
Area3	0.0051	0.0188	0.0027	0.0016	0.0169	0.0034	0.0005	0.0015	0.0008	0.0011
Area2	0.0017	0.0062	0.0009	0.0005	0.0056	0.0011	0.0002	0.0005	0.0003	0.0003

Environment

	Water Re						Cropping			
	Veg Cover	Soils	Rainfall	Topography	Waterbodie	Climate	Soil	Climate	Topography	Water
Area4	0.0035	0.0007	0.0099	0.001	0.0017	0.0032	0.0039	0.0016	0.0075	0.0036
Area1	0.0035	0.0004	0.005	0.0005	0.0009	0.0016	0.002	0.0008	0.0007	0.0018
Area5	0.0005	0.0004	0.005	0.0005	0.0009	0.0016	0.0039	0.0008	0.0038	0.0018
Area3	0.001	0.0002	0.0028	0.0003	0.0005	0.0009	0.0011	0.0004	0.0021	0.001
Area2	0.0003	0.0001	0.0009	0.0001	0.0002	0.0003	0.0004	0.0001	0.0007	0.0003

	Grazing					Forestry				
	Vegetation	Capacity	Water	Topography	Diseases	Soil	Climate	Topography	Water	Market Dist
Area4	0.0203	0.0085	0.0156	0.0014	0.0063	0.0022	0.0084	0.0012	0.0007	0.0075
Area1	0.0203	0.0085	0.0079	0.0001	0.0006	0.0011	0.0043	0.0001	0.0004	0.0038
Area5	0.0027	0.0011	0.0079	0.0007	0.0032	0.0011	0.0043	0.0006	0.0004	0.0007
Area3	0.0057	0.0024	0.0044	0.0004	0.0018	0.0006	0.0023	0.0003	0.0002	0.0021
Area2	0.0019	0.0008	0.0014	0.0001	0.0006	0.0002	0.0008	0.0001	0.0001	0.0007

	Nature C					Water Re						
	Endemics	Landscape	Ecosystem	Corridor	Legislation	Veg Cover	Soils	Rainfall	Topography	Waterbodie	Climate	Total
Area4	0.0962	0.0137	0.0428	0.0234	0.0295	0.0363	0.0075	0.1009	0.01	0.0176	0.0331	1
Area1	0.0962	0.0038	0.0217	0.0119	0.0082	0.0363	0.0038	0.0512	0.0051	0.0089	0.0168	0.532
Area5	0.0088	0.0038	0.0119	0.0021	0.0039	0.0048	0.0038	0.0512	0.0051	0.0089	0.0168	0.395
Area3	0.0268	0.0038	0.0119	0.0065	0.0082	0.0101	0.0021	0.0282	0.0028	0.0049	0.0092	0.279
Area2	0.0088	0.0013	0.0039	0.0021	0.0027	0.0033	0.0007	0.0093	0.0009	0.0016	0.003	0.092

Table 4.4: The overall rating of each of the potential land uses that can be undertaken in the areas with regard to economic development and environmental preservation.

Rank	Area	Economic					Environment					Total
		Cropping	Grazing	Forestry	Nature C	Water Re	Cropping	Grazing	Forestry	Nature C	Water Re	
1	Area4	**0.2571**	0.035	0.1613	0.0264	0.02	0.0166	0.0521	0.02	0.2056	0.2054	0.9995
2	Area1	0.0823	0.0251	0.078	0.0182	0.0119	0.0053	0.0374	0.0097	0.1418	0.1221	0.5318
3	Area5	0.1603	0.0105	0.0567	0.0044	0.0089	0.0103	0.0156	0.0071	0.0305	0.0906	0.3949
4	Area3	0.0717	0.0098	0.0451	0.0073	0.0057	0.0046	0.0147	0.0055	0.0572	0.0573	0.2789
5	Area2	0.0236	0.0032	0.0149	0.0024	0.0019	0.0015	0.0048	0.0019	0.0188	0.0188	0.0918

Table 4.5: The total ratings of the activities for each area.

Rank	Area	Cropping	Grazing	Forestry	Nature C	Water Re	Total
1	Area4	**0.2737**	0.0871	0.1813	0.232	0.2254	0.9995
2	Area1	0.0876	0.0625	0.0877	0.16	0.134	0.5318
3	Area5	0.1706	0.0261	0.0638	0.0349	0.0995	0.3949
4	Area3	0.0763	0.0245	0.0506	0.0645	0.063	0.2789
5	Area2	0.0251	0.008	0.0168	0.0212	0.0207	0.0918

4.3.1 Obtaining Output from the Model

The three tables are used in conjunction with each another. Table 4.5 ranks the land uses from most suitable to least suitable, Table 4.4 indicates which of the economic or environmental criteria is the greater determining factor for the land use suitability and Table 4.3 gives an indication of which sub-criteria has the greatest or least effect on determining the land use suitability.

Table 4.3 contains the ratings for each sub-criteria relevant to the specific land area. These ratings are the numeric values of the verbal ratings, "Outstanding" to "Poor" shown in Table 4.2 (and Appendix, Table A9). Table 4.4 is the sum of the values for each of the potential land uses for each of the criteria "Economic" and "Environment". Table 4.5 is the total sum of the values for the potential land uses. These tables are used to provide the data on the suitability of a piece of land and how was this conclusion reached. Table 4.5 gives the overall ratings of each area of land for the activities (potential land use). The higher the value, the more suitable that land use is for that area of land eg. the activity "Cropping" has the highest value (0.2737) for Area4. This means that cropping may be the most suitable activity for this area. Table 4.4 and 4.3 provide the information on why this activity is the most suitable. In this case, it is because cropping has the highest economic value of 0.2571 (Table 4.4) and the suitable topography (0.1162 and 0.0075) is the biggest reason why cropping may be most suited to that area (Table 4.3). The next section provides a more detailed interpretation of these values.

4.3.2 Interpretation of the Output from the Model

This will be done for each area in descending order of their overall ranking.

Area4

This area has the highest rating (1.000) of all the areas. This indicates that this areas has the most to offer in terms of natural resources which can assist in determining property value, choosing a property or assist in determining a land tax (if implemented). However, this does not tell us which potential land use(s) is most suited to this area.

In order to determine which land use is best suited for Area4, take the values for each activity in Table 4.5, Area4 has the highest value (0.2737) for Cropping, indicating that cropping should be carried out in this area. However, Nature Conservation (0.232) comes in second followed closely by water resource management. The large rating for nature conservation is largely due to the prevalence of endemic species (Table 4.3). Since it is considered to be unethical/immoral to cause the extinction of species therefore, depending on the size of this area, it would be best to first preserve the endemic species and then use the remainder of the land for cropping. It would also be wiser to give "Environmental" criterion a higher weight than the "Economic" criterion if it is known that the area has some unique environmental components. Also activities such as nature conservation, water resource management and grazing are not exclusive of one another i.e. they could be done on the same piece of land at the same time. Hence the values for these activities could be added which would then outweigh the value for cropping.

Area1

Area1 has nature conservation (0.16) as the highest priority followed closely by water conservation (0.134), hence this land should be used for conservation purposes. Conservation seems to have far outweighed cropping and forestry and hence they may not be considered as alternatives. The poor values for topography (Table 4.3) for the activities grazing, cropping and forestry especially under the environmental criteria indicates that this area has steep slopes that may be prone to erosion and from this point of view, area1 should be kept for conservation.

Area5

Area5 has cropping (0.1706) as the highest priority followed by water resource conservation/management (0.0995). Perhaps an integrated approach should be used to manage this piece of land whereby parts of the land is left uncultivated and/or cropping practises in line with water conservation policies should be used. An example of a cropping practise that caters for water conservation is minimum till. This practise leads to less soil erosion and preserves soil moisture. The poor values for vegetation and carrying capacity (Table 4.3) of this area indicates why grazing (0.0261) may be unfeasible.

Area 3

Area3 has cropping (0.0763) as the highest priority followed by nature and water conservation. Again perhaps an integrated approach should be used. Alternatively, if other considerations indicate that no more land can be used for cropping then the land can be used for one of the

purposes ranked 2nd or 3rd depending on wider land policy considerations.

Area2

Area2 could be used primarily for cropping followed by nature conservation and water resource management. However, it has poor qualities for all the criteria and activities and perhaps it should be used for other land uses such as urbanisation, industrialisation and/or transport facilities.

Discussion

In Areas 2, 3 and 4 which had a single rating of "Poor", "Average" and "Good" respectively, it was found that they had the same potential land uses namely cropping followed by nature conservation then water resource management then forestry and then grazing. This indicates that the model is stable enough to use in case studies. It also illustrated the balance in the model between the "Economic" and "Environmental" criteria since "Cropping" (Table 4.4) carried the highest rating in the Economic criterion and "Nature Conservation" carried the highest rating in the Environmental criterion.

Areas 1 and 5 had absolute ratings given at random. These areas showed differences in proposed land use indicating that the model is sensitive enough to pick up differences in different areas of land and then make recommendations based on these. The above section illustrates that the proposed model is sensitive enough to assess the differences in different areas of land and then use the inputs to suggest a particular land use and alternatives.

4.4 Concluding Remarks on the Development of the Model

This chapter has illustrated that MCDA and the AHP can be used to create a DSS for land suitability in natural resource management. This multi-criteria decision making model allows the incorporation of information from hard systems such as GISs and databases as well as soft systems such as local knowledge and expert judgements. The model would be used as an illustrative example in a web based tutorial on AHP. The model can also be used to assist in problem solving if a similar situation arises. This chapter illustrated that MCDA allows for a combination of a sound framework for decision making with a deep understanding of the local conditions and needs influencing potential land usage. What now remains is to test the model with real areas of land that have already been evaluated with other systems. This is done in the next chapter.

Chapter 5: Case Studies on the Implementation of the MCDA Model

To determine the effectiveness of the model, it was tested against areas of land that are well described and have been planned utilizing other systems. Three areas of land were nominated by the representative of the forestry industry: the Hlatikulu Vlei area, the Gilboa / Karkloof area and the Richmond area. These areas have not been delineated, so this exercise was treated as a regional land use planning effort. Even though no boundaries have been set, Figure 5.1 is a map to show the location of these areas.

As the areas are of high potential land, there is competition amongst different stakeholders since this quality of land is scarce in South Africa. In the past there has been considerable decisions made on the use of these areas of land. Most of these decisions were based on the rational approach as well as trial and error. As illustrated previously, this approach has its limitations. In this chapter, these areas of land would be evaluated according to MCDA but first the purposes of the case studies and a brief description of current land use patterns will be provided.

5.1 Purposes of the Case Studies

The major purpose of this section is an experimental validation of the proposed model, using data on several real areas of land in the KZN-Midlands region. The questions that need to be answered as a purpose of such a validation are:

- Is the model relevant to decision making in land usage
- Is the model flexible enough to combine general principles with deep consideration of the various local conditions
- Is the model easy to use

5.2 Current Land Use Patterns in the Case Study Areas

The Hlatikulu, Gilboa and Richmond areas are prime candidates for this case study due to the competition for the land. All these areas have been modified by humans to a certain extent, which presents some difficulties. However, this model may justify the activity or suggest a better alternative.

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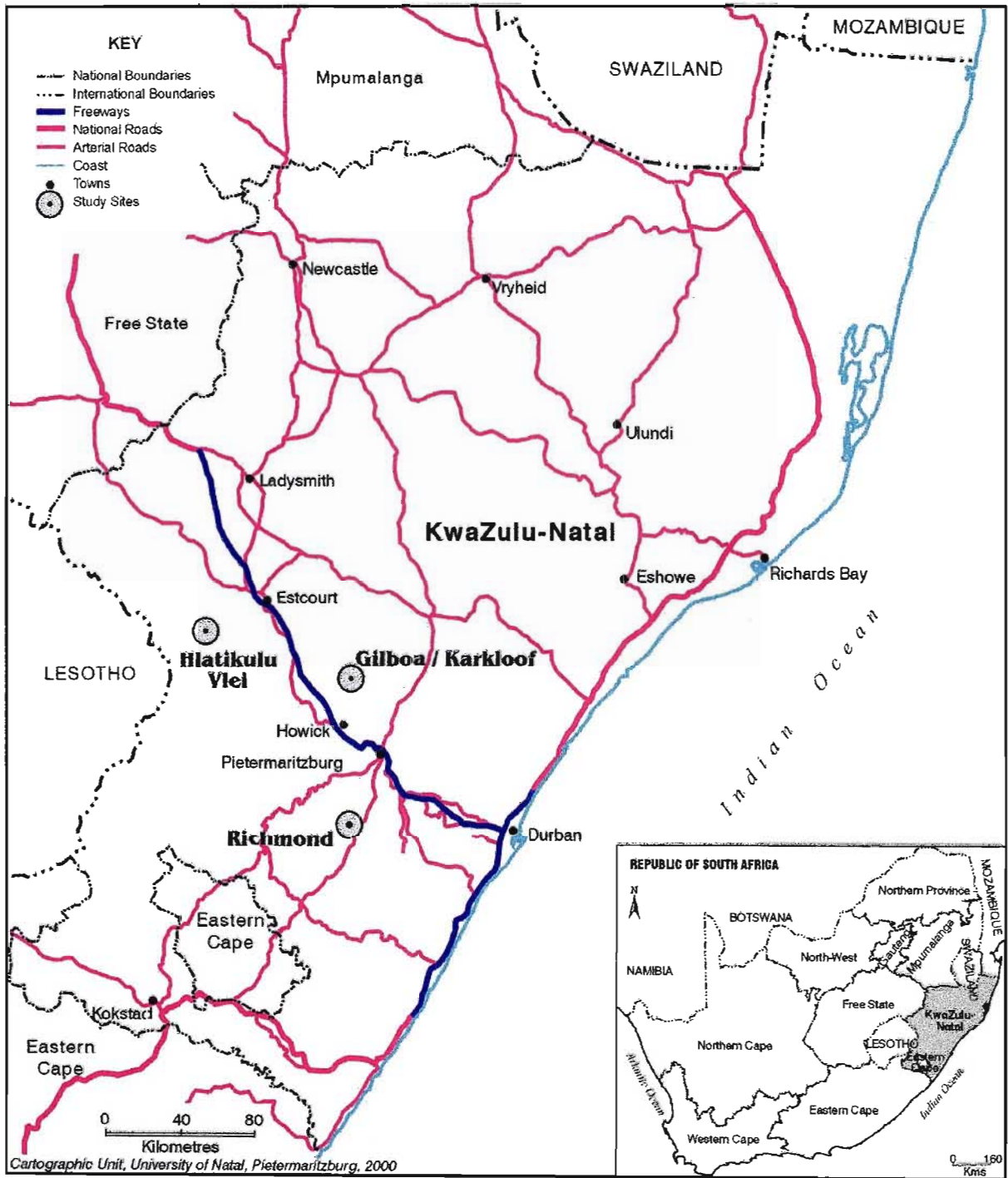
Figure 5.1: A map depicting the study areas which are located in the province of KwaZulu-Natal, South Africa.

5.2.1 The Hlatikulu Vlei Area

This area is at the foot of the Drakensberg Mountains in the vicinity of Giants Castle. The area consists of a vlei / wetland currently being rehabilitated (Figure 5.2). The area in and around the vlei has been heavily planted with exotic timber (Figure 5.3). There is also evidence of construction on the vlei (Figure 5.2). The rainfall in this area is very high and it is regarded as an important catchment area.

Figure 5.2: A view of the location of the Hlatikulu Vlei, which is at the base of the Drakensberg surrounded by steep hills. In the foreground is a building erected on the vlei.

Figure 5.3: The Hlatikulu vlei is heavily forested with exotic timbers. Some of these plantations lead right to the waters edge.

The land in the vlei is relatively flat with a few rises, the area around the vlei is steep with highly erodible soil. This was evident when an inspection of the area revealed evidence of erosion from a possible flash flood. Currently the vlei seems to be recovering even though there is still timber growing in it. The South African Crane Foundation has premises on the vlei where rare and endangered species of crane, such as the wattled crane, are bred.

In the past, land use planning for this area seems to have been done on a trial and error basis. This has led to the destruction of the wetland and associated ecosystem hence the subsequent need to rehabilitate it. The past destruction of the wetland could have been due to ignorance and poor planning as well as the Weltanschauung (world view) of the past era regarding wetlands. That is; if a wetland was regarded, in the past, as a waterlogged area of wasteland versus the current Weltanschauung which regards wetland as being crucial to the survival of rivers as well as attenuating floods. The past Weltanschauung contributed to the destruction of this wetland while the present Weltanschauung contributes to its rehabilitation.

5.2.2 The Gilboa Area

This area is situated in the scenic Natal Midlands, outside Howick. The area is hilly with the occasional vlei. Being in the midlands mistbelt, it also has a high rainfall though not as high as the Hlatikulu vlei. The main activity in this area is commercial forestry, with pockets of indigenous forest (Figures 5.4 and 5.5).

This area is home to several endemic species one of the more famous being the Karkloof Blue butterfly, the symbol of the tourism organisation called the Midlands Meander. The indigenous forests provide some unique habitats and ecosystems in the area. The landscape and scenery, such as the Karkloof Falls, in this area provides some suitable sites for tourism.

Figure 5.4: Indigenous meets Exotic. A tract of exotic timber planted adjacent to a pocket of indigenous forest.

Figure 5.5: A dense blanket of indigenous forest covering a side of a hill in the Gilboa/Karkloof Area.

In the past this area was heavily logged and deforested for its valuable yellowwood (Podocarpus species) timber. The (about 100 year old) tracks and furrows caused by timber being dragged across the forest floor are still visible in the indigenous forests. Almost all the large yellowwood,

and other species of, trees have been removed from these forests which were then abandoned and left to rehabilitate. Some of the areas that were heavily deforested are now commercial forestry plantations.

5.2.3 The Richmond Area

The Richmond area has some of the most diverse land use patterns. At the center of this area is Richmond town, an urban area. Surrounding the town is a mosaic of cultivated lands (Figure 5.6) with timber, sugarcane, citrus orchards and at least one cut flower grower. The rainfall in Richmond is not as high as Hlatikulu but it has a warmer climate favouring plant growth.
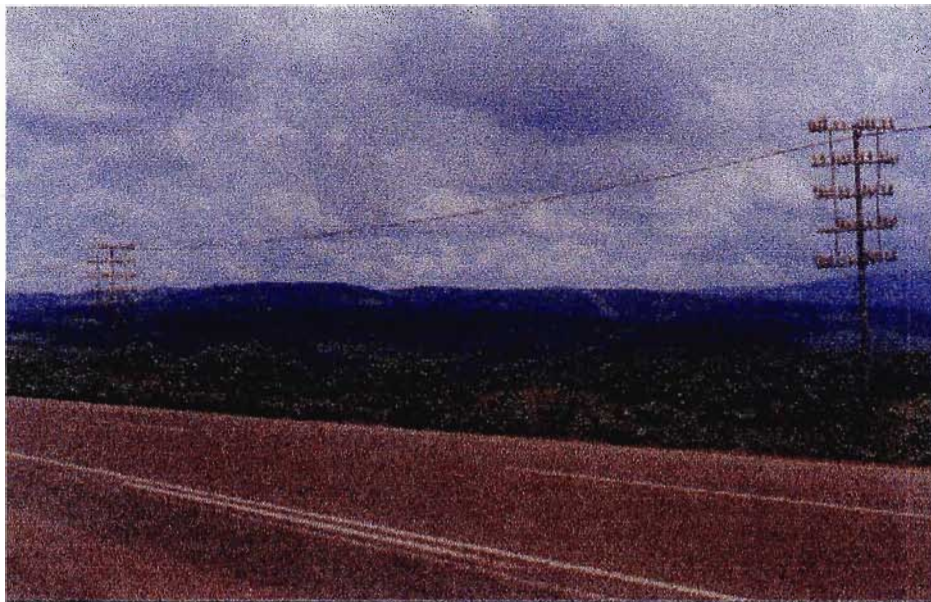
Figure 5.6: A plate of the Richmond area. The good road indicates that this place is near an urban centre. The land in the background shows a mosaic of cultivated lands with sugarcane, timber and citrus.

The Richmond area is developed for urban and agricultural purposes. Little remains of any indigenous areas. Poverty stricken people live in the townships surrounding the town. The Richmond area is ripe for development strategies in land use.

5.3 Assessing Land Suitability with the MCDA Model

The technique developed in Chapter 4 was used to assess land suitability with regards to natural resource management in these areas. The areas 1 to 5 in Figure 4.11 were replaced with

Hlatikulu, GilboaArea and RichmondArea (Figure 5.7). Table 5.1 provides the total weights of each of the activities for each area. A detailed Expert Choice printout is provided in the Appendix.

Inputs in the form of absolute ratings of the sub-criteria were provided by experts from the KZNNCS, KZN - Department of Agriculture, ATI consulting and Mondi forests. Most of these experts were the same people who provided the judgements that went into the hierarchical model.

The output of the model (Figure 5.7) is presented as Tables 5.1, 5.2 and 5.3. These tables are used in a similar fashion as presented in Chapter 4, section 4.3.1. The numerical values of the absolute ratings are given in Figure 5.1, this also illustrates which sub-criteria play the greatest role in deciding the potential land use of a particular area. Figure 5.2 shows the environmental or economical worth of a particular land use. Table 5.3 illustrates the numerical values of the activities thus suggesting potential land uses.
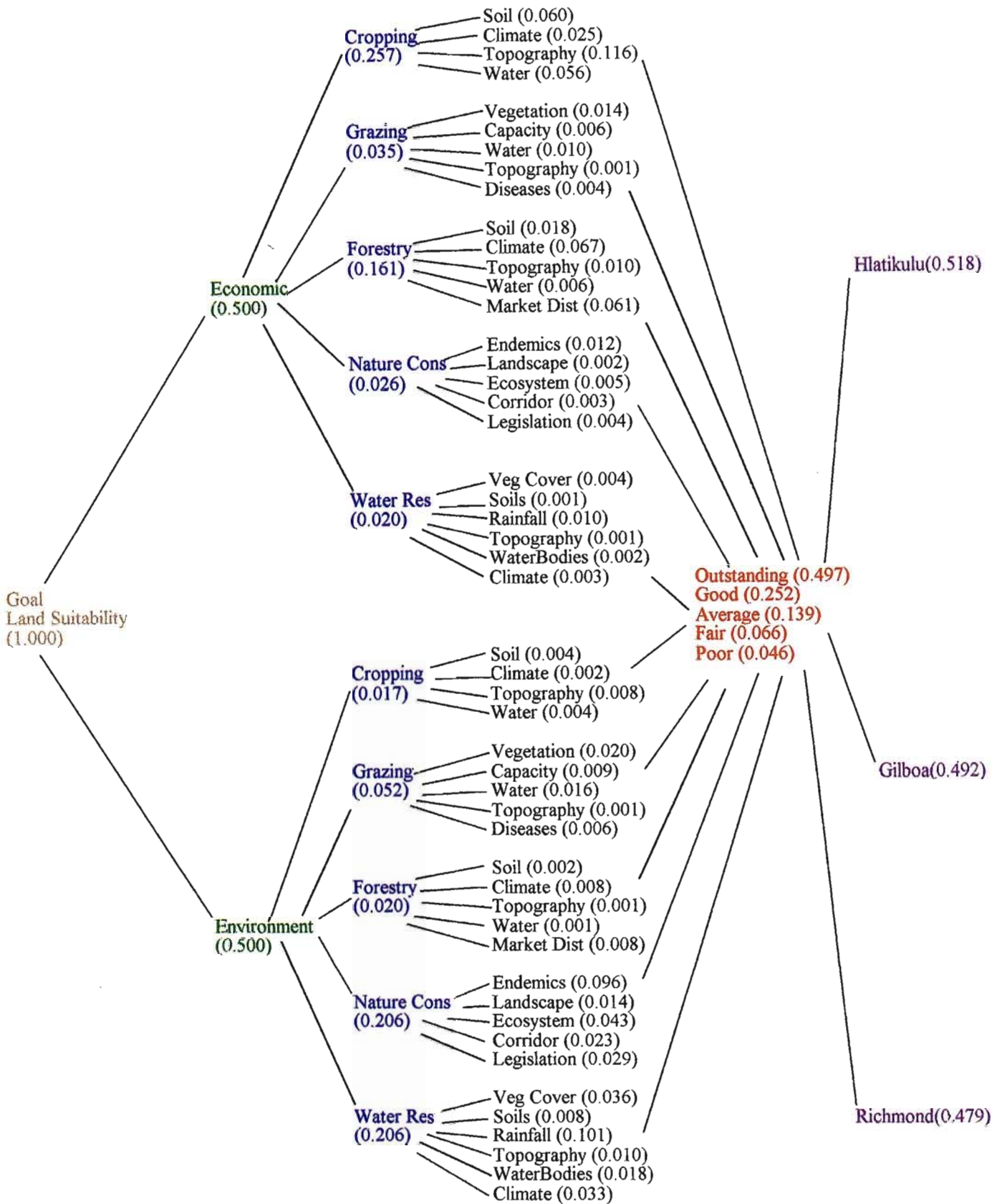
Figure 5.7: Hierarchical representation of the problem of prioritization of the criteria and activities towards the overall goal of finding the best use of land from a natural resources perspective for the Hlatikulu, Gilboa and Richmond areas.

Table 5.1: Ratings of each specific land area considering relevant sub-criteria for each of the potential land uses, done separately for the economic and environmental criteria. (The Appendix, Table A10 gives the verbal equivalent of this table.)

Economic									
Cropping				Grazing					
Soil	Climate	Topography	Water	Vegetation	Capacity	Water	Topography	Diseases	
Hlatikulu	0.0169	0.0033	0.059	0.0283	0.0069	0.0029	0.0053	0.0005	0.0012
Gilboa Area	0.0169	0.0069	0.0155	0.0283	0.0018	0.0008	0.0053	0.0003	0.0012
Richmond Area	0.0169	0.0126	0.0324	0.0283	0.0012	0.0005	0.0053	0.0003	0.0012

Forestry					Nature C				
Soil	Climate	Topography	Water	Market Dist	Endemics	Landscape	Ecosystem	Corridor	Legislation
Hlatikulu	0.0092	0.0188	0.0048	0.0029	0.0169	0.0062	0.0009	0.0028	0.0015	0.0005
Gilboa Area	0.0092	0.0342	0.0027	0.0029	0.0308	0.0123	0.0009	0.0055	0.0015	0.0019
Richmond Area	0.0092	0.0674	0.0048	0.0029	0.0606	0.0062	0.0002	0.0015	0.0008	0.0011

Water Re						Environ Cropping			
Veg Cover	Soils	Rainfall	Topography	WaterBodies	Climate	Soil	Climate	Topography	Water
Hlatikulu	0.0018	0.0007	0.0099	0.0003	0.0017	0.0032	0.0011	0.0002	0.0038	0.0018
Gilboa Area	0.0018	0.0004	0.005	0.0003	0.0009	0.0016	0.0011	0.0004	0.001	0.0018
Richmond Area	0.0018	0.0004	0.005	0.0003	0.0009	0.0016	0.0011	0.0008	0.0021	0.0018

Grazing					Forestry				
Vegetation	Capacity	Water	Topography	Diseases	Soil	Climate	Topography	Water	Market Dist
Hlatikulu	0.0103	0.0043	0.0079	0.0007	0.0018	0.0011	0.0023	0.0006	0.0004	0.0021
Gilboa Area	0.0027	0.0011	0.0079	0.0004	0.0018	0.0011	0.0043	0.0003	0.0004	0.0038
Richmond Area	0.0019	0.0008	0.0079	0.0004	0.0018	0.0011	0.0084	0.0006	0.0004	0.0075

Nature C					Water Re						
Endemics	Landscape	Ecosystem	Corridor	Legislation	Veg Cover	Soils	Rainfall	Topography	WaterBodies	Climate	Total
Hlatikulu	0.0488	0.007	0.0217	0.0119	0.0039	0.0184	0.0075	0.1009	0.0028	0.0176	0.0331	0.518
Gilboa Area	0.0962	0.007	0.0428	0.0119	0.015	0.0184	0.0038	0.0512	0.0028	0.0089	0.0168	0.492
Richmond Area	0.0488	0.0018	0.0119	0.0065	0.0082	0.0184	0.0038	0.0512	0.0028	0.0089	0.0168	0.479

Table 5.2: The overall rating of each of the potential land uses that can be undertaken in the areas with regard to economic development and environmental preservation in the Hlatikulu, Gilboa and Richmond areas.

Rank	Areas	Economic					Environment					Total
		Cropping	Grazing	Forestry	Nature C	Water Re	Cropping	Grazing	Forestry	Nature C	Water Re	
1	Hlatikulu	0.1075	0.0168	0.0526	0.0119	0.0176	0.0069	0.025	0.0065	0.0933	0.1803	0.5184
2	Gilboa Area	0.0676	0.0094	0.0798	0.0221	0.01	0.0043	0.0139	0.0099	0.1729	0.1019	0.4918
3	Richmond Area	0.0902	0.0085	0.1449	0.0098	0.01	0.0058	0.0128	0.018	0.0772	0.1019	0.4791

Table 5.3: The total ratings of the potential land uses for each area.

Rank	Area	Cropping	Grazing	Forestry	Nature C	Water Re	Total
1	Hlatikulu	0.1144	0.0418	0.0591	0.1052	0.1979	0.5184
2	Gilboa Area	0.0719	0.0233	0.0897	0.195	0.1119	0.4918
3	Richmond Area	0.096	0.0213	0.1629	0.087	0.1119	0.4791

5.4 Interpreting the Output of the Case Studies

The Hlatikulu Vlei area (0.5184) is ranked the highest (Table 5.2 and 5.3) in terms of the natural resources that it possess. The Gilboa area (0.4918) is ranked second followed by the Richmond area (0.4791). As in Chapter 4, Section 4.3.2; this merely ranks the natural resources for property value or taxation purposes and does not give an indication of which land use is suited to a particular area. In order to do this the individual values for each land use must be taken into account.

Hlatikulu Vlei Area

This area has the highest values for water resource conservation (0.1979) and nature conservation (0.1052) and hence should be kept for these purposes. Nature conservation and water resource management can be undertaken at the same time on this same area of land. This means that the values for nature conservation and water resource management are additive hence outweighing the values for other potential land uses.

Cropping (0.1144) got a high value because of its high economic worth (Table 5.2) and the flat land of the vlei led to a high value for topography (Table 5.1). However, due to the high conservation value (eg presence of the Crane Foundation) with endangered crane species as well as the water resource value of the wetland, cropping should not be carried out. Also the steep slopes and around the vlei is prone to erosion.

Gilboa Area

Nature conservation (0.1119) received the highest value for Gilboa. This was because Gilboa had the largest incidence of endemic species (Table 5.1). This is likely due to the number of indigenous forest patches as well as the Karlkloof Blue Butterfly which is endemic to the area.

Water resource conservation (0.119) recieved the second highest value, followed by forestry.

This could be due to the large difference in values between "Outstanding (0.479)" and "Good (0.252)". This was pointed out by the forestry candidate who suggested an intermediate rating such as "Excellent". So some of the criteria under forestry was rated Good instead of Excellent, giving forestry a disadvantage. However, the Gilboa/Karkloof area is a large one with enough land to support multiple land usage; so if sites of conservation importance are well conserved, the remainder of the land can be used for other activities. The poor value for grazing (0.0233) can be mainly attributed to its low economic value (Table 5.2) and poor vegetation (Table 5.1) since the grasslands in this area have been degraded due to poor decision making and management in the past.

Richmond Area

Forestry (0.1144) received the overwhelmingly highest value in this area, indicating that this area is best suited to forestry. Water resource conservation (0.1119) received the second highest value mainly due to the high rainfall (Table 5.1). Cropping (0.096) received the third highest value. Again this area is large and there is room for alternate land uses.

Discussion

Generally cropping faired more poorly than forestry in Gilboa and Richmond. This is because forestry can be undertaken on steeper slopes than cropping and the soils in the area are said to be acidic and trees tolerate soil acidity better than crops. Grazing generally faired poorly due to its poor economic worth and the poor vegetation due to mismanagement of the grasslands. Water resource management was prominent in all areas largely due to the high rainfall received in these areas as well as the water bodies such as rivers and wetlands. The recommendations regarding water resource management are also in line with current legislation which affords protection to areas such as wetlands, indicating that legal issues can be incorporated into such a model without adversely affecting the outcome.

The issue of an intermediate rating such as "Excellent" needs to be investigated. This means that the process of developing the model would have to be reiterated since some of the experts may want to change their ratings from either "Good" or "Outstanding" to "Excellent". However due to the robust nature of the AHP the final outcome may not be very much different but a re-

iteration would need to be carried out to assess this.

The results that emerged from this case study is consistent with what some of the stakeholders expected from, and what is currently happening in these areas. This indicates that the MCDA process does yield tangible results. Further reiteration of this process may be necessary to properly address some of the issues and identify new ones. Besides the point about their being too big a difference between Good and Outstanding, other points were raised. Some participants preferred to have the areas properly delineated, while the person who suggested that these areas be used in the case study wanted to see if this model can work on a regional basis. There has been a concern that current levels of transformation of the land may impact on the choice of ratings. This concern is valid and perhaps during a reiteration of this process criteria such as "potential for rehabilitation" be included. Some participants preferred to have the model in the relative mode of AHP. However, this mode would work only for less than seven areas at a time, this model was designed for more. During this exercise it emerged that the current model needs more issues and criteria in order to be more effective in land suitability decision making. These issues could be identified and modelled during further reiterations of the MCDA process. Further suggestions for future research is presented in the next chapter.

5.5 Acceptance of the Process

Generally the stakeholders who provided input into this model felt comfortable with the techniques used. As mentioned in chapter 3 the Biodiversity section of the KZNNCS uses the AHP extensively in its decision making. Other stakeholders who were not familiar with MCDA and AHP also felt a need for this technique. Enquiries were made for specific models dealing with issues such as:

• Decision making on land usage for the 590 bioresource groups, by the Bioresource Programme at Cedara (Camp, K. - Pers Comm., 1999) and

• Decision making on what species, cultivar and clones to use in specific environments by Mondi Forests (Gardiner, P. - Pers Comm., 1999).

These requests highlight the need for decision making incorporating objective and subjective criteria. The reiterative process of MCDA appealed to the stakeholders and reiteration is what is needed to incorporate some of the issues identified in the next chapter, for future research.

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5.6 Conclusion to the Case Studies

The model was found to be relevant to decision making in natural resource management since it allows for the incorporation of local knowledge and expert opinion to substitute for gaps in the knowledge in natural resource management. This indicates that the model is flexible enough to combine general principles with a deep consideration of the local conditions to produce effective decision support. This point is substantiated in the outcome of the case studies, where the model validates current land uses, land uses which were derived in the past by years of decision making combined with a "trial and error" approach.

The participants in this process displayed a keen interest in MCDA and the AHP. They understood and accepted the process of AHP in developing the model and wished to test and use the model personally themselves. It was through this participatory approach that MCDA was found to be a suitable process to create a DSS in land suitability with regard to natural resource management, as illustrated in the next chapter.

Chapter 6: Conclusion

6.1 On the Theoretical and Practical Outcomes of this Research

The goal of this project is to test the process of using MCDA and AHP in particular in developing a DSS for land suitability in natural resource management. It was found that MCDA is a suitable approach to develop such a DSS due to its ability to incorporate stakeholders and subjective information into the decision making process. The process implemented in this project has major implications for decision making in South Africa. It involves a paradigm shift from the rational approach to the systems approach.

The paradigm shift to the systems approach in decision making takes into account the stakeholders in the process. This has the effect of empowering those who would be affected by the outcome(s) of the decision making process. Stakeholders do, however, need to be well informed about the problem structuring techniques in order to obtain the full benefits of the systems approach. Only then, would the stakeholders be able to take ownership of the process and hence would be likely to accept the outcome of the decision. A stakeholder analysis helps in identifying the stance different stakeholders take on an issue. This aids in grouping the stakeholders and then encouraging debate over the issue.

Problem structuring techniques assist in understanding the problem situation and not necessarily finding a solution to the problem. This is accomplished by identifying the problem, developing alternatives, choosing alternatives, implementing the chosen alternative, monitoring the impacts of this and eventually performing a feedback or reiteration of the process. Information technology assists this process with computers performing the mathematics leaving the stakeholders free to concentrate on the problem.

There are several problem structuring techniques available such as stakeholder analysis and soft systems methodology (SSM). The most suitable approach for this study was a combination of stakeholder analysis and the AHP, to ensure that all views of relevant stakeholders are incorporated in the model. Belton's (1999) approach was used for the MCDA, which consists of cyclical steps to identify the problem, then structure the problem, build the model and

evaluate and implement the model. There is a feedback mechanism which provides feedback to each step, leading to a reiteration of the process.

In South Africa, decision making with regards to land suitability is largely performed using the rational method. This method has the disadvantage of distancing stakeholders from the decision making process leading to poor implementation of the decision since the stakeholders do not feel part of the process. The rational approach loses its efficiency if there is a lack of hard data or gaps in the knowledge, this is prevalent especially in natural resource management.

This research used a combination of stakeholder analysis and the cyclical, systems approach of MCDA to address the issue of land suitability in natural resource management. This has led to the development of an AHP model which uses inputs from hard systems such as GISs, databases, statistics and linear programmes integrated with soft systems such as expert opinions and local knowledge. These inputs can come from different organisations such as government departments, non-governmental organisations and commercial companies. This DSS had the effects of facilitating communication between these organisations and providing a decision support framework in the field of land suitability with regard to natural resource management.

The model consists of a goal which was land suitability in natural resource management, namely, what to do with a piece of land in terms of agriculture, forestry, nature conservation and water resource management. The second level of the hierarchy consisted of the criteria "Economic" and "Environmental". This is to assess to what degree the activities (from the third level of the hierarchy); "Cropping", "Grazing", "Forestry", "Nature Conservation" and "Water Resource Management"; are either environmentally friendly or yields the greatest economic returns. The fourth level of the hierarchy contains the sub-criteria for each of the activities, these sub-criteria are to assess the degree to which the relevant activities are feasible on that area of land. In this model, the absolute mode of AHP was used which enables each of the sub-criteria to be rated. The ratings were Outstanding, Good, Average, Fair and Poor. The final level of the hierarchy contained the alternative areas of land. These areas of land were rated according to the sub-criteria in order to determine which activity had the highest value followed by the second, third, etc. These values were then used as guidelines to which activity is the most suitable; as

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well as second, third, etc. choices; for that area of land.

Three well researched areas of land were chosen as case studies to test the DSS. These areas are the Hlatikulu Vlei area, the Gilboa / Karkloof area and the area around the town of Richmond. All these areas have high potential land, leading to competition for it. The results of the model were conducive to what other systems (after some failed cases of trial and error such as the damage and now rehabilitation of the Hlatikulu vlei) had proposed for land use.

While developing this DSS it became evident that when experts gave their judgement on an issue, they were calling upon their own ethical values as well as decades of experience in their field. This knowledge is then stored in the DSS for others to base their decision upon. This is a valuable form of knowledge storage, hence infrastructure. If a key person leaves an organisation or process, their knowledge can be stored in systems like the one used in this study allowing work to proceed.

It was also evident that gaps in the hard data on natural resource management could to a certain extent be substituted with the more softer expert opinion and local knowledge. While the expert opinion and local knowledge may contain elements of subjectivity, this can be overcome by choosing the most knowledgeable people available. Currently it may take too long or the technology does not exist to quantify certain observations and judgements but these could be analysed using a soft systems approach. However, as science progresses, the soft systems of today may become the hard scientific systems of tomorrow.

The systems approach to problem solving such as MCDA with its reiteration cycles are designed to be all encompassing and never-ending. However, in real life there are time constraints and solutions are needed urgently. This project faced a time and budgetary constraint, so the cycles of reiteration were limited, however, this work is to merely establish a process by which MCDA can be used in developing a DSS for land suitability with regard to natural resource management. The issue of land suitability is a very broad one, this project dealt with land suitability in a natural resource context but in order to have a comprehensive land suitability DSS other land uses must be considered. During the course of this research certain issues were identified that would be suitable for future research.

6.2 Recommendations for Future Research

During the course of this research several factors were identified that should be included in future research:

- A reiteration of the MCDA process in order to incorporate a rating of "Excellent" as an intermediate value between "Good" and "Outstanding"
- Incorporation of more cultural and socio-economic issues
- Incorporation of more land uses outside the scope of natural resources; such as urbanisation, industrialization and transport
- More legal matters should be included into the model
- Separate hierarchies should be developed for each of the potential land uses for each organisation that deals with theses land uses.

More details of these recommendations are provided below:

Land suitability in natural resource management is not only the realm of the natural resource managers. The issue of land has cultural, religious, historical and socio-economic value. Due to time constraints, these issues were not fully explored. For instance the activity "grazing" is more than just an economical issue to the Zulu culture. To the Zulu people, cattle represent economical value, status and cultural values such as the practise of "lobola". Hence the use of land for grazing might be given higher priority than some of the other activities. This would, however, need to be tested in a more case based situation. Another social issue that needs to be dealt with, in this model, is crime. Theft of stock and fresh produce has made these activities non-viable in some areas and farmers are resorting to other activities. This may also be another factor to include in a case study.

In this DSS the possible land usage (activities) are looked at in a broad sense however once a particular activity has been chosen for a piece of land, it would need to be investigated further. This could be done by contacting the relevant organisation, representing this activity, for more information. However, a more detailed investigation of this activity may need another hierarchy. Examples of which are given in Chapter 3, section 3.2.1.

When looking at land suitability in its broadest sense, it becomes evident that other issues are missing. For instance activities such as urbanisation, industrialisation, transport, recreation and tourism could be added onto the hierarchy represented in Figure 4.11 to give a more comprehensive DSS on land suitability. Elements of it can be incorporated in similar MCDM models.

Legislation plays an important role in a decision making process. The suggested model does include some legislation (even though the IUCN agreement is currently still a guideline) in the nature conservation activity but more is needed. This is especially the case for water resource management. So an area of future research could be to include the legislation into a comprehensive land suitability DSS.

A broad and practically important future area for research would be to explore how such a model can be used in practice by real life users. It will provide further insights for its improvement. It will also reveal more how real decisions on this important issue are made. However, this was outside the scope of this research given the time limitations on it.

The above issues are just some of the suggestions for future research into a DSS for land suitability. This project did not have sufficient time and financing to research all those criteria. However, the groundwork for the process of producing such a DSS has been developed in this project which can be used in future research to produce a more comprehensive land suitability DSS.

References

Alphonce, C. B. 1997. Application of the Analytic Hierarchy Process in Agriculture in Developing Countries. *Agricultural Systems.* **53**, 97-112.

Atkinson, C. J. 1989. Ethics: A Lost Dimension in Soft Systems. *Journal of Applied Systems Analysis.* **16**, 43-53.

Bailey, K. D. 1998. Social Ecology and Living Systems Theory. *Systems Research and Behavioral Science.* **15**, 421-428.

Banville, C.; Landry, M.; Martel, J. and Boulaire, C. 1998. A Stakeholder Approach to MCDA. Systems Research. **15**, 15-32.

Bawden, R. J.; Ison, R. L.; Macadam, R. D.; Packham, R. G. and Valentine, I. 1985. Farming Systems Research in Theory and Practise. *ACIAR Proceedings No 11: Agricultural Systems Research for Developing Countries.* ACIAR, Canberra, Australia. 31-42.

Bawden, R. J. and Packham, R.G. 1998. Systemic Praxis in the Education of the Agricultural Systems Practitioner. *Systems Research and Behavioral Science.* **15**, 403-412.

Belton, V. 1999. Multi-Criteria Problem Structuring and Analysis in a Value Theory Framework. To appear in, Stewart, T.; Gal, T. and Hanne, T. (eds). *Advances in Multicriteria Decision Making.* Kluwer Publ., Boston.

Brouwer, R. and Jansen, K. 1989. Critical Introductory Notes on Farming Systems Research in Developing Third World Agriculture. *Systems Practise.* **2**(4), 379-395.

Camp, K. 1999. *Guide to the Use of the Bioresource Programme.* Cedara Agricultural Development Institute, South Africa.

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Checkland, P. and Holwell, S. 1998. *Information, Systems and Information Systems: Making Sense of the Field*. John Wiley and Sons, Chichester, England.

Checkland, P and Scholes, J. 1993. *Soft Systems Methodology in Action*. John Wiley & Sons, Chichester, England.

Conway, G. R. 1985a. Agroecosystem Analysis. *Agricultural Administration*. **20**, 31-55.

Conway, G. R. 1985b. Agricultural Ecology and Farming Systems Research. *Farming Systems Research in Theory and Practise. ACIAR Proceedings No. 11: Agricultural Systems Research for Developing Countries*. ACIAR, Canberra, Australia. 43-59.

Dale, A.; Cowell, S.; Bellamy, J.; Zhu, X. and Bischof, R. 1999. Placing Decision Support Tools in Context: Where Do They Fit in a Planning Systems Approach to Natural Resource Management? *The 2nd International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Darke, P. and Shanks, G. 1996. Stakeholder Viewpoints in Requirements Definition: A Framework for Understanding Viewpoint Development Approaches. *Requirements Engineering*. 1, 88-105.

Duivenbooden van, N. 1995. *Land Use Systems Analysis as a Tool in Land Use Planning with Special Reference to North and West African Agro-Ecosystems*. Doctoral Thesis, Wageningen Agricultural University, Wageningen, The Netherlands.

Expert Choice Inc. 1993. *Expert Choice Version 8*: User Manual. Decision Support Software, Mclean, Virginia.

Farthing, B. and Mengersen, K. 1999. A Review of Decision Support Systems Used in the Management of a Natural Resource. *The 2nd International Conference on Multiple Objective Decision Support Systems. 1-6 August 1999*, Brisbane, Australia.(Unpublished).

Flood, R. L. 1995. *Solving Problem Solving: A Potent Force for Effective Management*. John Wiley & Sons, Chichester.

Hamalainen, P. R. 1988. Computer Assisted Energy Policy Analysis in the Parliament of Finland. Interfaces. **18** (4 July-August), 12-23.

Hamalainen, P. R. 1990. A Decision Aid in the Public Debate on Nuclear Power. *European Journal of Operational Research*. **48**, 66-76.

Harrison, S. R. and Qureshi. M. E. 1999. Choice of Stakeholder Groups and Members in Multi-Criteria Decision Models. *The 2nd International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Hella, J. P.; Huylenbroeck, L. D.; D'Haese, L. and Ashimogo, G. C. 1999. Multi-Criteria Nature of Decision Making in Smallholder Farming Systems in Semi-Arid Tanzania. *The 2nd International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Hoag, D.; Page, S. and Ascough, J. 1999. Using the Analytic Hierarchy Process to Determine Economic and Environmental Tradeoffs on Farms. *The 2nd International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Itami, R. M. and MacLaren, G. 1999. The Victorian Catchment Management and Sustainable Agriculture Decision Support System. *The 2nd International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Keeny, R. L.1992. *Value-Focused Thinking: A Path to Creative Decision Making*. Harvard University Press, Cambridge, Mass.

Keeney, R. L. 1996. Value-Focused Thinking: Identifying Decision Opportunities and Creating Alternatives. *European Journal of Operational Research*. **92**, 537-549.

Keeny, R. L. and Raiffa, H. 1976. *Decisions with Multiple Objectives: Preferences and Value Tradeoffs*. Wiley, New York.

Lane, D. C. and Jackson, M. C. 1995. Only Connect! An Annotated Bibliography Reflecting the Breath and Diversity of Systems Thinking. *Systems Research.* **12**(3), 217-228.

Liao, L. 1998. A Systematic Integration Model to Support Complex Decision-Making in a Dynamic Environment. *Syst. Res.* **15**, 33-45.

Malczewski, J.; Moreno-Sanchez, R.; Bojorquez-Tapia, L. A.; and Ongay-Delhumeau, E. 1997. Multicriteria Group Decision-Making Model for Environmental Conflict Analysis in the Cape Region, Mexico. *Journal of Environmental Planning and Management.* **40**(3), 349-374.

Martin, A. P. 1985. *The First Order of Business: Testing the Validity of the Objectives.* Professional Development Institute, Ottawa.

Mason, R. O. and Mitroff, I. I. 1981. *Challenging Strategic Planning Assumptions*. Wiley, New York.

Mawapanga, N. M.. and Debertin, D.L. 1996. Choosing Between Alternative Farming Systems: An Application of the Analytic Hierarchy Process. *Review of Agricultural Economics.* **18**, 385-401.

Norman, D. and Collinson, M. 1985. Farming Systems Research in Theory and Practise. *ACIAR Proceedings No 11: Agricultural Systems Research for Developing Countries.* ACIAR, Canberra, Australia. 16-30.

Palonen, J. and Mattila, P. 1992. Decision Support System for Field Crop Cultivation. *International Conference on Agricultural Engineering.* Paper No 920801.

Pers Comm (Personal Communication)

- Bainbridge, W. R. 1999. Wilderness Action Group, Pietermaritzburg, South Africa.

- Camp, K. 1999. KwaZulu-Natal Department of Agriculture, Cedara, South Africa.

- Gardiner, P. 1999. Mondi Forests, Pietermaritzburg, South Africa.

- Goodman, P. S. 1999. KwaZulu-Natal Department of Nature Conservation Service, Pietermaritzburg, South Africa.

- Rivett-Carnac, J. 1999. ATI Consulting, Pietermaritzburg, South Africa.

- Whitwell, P. 1999. KwaZulu-Natal Department of Agriculture, Cedara, South Africa.

Petkov, D. and Gialerakis, A. 1997. On Some Applications of AHP as a Group Decision Support Tool in University Management. *Management Dynamics*. 6(1) 26-44.

Petkov, D.1995. A model for the prioritisation of factors affecting child survival. *Development Southern Africa*. **12** (6), 815-822.

Saaty, T. L. 1990(a). *Decision Making for Leaders: The Analytic Hierarchy Process for Decisions in a Complex World*. University of Pittsburgh, USA.

Saaty, T. L. 1990(b). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation*. University of Pittsburgh, USA.

Saaty, T. L. 1979. Modelling unstructured decision problems - the theory of analytical hierarchies. *Mathematics and Computers in Simulation*. **20**, 147-158.

Saaty, T. L. (Unpublished). *Prioritization of Environmental Impacts Using Hierarchic Structures*.

Saaty, T.L. and Alexander, J.M. 1989. *Conflict Resolution: The Analytic Hierarchy Apporach*. *Praeger*, New York, USA.

Saaty, T. L. and Vargas, L. G. 1991. *The Logic of Priorities, Applications in Business, Energy, Health and Transport. Vol III, The Analytic Hierarchy Process Series*. RWS Publications, Pittsburgh, USA.

Saaty, T. L. and Kearns K. P. 1991. *Analytic Planning, The Organisation of Systems. Vol IV, The Analytic Hierarchy Process Series*. RWS Publications, Pittsburgh, USA.

Savage, G. T.; Nix, T. W.; Whitehead, C. J. and Blair, J.D. 1991. Strategies for Assessing and Managing Organisational Stakeholders. *Academy of Management Executive*. **5**, 61-75.

Schulze, R. E. 1995. *Hydrology and Agrohydrology: A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System*. University of Natal, Pietermaritzburg, South Africa.

Smith, J. M. B. 1996. Crop, Pasture and Timber Yield Estimates for KwaZulu-Natal. *Cedara Report No. N/A/94/4*, KwaZulu-Natal Department of Agriculture, Cedara, South Africa.

Van der Westhuizen, C. and Viljoen. M. F. 1999. The Relationship Between the Application of Multiple Objective Decision Support Systems (MODSS) and Management Performance of Farmers: A South African Experience. *The 2ⁿᵈ International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Viljoen, M. F. and Van der Westhuizen, C. 1992. The Implementation of Optimal Farm Plans Obtained from the Application of an Integrated Farm Planning Approach. *Agrekon*, **31**(2), 90-93.

Walker, D. H.; Byron, P. and Mayocchi, J. C. 1999. Decision Support for Integrated Natural Resource Management: Helping Resource Managers Explore New Issues. *The 2ⁿᵈ International Conference on Multiple Objective Decision Support Systems*. 1-6 August 1999, Brisbane, Australia.(Unpublished).

Weiner, E. and Brown, A. 1986. Stakeholder Analysis for Effective Issues Management. *Planning Review*. **May Vol.**, 27-31.

Whitehead, C. J.; Blair, J. D.; Smith, R. R.; Nix, T. W. and Savage, G. T. 1989. Stakeholder Supportiveness and Strategic Vulnerability: Implications for Competitive Strategy in the HMO Industry. *Health Care Management Review.* **14**, 65-76.

Whitley, D. L.; Wei-Ning, X. and Young, J. 1993. Use a GIS "Melting Pot" to Assess Land Use Suitability. *GIS World.* July.

Winkler, R. L. 1990. Decision Modelling and Rational Choice: AHP and Utility Theory. *Management Science.* **36**(3), 247-248.

Zeru, A. 1999. Decision Support for Water Resources Development: A Case Study in North-Gonder, Ethiopia. *The 2ⁿᵈ International Conference on Multiple Objective Decision Support Systems.* 1-6 August 1999, Brisbane, Australia.(Unpublished).

Zhu, X. 1999. MOCA: A Decision Support Tool for Project Evaluation and Prioritization in Regional Resource Use Planning. *The 2ⁿᵈ International Conference on Multiple Objective Decision Support Systems.* 1-6 August 1999, Brisbane, Australia.(Unpublished).

Appendix

This appendix provides the Expert Choice[R] output for the model presented in Chapter 4, Figure 4.11. This output shows the judgements that were given by experts for each of the criteria for each level of the hierarchy. The values in parenthesis ( ) are inverted i.e. (3) = 1/3. The priorities that are illustrated in Tables A1 . . . A are derived from the judgements. These judgements are based on the scale of intensities given in Chapter 2, Table 2.2. The priorities given here are the global priorities ie. they sum to 1.0 these priorities are then re-scaled to match the priorities given in Figure 4.11 which sum to the priority of the parent node (local priority).

The complete description of the criteria in each level of the hierarchy is given in Chapter 4, Section 4.2. However for presentation purposes, shorthand notation was used. This is explained in the following key:

Capacity = Carrying Capacity

Ecosyste = Ecosystem

Landscap = Landscape

Legislat = Legislation

Market D = Market Distance

Nature C = Nature Conservation

Outstand = Outstanding

Topograp = Topography

Vegetatn = Vegetation

Waterbod = Water bodies

Water Re = Water Resource Management/Conservation

Note that the judgements with respect to SOIL < CROPPING < ECONOMIC < GOAL provide the priorities for the ratings "Outstanding" to "Poor". These priorities apply to all the sub-criteria in the fourth level of the hierarchy.

Table A1: A matrix of pairwise comparisons of the possible land uses with respect to the economic criterion.

	Cropping	Grazing	Forestry	Nature C	Water Re	Priorities
Cropping	1	7.0	3.0	8.0	8.0	0.514
Grazing		1	(8.0)	2.0	2.0	0.070
Forestry			1	7.0	7.0	0.323
Nature C				1	2.0	0.053
Water Re					1	0.040

INCONSISTENCY RATIO = 0.063

Table A2: A matrix of pairwise comparisons of the possible land uses with respect to the Environment criteria.

	Cropping	Grazing	Forestry	Nature C	Water Re	Priorities
Cropping		(3.0)	(2.0)	(9.0)	(9.0)	0.033
Grazing			6.0	(7.0)	(7.0)	0.104
Forestry				(9.0)	(9.0)	0.040
Nature C					1.0	0.411
Water Re						0.411

INCONSISTENCY RATIO = 0.086.

Table A3: A matrix of pairwise comparisons of the sub-criteria determining the Cropping land use potential.

	Soil	Climate	Topograp	Water	Priorities
Soil		3.0	(2.0)	1.0	0.235
Climate			(3.0)	(3.0)	0.097
Topograp				3.0	0.452
Water					0.217

INÇONSISTENCY RATIO = 0.044.

Table A4: A matrix of pairwise comparisons of the sub-criteria determining the Grazing land use potential.

	Vegetatn	Capacity	Water	Topograp	Diseases	Priorities
Vegetatn		5.0	1.0	9.0	3.0	0.389
Capacity			(2.0)	5.0	3.0	0.164
Water				9.0	3.0	0.299
Topograp					(9.0)	0.028
Diseases						0.120

INCONSISTENCY RATIO = 0.098.

Table A5: A matrix of pairwise comparisons of the sub-criteria determining the Forestry land use potential.

	Soil	Climate	Topograp	Water	Market D	Priorities
Soil		(7.0)	3.0	5.0	(5.0)	0.112
Climate			7.0	7.0	1.0	0.418
Topograp				3.0	(7.0)	0.059
Water					(7.0)	0.036
Market D						0.376

INCONSISTENCY RATIO = 0.082

Table A6: A matrix of pairwise comparisons of the sub-criteria determining the Nature Conservation land use potential.

	Endemics	Landscap	Ecosyste	Corridor	Legislat	Priorities
Endemics		9.0	3.0	3.0	3.0	0.468
Landscap			(2.0)	(2.0)	(2.0)	0.067
Ecosyste				4.0	1.0	0.208
Corridor					1.0	0.114
Legislat						0.143

INCONSISTENCY RATIO = 0.060

Table A7: A matrix of pairwise comparisons of the sub-criteria determining the Water Resource Management/Conservation land use potential.

	Veg Cove	Soils	Rainfall	Topograp	Waterbod	Climate	Priorities
Veg Cove		5.0	(7.0)	3.0	5.0	1.0	0.177
Soils			(7.0)	(2.0)	(4.0)	(3.0)	0.037
Rainfall				7.0	5.0	3.0	0.491
Topograp					(3.0)	(4.0)	0.049
Waterbod						(3.0)	0.086
Climate							0.161

INCONSISTENCY RATIO = 0.094.

Table A8: A matrix of pairwise comparisons of the absolute ratings. Note that the priorities for the absolute ratings apply to all the criteria at the fourth level of the hierarchy.

	Outstand	Good	Average	Fair	Poor	Priorities
Outstand		2.2	4.1	7.0	9.0	0.497
Good			1.8	4.0	6.0	0.252
Average				2.2	3.3	0.139
Fair					1.5	0.066
Poor						0.046

INCONSISTENCY RATIO = 0.004

Table A9: Absolute ratings of the sub-criteria at the fourth level of the hierarchy. The numerical equivalent of the verbal ratings are given in Chapter 4, Table 4.3.

Economic

	Cropping				Grazing				
	Soil	Climate	Topography	Water	Vegetation	Capacity	Water	Topography	Diseases
1 Area4	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND
2 Area1	GOOD	GOOD	POOR	GOOD	OUTSTAND	OUTSTAND	GOOD	POOR	POOR
3 Area5	OUTSTAND	GOOD	GOOD	GOOD	FAIR	FAIR	GOOD	GOOD	GOOD
4 Area3	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5 Area2	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR

	Forestry					Nature Cons				
	Soil	Climate	Topography	Water	Market Dist	Endemics	Landscape	Ecosystem	Corridor	Legislation
1 Area4	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND
2 Area1	GOOD	GOOD	POOR	GOOD	GOOD	OUTSTAND	AVERAGE	GOOD	GOOD	AVERAGE
3 Area5	GOOD	GOOD	GOOD	GOOD	POOR	POOR	AVERAGE	AVERAGE	AVERAGE	FAIR
4 Area3	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5 Area2	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR

Environment

	Water Res					Cropping				
	Veg Cover	Soils	Rainfall	Topography	WaterBodie	Climate	Soil	Climate	Topography	Water
1 Area4	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND
2 Area1	OUTSTAND	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	POOR	GOOD
3 Area5	FAIR	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD
4 Area3	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5 Area2	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR

	Grazing					Forestry				
	Vegetation	Capacity	Water	Topography	Diseases	Soil	Climate	Topography	Water	Market Dist
1 Area4	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND
2 Area1	OUTSTAND	OUTSTAND	GOOD	POOR	POOR	GOOD	GOOD	POOR	GOOD	GOOD
3 Area5	FAIR	FAIR	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	FAIR
4 Area3	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE
5 Area2	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR

	Nature Cons					Water Res						
	Endemics	Landscape	Ecosystem	Corridor	Legislation	Veg Cover	Soils	Rainfall	Topography	WaterBodie	Climate	Total
1 Area4	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	OUTSTAND	1
2 Area1	OUTSTAND	AVERAGE	GOOD	GOOD	AVERAGE	OUTSTAND	GOOD	GOOD	GOOD	GOOD	GOOD	0.532
3 Area5	POOR	AVERAGE	FAIR	FAIR	FAIR	FAIR	GOOD	GOOD	GOOD	GOOD	GOOD	0.388
4 Area3	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	AVERAGE	0.279
5 Area2	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	POOR	0.092

Table A10: Absolute ratings of the sub-criteria at the fourth level of the hierarchy for the case study areas. The numerical equivalent of the verbal ratings are given in Chapter 5, Table 5.1.

	Economic									
	Cropping				Grazing					
	Soil	Climate	Topography	Water	Vegetation	Capacity	Water	Topography	Diseases	
1 Hlatikulu	AVERAGE	FAIR	GOOD	GOOD	GOOD	GOOD	GOOD	GOOD	AVERAGE	
2 GilboaArea	AVERAGE	AVERAGE	FAIR	GOOD	FAIR	FAIR	GOOD	AVERAGE	AVERAGE	
3 RichmondArea	AVERAGE	GOOD	AVERAGE	GOOD	POOR	POOR	GOOD	AVERAGE	AVERAGE	

	Forestry					Nature Cons				
	Soil	Climate	Topography	Water	Market Dist	Endemics	Landscape	Ecosystem	Corridor	Legislation
1 Hlatikulu	GOOD	AVERAGE	GOOD	GOOD	AVERAGE	GOOD	GOOD	GOOD	GOOD	FAIR
2 GilboaArea	GOOD	GOOD	AVERAGE	GOOD	GOOD	OUTSTAND	GOOD	OUTSTAND	GOOD	GOOD
3 RichmondArea	GOOD	OUTSTAND	GOOD	GOOD	OUTSTAND	GOOD	FAIR	AVERAGE	AVERAGE	AVERAGE

	Water Res						Environment			
							Cropping			
	Veg Cover	Soils	Rainfall	Topography	WaterBodie	Climate	Soil	Climate	Topography	Water
1 Hlatikulu	GOOD	OUTSTAND	OUTSTAND	AVERAGE	OUTSTAND	OUTSTAND	AVERAGE	FAIR	GOOD	GOOD
2 GilboaArea	GOOD	GOOD	GOOD	AVERAGE	GOOD	GOOD	AVERAGE	AVERAGE	FAIR	GOOD
3 RichmondArea	GOOD	GOOD	GOOD	AVERAGE	GOOD	GOOD	AVERAGE	GOOD	AVERAGE	GOOD

	Grazing					Forestry				
	Vegetation	Capacity	Water	Topography	Diseases	Soil	Climate	Topography	Water	Market Dist
1 Hlatikulu	GOOD	GOOD	GOOD	GOOD	AVERAGE	GOOD	AVERAGE	GOOD	GOOD	AVERAGE
2 GilboaArea	FAIR	FAIR	GOOD	AVERAGE	AVERAGE	GOOD	GOOD	AVERAGE	GOOD	GOOD
3 RichmondArea	POOR	POOR	GOOD	AVERAGE	AVERAGE	GOOD	OUTSTAND	GOOD	GOOD	OUTSTAND

	Nature Cons					Water Res						Total
	Endemics	Landscape	Ecosystem	Corridor	Legislation	Veg Cover	Soils	Rainfall	Topography	WaterBodie	Climate	
1 Hlatikulu	GOOD	GOOD	GOOD	GOOD	FAIR	GOOD	OUTSTAND	OUTSTAND	AVERAGE	OUTSTAND	OUTSTAND	0.518
2 GilboaArea	OUTSTAND	GOOD	OUTSTAND	GOOD	GOOD	GOOD	GOOD	GOOD	AVERAGE	GOOD	GOOD	0.492
3 RichmondArea	GOOD	FAIR	AVERAGE	AVERAGE	AVERAGE	GOOD	GOOD	GOOD	AVERAGE	GOOD	GOOD	0.479