GIS-BASED LAND SUITABILITY ASSESSMENT AND ALLOCATION DECISION-MAKING IN A DEGRADED RURAL ENVIRONMENT

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DECLARATION

I, the undersigned, hereby declare that the work contained in this thesis is my own original work and that I have not previously in its entirety or in part submitted it at any university for a degree.

Signature: ....

Date: ....

ACKNOWLEDGEMENTS

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> *"To exist as a nation, to prosper as a state, and to live as a people, we must have trees."*
>
> (U.S. President Theodore Roosevelt, 1902)

ABSTRACT

Rural development problems faced by the impoverished communities in the Transkei, South Africa, are numerous, and environmental degradation has already taken much of its toll. By working at a micro-catchment-level both the socio-economic and biophysical appreciation of the land resources were captured as encapsulated in the concept of resource management domains. Participatory decision-making allowed functional land use goals and evaluation criteria to be incorporated into computerised multi-criteria evaluation and multi-objective land use allocation models in order to reach an idealised or more sustainable land use situation. In the execution of the decision-making process seven procedural steps were followed, which are discussed in detail and applied in the case study. Synthesis of the results emphasised the envisaged rural planning potential of the methods used.

OPSOMMING

In terme van plattelandse ontwikkeling staar talle probleme die behoeftige gemeenskappe van Transkei, Suid-Afrika, in die gesig en omgewingsdegradering neem ongehinderd sy tol. Deur op ‘n mikro-opvangsgebied vlak te werk kon beide die sosio-ekonomiese en biofisiese waarde van die gebied se hulpbronne bepaal word en uitgebeeld word in hulpbron bestuursdomeine. Deur deelnemende besluitneming is funksionele grondgebruiksdoelwitte en evaluasie kriteria gebruik in gerekenariseerde meervoudige kriteria evaluering en veeldoelige grondgebruiksaanwysingsmodelle ten einde die ideale of ‘n meer volhoubare grondgebruik situasie te verkry. Vir die uitvoering van die besluitnemingsproses is van sewe opeenvolgende stappe gebruik gemaak en die uitvoering daarvan word in diepte bespreek in hierdie gevallestudie. Sintese van die resultate het die potensiaal van hierdie beoogde landelike beplanningsmetodes beklemtoon.

CONTENTS

TABLES

Page

FIGURES

Page

ACRONYMS AND ABBREVIATIONS

AIDS	Acquired immune deficiency syndrome
AHP	Analytical hierarchy process
BCA	Benefit-cost analysis
BEE	Black economic empowerment
C&I	Criteria and Indicators
CBD	Central business district
CLRB	Communal Land Rights Bill (being drafted)
CMA	Catchment management agency
CR	Consistency ratio
DEM	Digital elevation model
DWAF	Department of Water Affairs and Forestry
GIS	Geographic information system
HIV	Human immunodeficiency virus
IFMOP	Inexact-fuzzy multi-objective linear programming
IRP	Integrated resource planning
LP	Linear programming
LRAD	Land Reform and Agricultural Development (programme)
MADM	Multi-attribute decision-making
MAI	Mean annual increment
MAP	Mean annual precipitation
MAT	Mean annual temperature
MCDA	Multi-criteria decision analysis
MCDM	Multi-criteria decision-making
MCE	Multi-criteria evaluation
MC-SDSS	Multi-criteria spatial decision support systems
MODM	Multi-objective decision-making
MOLA	Multiple-objective land allocation
NLC	National Land Cover (programme)
NRM	Natural resource management
NWA	National Water Act (1998)
PRA	Participatory rural appraisal
RDF	Rural development forestry
SDSS	Spatial decision support system
SDTS	Spatial data transfer standard
SFRA	Stream flow reduction activity
SWAT	Soil and water analysis tool
WfW	Working for Water (programme)
WMA	Water management area

GIS-based land suitability assessment and allocation decision-making in a degraded rural environment

CHAPTER 1 RURAL DEVELOPMENT PROBLEMS: A RESEARCH CHALLENGE

Given that a sustainable livelihood for all is pertinent, it is becoming increasingly apparent that unique rural developmental initiatives are necessary to bring it in line with the more thriving urban developments. This chapter briefly introduces rural life in a global context first before focusing on the impoverished rural region this study was concerned with, i.e. the (previous) Transkei region in South Africa. The history and extent of the problems faced by these rural communities will be discussed, including the developmental challenges faced by government officials, planners and researchers alike in an effort to alleviate the hardships experienced by these citizens. In defining the research problem, the purpose of this study and its objectives is realised, and the selection of the particular study area can be rationalised. To engage in the quandary the researcher’s approach towards sustainable rural development and natural resource management is also briefly outlined before finally culminating in the research plan.

1.1 Introduction

When something develops, such as a country, it is expected to grow or change over a period of time into a better or more advanced form. Prosperity, however, was for the most part limited to rich nations and most likely urban societies. Elsewhere, the dilemma faced by traditional farming or rural communities on how to keep pace with this situation is compelling. The huge backlog in rural development is real and many nations acknowledge that this problem needs serious attention (Dalal-Clayton, Dent & Dubois 2003). However, strategies to increase human and land potential, retain people in rural areas and bring about prosperity to all seems daunting.

The list of hardships faced by rural communities in developing countries in particular often proves exhaustive, above all those finding themselves in degraded landscapes. The phenomena experienced could include dire poverty, inept government, political and financial instability, diseases, famine, illiteracy, the overexploitation of resources, or environmental degradation. In spite of a myriad of international, national and local initiatives aimed at avoiding or managing them, many of these phenomena are still prevalent in the tribal lands of various developing nations (Olbrich, Christie, Evans, Everard, Olbrich & Scholes 1997; Conway 1997). Innovative ways must be sought to alleviate this pressing problem and balances between top-down and bottom-up rural planning should be found. Whether this process can be enhanced by the infusion of local knowledge and effective technology transfer remains attractive to those concerned.

1.2 The travails of rural life in developing nations

Over a decade ago the World Bank (1990) indicated that poverty is particularly acute in rural areas, where it was estimated that roughly 80% of the poor in developing countries resided. More specifically, the World Bank (1990) projected that the number of poor in Africa would increase by more than 100 million by the end of the millennium, ironically at a time when the number of poor in the world as a whole is expected to decline by 400 million. On the other hand, diseases such as malaria and HIV/ AIDS are rife in many developing countries, particularly in rural areas due to the absence of medical facilities and medicines. The impacts of such diseases on human resources are therefore quite palpable. For example, in Africa today, 10 million AIDS orphans need care because their parents could not get access to antiretroviral drugs (Gates 2005). Complicating matters further are the acute shortage of food supplies many of these impoverished communities have to endure. Moreover, unfair trade rules effectively bar rural farmers in developing countries to reach self-reliance. The notion that some poor countries still shackled by old Cold War debts to the richest countries have to pay them back no matter the cost in human suffering is equally unjust. Nonetheless, it has become conventional wisdom to recognise that poverty leads to environmental degradation, and that the latter hits the rural poor hardest, leads to their further impoverishment, and actually undermines the very basis of their livelihood. Besides, widespread illiteracy makes it difficult to reach social units with environmental awareness campaigns, particularly in rural areas. For instance, overgrazing has been the chief culprit of land degradation in Africa, contributing to more than 200 million hectares of degraded land (World Resource Institute 1998). In fact, of the nearly two billion hectares classified as being degraded worldwide, three quarters (490 million hectares) is found in Africa (Pretty 2002)[1].

Generally speaking, the desire to safeguard the environment is something of a Northern concern with which policymakers in developing countries may not fully concur (Grimble, Chan, Aglionby & Quan 1995). Private ownership, whether allocated under traditional rights or legal deed, gives the user the strongest motive to develop and conserve its resources, at least in principle, and there is a well-established positive correlation between secure land rights and agricultural productivity (Dalal-Clayton, Dent & Dubois 2003). Unfortunately, the incentive to improve and conserve is

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[1] It was also estimated that nitrogen, phosphate and potassium nutrients are lost at an estimated rate of at least 30kg/ ha, with land in 23 African countries losing more than 60kg/ ha (Pretty 2002).

perceived as weak by poor communities and the short-term profit motive often overrides it even where farming is perceived by some as a socially or economically desirable occupation.

It is important to review arguments linking environmental degradation to large numbers of poor people in this context. Ahmed & Mlay (1998:2) aptly points out such arguments "tend to overlook the reality that it is frequently the alienation of land and resources, often to commercial interest, that is behind the degradation of the environment of local communities", and this "is the process by which local community members are rendered poor and hence the victims, not the culprits of environmental degradation". The insufficient content of local (indigenous) knowledge with regards to land tenure, inadequate and inappropriate methods, perceived socio-economic and environmental values, as well as biophysical constraints have been noted as the main contributors to project failure (Kerkhoff 1990; Glendinning, Mahapatra & Mitchell 2001). The two underlying causes of the general failure of top-down rural planning in poor and emerging countries identified by Dalal-Clayton, Dent & Dubois (2003) have been the absence of any local stakeholder input into the planning process, and the preference of donors to by-pass ineffective local administration by setting up financially and administratively autonomous project organisations that have further weakened local capacity. Let us compare this with the situation in Transkei.

1.3 Rural life in Transkei

Poverty is widespread in the Transkei region and is probably the main developmental constraint. Being far removed from any major development centre or port, the typical landscapes in Transkei contain several features that bear silent witness to the increasing loss in natural resources, human capital and general productivity. Whether a result of physical, socio-economic or historical reasons, land mismanagement and the overexploitation of natural resources have resulted in large-scale environmental degradation, which further impacts on the well-being of the people eking out a living here. This section will briefly describe the current state of the environment and poor living conditions of this rural region.

1.3.1 *Physical conditions*

One can easily scrutinize the degradation of the physical environment when observing the widespread loss of fertile topsoil, wetlands and indigenous vegetation, the invasive exotic jungles, the severely overgrazed rangelands, as well as the poor quantity and quality of water. Shown in Figure 1.1 (A-F) are photographs (recorded in summer) of the study region which depict such places. Indigenous forests and wood-/ bushland have over time been vastly over-utilised by the growing population in order to make a decent living (Beinart 2003). The many pockets of indigenous forests have been largely diminished or completely lost to croplands and other domestic uses (Photo A).

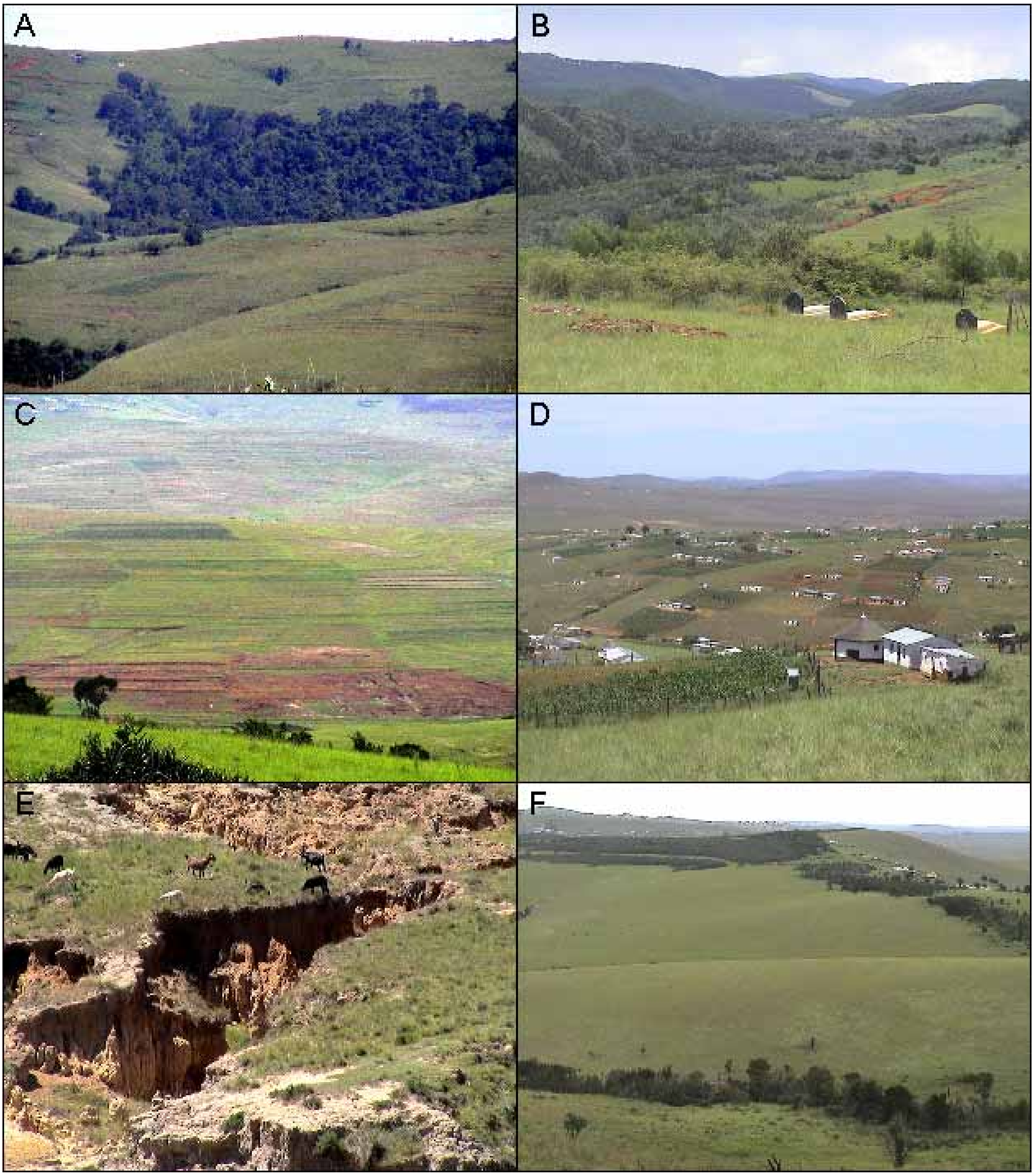

Figure 1.1: Assortment of typical landscape features in the study region

Land degradation is also manifested in invasive wattle jungle[2], often found covering large tracts of abandoned old croplands, rangeland and along watercourses (Photo B). Complicating matters somewhat ironically is the attempt to remove all these alien invader tree species by the national Working for Water (WfW) programme[3]. Its principle aim is clearing invading alien plants and restoring natural vegetation in catchments around the country. Thus, the dilemma being faced now is that the eradication of all alien invader species, useful or not, is required by law for ecological reasons despite a growing need for woody resources by the affected community. The loss of woody biomass largely contributed to the perturbing situation where local communities struggle to obtain sufficient resources essential to their well-being, such as fuelwood, poles (construction), medicine and fodder; a situation similar to that described by Clarke (1995) in Zimbabwe. Although several medium- and small-size state-owned timber plantations were developed in the Eastern Cape Province in the 1980s, it was a pure commercial activity with a predetermined market and of little value to the local residents. In fact, it effectively removed land that was previously a communal resource and which was often required as a component of the traditional use of the surrounding areas (grazing, hunting, burial sites, fuel, etc). Following this, locals often thereafter received large commercial tree planting initiatives fairly sceptically (Forsyth et al. 1997).

More importantly though are areas severely degraded by sheet erosion and gullies as shown in Photo’s C & E in Figure 1.1, respectively. These are mainly due to overgrazing, cropland mismanagement and scars left by animal and timber tracks. In fact, soil erosion has already (in the early 1980s) destroyed 25% of South Africa’s original fertile soil reserves (Fuggle & Rabie 1983). Despite four decades of several serious attempts at soil conservation nationally, annual losses as a result of erosion was estimated by Huntley, Siegfried & Sunter (1989) at 400 million tonnes (or about 3tonne/ ha). Other forms of degradation linked to erosion and runoff availability are the complete or partial destruction of wetland habitats[4] commonly found here, in most for their role in the perennial supply of water and habitats for wildlife and birds.

The mainly agropastoral systems or subsistence farming in place still display shifting tendencies with regards to crop cultivation and grazing behaviour as seen in Photo’s D & E. Yet, shifting cultivation itself is not the problem in terms of the loss of land productivity (it is rather analogous to crop rotation). Rather, intense land use for extended periods prior to abandonment, including

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[2] An invasive wattle jungle is defined as a clump or stand of invasive trees (wattle or other invader species), excluding legal or licensed plantations or woodlots, where the density, extent, and age of invasion are such that the natural biodiversity of the landscape has been largely or completely transformed. Typically this could be anything from 1 ha to 1000 ha in extent (Warren, Versfeld & Horak 2003).

[3] Initiated by national government in 1997, the WfW programme is driven by the Department of Water Affairs and Forestry (DWAF).

[4] In South Africa various treaties and government decrees protect these wetlands (and other very sensitive areas).

prolonged intense clean tilled crop production, and the failure to protect the land with a vegetation cover (grazing) while unused, typically led to severely degraded lands that require very long periods of recovery. Adding the effects of the frequent droughts this particular region have suffered in this water-stressed country[5], one can easily grasp the huge negative impacts this has on the livelihood of the affected local communities and already poor states of environment. It would thus need some serious long-term intervention to restore the land to a more acceptable or ‘ideal’ state, such as depicted in the scene in Photo F, more or less.

1.3.2 *Social services backlog*

Rural planning is by and large concerned with planning for development, land use, the allocation and management of resources. However, rural planning concepts vary and this often leads to confusion between planners, policy-makers and implementers. This is well illustrated in South Africa where, until 1995, rural was defined as all households not living in formally declared towns. Under apartheid, many areas defined as rural were, in reality, urban areas without services. In the era after apartheid, rural is now defined as the sparsely populated areas in which people farm or depend on natural resources, including villages and small towns that are dispersed through these areas (Khanya-mrc, 2000). A large number of households in Transkei thus fall in both urban and rural categories as they derive their incomes from a range of sources, including migrant labour to towns. Unfortunately many of these rural areas still lack proper infrastructure and basic services, such as clean (and safe) drinking water, sanitation, and reliable power supplies. The present-day situation is particularly tough on the elderly, women, and children, as shown in Figure 1.2.

The impact on women and children is apparent in the progressively longer time spent by them to collect resources (e.g. firewood, water, and livestock) on almost a daily basis, to the detriment of other household or social unit activities such as childcare, games, sanitation and food production (Ham 2000). The local communities rely heavily on woody vegetation for all their energy needs such as for cooking, washing, heating and lighting. This is not surprising since the majority of rural households in South Africa rely on firewood as an energy source[6], the bulk of which is normally collected by women from natural and exotic wood- and bushland as a common resource (‘free good’). Piped (domestic) water is still a dream to many and water from nearby streams, many polluted, is often the only available. Sanitation is still by means of the old ‘bucket’ system and

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[5] South Africa is considered a ‘water stressed’ country (1000-1666m^3/person/year), i.e. frequent seasonal water supply and quality problems, accentuated by occasional droughts (Turton & Henwood 2002).

[6] Hugo (2004) estimates that about 6 to 10 million tonnes of firewood is consumed per annum locally.

refuse removal is nonexistent in many places. Social grants and old age pensions, often the only household income, are not easily obtained due to the absence of roads and the long distances recipients have to travel in order to get to payout points. This lack of infrastructure, including rural clinics, also leads to ineffective medical support with regards to, for example, AIDS relief.

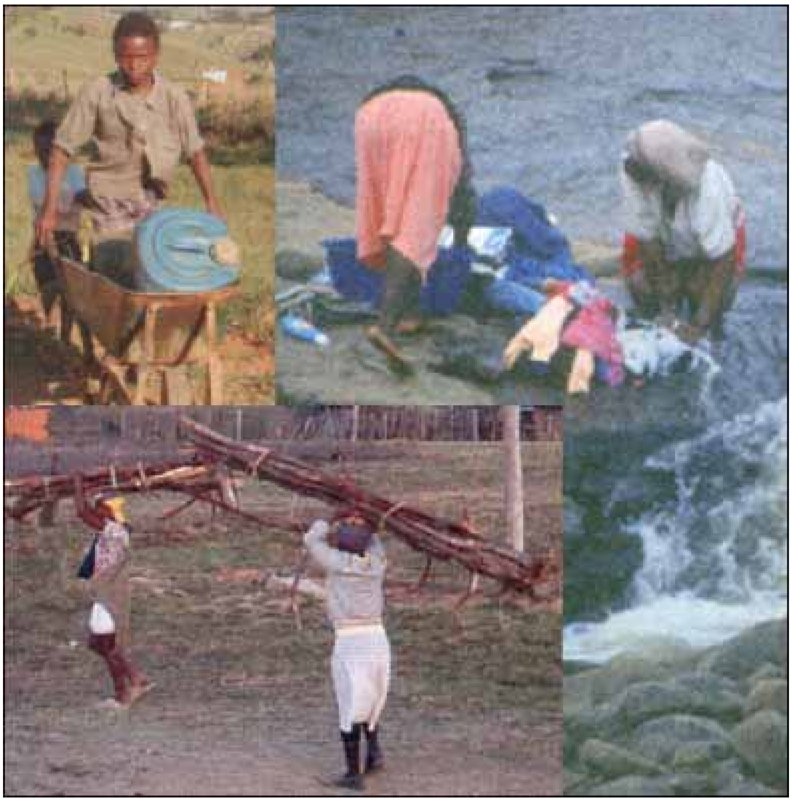

Figure 1.: Some rural activities that involve women and children (Source: Hugo 2004)

1.3.3 *A history of political neglect*

In South Africa the post-1994 dispensation, as enshrined in a pioneering constitution, has come of age and the expectations of its citizen's rose accordingly. However, in this region situated in one of the country's poorest provinces it still is a case of too-little-too-late in terms of rural development. Historically speaking, Transkei formed one of the so-called bantustans/ homelands[7] in South Africa developed during the apartheid era with its controversial racial segregation policies. Since the advent of true democracy in 1994, Transkei has been incorporated as part of the Eastern Cape Province, but conditions remained grim. The fusion of agricultural capital with the apartheid state resulted in what Greenberg (2003:2) describes as "a patronage that benefited white farmers at the expense of other sections of the society, including urbanised black workers, farm workers, black farmers in the bantustans, and the rural black population in general." In order to survive and with

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[7] In fact, the Transkeian Territories, heart of major pre-colonial chiefdoms such as Gcaleka Xhosa, Thembu, and Mpondo, formed the largest block of reserved land in South Africa as a whole (Beinart 2003).

the resources and limited technology at hand, large numbers of uneducated farmers were forced to work the land in any way they see fit. This in the light of the fact that in the 1980s, the average population density of the bantustans was estimated at 67 persons per square kilometre (Human Sciences Research Council 1986). In such communal tenure systems individual members of the community normally have land use rights. The community as a whole determines these rights and the land remains the property of the community. Such systems have, in the past, provided sustainable management of diverse resources and spread risk over a wide area of land – particularly useful for the grazing of marginal land (Beinart 2003). However, communal management was difficult to maintain where there was intense competition for resources and the social sanctions that underpin communal management have been eroded. Besides, there is no incentive for individuals to invest in long-term improvements or perennial crops, especially if the right to use a particular plot is periodically redistributed.

1.3.4 *Communal ownership and property rights complexities*

Due to the communal nature of land and other resources in the Transkei, the ownership thereof and associated right to use it is not a straightforward issue. In theory, land is the most important collateral asset in rural areas (Place & Swallow 2002). Naimir (1990:50) defined resource tenure as "the full and exclusive ownership of resources, or the right to use them without owning it, or something between the two". Ownership includes the right to use the resource, and the right to determine the extent and nature of use by others. Common property is defined by the joint use of resources by a group of community members (Otsuka & Place 2001). It follows that communal tenure implies enjoyment rights shared collectively by a community. However, communal tenure has been one of the most contentious and complex aspects of South African land reform and meaningful forms of tenure security in communal areas have yet to be initiated (National Land Committee 2001).

Ownership and actual use are not necessarily synonymous. Several factors determine whether a social unit's members will use the pool of resources they own. In the first place, although theoretically the land belongs to a community, a member's rights to its resources are based on continual exercise of those rights. If any area is abandoned then it reverts to the communal property of the social unit and can be used by any other member. Secondly, an area may belong to the social unit, but in any given year, only a small proportion of the community's members will actually use it, because of distance, availability of alternative resources and areas, changing needs, etc. Thus, both fundamental principles and socio-political power determines the enforcement of such territorial and resource rights. Yet, tenure should not necessarily act as a constraint for adopting new developments or technologies with long time horizons. Smucker, White & Bannister's (2002) study in Haiti, for example, indicated that tenure is not a constraint to agricultural intensification and soil conservation. Their study showed that the key constraint to wider adoption and continued extension services was in fact funding levels and the absence of a permanent institutional base for extension – rather similar to the situation at hand.

The necessary components of secure property rights (or tenure security) include excludability, duration, robustness, and assurance (Roth, Wiebe & Lawry 1993; Place, Roth & Hazell 1994). Excludability allows those with rights to exclude those without rights to a particular resource such as land. Duration refers to the temporal extent of one's rights. To have secure tenure, one must possess a sufficient time horizon to reap the benefits of one's investments (Meinzen-Dick et al. 2002). Robustness refers to the number and strength of the bundle of rights an individual possesses. The bundle of rights may include various types of rights to use, access, manage, control, or transfer of resources (Schlager & Ostrom 1992).

It is important to note that individuals, families, collectives, or other groups may hold property rights. Different individuals or institutions, including the state, may hold different bundles of rights over the same piece of land or other type of resource, e.g. water. Finally, assurance derives from an institutional framework capable of enforcing an individual's rights to land. However, this does not come about easily. As Ostrom (2002:130) reminds us, "when a group of individuals has held the right to access, harvest, and manage a natural resource, but not the right to sell their interest in the resource, these rights have been treated as if they were without economic value". For instance, the Communal Property Associations Act, which aimed to create a legal framework for communal ownership of land (South Africa 1996), was characterised by Greenberg (2003) as a failure because, by the year 2000, just one per cent of total farmland was actually transferred through the sub-programme. After the second national elections in 1999 and subsequent dumping of the welfarist approach to land reform, a classic 'modernisation' strategy emerged. The Ministry of Agriculture and Land Affairs launched the Land Reform and Agricultural Development (LRAD) programme (Department of Land Affairs 2002) to, in conjunction with the previous year's Strategic Plan for South African Agriculture (Department of Agriculture 2001), explicitly redirect the land reform programme to the task of building a black commercial farming class[8].

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[8] The LRAD programme extended the timeframe for the redistribution of 30% of commercial agricultural land to a period of 15 years (Department of Land Affairs 2002). The Communal Land Rights Bill (CLRB) is the current piece

1.3.5 *Labour problems*

The wider socio-economic dynamics of the Transkei is further reflected in the complexity of human resource (labour) migration (direction and duration), matched by variation in the composition of these flows. For instance, neither temporary and seasonal human movement, nor the age and gender of who stays and who moves are reflected in official census figures. Thus, determining significant impacts on source areas in terms of labour availability, remittances, household organisation and agricultural production systems can be challenging. Moreover, rural development plans may ignore the fact that migrants can be the key decision-makers while residents, e.g. women and disabled persons, may be better described as caretakers with no real power to make decisions over the use and management of local natural resources. This rural-urban interface is often a key element missing in many rural development approaches (Khanya-mrc 2000). For example, livestock management (herding, watering, etc) is quite labour intensive, and labour availability at the household level in part defines the viability of traditional grazing controls and techniques (Sandford 1984). Yet, it seems fewer of the younger generation are willing to remain pastoralist. Labour availability for herding in this region has generally decreased due to children being sent to formal schools elsewhere, and young men are leaving for further education, or other occupations perceived as more lucrative, usually close to or in larger towns and cities (rural-urban migration). Those remaining often have to take shortcuts to maintain present stock levels, e.g. larger, combined herds concentrated in one area, and could therefore accelerate degradation processes (overgrazing).

As for most African rural communities, the rationale of rotational grazing in fenced camps has largely failed because fences have become too expensive. ‘Kraaling’ is, in this view, an inevitable and acceptable practice[9]. The region nonetheless experienced significant levels of stock theft over the years (Beinart 2003). These facts, coupled with the large extent of degraded land, seem to limit to some extent the possibility of large-scale livestock production in this instance. Moreover, the author pondered the possible loss of productive, able-bodied individuals (male and female, young to old) involved in agricultural practices on the account of increasing HIV/ AIDS and tuberculosis related deaths and which could perhaps prove significant in the future, if not already[10]. This could culminate in even more abandoned agricultural lands and therefore neither produce nor income for

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of legislation being drafted to tackle the complex rural tenure issues at hand and only time will tell on its successes or shortcomings.

[9] A kraal in this context is an enclosure of some kind (rocks, thickets or fences) made for livestock (e.g. cattle) protection.

[10] In South Africa the proportion of people infected by the AIDS virus is said to be 25 per cent; the number of infected people seem to double every 14.5 months (Hugo 2004).

its owner or users. Assimilating the above information provides us with the actual research problem.

1.4 The research problem

The conundrum this study faced was the current unproductive land use options, coupled with land mismanagement, which currently leads to both the loss of income and employment opportunities in the Transkei and severe environmental degradation. The rather intricate traditional communal tenure arrangements and the lack of a workable institutional framework complicated matters further for these historically impecunious communities. Solving this problem whilst simultaneously advancing rural development therefore needed some sort of integrated approach and a full assessment of the situation at a landscape or community level. This brings us to the purpose of this study and its goals in terms of an idealised land use situation where sustainability on all fronts is envisaged.

1.5 The research aim and objectives

Within the environmental and socio-economic constraints to rural development presented, it appeared imperative to halt further land degradation and enhance the livelihood of the affected communities without large-scale or costly land use changes. The main purpose entails decision-makers to properly assess land suitability for maximum productivity by including local knowledge and satisfying traditional customs, and allocate land accordingly in a manner that allows for environmental sensitivity. The aim of this research was to demonstrate the use of MCE in GIS for land suitability assessment and decision making in a degraded rural environment in the former Transkei. To illustrate to local communities how their own thinking could facilitate the move towards what *can* be achieved, rather than what *must* be achieved with this spatial development strategy, the researcher’s objectives were the following:

i) Select an area of interest and at an appropriate scale delineate the study area.
ii) Review the available land evaluation and multi-criteria decision-making approaches to select the appropriate model(s), which accommodate a ‘bottom-up’ approach and local input.
iii) Obtain and digitally capture, manipulate and analyse spatial data describing the study area in terms of climate, topography, soils, current land uses, infrastructure, and other spatial elements useful for land use planning and resource management decisions.
iv) In conjunction with official development policies and initiatives, document the collective collaborations among stakeholder groups on social, environmental and economic impacts of the present-day land use scenario and development opportunities.

v) Recruit a single representative decision-making group and together determine the appropriate geographical strategies and priorities that would, via appropriate land use objectives and evaluation criteria, bring about the desired or ideal land use situation.

vi) Using this objective information, the generated spatial data, and advanced geographical information systems (GIS), implement the suitability assessment and allocation decision-making model to reach a satisfactory and multi-functional land use allocation solution.

1.6 The study region

The Transkei, a territory that significantly represents poor communities, incidences of land mismanagement and severely degraded landscapes, was chosen as the study region. Selection was further based on a national development strategy adopted by South Africa, namely water management areas (WMAs) and the subsequent catchment demarcation processes. This conceptual management strategy needs some explaining before the details are given on how the actual study area was determined.

1.6.1 *Catchment management area demarcation*

In the water-scarce South African situation, it made sense to focus on a whole river basin where national and regional development and planning is concerned. Because river basins appear to be well-bounded and their boundaries are ‘natural’, it would seem that they are removed from the arbitrariness and mutability of boundaries drawn by humans (Turton & Henwood 2002). After a country-wide process of public consultation 19 WMAs, covering the entire country, were established in October 1999 (DWAF 2002). The internal boundaries of the WMAs (that is, those that are not defined by international boundaries or South Africa's coastline) lie along the divides between catchments. These WMAs were subsequently subdivided further into secondary, tertiary and quaternary catchments. This scale of development that underlies WMAs is not whole river basins, but sub-quaternary catchments of smaller, more practical sizes of no more than several hundred hectares in which, as Pretty (2002:159) puts it, “people know and trust each other”. For practical reasons the natural resource management focus moved to sub- or micro-catchments (of no more than several hundred hectares) within a larger quaternary catchment. This micro-catchment approach is not new and has of late been widely expanded in many parts of the developing world, as well as in industrialised countries. In fact, some authors indicated that some 50 000 watershed and catchment groups have been formed in the past decade in Australia, Brazil, Burkina Faso, Guatemala, the Honduras, India, Kenya, Niger, and the United States (Hinchcliffe et al. 1999). The resulting uptake has been quite remarkable, with Pretty (2002) reporting that participatory watershed programmes yielded substantial improvements, together with substantial public benefits, including ground water recharge, reappearance of springs, increased tree cover, micro-climate change, increased common land re-vegetation, and benefits for local economies.

The Department of Water Affairs and Forestry (DWAF) considered five factors in developing the number of water management areas and the location of their boundaries. They were: i) the establishment of catchment management agencies (CMAs), ii) the location of centres of economic activity, iii) social development patterns, iv) the location of centres of water-related expertise from which the agency may source assistance, and v) the distribution of water resources infrastructure (DWAF 2002). Nonetheless, it remains to be seen whether the institutional efficiency of creating a large number of catchment management agencies, each managing a relatively small area, or a small number of agencies, each managing a larger area, will be realised in an effective manner. The boundaries are not irrevocably fixed for all time though. DWAF stressed that "if, in the light of operational experience, it proves necessary to change the boundaries to achieve greater efficiency or effectiveness, the changes will be made after consultation with all those who will be affected" (DWAF 2002:80). All South Africa's 19 WMAs and the location of the quaternary catchment (T34H) – in which the final calculated study area was located – can be viewed in Figure 1.3. In this context we will see how the study area was demarcated next.

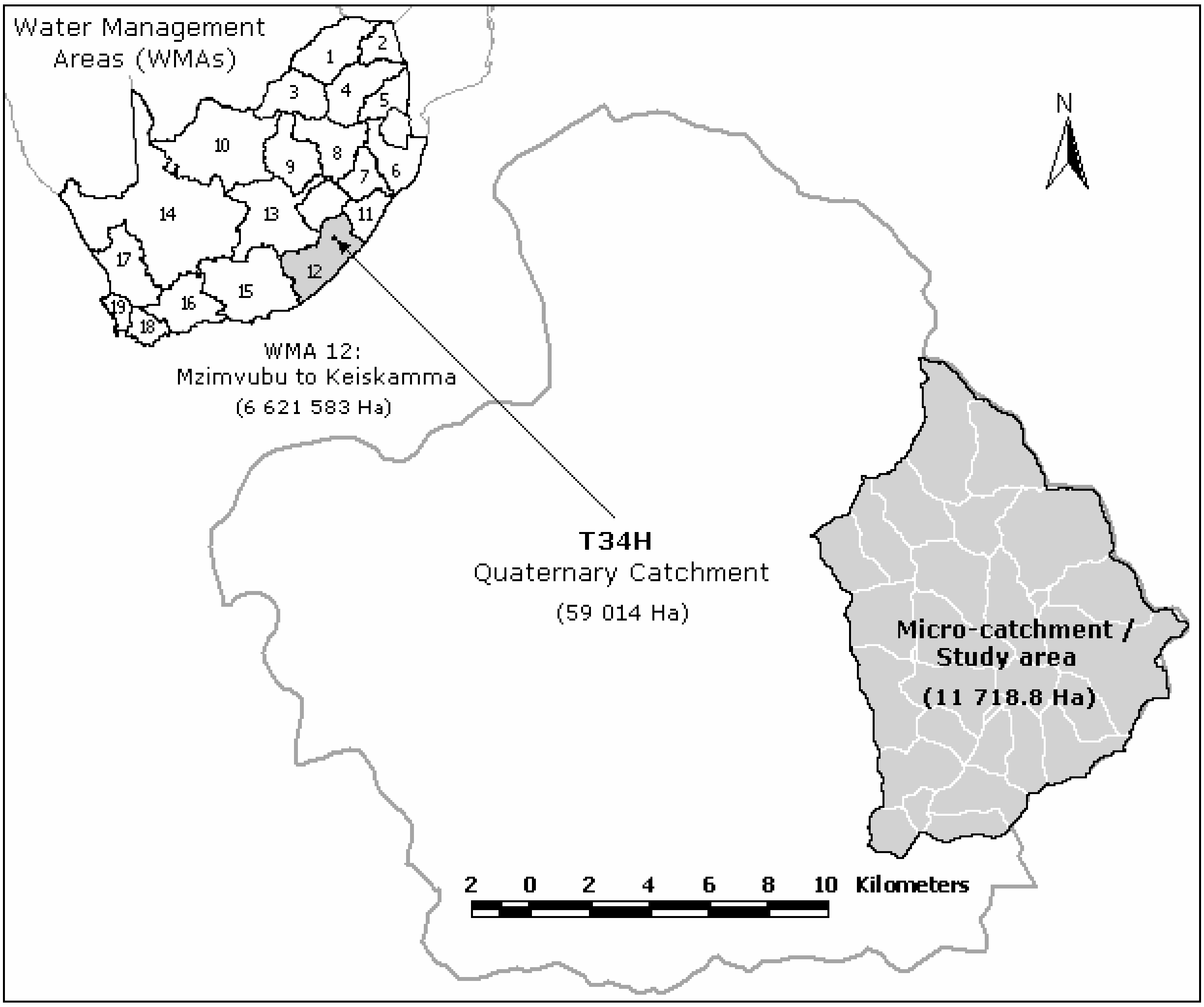

Figure 1.2 Study area orientation within the national WMA concept

1.6.2 *Study area demarcation*

The first steps in the demarcation process were to visually and manually identify a micro-catchment of practical dimensions for land use planning purposes. To assist in the study area orientation and demarcation process, all the necessary or useful information available was obtained from various reputable sources[11]. Invariably in point, line and polygon format, it included catchment, climatic, plantation, soil, and other topographic data, as well as district or municipal borders and roads. Quality high-resolution digital images of the study region were, via ArcView (3.x) [12] and MrSID Image Support[13], closely studied next. These images were generated from low-altitude aerial photographs (1:10 000) taken of the region in 2001 and subsequently converted into

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[11] Note that at the end of the document in Appendix J, a summary of the sourced themes and most of those created during the study appears, including some of their characteristics.

[12] ArcView GIS (3.x) is a product of Environmental Systems Research Institute Inc. (ESRI, Redlands, CA).

[13] MrSID is a multi-resolution wavelet-based image format that allows for high compression ratio and fast access of large amounts of data at any scale. To use MrSID images with ArcView (3.x) you must first load the MrSID Image Support extension (for more information visit http://www.lizardtech.com).

digital images; each registered, ortho-rectified and atmospherically corrected. The terrains that occur in a mosaic pattern in a region are termed landscapes, which in turn constitute the building blocks of a catchment area. Aided by the acquired water management areas (WMA) data and using the elementary landscape features indicative of catchment boundaries (e.g. mountain tops, ridges, drainage lines, roads, etc), the initial micro-catchment was identified and roughly outlined. A rectangular extent capturing this micro-catchment, as well as some significant features surrounding it (e.g. the town of Mount Frere), was produced digitally. Working from the MrSID images on a 1:3000 scale, other base map features crucial for this study were also digitised and mapped as point, line and polygon themes at this stage. These contained drainage features, dams, roads, power lines, and other important infrastructure. Combining the river and dam layers with sourced contour (20m intervals) and altitude (meters) data within this extent, a digital elevation model (DEM) was constructed in ARC/INFO GIS[14] using the GRID module and a 20x20 meter resolution. Once imported back into ArcView, the *Surface/ Compute Hillshade* toolbutton computed illumination values for the DEM for enhanced display purposes.

To finally arrive at the exact study area or micro-catchment boundary, the DEM was then further processed (sink removal) and analysed in ArcView coupled with the Soil and Water Analysis Tool (SWAT)[15]. The resulting polygon theme represented the final calculated study area. In addition, 29 even smaller sub-basins making up the entire micro-catchment were automatically calculated (as shown earlier in Figure 1.3) to serve as useful auxiliary information. Covering a total of 11 718.8 hectares (or 292 970 cells), the micro-catchment made up just less than a fifth of quaternary catchment T34H (or about 0.2% of WMA 12). The location of the study area on the grass-covered foothills of the Drakensberg in the area of interest is graphically revealed in Figure 1.4. The map (draped over the constructed DEM) includes some digitised and sourced base map elements such as the current associated infrastructure, municipal boundaries and drainage features.

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[14] ARC/INFO GRID is a product of Environmental Systems Research Institute Inc. (ESRI, Redlands, CA).

[15] A user- friendly, PC based tool, AVSWAT has been developed at the Blackland Research Center (USA) integrating SWAT and ArcView GIS (3.x) software along with the Spatial Analyst (1.1) extension.

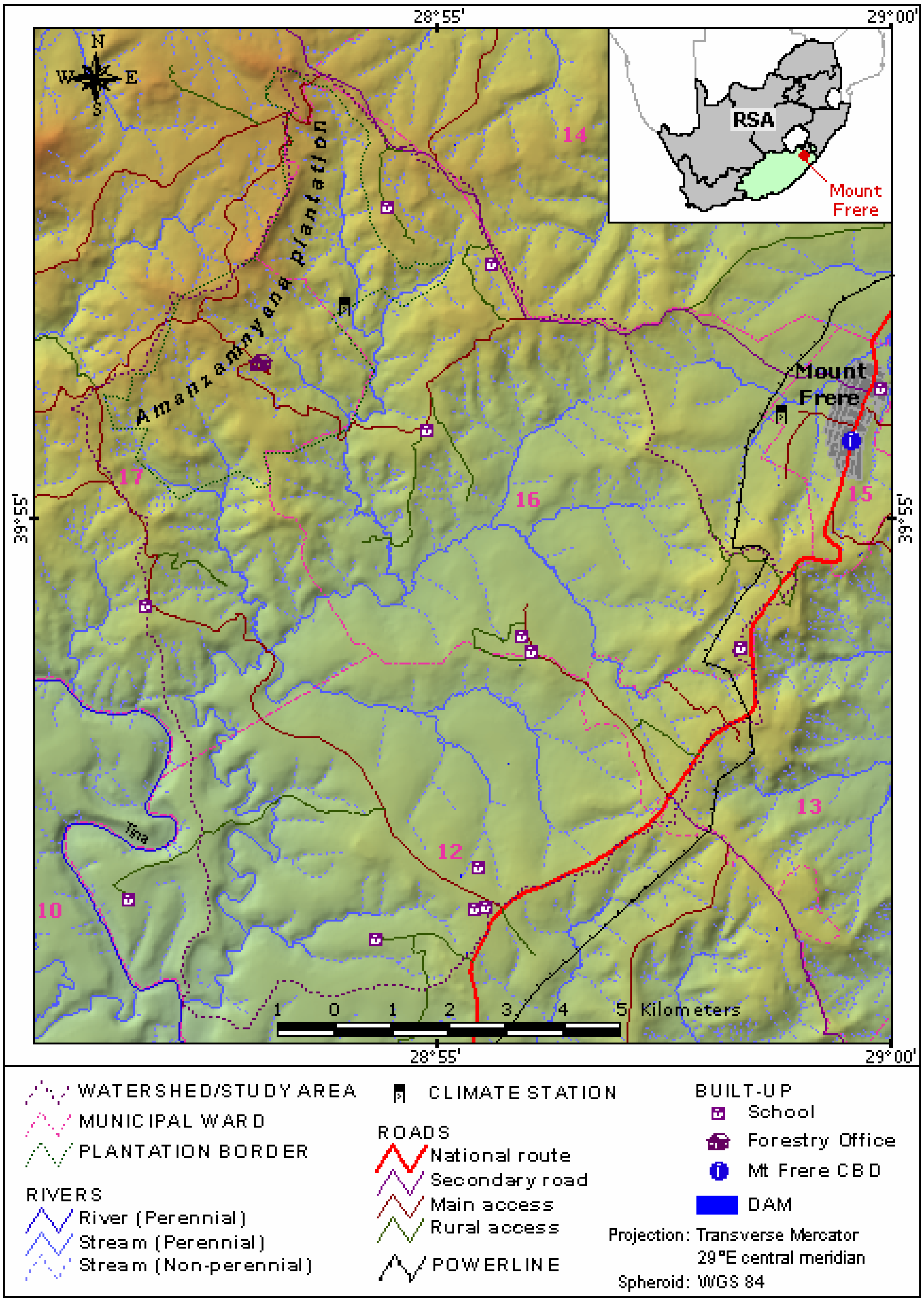

Figure 1.4: Area of interest and catchment boundary

1.7 The research approach

Since the 1970s, developing countries have seen many initiatives in decentralised rural and regional planning. The most cited reasons for such actions include i) concern at the flight of people from rural areas to cities, ii) a desire to reduce regional inequality by some redistribution of resources and by responding to local needs, iii) a wish to secure rural livelihoods by more effective delivery of services like education, healthcare and agricultural extension, and iv) concern about the degradation of natural resources (Dalal-Clayton, Dent & Dubois 2003). This clearly conforms to the current situation in the study region. The research approach therefore needed a strong emphasis on concepts such as sustainable livelihoods and natural resource management. These will now be discussed briefly and put into context with the research aim.

1.7.1 *Sustainable livelihoods*

Sustainable development, as a concept, essentially means meeting the needs of the present without impairing the needs of the future (Bruntland Commission 1987). The influential Bruntland Commission stated, amongst other facts, that economic growth will eventually be inhibited, and effectively cut off, in any location with seriously degraded natural environment. A first effect will be that people who have a choice will in significant numbers choose to live and work somewhere else. A further effect will eventually be a lack of resources needed for a substantial level of economic activity. Therefore, Franklin (1997) argued that the basis for sustainability lies with two guiding principles: the prevention of the degradation of the productive capacity of ecosystems, and prevention of the accelerated loss of genetic diversity. Today the sustainable livelihoods concept offers a powerful focus for development planning (Carney 1998). A livelihood comprises the capabilities, assets (including both material and social resources) and activities required for a means of living. A livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain and enhance its capabilities and assets both now and in the future, while not undermining the natural resource base.

In this context the paradigm shift in sustainable rural development towards sustainable livelihoods is summed up well with the following extract from Dalal-Clayton, Dent & Dubois (2003: 9): *"The objectives of planning have evolved over the years from a focus on increased production, through greater efficiency and effectiveness, to explicit concerns about equity and the reduction of poverty and vulnerability. The focus of rural planning has also broadened away from agricultural issues, e.g. concentrating on water resource allocation and comprehensive watershed management rather than irrigation and drainage. The management of natural resources in sustainable production systems is beginning to replace the independent focus on arable land cropping, livestock production or forestry. Human capital development, infrastructure and social development are being woven into integrated rural development strategies."* The challenge nonetheless remains to translate the sustainable livelihoods concept into practical guidelines for decision-making and action on the ground. Rasheed (1998) feels that the needs of the poor should be brought into the mainstream of development through conscious and deliberate policies to both alleviate their impoverishment and enlist their collective investment. He further claims that this can be achieved with two main thrusts: i) by increasing the production and productivity of the poor through granting them access to land, assets, capital, infrastructure, technology and markets, as well as ii) by eliminating economic distortions and social biases against the poor, particularly as related to poor women. For instance, watershed development requires secure property rights because it may involve long-term investments in dams, land contouring, erosion-control, wetland restoration, and tree planting in water catchment areas, and it is most successful if the entire community living within the relevant landscape is mobilized to support collective action (Place & Swallow 2002).

1.7.2 *Natural resource management*

Participatory rural assessment (PRA) needs to be augmented with knowledge of who *should* and *can* participate (Bliss 1999). Dalal-Clayton, Dent & Dubois (2003) offer valuable advice when innovation is required to deal with these two issues. The first is to develop and use methods that allow people to collaborate, coming together to discuss and negotiate over competing claims and priorities. Ask questions like: what are the possibilities and constraints here? The second is to provide a means of valuing the resource and associated trade-offs between differing possible ways of using a mixture of resources, whilst keeping in mind that monetary values alone are not enough. It is important that both the socio-economic and biophysical appreciation of the land resources are encapsulated in the concept of resource management.

As resource development indicates the concept whereby resources are given specific value owing to development, natural resource management (NRM) is an even wider concept that involves controls relating to the amount, quality, timing, availability and the general direction of resource development (Hugo 2004). Nonetheless, the sensible option is to transfer the resource management domain to a landscape unit as a spatial unit that offers opportunities for identification and application of resource management options to address specific issues (Craswell, Rais & Dumanski 1996). Derived from georeferenced biophysical and socio-economic information, it is dynamic and multi-scale in that it reflects human interventions in the landscape. In other words, it implies a patch of land in which the biophysical features are homogenous *and* so is the management.

Physical land evaluation tries to explain and predict the potential of land for one or more uses by systematic comparison of the requirements of land use with the qualities of the land. An index of potential performance in terms of capability or potential to support broadly defined categories of use, or productivity (e.g. crop yield) of a specified land use is returned. By doing so, the range of feasible land use options may be identified. Still, the step from land evaluation to land use planning is substantial. Planning in this case involves weighing land use opportunities against problems involved, generation of a range of land use options, and making choices between these options. Not only does planning demand a broader range of professional expertise than for land evaluation, but the decisions made are much closer to the lives of land users. Thus, where land management is concerned, it is not merely a case of applied science, but a complex public policy debate as well (Daniels & Walker 2001).

In most developing countries, policymakers are grappling with creating a policy environment that fosters economic growth and provides opportunities for the poor to escape from poverty while also maintaining or enhancing the natural resource base (Otsuka & Place 2001). To address the natural resource limitations effectively, an innovative and imaginative application of modern science and technology, with a parallel implementation of economic and social reform emerged. It required institutional arrangements to ensure land tenure and product ownership by local communities or to meaningfully involve local participants in decision-making processes (IPCC 2000).

In South Africa, Integrated Resource Planning (IRP) is the process currently determining the appropriate mix of demand-side and supply-side resources in the hope to provide long-term, reliable services to users at the lowest reasonable total cost, maximise benefits to society and minimise the impact to the environment (DWAF 1999). A noteworthy recent development to this effect could be the National Water Act (NWA), which introduced the innovative concept of the ‘Reserve’ (South Africa 1998a:section 1.xviii). The Reserve comprises the quantity and quality of water required to satisfy the basic human needs of all people who make use of, or may make use of a particular water resource and protects aquatic ecosystems in order to ensure ecologically sustainable water development and use. The Reserve is therefore an unallocated quantity of water that is not subject to competition with other water demands. In order to ensure that the ecological integrity of these river systems is protected, Turton & Henwood (2002:122) established that a certain minimum volume of water (25 liters per person per day at present) is required in South Africa’s rivers. The same authors claim the Reserve is “designed to give effect to the constitutional imperatives of the right to access to sufficient water for basic human needs, as well as the right to have the environment protected through legislative and other measures that secure ecologically sustainable development, and promote justifiable social and economic development”. Where rural development is concerned, this concept therefore implies an integrated (water-based) management strategy nationally that requires a type of stakeholder-partnership approach. This brings us to the study’s frame of reference and report details.

1.8 The research framework and report structure

The research plan was to a large degree based on the basic natural resource allocation model suggested by Van der Merwe's (1997) study where he investigated GIS-aided land evaluation and decision-making for regulating urban expansion in the Western Cape, South Africa. To aid the land evaluation and the decision-making process, his design consisted of seven main procedural steps that incorporated multi-criteria decision analysis (MCDA) methodology (available on GIS platforms). This model allowed for possible public or community participation as well, which made it ideal for the purpose of this study. To suit the rural problem at hand, the model was adapted accordingly by incorporating additional preliminary actions and scheduling authentic participatory components into the seven steps. The iterative nature of the model authorized the calibration thereof. The resulting framework is shown in Figure 1.5.

Orientation commenced with the earlier demarcation of the study area and related infrastructure. This information, together with a detailed description (in digital format) of the land cover that followed, was made available as field maps. These aided value judgements and decision-making during meetings and a workshop with the appropriate stakeholders and the final focus group, respectively, to collaborate on present-day and future land use options and possible changes. In describing the study and its results, the logic of the seven steps above is followed.

The first step in the actual allocation and decision-making process was to define the particular land use objectives for the watershed. To satisfy perceived local needs, the decision-makers decided upon area goals and the objectives were weighed against each other during the same session. To measure the suitability of land parcels for each objective, adequate and appropriate evaluation criteria were identified, selected and prioritised in the second step. Land use, ecological and technical allocation constraints were listed in the same step. These first two steps satisfied (in part) the need for direct communal participation through a single workshop.

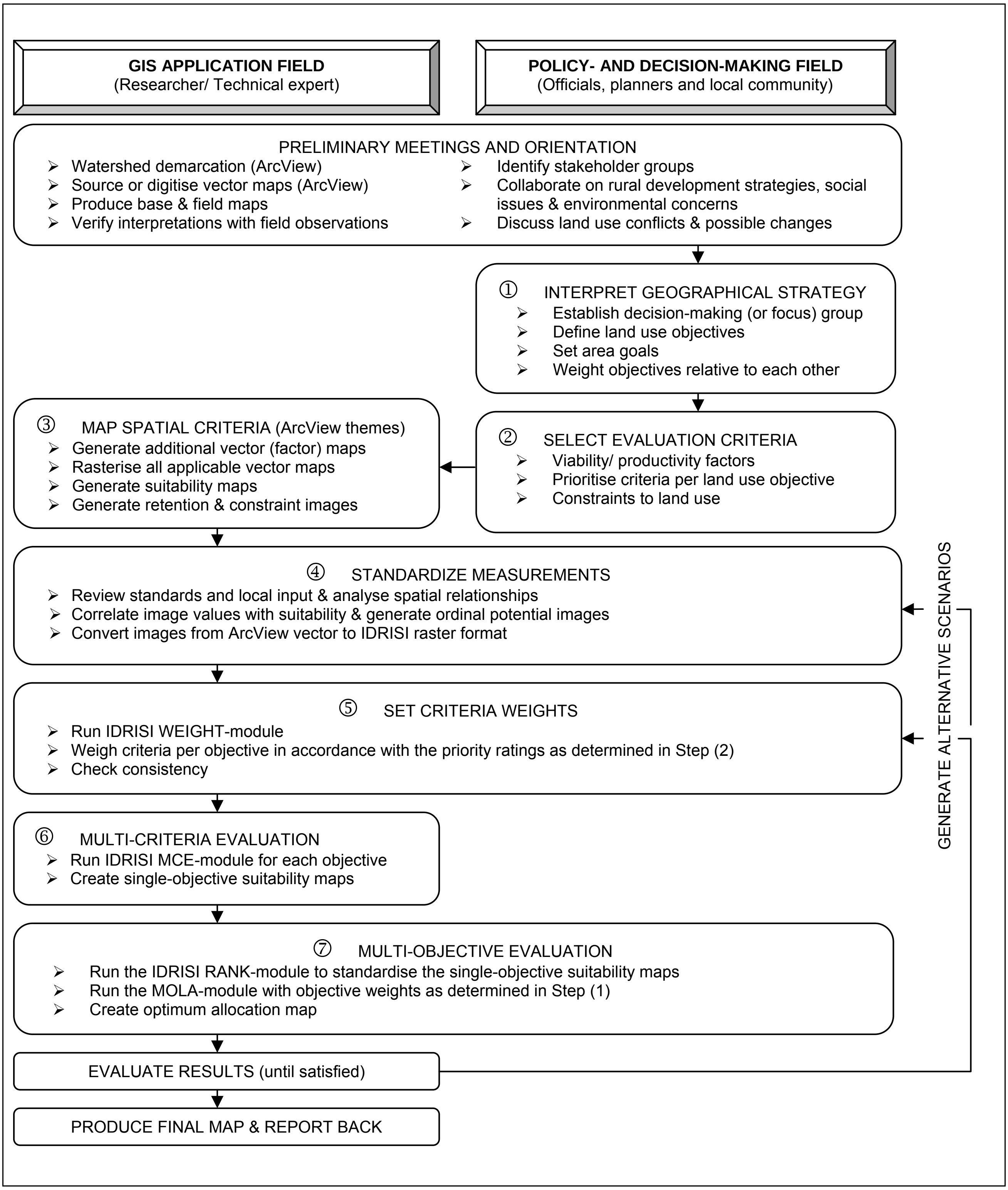

Figure 1.5 : The research plan

The criteria or factors decided upon need to be of a spatial nature so that their locational distributions may be digitally mapped using GIS – the third step. Due to its highly technical nature the researcher conducted this phase. The fourth step involved the standardisation of all criteria to a common measurement system or scale. Since the standardised value range replacing the unique variable codes had to correlate with perceived suitability rating, the thresholds settled on by locals (mainly in Step 2) were used whenever possible. Alternatively, applicable standards or guidelines presented in the available literature or practical parameters applied. The same was true in Step 5 where the relative importance of each objective was rated by applying a system of differential criteria weights for each objective. The participants' judgements in terms of each criterion's importance came to good effect in this weighting process.

The penultimate step involved the application of the constraints and criteria weights to the factors in a single procedure by the researcher, i.e. implementing multi-criteria evaluation (MCE) to compile an individual suitability map per objective. In the seventh and final step these potential images were subjected to a multiple-objective land allocation (MOLA) procedure. It effects multiple objective decision-making logic to produce an optimum allocation solution. In order to reach a satisfying final allocation map, Steps 4-5 was of an iterative nature as illustrated in the diagram in Figure 5.1.

So therefore, after a short review on decision-making theory (and MCDA) and the description of the current resource base that follows next, Step 1 sets off in Chapter 2, then Step 2 in Chapter 3, followed by Steps 3 to 7 in Chapter 4.

CHAPTER 2 DECISION-MAKING AND GIS: PUTTING THEORY TO PRACTICE

With sustainability in mind, one can expect that people (especially those finding themselves in areas with limited resources) will have to carefully decide which and how much of the available resources can be utilised, by who it can be done and where it should be exploited. A discussion on some decision-making theory, spatial multiple criteria decision problems in particular, will therefore be dealt with first in this chapter, citing examples where advanced GIS aided decision-makers towards acceptable solutions. An explanation will follow on how the resource base of the study area was captured and described to – as the first step in the research plan – arrive at agreed upon and prioritised land use objectives and area goals. It includes the details on how local stakeholder participation was promoted in the land use planning process.

2.1 Decision-making theory and GIS

Humans inevitably make a multitude of decisions during their daily interaction with themselves, other humans and the environment. Some decisions are simple, whereas others require a substantial amount of related information before execution. Concurrently, humans depend on various natural resources for their livelihood and prosperity. Cowlard (1990:5) defines decision-making as “the process of evaluating the alternative and choosing a course of action in order to solve a problem”. For instance, land suitability assessment and the optimal allocation of resources have long been a rather challenging and complex process, even emotional at times (Burch 1986; Grimble et al. 1995; Daniels & Walker 2001). Conventional multi-criteria decision-making (MCDM) techniques were to a large degree aspatial in the sense that they assume a spatial homogeneity within a particular study area. Decision situation complexity is a function of the number of alternatives and evaluation criteria under consideration, as well as the number of decision makers (interest groups) involved in the decision-making process (Malczewski 1999).

Sources to date now suggest that advanced GIS (e.g. integration with decision-making techniques) make sense when working on a regional basis with associations of communities or with long-term environmental management institutions (Poole 1996). In this context, Malczewski’s (1999:81) definition for spatial (or GIS-based) MCDA as “a collection of techniques for analysing geographic events where the results of the analysis (decisions) depend on the spatial arrangement of the events" applied in this case. In general, georeferenced data that has been processed into a form that is meaningful to the recipient (or decision makers in this case), and is of real or perceived value in the decision-making process, is known as geographical information. In essence then, a spatial multiple criteria decision problem involves a set of geographically defined alternatives or events from which a choice of (one or more) alternatives is made, i.e. their ordering or ranking performed with respect to a given set of evaluation criteria (Jankowski 1995). It follows that each spatial decision alternative to be considered consists of at least two basic elements: action (*what to do?*) and location (*where to do it?*). The real challenge though, arrives when the decision-maker is confronted with a large number of attributes or factors pertaining to the problem. The following section will offer a short overview on the advantages MCDA offers in such situations.

2.2 Multi-criteria decision analysis

The focus of MCDA is on informing decision-making; it is not prescribing how decisions 'should' be made, nor is it about describing how decisions are made in the absence of for instance, a formal support base. Belton & Steward (2002:4) suggested MCDA to "aid decision makers in learning about the problem situation, about their own and other values and judgements, and through organisation, synthesis and appropriate presentation of information to guide them in identifying, often through extensive discussion, a preferred course of action." They further argued that MCDA is a process which seeks to i) integrate objective measurement with value judgement, and ii) make explicit and manage subjectivity. MCDA does not limit the number and nature of objectives and criteria or dimensions chosen. Thus, the process of selecting and assessing criteria in MCDA is context dependent and iterative. Moreover, the approach is rooted in utilitarian precepts aimed at the maximisation of social welfare. MCDA is therefore inherently participatory and transparent in a number of senses. In contrast to, for instance in benefit-cost analysis (BCA), it can address equity issues directly. By using improvement in income or non-income equity as land use selection criteria, and by allowing stakeholders to participate in the process, it thereby permits the poorer section of a social unit to address particular issues themselves (Steward et al. 1997). Besides, it can do so with utility measured on an interval rather than a monetary scale, thus avoiding biases caused by differences in marginal utility of income. The use of a preference rather than a monetary scale means that choices are not limited by a group's ability to pay (and thus no adjustment need to be made) – a significant advantage from the perspective of developing countries. The critical aspect of spatial MCDA in this study would thus involve the evaluation of geographical events based on the criterion values and the decision makers' preferences with respect to a set of evaluation criteria. In this context we will now briefly look at some MCDA methodologies available.

2.2.1 *MCDA approaches*

MCDA is a broad expression to describe a collection of formal approaches that seek to take explicit account of multiple criteria in helping individuals or groups explore decisions that matter. The consideration of different choices or courses of action becomes a MCDM problem when there exists a number of such standards that conflict to a substantial extent (Belton & Steward 2002). In other words, MCDM problems involve a set of alternatives that are evaluated on the basis of conflicting and incommensurable criteria (Bantayan & Bishop 1998). Here one may first consider the decision space itself as related to the problem at hand. For instance, MCDM concentrates on problems with discrete decision spaces. This opposed to multi-objective decision-making (MODM) where the 'best' solution may be found anywhere within the region of feasible solutions (Triantaphyllou 2000). On the other hand, the distinction between MODM and multi-attribute decision-making (MADM) is based on the classification of evaluation criteria into attributes and objectives. Solving a MADM problem is a selection process, as opposed to a design process. Conversely, the decision makers' preferences are contained in the multi-objective decision rule that combines the geographical data and data on decision makers' preferences into a composite score (criterion or objective outcomes) with respect to each feasible alternative. Note that the model implicitly defines the alternatives. Given a decision rule, the MODM problem therefore involves finding the 'best' alternative (or ranking the alternatives) in the set of feasible alternatives according to the values of the objective functions. MODM decision rules define the set of alternatives in terms of a decision model consisting of a set of objective functions and a set of constraints imposed on the decision variables. Yet, remember MCDM is regarded as a blanket term that includes both MADM and MODM[16] (Malczewski 1999).

Each MCDM problem is associated with multiple attributes. Attributes are the properties of elements of a real-world geographical system, viz. quantitative and qualitative factors of measurable proportions over a geographical entity or a relationship between geographical entities. Attributes are at times also referred to as decision criteria. To meet a specific objective several criteria needed therefore to be evaluated. Eastman et al. (1995) named such procedures multi-criteria evaluations (MCE). A criterion is a standard of judgement or a rule to test the desirability of alternative decisions. Regarding the decision alternatives, all decisions are made in some kind of environmental context and therefore involve many factors beyond the control of the decision maker (e.g. a climatic criterion). These states of the environment factors, together with the other

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[16] MADM and MODM problems are often referred to as discrete and continuous decision problems, respectively (Hwang & Yoon 1981).

decision variables controlled by the decision makers (including constraints) may be rather comprehensive. The need to structure the problem in a manageable, hierarchical fashion becomes apparent. Saaty's (1980 and 1994) Analytical Hierarchy Process (AHP) is one such approach where a large number of criteria are arranged in a hierarchical manner.

2.2.2 *The Analytical Hierarchy Process*

The AHP is a MCDM development that appeared to be one of the most promising techniques for the development of weights (Eastman et al. 1995). After decomposition, AHP requires the assessment of pair-wise comparisons and uses a linear 9-point continuous scale to quantify them. It is mainly in context of these pair-wise comparisons that Saaty's judgement matrices have received a relatively wide acceptance as being an effective way for extracting qualitative information for real world MCDM problems. Yet, a severe drawback of pair-wise comparisons is often the large number of them[17]. Nonetheless, to achieve the last part of the analytical process, i.e. the synthesis of priorities, Saaty's method makes use of eigenvalue theory[18] (a modified least squares problem in AHP) and entails the construction of a decision matrix by using the relative importance of the alternatives in terms of each criterion. With regards to internal uncertainty, an index of some sort was required to evaluate the reasonable level of consistency in the pair-wise comparisons. Saaty (1980) developed what he calls the *consistency ratio* (CR), which involves the maximum right eigenvalue. In essence, the CR is designed in such a way that if $CR < 0.10$, the ratio indicates an acceptable level of consistency; if however, $CR \geq 0.10$, the values of the ratio are indicative of inconsistent judgments and revision is required. Because computing time becomes of essence in such complex problem situations, the need for powerful computing platforms to digest and analyse this spatial information arises. This brings us to the advantages of GIS when used in combination with MCDM models.

2.2.3 *Combining MCDM and GIS*

Since the early nineties the integration of MCDM models with GIS evolved significantly with Carver's (1991) search for suitable nuclear reactor sites and Hall & Wang's (1992) land use suitability ratings for wetland rice and soybean land allocation. Integrating linear programming (LP) was implemented when Chuvieco (1993) tailored his model to deal with the planning of new land uses to reduce rural unemployment using IDRISI[19] for spatial analysis. A valuable study was that of Davidson, Theocharopoulos & Bloksma (1994) in which they developed a land resource

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[17] For instance, if there are n objects to be analysed, then a complete set of pair-wise comparisons is of size $n(n-1)/2$.

[18] The eigenvalue concept (a modified least squares problem in AHP) falls outside the scope of this study and the reader is referred to Saaty's (1994) latest work for detailed information on the subject.

[19] A grid based geographic analysis system (Clark University Graduate School of Geography, Worcester, MA).

information system that could relate the incidence of soil erosion to slope, soil order and surface texture. Their approach reflected the popularity of a class-based view of the world in that the division of land into suitability classes is seen as more important than the detection of gradual change. Land assessments characterised by multiple-choice alternatives and factors can therefore be enhanced significantly by the effective integration of MCDA models with GIS (Eastman et al. 1995). In his study, Jankowski (1995) offered a comprehensive classification of MCDM techniques and a framework for the integration of MCDM models and GIS towards either a spatial decision support system (SDSS) or the simple integration of GIS and specialised analytical models.

It follows that model building has been increasingly viewed as a tool to structure discussion and debate about issues, and to create a learning environment where model assumptions can be tested (Vennix 1996). In this view, models are no longer seen as providing solutions; rather, they are methods to understand and learn more about the system being modelled.

The advent of landscape modelling or landscape analysis prompted more uses for these MCDM methodologies and GIS (Van der Merwe 1997, Watkins, Cocklin & Laituri 1997; Bartel 2000; Kangas et al. 2000). To balance development and economic growth and conservation in a coastal zone, Van der Merwe & Lohrentz (2001) applied a GIS-based MCE model to legitimise the demarcation of a vegetated buffer zone as an environmental element in coastal planning frameworks. Since the design also incorporated public decision-making, the choice of variables (or factors) and their priority ratings used during analysis delivered a highly functional final solution. Georeferencing should therefore definitely be used in community-level studies, where primary data collection can be easily linked to other variables likely to differ across communities (Place & Swallow 2002). In a recent study by Wang, Yu & Huang (2003) in the Lake Erhai basin, China, a GIS model was used to allocate future land uses based on the results of an inexact-fuzzy multi-objective linear programming (IFMOP) model of a MODM problem. Three factors were considered in implementing the optimal land use change: existing land use, land suitability, and what the authors call “land conversion preference”. The land allocation model was implemented with ArcView GIS (3.x) and its relatively easy to use Avenue programming scripts. The same researchers concluded that GIS makes it possible to identify spatial allocation of the optimal land uses by analysing the location of existing land use and suitability of physical features (slope and distance to surface water in their case). This was critical because it provided decision makers with specific recommendations about where land use changes should occur to achieve the optimal outcome.

The actual linking or coupling of the respective systems mentioned above varies. Nyerges (1993) distinguished two general coupling strategies: loose coupling and tight coupling. The first strategy combines the capabilities of separate (outside a GIS) MCDM models for GIS functions and MCDM by transferring electronic (digital) files. The data interchange standards and formats are important for spatial decision making in that they provide a means for an effective and efficient integration of input data to be used in the particular decision making process (Malczewski 1999). The transfer is often in ASCII[20] format (Jankowski 1995), but is not limited to it only since a wide range of alternative transfer formats exists at present. Tight coupling, the second strategy, involves calling up MCDM analysis routines bundled within GIS software, thus allowing both modules to run simultaneously and to share a common database. Amongst its many capabilities, a wide range of decision support functions can be found in the IDRISI Decision Analysis module (Eastman 1997). In fact, to complement the concept of interoperability, Malczewski (1999) regarded IDRISI as the only full-featured GIS package that fully supports multi-criteria spatial decision support systems (MC-SDSS). This study's MCE (based on the AHP) and MOLA (based on goal-based linear programming) processes were thus performed on the IDRISI GIS (14.02) platform. To effectively deal with natural resource management and the potentially tough deliberations during land evaluation and decision analysis, a large scale and truthful description of the resource base in question was called for next.

2.3 Reality in the study area: The resource base

It was vital to record and evaluate the study area accurately enough in terms of its resources to guarantee credible suitability ratings and more realistic allocations. This was achieved with a land cover mapping system based on the (updated) National Land Cover (NLC) 2000 programme[21], and since 2005 accessible for the entire country to those familiar with its uses. All natural or man-made features in the micro-catchment were captured and classified accordingly. The resulting land cover map offered valuable clues about the status of the resource base and areas of environmental concern. These land cover classes, once converted into generalised and practical land use parcels, aided decision-making significantly.

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[20] ASCII is an acronym for American Standard Code for Information Interchange. The ASCII raster file format is basically a few lines of header data (keywords and values) followed by lists of cell values.

[21] Jointly co-ordinated by the Council for Scientific and Industrial Research (CSIR) and Agricultural Research Council (ARC).

2.3.1 *Land cover mapping: The method*

Incidentally, in terms of NLC maps nationally, the study area falls exactly in a larger region being processed at the time – one of the last – and an indication of the low ranking the region receives in term of development potential nationally. Hence the more elaborate mapping method used in this study. Linked to the NLC system, a unique land cover code (index or primary field) was employed during field analysis and digitising. Appendix B lists the standard land cover classes and descriptions as implemented in this study. In addition to the existing NLC classes encountered, four additional land cover codes were introduced and two existing classes were also slightly redefined in this case however. This was necessary to distinguish between planted, fallow and abandoned land of the cultivated kind, as well as to cater for land reserved for roads. Moreover, these additional distinctions enabled the calculation of the actual proportion of productive (cultivated) land at that time, and aided future projections.

Productive cropland in this study is defined by both planted and fallow cropland. Where cultivated land was classified as commercial cropland, it was done so in a broad sense. Put differently, it indicates the larger continuous farmlands that produce food to more than just a family unit or small social unit and is often protected in some way or another. The insignificant percentage of irrigated and permanently planted agricultural land could safely be grouped with the mainly subsistence and commercial type of dryland crop production in existence here. On the other hand, the abandoned cultivated land classification facilitated the ‘old cropland’ land use class. Deciding whether a cropland is fallow (long or short) or simply abandoned was another interpretation problem encountered. What length of time must pass before cropland can be referred to as ‘old’ cropland? This is important because land laws often stipulate that land is declared “abandoned” if uncultivated for more than a certain number of years, frequently much shorter than an adequate fallow period - the case in Mozambique (Unruh 2002:172). For the purposes of this study and when compared to the initial information gained from the aerial photos taken in 2001, it was set at four planting seasons[22]. Besides, many land uses that are ‘shifting’ in nature are also often difficult to interpret or define and overlap to various degrees. Examples in the Eastern Cape Drakensberg could include the grazing behaviour of livestock (goats and cattle) observed on communal pasture, (used or unused) cropland, degraded land (see Figure 1.1 E), and even grassland patches or strips within plantations periodically. Cattle are also inclined to graze in areas newly cleared of alien jungle (Hosking et al. 2002). The digitised land cover layer therefore contained a special field to capture vital attributes for specific classes. It included supplementary information (sub-classes) on

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[22] Interpretation was, until the end of this study, verified by field visits during 2001-04 (each winter and summer)

forests, plantations, bushland, wetlands, built-up features, natural grassland, degraded areas or any other significant observation.

A special ‘reserved’ land cover class was finally introduced to accommodate the proportion of land currently occupied (or reserved) by selected roads. A ‘selected’ road means that it is either currently administered in some way (national and municipal) or regarded by the community in question as a popular (public) access route of acceptable surface condition and traffic volume to justify its current (thus also future) existence. When digitising the land cover theme (in ArcView), the process was initiated by assigning a suitable buffer distance, in the *Create Buffers wizard,* that correlated (in width) with all the various road categories encountered. Using the *GeoProcessing Wizard* the resulting road buffer zones theme was then used to ‘cut’ another single polygon theme, which was generated by buffering the calculated watershed polygon 500 meters on the outside. The latter distance was chosen arbitrarily, as it was mainly done to save on digitising time. It was not necessary to digitise land cover units for the entire area of interest or extent, but only the micro-catchment at the required 1:3000 scale. Additionally, it enabled the return of more reliable image values on the catchment border when rasterising the vector data later. The result is a theme containing, together with the road polygons, smaller and more manageable individual polygon units for the rest of the digitising exercise. Appendix C offers a full description on how all the natural and man-made features in the study area were classified into the standardised land cover classes, as well as rationalising any additional descriptive information that was documented in certain instances to facilitate the conversion to land use and evaluation phases. A map for perusal of the land cover classification results accompanies these.

2.3.2 *Land cover: The local situation*

The final land cover theme yielded 25 of the 49 NLC classes available plus the four additional classes mentioned. Examining the results (as mapped in Appendix C and tabled in Appendix D) revealed the low proportion of productive cropland (24,5%), large proportion of old or abandoned land (16%), and some alien bush encroachment (on the eastern plantation border). Also noteworthy was the relatively high incidence of wetlands, particularly with regards to their location (in or adjacent to cultivated land). This implies large-scale draining operations in the past for perceived agricultural gains. The full and worrisome extent of environmental degradation for the study area is reported in Figure 2.1 A.

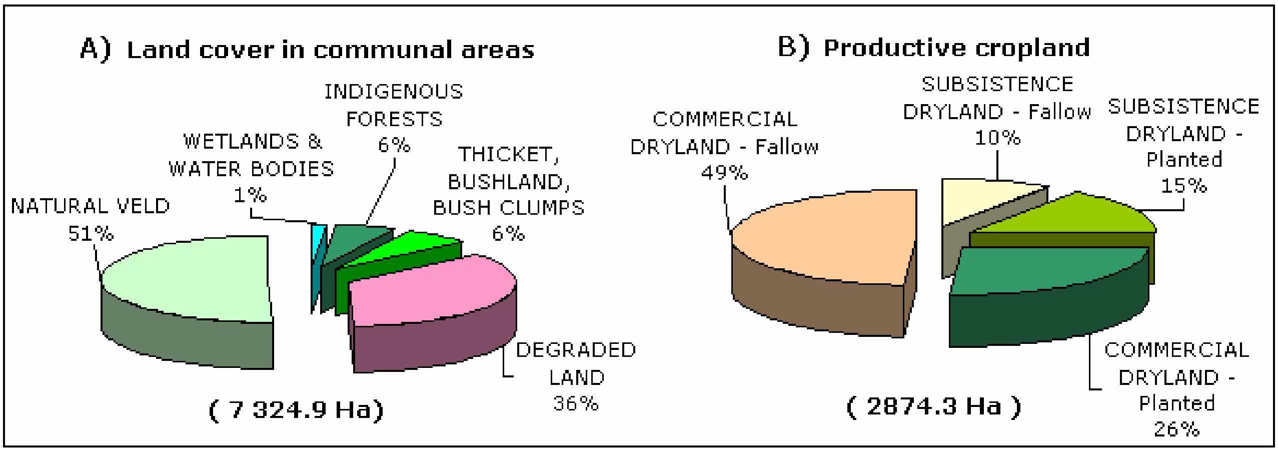

Figure 2.1 The distribution of some of the natural resource base components

More than a third (2 637 hectares) of the current land typically perceived as being community owned is degraded when one includes old cropland and erosion features with the rest of the observed (classified) degraded grassland. Since communal land excluded productive cropland (2 874ha), built-up and afforested areas (1 520ha), it practically left just over half of the communal area to locals needing quality rangeland. Preciously few original wetland systems (106.4ha) and indigenous forests (414ha) are left at present. Wetlands in the micro-catchment comprised of riparian zone wetlands and high altitude bogs[23]. Unfortunately, farmers have drained many of these over the decades and they are often subjected to severe erosion. Adjacent activities, such as tilling and intense grazing have a huge impact on some wetlands owing to increases in sedimentation or runoff velocity, particularly in steeper places in the landscape (shown in Figure 1.1 C).

The problem with agricultural productivity is illustrated in Figure 2.1 B. Just over a quarter (749ha) of the available commercial cropland is actually planted – a continuous trend over the study period. The fact that almost half of the total productive cropland is fallow would naturally be a concern during decision-making. In contrast, of the total subsistence farmland of 717ha (and thus associated with settlements), well over 60% (about 440ha) is under crops – a more acceptable trend. At the same time, ‘old cropland’ covers almost sixteen per cent of the entire watershed or as much as the total wooded areas. Of the latter, plantation forestry, which includes clearfelled areas, occupies just over half (970.1ha)[24]. The dominant commercial tree species is pine (about 84%), which is not particularly useful to locals, followed by more sought after gums and wattle. Where

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[23] Described by Forsyth et al. (1997) as consisting of small ox bow lakes and pans, riparian zone wetlands were the more frequently found type. Yet both wetland and bogs are regarded to have important hydrological functions, such as the slower release of stored water, sediment trapping, and flood peak attenuation.

[24] The clearfelled areas (about 68 hectares) will change constantly under normal circumstances and the Amanzamnyama status reflects the situation as updated until 2003.

agroforestry is concerned, it must rather be seen as an approach to land use (communal land is at stake) than a fixed arrangement or combination of woody plants. It can be defined as all practices that involve a close association of trees, bush or shrubs with crops, animals and/ or pasture, for ecological, economic, and even cultural reasons (Sanchez 1995). In other words, it combines the best attributes of forestry and agriculture and has a broad inter-disciplinary base. Features in the landscape that could be of significance in this case included windbreaks, hedges or avenues, jungles of invasive woody species, as well as single trees. Woodlots cover relatively small areas (somewhere between 1 to 30 hectares) containing trees intended for fuel wood, building material, poles, laths and droppers for a particular social unit[25].

2.3.3 *Converting to land use: The local situation*

The land cover classes found in the entire micro-catchment were, after careful consideration, successfully grouped to describe the present day land use situation clearly and accurately enough for the purposes of this study. The resulting final land use distributions were then mapped, and are presented in Figure 2.2. Also appearing in the map are the names of a few villages and other infrastructure for orientation purposes. Observe that indigenous forests appear to be more successfully preserved within the plantation extent. This can probably be attributed to restricted access if compared with the diminishing small patches of natural forests found elsewhere. The map reflects these details with respect to agricultural productivity by also showing the distribution of planted and fallow farmland. Although dryland crops make up a quarter of the study area, almost sixty per cent remain unplanted. Built-up areas, including roads, make up five per cent (about 550ha) of the entire micro-catchment. The importance of roads in terms of settlement developments is obvious – the built-up areas are closely associated with primary routes. The relatively large built-up ‘patches’ appearing in the villages on the map are a result of schools and the fact that sports fields were included under built-up as land use.

The conversions from land cover necessary to obtain this land use image were achieved reasonably easily. Water bodies occupied an almost insignificantly small proportion of land and were thus grouped with *wetlands*. This would also ensure their current status would be retained to the same extent as would wetlands (wetlands would be conserved). The *forest* and *bushland* classification from land cover to land use remains the same. Sports fields and quarries[26] were grouped with the

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[25] Potentially profitable contract-farming in the form of small timber ‘plantations’ were also accommodated in the woodlot concept.

[26] Both excavation sites were small and also less than 100m from current built-up zones.

generalised *built-up* class. These sites would thus be retained, although slope constraints would rule out the possibility of adjacent settlements or cultivation in the latter case – a desired effect.

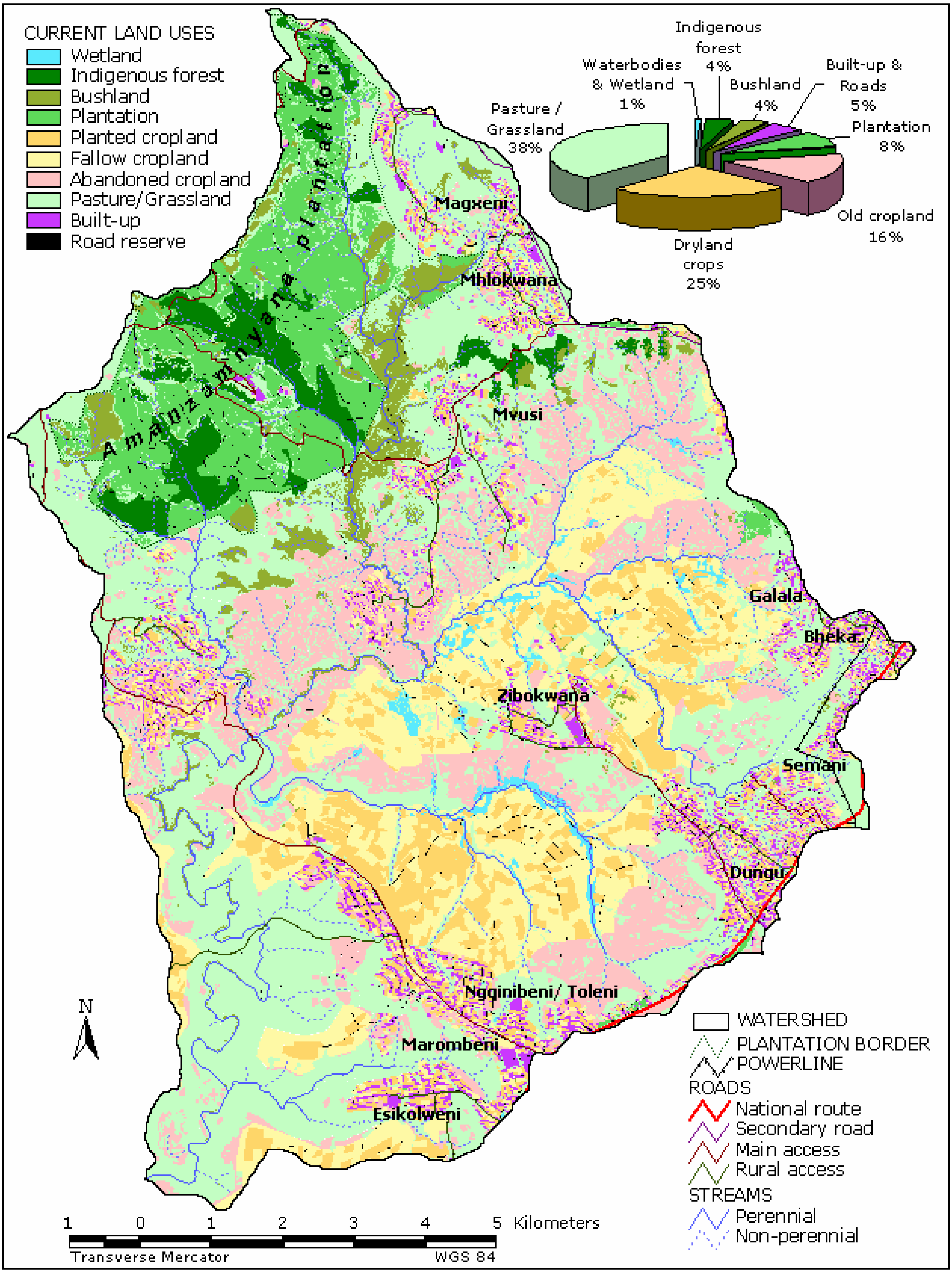


Figure 2.2: Current land use distribution

The built-up class also included roads. The *plantation* land use class follows logically, and so does the *productive cropland* class with its additional and slightly modified subdivisions. The *old cropland* land cover class was the remaining newly introduced class and were retained as such. The rest of the land cover classes were grouped together as *grassland*, the dominant biome.

Appendix D provides more clarity on the classification, distribution, and conversion of the resource base to general land uses. The columns on the left list the land cover classes and their extent as described in Section 2.3.2, whereas the columns on the right list the eight generalised land uses and their proportions as derived from these land cover components. A simple reclassification was performed to apply the conversion. Having then fully captured the resource base and expressed as functional land use classes, the first procedural step in the research plan could begin in earnest.

2.4 Putting participatory theory to practice in the Transkei

Ideas about what constitutes desirable environmental transformation inevitably include some cultural and social elements, and are informed by new scientific developments. The paradigm shift towards the sustainable livelihoods concept is noticed for its affects on natural resource management, and the new roles assumed by social units within affected communities. Strategic rural planning can no longer ignore local/ community input and environmental integrity.

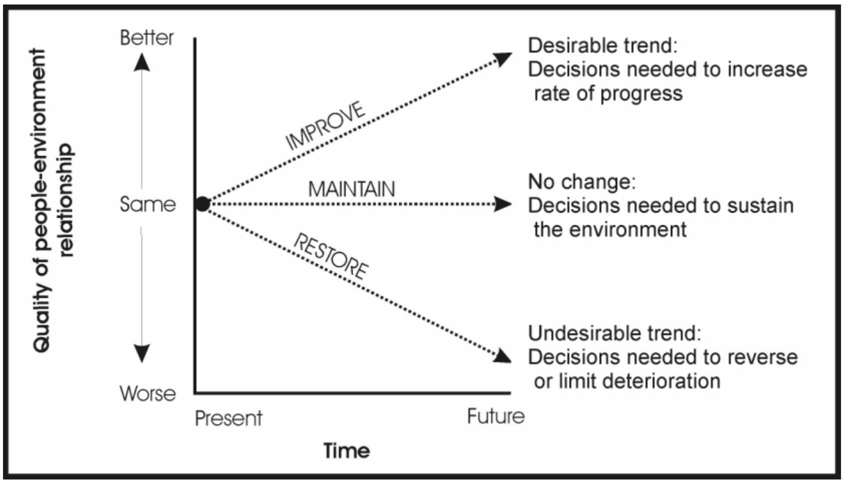
2.4.1 *Participatory development*

Successful implementation of development plans depends upon common ownership of the problems and the proposed solutions by the people who will be affected. This common ownership may arise from a consensus about the goals and the actions necessary, or from a negotiated compromise between groups with different goals and insights (Dalal-Clayton, Dent & Dubois 2003). The World Bank’s (1994:91) Learning Group on Participatory Development has defined participatory development as “a process through which stakeholders influence and share control over development initiatives, and the decisions and resources which affect them”. While the complexity of integrated land management invites centralisation and technocracy, participation suggests subsidiarity and small-scale operations, engaging people to think creatively about issues intimately linked to their lives (Turton & Henwood 2002). Here the primary rationale for enhanced stakeholder participation in land use planning is based on the democratic maxim that those affected by a decision should participate directly in the decision-making process (Moote, McClaran &

Chickering 1997). If local (participatory) action is the aim, then the priority is likely to be building capacity and competence for local analytical processes.

2.4.2 *People-environment relationship*

A simple method to relay the available or possible development strategies at a specific spatial scale to audiences effectively was essential in this study. The decision-making model within the context of a people-environment relationship supplied by Cowlard (1990) was most useful in this respect. This model was easy to grasp when used to explain the objectives of the study and the value of stakeholder input towards acceptable resource management strategies. In Figure 2.3 the arrows represent the trend of change and the boxed actions the respective geographical decisions strategy. Taking the current scenario of social hardships, low farming potential and land degradation as the point of departure, participants readily understood the positive and negative implications each action or change would bring about over time.



(Source: Cowlard 1990:6)

Figure 2.3: Geographical decision-making and the people-environment relationship

All common-pool resources (e.g. rangeland, streams, forests, etc.) share two attributes of importance for economic activities: i) it is costly to exclude individuals from using the good either through physical barriers or legal instruments, and ii) the benefits consumed by one individual subtracts from the benefits available to others (Ostrom 2002). Careful analysis of rural farmer innovation and experimentation provides clues as to the nature of local priorities and the scope and trajectory of endogenous agricultural change (Richards 1986). Interactive participation and the dissemination of local knowledge were thus encouraged in this case, whilst the current resources scenario was adequately illustrated with the help of the prepared base maps.

Although tenure status and soil fertility are related (Smucker, White & Bannister’s 2002), farmer assessments of fertility also appear to integrate other productive factors not measured by laboratory analysis of soil nutrient levels. Most pastoralists have devised systems to help them evaluate the productivity of rangelands. From this they can calculate an approximate carrying capacity. In normal circumstances such systems are based on monitoring detailed signs and indices of environmental health, stress, and change. As Naimir (1990) explained: local knowledge of natural resources is made up of three types of information: i) accumulated cultural knowledge, ii) knowledge modified through contact with other cultures, and iii) progressive learning of the environment. It is thus important to understand how farmers or herders measure yield, and what the standard deviations of their estimates are, since subsequent innovations must increase yield higher than this standard deviation before they will be adopted by the people. When extracting local knowledge though, one should go about it in a sensitive and responsible manner[27]. Nonetheless, such information was much more forthcoming in this case when it was explained that such knowledge would largely contribute towards a more acceptable outcome that would reflect *their* (the community’s) needs rather than *our* (the official planner’s) needs. In light of limited resources in the study area in general, the alternative strategy included here retains as much as possible of the current land use status. This trend reflects the 'maintain' strategy, i.e. no change but decisions needed to sustain the environment. Alternatively, decisions were also made to increase the rate of developmental progress, or reverse (or limit) environmental deterioration. The first implied the quality of people-environment relationship improves in future, the latter a restoration (or rehabilitation) strategy.

2.4.3 *Stakeholder participation: Consultation and group selection*

The planned procedures required role-players whose value judgements concern the land use issues at hand. Three main stakeholder groups were identified and consulted: the affected communities in the study area, relevant state officials, and independent advisors. Besides the researcher (GIS expert) and interested land users and community members, other participants included tribal headmen (*Nkosi*) or elders, regional authorities, two independent land use consultants, and a black economic empowerment (BEE) agent.

Discussions took place through a formal meeting at a headman’s house, an open meeting at a community hall and later a final workshop. The objective was to, in general at first, extract

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[27] For example, nobody was expected to reveal the whereabouts of plants in the area that some community members might feel have a high cultural or medicinal value.

sufficient useful information regarding rural development problems from these sources. An obstacle in this respect was the fact that, although quite well represented at the open meetings, women were conspicuously absent in the *actual* decision-making processes at community level[28]. A Xhosa translator attended all contact sessions to convey and explain concepts more clearly to community members when English alone failed. Salient issues raised by the three stakeholder groups were recorded and loosely grouped under an economic, environmental or social heading. Some concerns could however appear under more than one heading (e.g. the negative effects of fires).

Although the economic sector seemingly contains the most entries, many of them are rather a result of the problems experienced on the environmental and social front (e.g. poor quality crops due to drought or insufficient care-taking). Variables that may be related to property rights variables at the plot or household level can be income, soil fertility, and distance from house to other land use parcels. Still, most issues brought forward then have already been highlighted in the first chapter and will not be repeated here. A summary of the issues and concerns raised with regards to rural development can however be viewed in Appendix E. With respect to the spatial information at hand and allocation decision-making phase though, only the entries shown in bold print represent those issues deemed practical enough for modelling, in either a direct or indirect sense. Also noteworthy was the difference (and similarities) in focus between the stakeholder groups as shown, and the concentrated attempt to include the larger community's expectations into the analysis.

During the open meeting, a relatively small focus group was recruited representing all the communities within the micro-catchment and their interests in terms of resource utilisation and evaluation. This decision-making group was for practical (budget and time) and technical (computing cost) reasons limited to ten individuals only for the purpose of this study. The eventual decision-making group consisted of two herders, two foresters, two crop farmers, two village elders, a traditional healer, and a welfare official. As for the first three pairs, the three dominant land uses, *viz.* livestock production, plantation forestry, and dryland crop farming represented local community interests best. It was expected that the remaining pair of elders would, together with the last two individuals, adequately represent common resource ownership and the right to use it, or other important socio-economic needs.

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[28] Similar findings by Bird & Metcalfe (1999) with Zimbabwe's well-known CAMPFIRE project reiterates the urgent need to specifically address women's groups in an effort to increase their involvement in decision-making.

Group members were not limited to opinions related to their occupation or community status alone – they decided on a range of sustainable livelihood elements. In this regard, within the pairings there were noteworthy differences (variance) as well. One herder was an owner and the other a caretaker-herder, both male. The same applied to the crop farmers, except for the fact that the caretaker-farmer was female. The foresters, both male, consisted of a forestry official from Amanzamnyama plantation and a local forestry extension officer. Due to other commitments on the day, a headman agreed at a previous private meeting that the two village elders (men) would, as proxies, represent tribal or traditional authority. Moreover, one elder was a respected high school teacher and could therefore contribute significantly towards educational and youth issues. Because her status and knowledge base was regarded as significant in the larger scheme of things, the traditional healer fortunately agreed, after extensive argumentation, that she would partake in the decision-making phases. The group was completed by a female social worker servicing the area and thus relatively well informed on local social needs. A workshop with this single representative stakeholder group then ensued to, based on the issues so far, consolidate local concerns and goals, select and prioritise practical land use objectives, and express feasible area goals.

2.5 Land use objectives and area goals

An objective is a statement about the desired state of the system under consideration, in this case the desired (and sustainable) pattern of land use. Participants of the final (representative) decision-making group were shown the current distribution of land uses. Large field maps similar to Figure 2.2 were prepared to aid in this respect. The current agropastoral systems were again scrutinised, possible land use conflicts were mentioned, degradation issues were readdressed, and social needs were properly outlined. Assimilating this information, it was agreed that five general land use objectives would suffice for further decision-making analysis. Loosely ranked in order of perceived importance initially, they were forestry, agriculture, communal use, conservation, and built-up (settlements).

2.5.1 *The forestry objective*

In the developing world, economically valuable trees are among the most common and valuable forms of customary evidence for claiming "ownership" of land (Unruh 2002:172). *Forestry* development (and extension) was, due to its suitability and current application in the region (Forsyth et al. 1997; Celliers, 1999), identified as the first realistic land use objective. For this study, Clarke's (1995) definition of rural development forestry (RDF) as a range of practices involving the deliberate retention, cultivation and management of trees in small-scale farming systems, applied. RDF or social forestry (Arnold 1992) is often used interchangeably with community forestry and others to describe an implicitly narrower spectrum of activities surrounding the fuel wood, deforestation, and woodlot issues by those involved in community forestry. Yet, the many species and niches of agroforestry systems and their multipurpose nature complicated the task of classifying tree management strategies.

As Place & Otsuka (2002) reminds us, these differences are all the more difficult to identify at the community level. Different households may adopt similar tree species in similar configurations for different purposes, or see tree planting as a way of establishing long-term rights to land. Certain tree species carry with them tenurial implications for example, such as those customarily used for boundary demarcation or others viewed as ‘communal’ trees. Still, in some parts of the developing world the profit motive is a powerful incentive for farmers to change their ways according to a number of reports (Glendinning Mahapatra & Mitchell 2001; Leakey 2001; Sandewall, Ohlsson & Sawathvong 2001), especially when farmers have rights over the trees and land. But commercialisation of resources also puts pressure on common property resources because of the mix of local and outside interest it generates and the power relations involved (Dalal-Clayton, Dent & Dubois 2003). There is the risk that the most powerful – local elites or outsiders – will reap most of the benefits. Also, in some areas the clearing of wattle jungle for ecological purposes (i.e. WfW) means the loss of a valuable fuelwood resource. In the case of allocating water use licences for stream flow reduction activities (SFRAs) on areas invaded by jungle wattle a guideline document by the Directorate of Water Utilisation (Warren, Versfeld & Horak 2003) applies. It sets out the objectives, process and conditions under which a water use licence may be allocated for the practice of a SFRA (this being forestry, and the licence therefore also often referred to as a forestry licence). In this case the key reason for licensing would be to provide an incentive to affected communities to gain control of the spread of wattle, restore degraded areas and gain other benefits. The application hereof becomes most important in stressed catchments because this is where applications for further licences would normally stand very little chance of success[29]. Nonetheless, the needs of the Reserve still take precedence, and there must be agreement that there is sufficient water either available, or made available through the conversion process, to allow for an allocation without short or long-term detriment to society or to the environment. This applies to poor rural communities in particular – people who need both the income that might be generated, and a steady fuelwood resource. Thus community forestry options could take the form of contract

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[29] Warren, Versfeld & Horak (2003) accentuated that these are the areas most in need of good land management, hence the need for a pragmatic approach. Along with better management and control, it ultimately aims to bring a reduction in the total area under trees.

farming or group schemes, or potentially profitable contract farming in the form of small timber woodlots. Although agroforestry or woodlot schemes for fuelwood or poles as envisioned by this study requires an extended duration for production, the practise is more individualised and requires much less, if any, coordination beyond the community or even household level once established. Yet, Celliers (1999) reiterates that, in terms of his woodlot model, a fundamental paradigm shift will be required for large timber companies to allow commercial woodlot growers to achieve sustainable and appropriate rural development[30]. In light of domestic land reform policies, the significant aspects related to this type of stakeholder-partnership combinations or BEE deals are that communities became shareholders in the forest industry and thereby increasing black involvement in the forestry sector (DWAF 2001).

2.5.2 *The agriculture objective*

Vital in terms of its current use and role in food security, the second prioritised objective was *agriculture*. Although agropastoral systems are defined as those that involve some form of (dryland) crop cultivation in addition to livestock production (Naimir, 1990), livestock production or herding in this case was more associated with the communal use of rangeland (pasture). When the term “agriculture” is mentioned casually in the text from here on, it means crop farming. In union with the local concerns pertaining to farming, the FAO (1997) recognizes several specific issues associated with sustainable agriculture, including the following: i) adopting farmer-centred participatory approaches and carefully recording and assessing indigenous knowledge and technology, ii) promoting use of environmentally friendly technologies to intensify production on high-potential land already converted to agriculture, iii) promoting recycling and use of organic materials in low-input farming systems, and iv) rethinking priorities for conserving and using agro-biodiversity, including the use of locally adapted crop varieties and crop diversification. For the most, and not an easy task in a poor region, the above implies improved or intensified agricultural practices on existing cultivated land (current and old) by means of extension, including the consolidation of the ‘best’ suited productive cropland. In the case of commercial produce, market-led development fundamentals would call for a readily available market, which unfortunately lacked here at the time. Likewise, owing to present day water allocation problems in the micro-catchment and implementation costs, irrigation would not readily be one of the methods chosen to intensify crop production. Protecting crops grown on arable fields some distance from villages with expensive fencing proved almost impossible. As the resource base description indicated, and

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[30] Earlier indications showed that about 10-15% of the woodlots in this (Transkei) region were profitable, and communities would be encouraged to set up small businesses, selling pulp and poles, while the less profitable woodlots communities would be able to set up joint management schemes to reap subsistence benefits (Ham 1999).

together with other factors mentioned - such as drought and land degradation - a good deal of this arable land was left fallow, or incorporated into communal pastures. Part of the land allocation process would (in the long run) therefore endeavour to restore farm productivity in suitable agricultural areas. Sustainable agriculture normally starts with the soil by seeking to reduce soil erosion and to make improvements to soil structure, organic matter content, water-holding capacity and nutrient balances (Pretty 2002). Alternatively, it was expected that present-day old croplands could, if not reclaimed by agriculture at first, provide for much of the other objectives - forestry or communal use in particular.

2.5.3 *The communal use objective*

Since its status affects a large section of the population in the watershed, the *communal use* objective received a fair amount of attention. This rather ambiguous term would in real life constitute the rangeland or veld available to herders (cattle and goats), hunters (birds, hares, and bees), gatherers (firewood, bark, thatch, medicinal plants, water, etc), or any visitor for that matter (recreation, gravesite visits, etc). Wide ranging points of view made it rather difficult to properly evaluate, but its importance as a ‘land use’ was evident. As Dalal-Clayton, Dent & Dubois (2003) warns, community members tend to be reluctant to accept responsibility for resource management, and community management will be difficult to achieve if the proper ingredients are not in place. These include i) real power and rights (if not ownership rights, at least management rights allowing villagers to commercialise resources without needing to follow cumbersome and sometimes restrictive procedures), ii) competence, and iii) economic interest. The importance of communal land as rangeland or grazing area was however predominant in this case. More so if taking into account that the essential rangeland elements are grazing quantity and quality, which are again directly related to livestock quality. Livestock currently utilising the veld may not necessarily be of desired stock quality though. Still, they (cattle in particular) are directly related to wealth, power and status. A decade ago various causes of lower stocking rates of livestock (mainly cattle and sheep) in the (then) Cape Province were examined by Dean & MacDonald (1994). They concluded that the stocking rate at that time in the semi-arid and arid rangelands was unrelated to market forces or state policy but was determined by utilisable primary productivity of rangelands. Sufficient suitable and accessible rangeland should thus be secured for the communal use objective in this regard.

2.5.4 *The conservation objective*

Everyone readily agreed that something should be done to improve the environment with regards to land potential reduction due to degradation, and erosion in particular. This brought the fourth land use objective, *conservation*, into the fold. It was acknowledged that many erosion processes directly affected the catchment's water quality. Discussions around wetland conservation therefore proved informative, although the role of wetlands was poorly understood. Society values wetland functions to various degrees, yet there is no absolute, general association between wetland function and wetland value to society, partly because values are difficult to determine objectively (Lewis 1995). Moreover, the social priorities for protection of wetlands and for investing in wetland protection are matters of policy that must reflect in part the value that society places on wetland. It follows that, if one objective is preservation of wetland attributes that have societal value, the association between selected wetland values and their supporting wetland functions will dictate the kinds of protection mechanisms that will be the most effective. The association between the values of wetlands to society and the functions that are characteristic of wetlands is therefore important in the design of wetland protection systems.

The aim of catchment conservation planning would be to direct the people to utilise suitable land, to use the best methods applicable to the area and to make sure that controls to land use are implemented in both the mechanical and cultural spheres (Dalal-Clayton, Dent & Dubois 2003). Biodiversity is a function of disturbance which itself occurs at multiple spatial and temporal scales and intensities across a landscape (Brady & Whysong 1999). The conservation objective is therefore closely related to two basic land degradation elements, namely the unacceptable quality and quantity of natural resources (water, grazing, timber, soil) and the perceived loss of biodiversity. Hence conservation efforts would concentrate on wetland and veld (environmental) management awareness, practical erosion control measures (improvement of soil potential), alien bush control, and halting the demise of natural forests.

2.5.5 *The built-up objective*

To cater for human settlement and their economic activities, the final land use objective was obvious. The *built-up* objective was understandably a more urban orientated need, yet one often detrimental to the truely rural surroundings. Although land for housing seemed to have the lowest priority, more developments on this front (e.g. low-cost housing) were projected for the study area to capture natural population growth. Furthermore, it was eminently possible to locate the most feasible land for such developments by formulating relevant decision criteria.

These five objectives were directly related to the present-day land uses determined in Section 2.3.3. The forestry and agricultural objectives directly relate to the plantation and cropland

land use class respectively. Water bodies and wetland, indigenous forest, bushland, and pasture/grassland were all captured under a communal use objective. The built-up objective was directly based on the built-up land use class, most notably the rural cluster type. Note that the reserved class was treated as a separate objective once more and the initial ranking was not applicable here.

2.5.6 *Setting the area goals*

The participants were eventually asked to come up with area allocation goals for each objective. To start the process, roughly estimated area targets per land use objective were decided upon and, by further debate, these were refined to acceptable area goals. The decision-making group found that, when the proportional (as opposed to area in hectares) gains and losses in area were considered together with area goals per objective, a more meaningful allocation could be decided upon. Thus, either acceptable proportional gains or losses (in percentage) in current land uses or that of the desired area goals themselves were used to reach a conclusion in each instance. Ultimately, each objective still ended up with an agreed-upon calculated target area (in hectares).

Forestry targeted a 15% increase in tree cover over the catchment. As far as agriculture was concerned, it was initially decided that at least a third of the total watershed should be available to cultivation, yielding an initial gain of nine per cent. It was further reasoned that about a quarter of the total area in question should be available to the communal use objective. Targeted areas would eventually include indigenous trees or forests, wetlands, and other degraded land (eroded or severely overgrazed areas). Conservation would be a newly introduced objective and, after correlating it with the land cover information gathered, received a modest 12% area target. Built-up land was apportioned a reasonable two per cent increase. Since no new roads are anticipated in the near future, but rather upgrades of the existing land, no change in extent was made to the reserved objective.

Nonetheless, concerns then arose that realizing and maintaining the initial agricultural gain in extent seemed highly improbable. The current practice shows that prevailing farming methods are outdated, crop quality is poor, modern farming equipment is unaffordable, and the financial (market) incentive is totally lacking. Moreover, some participants were of the opinion that the initial 40% loss in communal area was rather excessive and preferred at least a third of the total study area to rather be allocated for community use. Therefore, and also considering the large proportion of fallow land, it was suggested that a more acceptable norm would be to allocate at least two-thirds (or 1916ha) of present-day productive cropland to farming, allowing the balance to rest for one or two seasons or be grazed lightly only. This implied improved or intensified agriculture on existing cultivated land (and extension), as well as consolidating the 'best' productive cropland[31]. It follows that 728 hectares of existing fallow cropland had to be converted for this purpose, freeing the remaining 957ha for communal use. For agriculture this translated into an actual gain of just one per cent overall or covering just over a quarter of the entire study area. As desired though, the communal use land parcels now added up to just under a third of the entire micro-catchment. The current and projected area goals and proportions per land use objective are tabulated in Table 2.1.

Table 2.1: Final land use objectives and calculated area goals.

Initial ranking	**Land use objective**	**Current area**		**Initial area goals**		**Revised area goals**		**Total gain/ loss**	
		Ha	**%**	**Ha**	**%**	**Ha**	**%**	**Ha**	**%**
1	Forestry	970.1	8	2730.5	23	2730.5	23	1760.4	15
2	Agriculture	2874.3	24	3925.8	34	2968.4	25	94.1	1
3	Communal use	7324.9	63	2870.2	24	3827.5	33	-3497.4	-30
4	Conservation	0.0	0	1406.2	12	1406.3	12	1406.3	12
5	Built-up	431.4	4	668.0	6	668.0	6	236.6	2
N/A	Reserved	118.1	1	118.1	1	118.1	1	0.0	0
	TOTAL:	11718.8	100	11718.8	100	11718.8	100	0.0	0

Finally the decision-making group found these revised area goals and the other initial targets to their satisfaction and proceeded in determining the objective weights or priorities for MCE application.

2.6 Weighting objectives: The local experience

One could expect that the pre-emptive setting of priorities (or goals) would be difficult to specify, especially when dealing with group decision-making. A unique method to facilitate the participatory allocation decision-making process further, set the land use priorities and reach some sort of consensus on judgement was thus imperative in this case. As required by the research plan, the objective weights provided by the ten participants ultimately represented the relative weights entered for each objective during the application of the MOLA module in IDRISI.

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[31] As no reliable and detailed large-scale soil data of any kind was available for the study area, soil potential was essentially gauged by assuming that crop production is best on available deep, well-drained fertile soils on relatively flat terrain.

2.6.1 *The method in practice*

To extract functional values that prioritise each land use objectives from the final group, the researcher developed a technique relying on symbolism (to simplify) and a basic value system (to prioritise). First, as depicted in Figure 2.4, each land use objective was represented with a familiar object: forestry with a bundle of firewood, agriculture with a bag of maize, communal use with a calf, conservation with two buckets of water from a nearby stream, the built-up objective with a small stack of cement building blocks.

Figure 2.4: Participatory decision-making in land use evaluation

After a lengthy explanation each participant received ten tennis balls to proportionally allocate to each objective in terms of the rural development framework presented thus far. Tennis balls were appropriate objects to 'weight' the objectives because they could not be associated with pervasive local activity, nor could it be readily associated with currency or power. A container, placed in front of each object/ objective, received the weight or 'value units' each participant perceived it was worth earning. Basically, the instruction went: "*Considering the land use objectives available and symbolized in front of you, distribute your quota of equal 'value units' (tennis balls) to the land use objectives in such a manner that the use(s) of perceived higher value – in terms of current use (or retention) AND possible improvement (through investment) – will receive the most weight. Conversely, the use(s) with no or the least value units will be ranked lowest in terms of development priority as related to the future objectives.*" Land use objectives were placed in random order so as to not fortify the initial ranking. Members were taken two at a time to allocate their allotted quota of balls to the objectives. This took place some distance away to prevent members from possibly influencing each other's judgements. After allocation, the results were recorded, all the balls were removed and handed to the next person and the process was repeated.

2.6.2 *The results*

Compared to the initial ranking, the priorities given to each objective this time around differed as shown in Table 2.2, particularly in the case of the conservation and agriculture objectives.

Table 2.2: Scoring and relative weight per land use objective.

		Score per land use objective					
Decision-makers	**Gender**	**FOR**	**AGR**	**COM**	**CSV**	**BLT**	**Total**
1) HERDER #1	M	2	2	3	3	0	10
2) HERDER #2	M	2	1	3	2	2	10
3) FORESTER #1	M	3	2	1	3	1	10
4) FORESTER #2	M	4	2	1	2	1	10
5) CROP FARMER #1	F	2	2	2	2	2	10
6) CROP FARMER #2	M	2	3	2	2	1	10
7) ELDER #1	M	3	1	2	3	1	10
8) ELDER #2	M	2	2	2	3	1	10
9) TRADITIONAL HEALER	F	2	1	3	3	1	10
10) SOCIAL WORKER	F	2	3	1	2	2	10
Total Score:		24	19	20	25	12	100
Relative Weight:		**0.24**	**0.19**	**0.20**	**0.25**	**0.12**	**1.00**
Standard Deviation:		0.70	0.74	0.82	0.53	0.63	

FOR=Forestry; AGR=Agriculture; COM=Communal Use; CSV=Conservation; BLT=Built-up

Conservation received the largest score or relative weight (0.25) with the least deviation among members, and thus relegating forestry to second place (0.24). Nevertheless, agroforestry systems can be superior to other land uses at the watershed scale because they optimise tradeoffs between increased food production, poverty alleviation, and environmental conservation (Sanchez 2000). Communal use (0.20) remained the third priority with the largest deviation, but agriculture (0.19) moved down to fourth position. Built-up land remained, as expected now, the lowest priority (0.12).

The variance or standard deviation reflected the consistency of judgments among the participants. With respect to the importance of each land use objective, a zero variance implies complete agreement or consensus among the decision-making group. Higher standard deviation indicates diverging opinions; the larger the standard deviation, the more varied the opinions or judgments. Consensus on prioritising conservation seemed the most uniform, stressing the negative effect of environmental degradation. Slightly less uniformity was observed with the built-up objective. On the other hand, and in the light of the current troublesome situation in agriculture mentioned earlier, agreement on agricultural allocation was relatively varied. Yet it was, as expected, the communal use objective that indicated the highest diversions in judgement.

In essence then, this spatial multiple criteria decision problem involves five geographically defined alternatives (land uses) from which a choice of (one or more) alternatives is made, yet how they will perform with respect to a given set of evaluation criteria is still undetermined. We now know what to do, but still need to know where to do it. To attain the appropriate suitability maps for each land use objective, the next phase of the research plan, Steps 2 and 3, required the selection and mapping of a variety of decision-criteria for each objective for the impending MCE procedure. The next chapter deals with this phase in the study design.

CHAPTER 3 PREPARING SPATIAL DECISION FACTORS: SELECTION AND MAPPING

This study engaged in finding solutions to decision problems characterised by multiple-choice alternatives, which could be evaluated by means of performance characteristics called decision criteria (Jankowski, Andrienko & Andrienko 2001). For any given objective then, several different attributes were necessary to provide complete assessment of the degree to which each objective might be achieved. The results of the analysis depended not only on the geographical distribution of events (attributes), but also on the value judgements involved in the decision-making process. To aid the land suitability assessment and allocation processes at hand spatial decision factors were carefully selected, prioritised where necessary, and prepared for MCE analysis. The group members completed the latter (Step 2 in the research plan) and the GIS-expert the manipulation and mapping (Step 3).

3.1 Selection principles

Evaluation criterion maps (or attribute maps) are unique geographical factors that determine alternative decision performances. The attributes must be comprehensible and spatially measurable, though. Ideally, a set of attributes should be complete, operational, decomposable, non-redundant, and minimal (Malczewski 1999). In other words, attributes should cover all aspects of the decision problem; be used meaningfully in the analysis; can be broken into parts to simplify the process; avoid problems of double counting; and the number of attributes should be kept as small as possible. However, no universal techniques are available for determining a set of problem-specific criteria and may be developed through an examination of the relevant literature, empirical analysis, and opinions from stakeholders, as was done in this study.

To ultimately meet each specific land use objective, MCE was performed using the AHP approach. The objective and underlying attributes formed a hierarchical structure of evaluation criteria for this particular decision problem. The process of selecting activities would thus be facilitated and made more transparent and consistent by the development of criteria for activity selection. The criteria forming the basis of the MCE process were of two kinds *viz.* factors and constraints. According to Eastman et al. (1995), a factor is defined as a criterion that enhances or detracts from the suitability of a specific alternative for the activity or use under consideration. On the other hand, a constraint serves to limit the alternatives under consideration. A constraint map displays the limitations on the value that attributes and decision variables may assume. In any case, all decisions are made in some kind of environmental context and thus normally involve many factors beyond the control of the decision-maker (e.g. mean annual temperature). All the factors were ultimately ordered in terms of its importance (towards local development) as perceived by the group members. However, note that, although the latter action was scheduled at this point in the research plan for logistical reasons and other practicalities, the full reasoning behind this action, including the results, had to be discussed in Section 4.2 only.

3.2 Selection of mapped factors and constraints for MCE application

Based on the local and geographic information acquired thus far, the spatial decision factors were narrowed down to five principle groups, namely climate, topography, relative distances, soil qualities and present-day land cover and land uses. State of the environment factors were represented by climatic, topographic, and soil suitability criteria. The two remaining main factor groups included those decision variables controlled by the decision-makers and the GIS expert, namely the presence of landscape features or land uses, their proximity characteristics, as well as two technical (or strategic) constraints. All the decision criteria selected as factors and constraints for MCE application are listed in Table 3.1 under the relevant land use objective(s). This table forms the reference for much of the discussions in this chapter. A negative correlation between the measured land parcel value in the map image and its suitability for a particular objective means that a higher image value disadvantages the objective.

Conversely, a positive correlation implies the opposite. For instance, the greater the distance from major roads, the lower the suitability for future crop production, especially if an alternative involves fresh produce as cash crops. A ‘forced’ or deterministic high rating of five, which correlated positively with some features (e.g. indigenous vegetation and productive cropland), protected them and ensured further functional clustering. A discrete option is exercised when qualitative scales are encountered (e.g. soil form).

Conversely, constraints act in a nominal manner: an item is either included (available) or excluded. Other than for technical reasons, this contributed mainly towards land preservation of mainly sensitive areas and land use retention (minimal changes) in this case. The two technical constraints can be emphasized at this point. The areas reserved for *roads* were excluded from all other objectives since technically it made up an objective in itself, i.e. the retention of existing (selected) road infrastructure. Factors that directly influence their own suitability were not considered

Table 3.1: Factors and constraints selected for suitability assessment

FACTORS	**LAND USE OBJECTIVES**				
	CSV	**FOR**	**COM**	**AGR**	**BLT**
Climate					
> Mean annual precipitation (mm)		⊞		⊞	
Topography					
> Aspect (Degrees)		⊟		⊞	⊞
> Slope (%)		⊟	⊞	⊟	⊟
Distance to					
> Built-up areas (m)			⊞		⊟
> Central business district/ Marketplace (km)				⊟	⊟
> Erosion hazards (m)	⊟	⊞		⊞	⊞
> Forestry office and nursery (km)		⊟			
> Major roads (m)		⊟	⊞	⊟	⊟
> Old cropland (m)			⊟		
> Plantation and bushland (m)		⊟			
> Productive cropland (m)				⊟	
> Rivers (m)		⊞			
> Schools (m)					⊟
> Wetland (m)	⊟	⊞		⊞	⊞
Soils					
> Curvature (Std Dev)	▨	▨	▨	▨	▨
> Land type (Soil form)	▨	▨	▨	▨	▨
Occurrence of (factor: 0/5; constraint: 0/1)					
> Built-up areas and sports fields	◆0	◆0	◆0	◆0	■5
> Entire Amanzamnyama plantation extent				◆0	◆0
> Fire belts and rocks		◆0		◆0	◆0
> Indigenous bushland only	■5	◆0		◆0	◆0
> Indigenous forest and wetland	■5	◆0		◆0	◆0
> Non-indigenous bushland		■5			◆0
> Plantations and large woodlots		■5	◆0		
> Productive cropland		◆0		■5	◆0
> Riparian zones		◆0		◆0	◆0
Technical (0/1)					
> Road reserve	◆0	◆0	◆0	◆0	◆0
> Study area/ Micro-catchment extent	◆1	◆1	◆1	◆1	◆1

FOR = Forestry; AGR = Agriculture; COM = Communal Use; CSV = Conservation; BLT = Built-up.
■ Factors; ◆ Constraints; 0/5 and 0/1 = two-value alternatives.
Correlation (image value with suitability): ⊞, ■5 = Positive; ⊟ = Negative; ▨ = Discrete options.

(minimum landuse change as a ‘maintenance’ strategy). The same applies to areas outside the *micro-catchment extent*, which were logically excluded or masked. Besides, edge effects on the study area’s border were accounted for earlier during the demarcation process. Thus, while the inclusion of each criterion will be discussed and justified over the next five subsections (separately for each land use objective), road reserves and the study area extent acted as a constraint throughout and will not be mentioned there.

3.2.1 *Criteria selection for the conservation objective*

Properly accounting for environmental degradation in all its relevant forms was vital in this study. The challenge was to incorporate the conservation objective into an appropriate and meaningful rural development framework designed to protect environmentally sensitive areas, minimise the need to utilise them, and mitigate present-day harmful land use practices influencing them. As concluded by Terrence, Foster & Renard (2002), and applicable here, the major principles of (soil) conservation are: i) erosion and sediment controlled to applicable standards; ii) the landowner's or user's preferred land use accommodated where possible; iii) the recommended conservation practice is profitable, convenient, maintainable, and accommodates personal preferences; iv) local customs are respected; v) resources to install and maintain the recommended practice are available; and vi) the resulting land use system is sustainable over the long term.

3.2.1.1 Criteria

The worst cases of degradation recorded in the study area occurred in the form of erosion, mainly due to rain-induced runoff and soil quality loss. Included were degraded areas associated with sheet erosion and/ or donga formation, of which both incorporate abnormal sedimentation loads or areas of deposition. The biggest threat soil erosion poses is the fact that sheet erosion, the most dangerous type of erosion (Hugo 2004), is not clearly noticeable until irreparable damage has been done. Although donga's were more obvious in the landscape than sheet erosion, the latter is more detrimental because the topsoil is removed over a large area. A full understanding of erosion risk was thus essential in this case. Many complex and interacting variables affect erosion so that the relative effectiveness of an erosion-control practise would vary from location to location.

Olsen et al. (1994) observed that the variables complicating the relationship between land productivity and soil erosion include i) landscape position and hillslope components, ii) natural versus artificial erosion control treatments, iii) soil properties, iv) surface and subsurface water flow, and v) past and present land management. Although not selected under the conservation objective, topographical variables (aspect and slope) suited other land uses associated with erosion risk, i.e. crop and tree planting, livestock management, and settlement. Natural erosion control measures would not tolerate these developments close to such features or areas. *Distance to erosion hazards* thus displayed a negative relationship with conservation. It implies localised erosion control on a scale compatible with the financial and human resources on hand.

Discrete options were exercised with regards to the suitability of *soils* since categorical data was the only kind available. The correlation with conservation was negative or positive depending on the suitability associated with the categories or values of two data sets. Some *soil forms* are more susceptible to erosion than others, e.g. soil formed from mudstone. A localized patch in the eastern part of the study area for instance, which displays severe erosion features, contains mainly Beaufort mudstone. Elsewhere soils derived from grey mudstone in particular often displayed a duplex morphology (i.e. a permeable topsoil overlying a less permeable subsoil), and severe signs of erosion where prolonged tilling and/ or overgrazing occurred. Such soils will thus receive a high suitability rating for conservation. On the other hand, deep, freely drained apedal soils will receive only medium ratings .

Curvature, a second derivative of slope, proved quite difficult to explain to some decision-makers in this case. Yet, from an applied viewpoint, curvature can be used to better describe the physical characteristics of a catchment in an effort to understand erosion and runoff processes. High erosion risk areas were associated with both convex and concave slopes of any steepness. It thus includes even slightly convex slopes where land mismanagement, e.g. prolonged tilling and/or overgrazing, accelerated sheet erosion and/or wetland draining practices lead to some of the donga formation. Sheet erosion featured quite strongly on slightly concave slopes as well, mainly due to overgrazing. Dongas dominated the increasingly steep concave and convex areas though. Conservation should receive at least a medium to high suitability rating at all these high erosion risk areas as determined by curvature. Moreover, most wetlands were situated within slightly concave slopes and hence featured the highest incidence of dongas in this case.

One of the most defining characteristics of the midland areas of the North-Eastern Cape is the variability and widespread *presence of wetlands*, and their patch-like distribution within landscapes (Forsyth et al. 1997). The threat towards and disturbed nature of wetlands in this case required that their locations be identified for thoughtful evaluation (of risks), preservation and management. Drainage channels have been dug through a number of the wetlands in the study region whilst other existing channels have become deeply incised. The channelling of flow through the wetland, at deeper levels, drained the wetland and reversed its function, as well as negated the delaying effect on streamflow. Rehabilitation of these channels may revive the function of the wetlands and lead to flood retention and release of water in low-flow periods (Forsyth et al. 1997). Wetlands were thus positively correlated with conservation and awarded the highest suitability rating (5) for protection. Following Taylor’s (1999) conclusion in his study in Maputaland/ St

Lucia estuaries, the principle of limiting rather than preventing access applied though. It could therefore deal with local issues such as water availability (and quality) and increasing grazing pressures. The desired state here involves maximising water to communities and boosting minimum low stream flow levels, i.e. maximise flow in terms of mean annual, low and peak flow (Steward et al. 1997). Simultaneously, a wetland's value can be weighed directly or relative to other uses that could be made of the site, thus the location of a wetland may affect its value to society. Since clustering of conservation (and rehabilitation) activities designed for wetlands are desirable and distance it from harmful practices, *distance to wetland* was negatively related to the conservation objective. Landscapes associated with water abundance, such as wetlands and river courses, often display a relatively high level of biodiversity in normal conditions (Fuggle & Rabie 1983).

Biodiversity may also be closely associated with the preservation of indigenous vegetation (Hosking et al. 2002). Again the principle of limited, rather than restricted access applied here. For instance, it was pointed out earlier on that indigenous forests appeared to be more successfully preserved within the plantation extent. Yet, the continued loss of indigenous forest areas and alien bush encroachment remain worrisome. Nevertheless Findley, Carrol & Blatner (2001) acknowledges that, in terms of society's relationship to it, the forest's use or value cannot readily be reduced to a simple metric since people, organisations, agencies and cultures add subjectivity and diversity. For instance, areas with the highest species richness may receive the highest conservation priority, or areas that contain many of one specific tree species of perceived high value, be it for commercial, medicinal, or other traditional value. The total number of plant species may act as a surrogate for ecological integrity in other cases (Steward et al. 1997). In the latest research Phua & Minowa (In press) demonstrates how forest conservation planning can be tackled successfully as a decision-making problem or process.

The same authors conclude, amongst other, that riparian vegetation is an important aspect to forest conservation and the legislation to protect riparian zones should be strengthened. This approach with regards to riparian zones was echoed in this study and the role of the WfW came into play here again. It was assumed that riparian zones would (or should) be cleared of alien invaders, although some of the larger patches found on terrestrial terrains may be converted into managed woodlots if found suitable. Ham (1999) reported that, after studying aerial photographs of the Eastern Cape, the impact on indigenous forests was lower in areas where woodlots had been established. Assimilating this information then, the mere *presence of indigenous forest* and *bushland* was enough to protect them. This was achieved by the positive correlation with conservation, even more so by awarding it the highest suitability rating (5).

3.2.1.2 Constraints

As for constraints to the conservation objective, the *occurrence of built-up areas* was singled out at the outset. Yet, note that conservation, as a goal in itself, is somewhat inherent to all land uses in this study's framework, therefore criteria chosen under other objectives will also relate to conservation in many respects, and vice versa. It explains why the least number of criteria (nine in total) appears in Table 3.1 under the conservation objective. Thus, where no relationship with a seemingly relevant criterion was listed under this particular objective, it implied that it was, in fact, destined to be assigned to conservation by virtue of exclusion of such environmentally sensitive or 'valuable' features by the remaining objectives.

3.2.2 *Criteria selection for the forestry objective*

The central axiom of ecological forestry is that manipulation of a forest ecosystem should occur within the limits established by natural disturbance patterns prior to extensive human alteration of the landscape (Hurter 1999). The forestry objective incorporated a wide range of activities in addition to those associated with silviculture[32]. It includes the production of non-timber products, watershed management, wetland and indigenous forest protection, and extend to activities such as erosion control and fire management. Assistance by extension alone would encourage activities that involve the planting of trees – single trees, rows, or patches thereof – for a variety of benefits. Tree-planting practices could vary according to local preferences, the extent of deforestation, the proximity to towns, and the natural vegetation, climate and soil of the area (Hosking et al. 2002). Agroforestry is a management system that integrates trees on farms and in the agricultural landscape, whether already present or planted. The criteria had to therefore take in account agroforestry practices and feasible community forestry situated, along (or integrated) with the already established plantations, on suitable sites in a manner that is 'environmentally friendly'.

3.2.2.1 Criteria

To cater for forestry's dependency on *climate*, one often considers the rainfall and temperature distribution that prevail in a specific area. Mean annual values should not actually be the critical values to consider when growing trees (or crops), since no inference can be made about the

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[32] Silviculture refers more specifically to the planting and tending of growing trees. Production silviculture in sustained-yield forestry is where foresters try to define precise objectives for the specific ecosystem components and use sophisticated quantitative methods to determine optimal management strategies.

variability thereof. Rather, it is the extreme (minimum and maximum) observed values that should count, particularly the minima (Theron 1995). For instance, catchments in this region experience dry winters with occasional heavy frost (especially in valleys) and a great variation between day and night temperatures. Unfortunately these types of climatic data for the region were not available yet, but only annual means at different scales. Frost risk thus rendered the available mean annual temperature (MAT) data less useful (about 14.5 to 17.0°C; mean of 16°C). Yet, most of the species chosen in forestry practices here specifically owe it to their frost tolerances, but possessed only limited drought resistance. Besides, runoff (rainfall) amounts were critical in this study where erosion is concerned. Therefore, at least one important criterion available for useful manipulation at the related scale was included, namely *mean annual precipitation* (MAP). MAP (about 698 to 1132mm: mean of 877.2mm) plays its respective role in tree growth naturally and was therefore positively correlated with suitability. This implies sites with adequate water availability (as required by the tree species grown) will be highly rated.

Topography, the next environmental factor group, contained criteria relevant to forestry in general, namely slope and aspect. *Aspect* relates to the direction in which a topographic slope faces, usually expressed in terms of degrees or percentage from north (0°). A poleward slope is generally moister and cooler than one on the equator-side of a mountain and, therefore, normally has better soil development (Theron 1995). Drought factors can, on the other hand, play a significant role on north-facing slopes. Drought resistant species may even be considered, depending on exposure. It follows that aspect was negatively correlated with the forestry objective. True north-facing slopes therefore would rate lowest and south-facing ones the highest. When considering existing erosion hazards and ease of cultivation *slope* is less restricting on plantation or woodlot development than on, say agriculture. Yet, in this case it was more restricted than normally permitted for commercial plantations. Besides, steep slopes are normally associated with shallow soils and would rather be avoided. Thus a negative correlation exits between forestry and land steepness as well. Areas with increasing slope values will receive increasingly lower ratings. Notice here the relationship with aspect, since light intensity, quality and duration is modified by the steepness of hillsides, the shifting of the angle of incidence of the sun’s rays, and of course land cover.

Based on the land cover and land use information, a number of *distance* criteria were developed for the forestry objective. Once more degradation in the form of erosion was considered and mitigated. Forestation of denuded (eroded) hilly land will normally reduce peak runoff, lessen the risk of flooding, conserve soils, and prevent severe siltation and gully formation (IPCC 2000)[33]. It is however acknowledged that mono-specific plantations without an understory may not always provide such conditions, and site-specific criteria should be reviewed carefully beforehand. In order to effectively withdraw forestry practices from erosion 'hotspots', the *distance to erosion hazards* was positively correlated to it. Areas in close proximity of these features will thus receive the lowest ratings.

Keep in mind though that the diverse activities within agroforestry at least imply that experimentation with useful suitable indigenous trees is possible. This implies the dissemination of forestry knowledge to local tree growers. The *distance to the forestry office* situated almost in the centre of Amanzamnyama plantation, is relevant in so far as it forms the hub of forestry knowledge (extension) and possible seedling supplies – acting as an inoculation point of some sort. In this regard a ten-kilometre radius was expected to effectively capture most of the area accessible to proficient forestry extension. The negative correlation here means the closer to this office the more advantageous it is to any prospective tree farmer or other interested party, and would be rated higher than areas further away. Simultaneously, because of the desired decrease in fuel wood collection time (Ham 2000), transport logistics requirements (in the case of commercial timber), and general accessibility, *distance to roads* was also correlated negatively with forestry. This conforms with Steward et al.'s (1997) finding that the most important criteria from a forestry point of view in their case was distance to tarred roads, mean annual increment (MAI), and harvest cost (if less than 10km then MAI and harvest cost becomes first and second priority). This factor also represents the distance criterion to built-up areas that, if also included, would amount to double counting since most settlements are closely associated with important roads anyway.

Given the incentive of an official water use licence – as a stream flow reduction activity[34] (SFRA) or forestry licence – some landholders or users could bring some of the invasive bush found here under control, either through converting them to well-managed forest stands, or by replanting with other species. More so since such locations are presumed suitable for growing trees owing to their mere presence there. Such areas were closer than two kilometres from the present-day plantation

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[33] This practice, i.e. using agroforestry activities to restore severely degraded land, may then lead to an increase in aboveground biomass on soil that previously could not support such cropping, increased fertility and profitability, reduced erosion and environmental problems such as the silting of water courses, and 'recycling' of land where land is scarce (Meintjies 1995; Steven, Schackleton & Robinson 1999).

[34] Section 21(d) of the NWA includes SFRAs as one (of eleven) forms of water use, and Section 36 regards the use of land for afforestation established for commercial purposes as a SFRA. A SFRA is defined as any dryland land-use practice which reduces the yield of water from that land to downstream users. The reduction in yield is measured in relation to the runoff from natural, undisturbed veld on similar land in the same area (South Africa 1998a).

boundary. Although land use change is determined by its impact on biodiversity, conversion from jungle to plantation does not comprise a land use change, but responsible forest management. The *distance to existing plantation and bushland* was thus negatively correlated with forestry. This prevented incompatible land uses intruding into the plantations as well. Afforestation restrictions set here would be stricter than normal though, particularly if wattle is to be retained as the forestry species owing to its recognised invasive properties. As a mitigation measure in the event of areas of wattle bush being licensed as forestry plantation in the Eastern Cape, DWAF Community Forestry will advise applicants on site selection for the plantation to reduce the potential for spread (Warren, Versfeld & Horak 2003), i.e. taking into account the position in the landscape, slope and proximity to water courses and wetlands. This approach does not suggest the issue of licenses for water use by wattle or other invasive jungle areas, but for the highly conditional licensing of forestry as a SFRA, on certain select areas currently infested by invasive alien plants. The guidelines mentioned provide the principles and practices by which areas of invasive wattle jungle (and jungles of other invasive woody species) might be upgraded and converted into, or exchanged for, licensed and productive forestry stands of any species. Moreover, it is of particular relevance in catchments which are considered to be fully subscribed in terms of allocations already made to SFRAs, or which are off-limits to further licensing because of limited water availability. This, in possible conjunction with the WfW programme, would ensure no plantings or escaped trees (including current invading exotics) are allowed close to water courses. A positive correlation with *distance to rivers* in this case was therefore appropriate. For example, active WfW teams operating in the region carry felled wattles a distance of 30m away from the water courses (Hosking et al. 2002). It follows logically that the d*istance to wetlands* was also positively correlated to forestry practices in order to sufficiently separate them from wetlands as well.

With regards to the suitability of *soils*, discrete options were exercised once more. Sourced geological and *land type* data obtained indicated at the outset that, in conjunction with several field observations, the dominant parent material for soil formation of this region consists of mudstone, shale or sandstone belonging to the Subgroup Tarkastad of the Beaufort Group of the Karoo Sequence. Dolerite intrusions of the latter occur in some places – along the extreme western border of the micro-catchment, for example. *Soil forms* derived from this mother materials are normally influenced by various biophysical factors, e.g. slope shape and position, and moisture relations. The lower lying, less steep hills (which make out most of the centre of the watershed) are mostly associated with Mispah and Glenrosa soil forms in which lime is rare or totally absent and rocky sub-horizons are the norm. Soil formed from mudstone may display shallow rooting depths

(<600mm), thus often unsuitable for planting. Soil forms associated with these places may include, amongst other, Sterkspruit, Estcourt, and Klapmuts soils, but patches of more suitable soil forms may also be found here. In general though, most soils in the micro-catchment have a low pH and base status, which implies the possible use of fertilizer during tree establishment (Forsyth et al. 1997). Such areas would thus not earn that high a suitability rating. Rather, it is the higher lying areas of predominantly red-yellow apedal, freely drained soils (dystrophic and/or mesotrophic), mostly of Tarkastad mudstone origin, which is rated highest. Many of these soils are deep, i.e. more than a meter to any restriction. Soil forms commonly found here and which are regarded as most suitable for planting or retention may include Magwa, Kranskop higher up, and Clovelly, Hutton, Griffin and Avalon forms elsewhere.

The role of *curvature* in relation to soil suitability is coupled with that of slope in principle: runoff behaviour on mountainous terrains or land types, as well as soil loss and depositions in the landscape due to erosion processes. Very slightly convex slopes were considered highly favourable for forestry practices. Compared to the much more convex slopes, runoff velocities here are still relatively low if freely drained soils are predominant. This explains the drastic decrease in potential for the forestry objective when approaching the increasingly steeper curved sections in the landscape. Although one could argue that since concave areas could benefit from sediment depositions and thus implying deeper soils, it can also mean waterlogged soils in other cases. Yet, slightly concave areas would be rated highly towards forestry and suitability will decrease as curvature increases. To ultimately ensure further functional clustering and current usage, as well as aid in the attempt to convert unmanaged alien bush to managed woodlots where feasible, the *presence of plantation*, *large woodlots*, and *non-indigenous bush* was positively correlated with forestry and rated the highest (5) suitability.

3.2.2.2 Constraints

The *occurrence of particular man-made and natural features* acted as constraints to forestry. Here the discussion enabled consensus seeking in NRM in situations where afforestation is involved. Similar views arose as those documented by Steward et al. (1997) during a comparable workshop in this region earlier. For example, the view that land allocated to forestry was automatically lost to conservation, was countered by the argument that forestry could and would never use all the ground permitted for forestry, and conservation corridors would be retained at all costs. In requisite of standard forest guidelines and conservation efforts in place, forestry would not degrade any sensitive areas any longer anywhere (FIEC 1995). Here all *indigenous forest* and *bushland*, *wetlands*, and *riparian zones* were protected, thus unavailable for forestry practices. To exclude places containing *rocks* was a logical decision in terms of tree planting practices. Other important land uses were made unavailable as well to protect their current utility. The latter constraints logically included *built-up areas* and *productive cropland*.

The presence of *fire belts* suggests that one should not underestimate the role of fires in this grassland region. By far the greatest use of fire is to obtain green re-growth from perennial grasses (for grazing), yet naturally occurring fires also regularly come to pass in the region (e.g. from lightning). Fire has positive and negative factors associated with it, depending on its frequency, intensity, and duration. Versfeld, Le Maitre & Chapman (1998) estimated that grassland fire cycles repeat themselves every 1 to 4 years, but that the fire frequency amounts to two years in average. Under the ‘right’ conditions, large fires sometimes have devastating effects on livestock numbers, trees, crops and human belongings (Kromhout 1990). At the same time, wattle seed banks may be stimulated to germinate by the high temperatures normally associated with fires and increased soil erosion could occur as a result of increased fire damage (Hosking et al. 2002). Positive effects on the other hand are more immediate. Fire could include an increase in available nutrients in the short term (but less in total), soil pH generally increases, and nitrogen fixation may increase as conditions may become more favourable for the micro-organisms involved in the process (Theron 1994). However, because fire behaviour involves too many complex and unpredictable elements interacting beyond the scope of this study, burning practices was not explicitly considered as either a factor or a constraint. Only the control thereof was implied by retaining fire belts and the reduction in woody biomass through the removal of invasive aliens. Yet, all fire belts presently in the micro-catchment were regarded to act as constraints, and will be retained to serve its important function in fire management.

3.2.3 *Criteria selection for the communal use objective*

It was established at the onset that the overall character of communal tenure is that rights to land and natural resources are shared and relative, i.e. relative rights are nested within a hierarchy of social and administrative units or levels (Cousins & Claassens 2003). The communal use objective represents the rangeland/veld (which includes water courses, bushy ravines, rocky outcrops, shrubland, etc.) available to herders, hunters, gatherers, and visitors. Within the traditional rights and land use agreements that exist between local communities, this objective thus assumes freedom of access to a large extent. This implies that in relation to the other land use objectives, except for conservation and roads, areas suitable for communal use would have the least conditions to comply with and would basically display a high degree of suitability over the entire watershed. Yet, because cattle in specific are, in a traditional sense, directly related to wealth, power and status, the importance of communal land as pasture or grazing area was stressed. In any event, output is difficult to evaluate where animals have multiple uses, as is the case here (meat, milk, hides, symbolic/cultural uses).

3.2.3.1 Criteria

Good rangeland management was an essential aspect to highlight during discussions with the ‘rightful’ users of these communal resources. This warranted a closer look at specific Grassland biome characteristics and herding behaviour at first. For rangeland management purposes it is important to know that with grassland a distinction was made between ‘sweet’ and ‘sour’ grass veld[35]. Sweet veld was found in patches of various sizes in dryer and/ or higher lying areas in the study area. Elsewhere ‘sour’ grassland, the second but predominant veld type, occurs. Each veld type received a different suitability rating in terms of grazing. Sour grass veld implies a decrease in forage acceptability and nutritional value (Hugo 2004), especially during the dry winter months. It would thus be rated average or medium in terms of suitability. The sweet grass veld refers to grasses that have a lower fibre content, is more palatable, and maintain higher above-ground nutrient in winter (Rutherford & Westfall 1986), i.e. species whose acceptability and nutritional value remain relatively unchanged during the winter months. Where this veld type occurs the suitability rating would be high. Herding behaviour, which is linked to stocking rates and seasonal movements, can therefore greatly influence the composition of grassland. Beinart (2003) reported that some rural communities might argue that heavy, continuous grazing on communal rangeland diminishes selective use of pasturage and may not permanently alter or destroy the veld. He also added that communities felt that stud animals may find it difficult to survive in such systems, but heavy stocking of poorer-quality animals can produce an output similar to a smaller number of well-bred stock. It is particularly in the zone of niche overlap between sweet and sour veld that grazing management is most effective in maintaining a favourable balance between these two veld types. For example, overgrazing often results in *Aristida* replacing *Themeda* (Hugo 2004). In other cases overgrazing increases the invasion potential of the more unpalatable Wiregrass, as well as herbaceous weeds such as *Senecio retrorsus* and *Helichrysum argyrophyllum* (Forsyth et al. 1997).

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[35] In compliance to Acocks’ (1988) Themeda-Festuca Alpine Veld and Stormsberg Plateau Sweetveld or South-eastern Mountain Grassland (Low & Rebelo 1996) in the first case, and Highland Sourveld and Dohne Sourveld or Moist Upland Grassland in the second. Other than the commonly found *Themeda triandra* (Redgrass), species representing sweet veld may include *Elionurus muticus* (Wiregrass), *Aristida congesta* (White grass), *Festuca scabra,* and *F. costa*. The outright dominant species in sour veld is Redgrass, while other grasses found here include *Trachypogan spicatus* (Bearded grass), *Heteropogon contortus* (Assegai/Speargrass), *Hyparrhenia hirta* (Common Thatchgrass), *Elionurus muticus* (Wiregrass), and *Sporobolus pyramidalis* (Catstail).

These conditions held true for the study area as well. Even indigenous woody vegetation could invade highly overgrazed land, as manifested by the *Leucosidea sericea* (Ouhout) proliferating on stressed grassland at some places in the micro-catchment. Elsewhere *Euclea crispa* (Blue guarri) shows the same tendencies. Of importance here is that where land has become degraded, the underlying causes must be addressed, or the overgrazing is likely to happen once vegetation is restored (IPCC 2000). Besides, in context of the conservation objective, Terrence, Foster & Renard (2002) stressed that the objective of erosion-control is to manage livestock so that the vegetative cover is greatest during the season of greatest erosivity. What remained was to link factors influencing this likely distribution of these two grass veld types with rangeland suitability.

The distribution is mainly influenced by climate, *topography*, and edaphic factors. Broadly put, the distribution substantially depends on the amount of rainfall and to what degree local *soils* are leached. Sour grassland, most common at the Drakensberg foothills of the Eastern Cape (and KwaZulu-Natal), prevails at higher rainfall and on more acidic soils. Sour veld generally occur at altitudes of 600 to 1400 meters and, in terms of MAP, start to dominate above the 625mm isohyet (Rutherford & Westfall 1986). However, the smallest MAP value for the study area was 698mm and much of the micro-catchment lies between 840 to 1400 meters in altitude. This partially explains the dominance of sour veld in the micro-catchment, but technically cancelled out rainfall and altitude as evaluation factors. The positive correlation with *slope* on the other hand dictated that steeper areas are allocated towards communal use. This implied that small, localised, steep sections in the relatively flatter central part of the micro-catchment or the higher lying (much steeper) mountainous parts would be rated progressively higher in suitability, given that these places might contain less moisture (at least with freely drained mesotrophic soils) and therefore possibly sweet veld. Owing to sweet veld’s distributed nature though, flat areas would still receive a medium suitability rating. Altogether, this also allowed for the inclusion of features such as river embankments, rocky outcrops, cliffs, and patches of afromontane forests or bushes occurring in small sheltered ravines, which are in turn associated with different communal uses (e.g. hunting) or even other livestock species (e.g. goats).

Since *curvature* is derived from slope and gives invaluable insight on erosion and runoff processes on a particular land type, it was included as a soil suitability criterion, but (compared to slope) over a smaller range and having a higher overall suitability rating. Where shallow, rocky, leached, dystrophic soils derived from Karoo Sequence sediments and dolerite intrusions (Forsyth et al. 1997) occurred, sour grass was expected. The *land type* information could therefore be included to separate such areas. Nonetheless, since Glenrosa and Mispah *soil forms* prevail for much of the central part of the study area and thus include several other communal features or uses (e.g. wetland or shrubland), it is rated very highly. Alternatively, because deeper red-yellow, freely drained soils would rather suit forestry or crop farming, it was rated slightly less suitable towards the communal use objective.

Three *distance* factors were selected for the assessment of communal use. The first criterion was *distance to old cropland*, it frequently being the first choice for grazing where found unsuitable for further cultivation or conservation. The correlation is negative, i.e. the closer to old cropland, the higher the suitability ratings. The other two distance criteria, *distance to roads* and distance to *built-up areas*, argue that activities such as grazing and hunting require open pastures as normally found some distance from human settlements and associated infrastructure. The positive correlation would inevitably allocate land close to built-up areas and roads to land uses that, for economic or social reasons, rely on being in close proximity thereof, such as crop farming, woodlots, or new housing developments.

3.2.3.2 Constraints

All current *built-up land* would be retained and was thus unavailable to the communal use objective. Current *plantation and large woodlot forests* were logically unavailable to communal use as access are presumed to be more limited here than elsewhere (considering fire risk). Nonetheless, firebelts were not included as a constraint. This would be unnecessary, since it could still suit other communal activities like hunting. Although wetlands, indigenous forests/bushland, and riparian zones are strictly speaking communal use features, subject to conservation measures and agreed upon access restrictions, such places already received adequate protection under the conservation objective.

3.2.4 *Criteria selection for the agriculture objective*

Taylor (1999) warned planners that agriculture is not simply reliant on biophysical elements but also on political and socio-economic forces that interact with farming systems, together with the history and culture of the farmers themselves. The emphasis on market-led (agricultural) development has led economic planners to treat society as an undifferentiated whole (Dalal-Clayton, Dent & Dubois 2003). This is a mistake because it diverts attention from the most vulnerable groups in both rural and urban areas. Beinart (2003) observed that in the bantustans (particularly those in the Eastern Cape), crop cultivation declined significantly in the 1980s and 1990s and many African smallholders found the cost of production and labour on small areas of land prohibitive and the outcome too uncertain. Commercial cropland was broadly defined in this study and, in terms of agricultural produce, no real market exits for the crop farmers in the study area[36]. Other than considering the above, criteria selection should also accommodate subsistence farming concepts and constructively deal with environmental degradation to restore farm productivity in suitable agricultural areas and secure food.

3.2.4.1 Criteria

In agriculture *climate* is logically associated with plant growth. In the study region the normal growing season coincides with spring and summer when annual precipitation peaks. Five to ten per cent of the annual precipitation falls between April and September (Hosking et al. 2002). Where more water implies better growth, *MAP* was positively correlated with annual precipitation. Although the relatively small annual temperature range would have been positively correlated under the same logic, it was not considered a factor for agriculture, because the extremes, particularly winter frost, would normally not affect the dominating crop type or planting period. Where *topography* and *soils* are concerned, similar circumstances pertained to agriculture as for forestry, except for *aspect*. That was positively correlated with agriculture. Presuming sufficient water availability, it entails crops receiving a good deal of exposure to sunlight (intensity, quality, and duration) for optimal growth. North-facing sections of the flatter, central parts in the micro-catchment (where most commercial cropland is located anyway) would thus rate highest in suitability. The *slope* factor remained negatively correlated, except that more restrictive slope parameters were set than those for planting trees, especially since tilling would still be the preferred cultivation method. Steep areas are not only mechanically challenging, but also usually associated with much shallower soils or even erosion. Suitability ratings will thus decrease as the terrain becomes steeper. Mudstone derived soils, often associated with old cropland, may display shallow rooting depths as well.

Again, in relation to forestry, stricter limitations were set in *land types* associated with Mispah or Glenrosa *soil forms* (thin soil layer on a rocky substrate). Such places would only receive a medium suitability rating because they could severely impede tilling practices, among others. Yet, in these areas where lime is rare or absent in the entire landscape, pockets of suitable soil forms, e.g. Oakleaf and Katspruit can be found in localised areas. These soils, together with deeper red-yellow, freely drained soils, would be rated highly suitable for crop farming.

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[36] In fact, Statistics South Africa (1997) reported that just six per cent of the estimated 1.7 million households in the former bantustans with access to farming land actually sell part of what they produce, and that most requests for assistance are for water, finance, more land, and training.

Used to describe the physical characteristics of the micro-catchment, *curvature* once more gave insight into erosion and runoff processes and the mutual effects thereof on cultivated land. Following the same reasoning as for forestry and in compliance of conservation, this slope derivative guaranteed no cultivation on steeply curved terrain. Rather, rated highest in suitability would be the flat to slightly convex sections of the micro-catchment. Still, where an associated land use factor is concerned (e.g. in a simple erosion model), it is important to know that for agriculture erosion differs among various crops. It may depend on crop type, how the crop is farmed, and the seasonal growing pattern of the crop in relation to the temporal distribution of rainfall/runoff erosivity at a particular location. Terrence, Foster & Renard (2002) suggest that one way to reduce erosion on cropland is to choose a crop where the pattern of growth provides the maximum cover during the period of maximum erosivity. In this respect, the dominant dryland crop in the study area would remain maize (*Zea mays;* white and yellow), with land-races the predominant varieties and hybrid maize planted for their early maturity trait (Forsyth et al. 1997). Within the subsistence farming patterns at this scale, only a few patches of sorghum (*Sorghum bicolour*) occurred, as well as some small potato and pumpkin fields (or gardens). The different crop types (and management thereof) were therefore not explicitly selected as a criterion. This present-day productive cropland was protected by its positive correlation with agriculture. Assuming that *productive cropland* occupies the ‘best’ soil currently in the judgement of local farmers in most cases, assigning it the highest possible suitability rating of five would most likely result in it all being retained.

Five *distance* factors were selected for the agriculture objective. Spatial proximity to markets does not necessarily improve farmers’ access to the inputs and services required to increase agricultural productivity. In their study in Paraguay Zoomers & Kleinpenning (1996) found that, despite their proximity to the capital city, smallholders’ production was hardly stimulated by urban markets. This was mainly because poor people did not have enough income to invest in cash crops or in production intensification. The same study also revealed that patterns of attendance at periodic markets indicated that distance is a much less important issue than rural consumers’ purchasing power in determining demand for manufactured goods, inputs and services. Access to land, capital and labour might thus be far more important in determining the extent to which farmers are able to benefit from urban markets. Nonetheless, it was assumed that improved and intensified agricultural practices could be implemented in the study area. With effective extension services and technology transfer, a negative correlation with *distance to the local marketplace* (in Mount Frere) makes commercial crop farming – as a future objective – thus more desirable closer to town. Agriculture's positive correlation with the *distance to productive cropland* was a logical option in terms of consolidating it. Land immediately adjacent to productive cropland will have the highest suitability. One kilometre was suggested as an optimal distance in this regard. In addition, most built-up areas contain subsistence farmland (i.e. productive cropland), and this criterion sensibly kept crops in close proximity to settlements for protective and care taking reasons as well. Therefore, selecting distance to built-up areas as a factor was unnecessary. Because of its close association with settlements, it follows that *distance to roads* was also positively related to agriculture, thus rating remote parts least suitable. Distances to degraded or sensitive areas were treated in exactly the same fashion as for the forestry objective. Since land use has more effect on erosion than any other single factor (Terrence, Foster & Renard 2002). Type of vegetation is determined primarily by climate and soil, but management of farmed and grazing land determines the amount of vegetation. *Distance to erosion zones* was thus correlated positively with the planting of crops to dissociate it from high erosion risk areas and rather conserve it. *Distance to wetlands* was treated similarly. It would 'push' agricultural activities out of such precious, moist areas as well by rating it progressively lower in suitability when approaching a wetland. Thus, being the inverse of conservation, it would better protect wetlands against degradation. It was hoped that together the last two distance factors would give rise to better quality runoff (less sediment) and clearer streams.

3.2.4.2 Constraints

All current *built-up areas* were logically unavailable for agriculture. Similarly, the *entire Amanzamnyama plantation* was unavailable to crop farming since it is reserved for forestry i.e. where only tree planting is permitted on suitable terrain. As can be expected though, the protection of other man-made structures and sensitive areas were correlated in exactly the same manner as for the forestry objective. The occurrence of *fire belts* and *rocks* again acted as logical constraints in terms of their utility and ease of cultivation respectively. The protection of *indigenous vegetation*, *wetlands*, and *riparian zones*, in combination with current environmental legislation (and conforming to the envisioned local conservation initiatives), received high priority as well. This made it totally unsuitable for agriculture.

3.2.5 *Criteria selection for the built-up objective*

The built-up objective is mainly made up of rural clusters and small-scale subsistence farms. Although perhaps trimmed down slightly by urbanisation trends and poor health conditions, an increase in local population and their needs remained imminent. Because accurate population data was lacking, only a modest two per cent increase in built-up (urban) areas was projected for the study area. At the community level there may also exist a systematic relationship between population pressure and property rights (Place & Swallow 2002), distance to market (Zoomers & Kleinpenning 1996), and transport routes. In terms of rural development then, and considering the poverty situation in the study region, the built-up objective was primed to fully conform to the maintenance strategy, i.e. least land use change. Other environmental factors or constraints were naturally accounted for, and the logic extended further to relevant man-made constraints and land use restrictions.

3.2.5.1 Criteria

All built-up areas, which included ‘open’ areas used for extraction, cultural, or recreational purposes, retained their current status as planned, were correlated positively and awarded the maximum suitability rate. Where any form of development (settlement) was concerned, *topography* was considered for selection in the form of *aspect* and *slope*. Daylight hours are important to rural communities because few households have electricity supplies. Thus, north-facing slopes were, where possible, preferred to the generally shadowy and colder southern slopes, and rated highest in suitability when positively correlated. Steep land was viewed as undesirable for built-up developments, mainly for practical engineering and landscaping reasons, and thus negatively correlated therewith. Four *distance* parameters were selected to curb unwanted ad hoc settlement. To consolidate rural clusters to some degree it included distances to important existing infrastructure, *viz. built-up areas*, the *central business district* (Mount Frere CBD), *roads*, and educational institutions or *schools*. These factors were all negatively correlated with the built-up objective. For example, in the case of distance to built-up areas, the closer to it the higher the suitability rating.

The distance from the town centre not only served to simulate a market effect in the closest official town, but also to contain excessive urban expansion in the sense that farming activities are stimulated around existing (or even new) rural clusters. The land use map (Figure 2.2), confirms the close association between important roads and built-up areas since the average distance from settlements to important roads was only about 500 meters. Suitability was thus rated high up to that point, but decreased progressively as one travels further away from these routes. Similarly, some community members regarded three kilometres as an acceptable distance to a school for a pedestrian scholar, locations beyond that would thus simply be rated very low in terms of suitability. To prevent developments in degraded or sensitive parts of the landscape, two more distance factors were selected in the same fashion as for the forestry and agricultural objectives. The *distance to erosion hazards* and *wetlands*, due to positive correlation with built-up land, serve to protect such areas and reserve them for rehabilitation or conservation efforts.

As with the other prioritised objectives, the discrete options regarding the suitability of *soils* for settlement are linked to *curvature* and *land type*. The selection principles for the built-up objective relating to terrain steepness copied those of the forestry and agriculture objectives, excessively curved sections in the landscape were largely avoided due to its low or no suitability rating. On the other hand, land types containing *soil forms* unfavourable to agriculture and/or forestry received the maximum suitability rating. Similar in principle to that of conservation and communal use, it readily targeted soil forms in which lime is rare or totally absent and rocky sub-horizons are the norm. Yet, by also being slightly more restricted in terms of the deeper fertile soils, it advantaged crop or tree planting in such places.

3.2.5.2 Constraints

That the *Amanzamnyama plantation extent* and surrounding *fire belts* acted as a constraint to any built-up developments was a logical decision. So is the exclusion of exposed or piled *rocks*. *Indigenous forests, wetlands*, and *riparian zones* were protected for reasons similar to that pertaining to agricultural and forestry activities, and were made unavailable to settlement. Additionally, *all bushland* types (native and exotic) were made unavailable for this objective due to its role in fuelwood supplies in particular forestry and communal use value. The assumption that any *productive agricultural land,* which in this case could include tree farming, was situated on land considered best suited for this purpose and was made unavailable as such. In terms of soil productivity these often include the deep red or red-yellow apedal, freely drained soils, so one needs to prevent the intrusion of land uses not making optimal use of these favourable soil conditions.

Having dealt with all this information, the decision-making workshop with the ten participants and direct participation were brought to a close. Participants were sincerely thanked for their valuable contributions and informed when they could expect feedback after completion of all data analysis. Obviously the decision criteria still had to be digitally manipulated and mapped to produce the relevant maps. The GIS procedures involved in Step 3 in the study plan to capture the suitability of land parcels as defined per land use objective, can therefore now be discussed.

3.3 Digital mapping of criteria

In the third step in the research plan most of the preparation and manipulation of data were performed in ArcView 3 and its associated extensions (e.g. *Spatial Analyst* and *Geoprocessing Wizard*). It involved the creation of various surfaces to reflect the relevant climatic and topographic phenomena, as well as distance parameters or buffers. Value measurements of the raster data layers were indicated as being discreet (nominal or ordinal) or continuous (interval) scales, depending on their role in the assessment process. Where necessary, interval data was reclassified into ordinal or nominal values, thus all the layers eventually ended up in an acceptable format for the MCE in IDRISI.

The question of scale was pertinent, since the resolution should ideally be compatible with the scale of human activities (IPCC 2000). The horizontal grid resolution opted for was 20 meters, with each image cell (or pixel) representing the minimum unit area of 0.04 hectare[37]. This matched concepts such as subsistence farming, fire prevention, community forestry, and agroforestry in its many guises well. Relatively small units such as a single patch of maize in a household’s backyard, a fire belt, small oddly shaped woodlots, or a single long windrow were readily captured for this suitability assessment. Therefore, by their mere occurrence alone could these and other features (or other land uses) be buffered realistically or act as constraints if necessary. It includes the important technical role fulfilled by the road reserve and micro-catchment extent as constraints during analysis. When converting a polygon theme to a grid in ArcView, cells inherit the value of the polygon found at their centres. Although some digitised data is normally lost in this process, this was limited by the fine resolution. For instance, the road polygons produced earlier inevitably ended up as ‘noise’ in the dataset. Nonetheless, because one cannot readily develop anything else on land currently occupied by a road and its reserve, it was treated as a distinct class and land use objective. One should thus accept these ‘road cells’ as the average proportional representation of the real world situation (about one per cent in this case)[38]. Since it was also assumed that riparian zones would (or should) be protected, and be cleared of alien invaders, a crude buffer zone was created to represent it. This was constructed 20m on both sides of non-perennial streams’ centrelines (i.e. two cells), and 40m from perennial stream centres (i.e. 4 cells). It not only served

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[37] The same resolution applied during the initial (digital) mapping procedure for the micro-catchment from the aerial images, viz. the DEM construction, watershed boundary demarcation, land cover mapping, and capturing of noteworthy infrastructure, such as roads.

[38] Area calculations on the vector and raster data over the entire watershed for this specific class yielded 117.03 and 118.08 hectares respectively. It therefore seems that the effect of rasterising on all the land cover class distributions should all more or less even out over the whole catchment when using this particular scale and thus remained valid for the purpose of this study.

as a constraint to most future objectives as pointed out, but was also used to eliminate any cell currently classified as bushland from being selected as a potential forestry site under the forestry objective. In other words, when criterion maps were produced to account for the negative correlation with distances to bushland for example, this riparian zone contained no exotic bushland to associate with forestry because it was masked beforehand.

The raw climate data was manipulated with the *Surface/ Interpolate Grid* tool (linked to the Spatial Analyst extension). Different interpolators will produce better estimates relative to the actual values, depending on the phenomena the values represent and on how the sample points are distributed. No matter which interpolator is selected, the more input points and the greater their distribution, the more reliable the results. The precipitation data points in this case were in a 1.5x1.5km grid pattern, so regularized splining generated a continuous precipitation surface over the study area. The spline method is a general-purpose interpolation method that fits a minimum-curvature surface through the input MAP points. Here the interpolator utilized the nearest neighbour method, which included 12 points during analysis. Best for gently varying surfaces, it fits a mathematical function to a specified number of nearest input points, while passing through the sample points[39].

The DEM was used next to produce the necessary topographic criteria. From it aspect in degrees and slope percentages were derived. Due to the study area being located in the foothills of the Drakensberg and thus in relatively rough terrain, the DEM Analysis Tool (DEMAT extension) with the appropriate Horn algorithm (Burrough & McDonnell 1999) was used for this purpose. The same method applied when a curvature surface (in z-units) was derived as a factor to determine soil suitability. The other soil suitability factor, i.e. land type, was left unchanged from the original dataset, though. Using the previously digitised features or factors once more, the *Analyst/Find Distance* tool was used to create grid themes of the distance to the nearest criterion for each cell. Euclidean distance was calculated between each of the output cells that did not contain a feature, and the closest feature, and output cells that contained features were given a value of zero. Where distances to rivers or roads were involved, it was calculated not from the buffer zone, but from the centrelines of the digitised line features themselves.

To visualise the above decision criteria, nine example criterion maps are reproduced in Appendix F. It graphically illustrates the standard suitability ratings in association with a particular

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[39] Selecting “Regularized” as an option on the interface as in this case, the weight parameter defines the weight of the third derivatives of the surface in the curvature minimization expression.

land use objective over the entire study area and includes a short discussion of these images and related matters. As the large number of data layers suggests, these raster values or measurements needed to be standardised to, ‘compare apples with apples’ during the allocation decision-making, and attain a high level of convergence between the desired land use pattern and present-day situation. The next chapter deals with this matter as the last four procedural steps of the research plan.

CHAPTER 4 MCE IN GIS FOR RURAL ALLOCATION DECISION-MAKING: THE RESULTS

Embarking upon sustainable rural development on five land use fronts on under- and over-utilised, degraded land as desired by its owners or users would seem a daunting task. For instance, it has proven somewhat difficult to accurately document the relationship between land productivity and soil erosion because both soil erosion and productivity rates are influenced by numerous conditions that vary temporally and spatially. Thus each criterion’s deterministic or strategic role at a particular scale had to be considered in each instance. Since MCE entails the allocation of land to the uses for which they are best suited, the research plan required that each evaluation criterion be standardised first (Step 4), as well as compared and given a relative importance or weight as the next step (Step 5). Both steps made extensive use of the local knowledge and value judgements obtained during earlier deliberations among the decision-making group members. Running the MCE procedure (Step 6) in IDRISI allowed suitability maps for each objective to be constructed. These were, together with the objectives’ relative weights and area targets, made available for the final MODM procedure (Step 7) to produce the final land use allocation map.

4.1 Standardising measurements across the criteria

Employing a standardised measurement system across all factors in the evaluation process was vital to the outcome of this analysis. Most of the images were still expressed in the original map codes (land cover type, land use class, and land type information) or values, the latter in different units of measurement (mm, m, km, percentage, degrees, and z-units). Therefore, in this fourth procedural step, all maps were standardised to a uniform suitability rating scale– between 0 and 5 in this case. Broadly put, a positive correlation between the value awarded and suitability existed. Zero would assign no potential and thus totally unsuitable for the objective under consideration. Values one to five represent the potential range from very low (1) to very high (5). For deterministic criteria there will be a deterministic relationship between an alternative and its consequences. A deterministic criterion map assigns a single value to each object (cell) in a data layer. Present-day land uses positively earmarked for retention was prepared by allocating it the highest potential value possible (5). Only the weight of each of these criteria (as determined in the next section) would therefore influence the actual proportion of current land use that will be retained eventually.

The rest of the deterministic criterion maps acted as constraints, whether implicated in terms of current land use, ecological importance, or technical parameters. Implementing Boolean logic, unavailable cells received a zero-value, while a value of 1 was assigned to cells available for any development as per future objective. The four retention factor images and nine constraint images are listed in Table 4.1 per land use objective.

Table 4.1: List of retention and constraint images

Factor	**LUO**	**Image Value / Grid Code**		
		0 (unavailable)	**1 (available)**	**5 (present)**
FACTORS: **Land Use Retention**	FOR	Rest of image	—	Timber plantation and bushland
	AGR			Productive cropland
	BLT			Built-up areas
	CSV			Wetland, forest, and bushland (indigenous only)
CONSTRAINTS: **Current Use**	FOR	Built-up, productive cropland and firebelts	Rest of image	—
	AGR	Amanzamnyama plantation, firebelts and built-up		
	BLT	Amanzamnyama plantation, firebelts and productive cropland		
	CSV	Built-up areas		
	COM	Built-up areas and timber plantation / large woodlots		
Ecological Importance	FOR AGR	Forest, bushland (indigenous only), wetland, riparian zones and rocks	Rest of image	—
	BLT	Forest, bushland, wetland, riparian zones and rocks		
Technical: Road reserve	FOR AGR BLT CSV COM	All road surface cells generated	Rest of image	—
Study area/ Micro-catchment	FOR AGR BLT CSV COM	Rest of image (mask)	Micro-catchment extent	—

LUO =Land Use Objective; FOR =Forestry; AGR =Agriculture; BLT =Built-up; CSV =Conservation; COM =Communal Use.

These constraint images were further condensed to four constraint images (one per objective) in order to abridge the MCE analysis. Assigning rating values to specific factors thus amounted to the making of decision rules in the form of a threshold for each criterion (Eastman et al. 1995). The decision rules and critical class boundaries developed in this case were based on the analysis of the real mapped landscape, on the local knowledge gained, and commonly used conventions and divisions found in the literature or operational guidelines. Those applicable to the climatic, topographic, edaphic, and distance decision variables will now be discussed and rationalised individually per factor group.

4.1.1 *The standardised climate factor*

The positive correlation with forestry and agriculture in this case assumed higher rainfall areas to be more suitable in terms of plant growth and quality. Yet, the MAP range (697.7 – 1131.8mm) could not depict any land as totally unsuitable, thus no zero rate applied. The class with the highest values in the MAP range received a very high potential, but very low for the class containing the lower MAP values. As seen in Table 4.2, the MAP range over the watershed allowed for equal 100mm divisions from 600 to 1200mm and produced image Fi in Appendix F.

Table 4.2: Standardised suitability ratings for the climate factor

		Potential Rating/ Image Value					
Factor	**LUO**	**0 (none)**	**1 (very low)**	**2 (low)**	**3 (medium)**	**4 (high)**	**5 (very high)**
CLIMATE: MAP (mm)	FOR AGR	~	600 – 799	800 – 899	900 – 999	1000 – 1099	1100 – 1199

LUO =Land Use Objective; FOR =Forestry; AGR =Agriculture.

4.1.2 *Standardised topographical factors*

No aspect value would ever completely rule out any kind of development. Aspect values for agriculture and built-up areas were compiled by assigning the highest suitability to true north and the lowest to south and the other in between by making the tertiary directions (NNE, ENE, etc.) the class borders. In terms of suitability for forestry the inverse applied. Analysis of the reality in the study area indicated that these divisions showed a degree of correlation with productive cropland and settlements location (Figure 4.1).

The incidence of crop farming and built-up areas on southwestern slopes can be attributed to the local foothills situated diagonally in the watershed (see Figure 1.4). Where slope was concerned, relatively flat terrain slope (<2%) was naturally well suited for cultivation, tree planting or housing, but became less so with increasing steepness because of the associated physical constraints, shallower soils, and erosion risk. We know land use affects erosion more than any other factor. For land to remain a viable resource indefinitely it must be protected against excessive soil erosion, because any land is potentially threatened where accelerated erosion occurs.

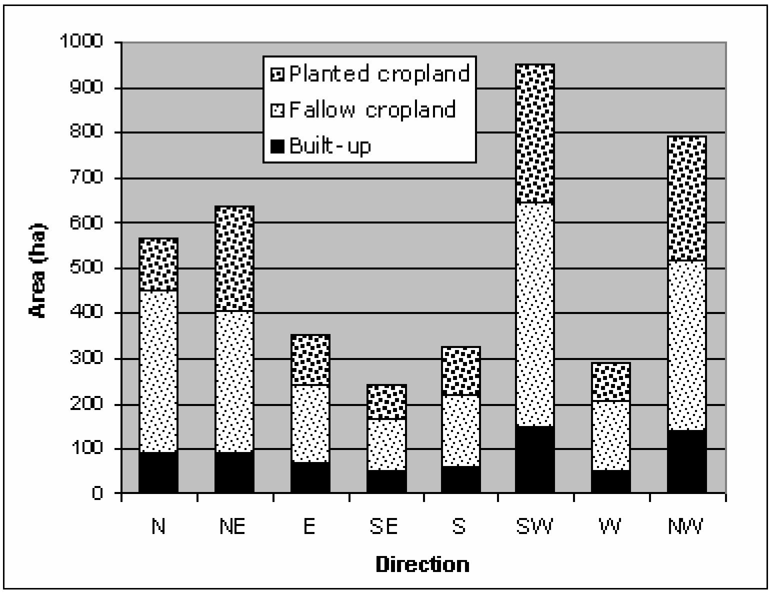

Figure 4.1: Distribution of productive cropland and built-up areas with regards to aspect (slope direction)

A few years of careless use can greatly accelerate soil erosion that degrades the land permanently, especially for food production. Meaningful observations were made in this respect when the area distribution of present and past agricultural land and erosion hazards (based on the land cover data set) over the range of slope classes (from the DEM) was examined. In order to detect any relationship between these features and steepness more accurately, a smaller (5%) slope division was plotted in Figure 4.2.

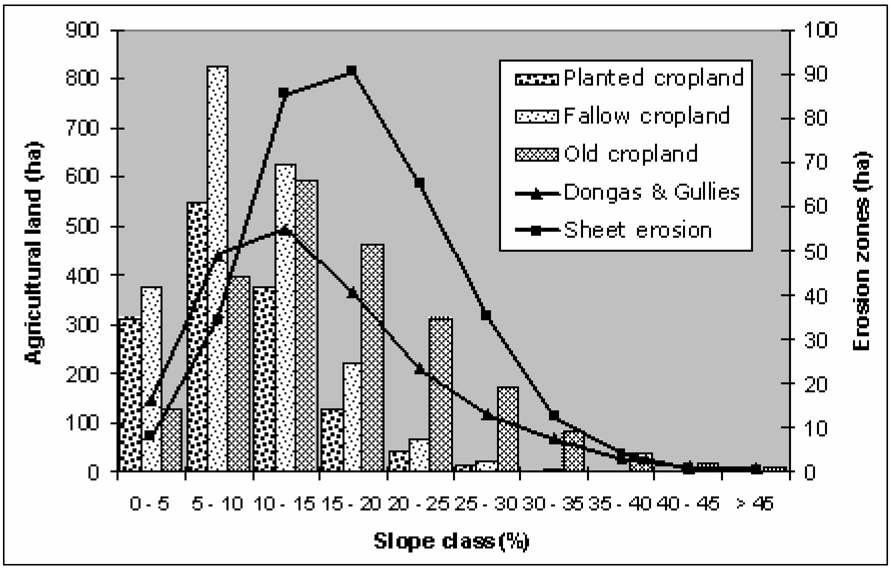

Figure 4.2: Distribution of erosion hazards and agricultural land (present and past) over the slope classes

It highlights the extensive (subsistence) farming in rather mountainous terrain, as suggested by the high proportion of cultivated and abandoned land on slopes steeper than normally allowed. At present the bulk of productive cropland lies more or less within the ten to twenty-five per cent slope classes. Erosion risk is related to the steepness of the uniform slope (Hudson 1995), and arises at slopes steeper than 5% when ploughed. Donga formation was highest in the 10 – 15% slope class, coincidentally the same class with the most abandoned cropland. Slopes up to 15% were therefore rated as having only medium potential for communal use (i.e. grazing). Additionally, these old fields, including those higher up and other fallow land, were often overgrazed, which explains both the peak in sheet erosion occurrence in the 15 – 20% slope class and the abundance of dongas lower down. Erosion at a location on a slope is a function of the distance from the surface runoff origin and the steepness at that location (Terrence, Foster & Renard 2002). For instance, if the location is far down the slope where much runoff has accumulated, the erosion rate will be high. This correlates with donga formations in particular[40].

It follows that, in terms of suitability, for these erosion prone slope classes the potential rating were much lower in the case of agriculture and forestry. In addition, above 15% heavy agricultural equipment is technically rendered ineffective and tractors find a use limit at 21% (Van der Merwe 1997). In any case, the National Soil Conservation Act prohibits all cultivation at slopes above 20%. Only forestry was permitted above 21%. Above 30% cable-yarding is normally involved (Brink, Kellogg & Warkotsch 1995), thus excluding woodlot development in particular. For settlement the maximum slope limit was taken at 21%, steeper than the 17% development limit set by Cooke & Doornkamp (1990). This is because households often occupy relatively steep hillsides by landscaping a dug-in for this purpose.

Yet, potential drops drastically beyond two per cent. Listed in Table 4.3 are the class boundaries and standardised suitability ratings for both topographic factors as determined above, each for the relevant land use objective.

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[40] Permanent, incised gullies form in concentrated flow areas by headcuts advancing upstream. In addition, permanent incised gullies are eroded by laterally retreating sidewalls where the process is cyclical.

Table 4.3: Standardised suitability ratings for topographical factors

Factors	LUO	Potential Rating/Image Value					
		0 (none)	1 (very low)	2 (low)	3 (medium)	4 (high)	5 (very high)
TOPOGRAPHY:	FOR	~	0 – 22.4; 337.5 – 359.9	22.5 – 67.4; 292.5 – 337.4	67.5 – 112.4; 274.5 – 292.4	112.5 – 157.4; 202.5 – 274.4	157.5 – 202.4
Aspect (Degrees)	AGR		157.5 – 202.4	112.5 – 157.4; 202.5 – 274.4		22.5 – 67.4; 292.5 – 337.4	0 – 22.4; 337.5 – 359.9
	BLT						
Slope (%)	FOR	≥ 30.0	21.0 – 29.9	15.0 – 20.9	5.0 – 14.9	2.0 – 4.9	≤ 2.0
	AGR	≥ 21.0	~				
	BLT		5.0 – 20.9	~	2.0 – 4.9	~	
	COM	~	~		0 – 14.9	15.0 – 29.9	≤ 30.0

LUO =Land Use Objective; FOR =Forestry; AGR =Agriculture; BLT =Built-up; COM =Communal Use

4.1.3 *Standardised soil factors*

Accelerated erosion is usually triggered by micro-relief (Hudson 1995), and this has thoroughly been investigated at field scale in this case. An analysis of hillslope variables on degraded areas indicated that some curvature classes were strongly associated with erosion hazards as expected, including wetland locations. The latter was added here because many marshy areas in the micro-catchment were also severely degraded (or eroded). As indicated in Figure 4.3, some significant insights on erosion risk were gained by the reclassification of the ‘slope of the slope’ units (one over one hundred z-units) into standard deviation classes.

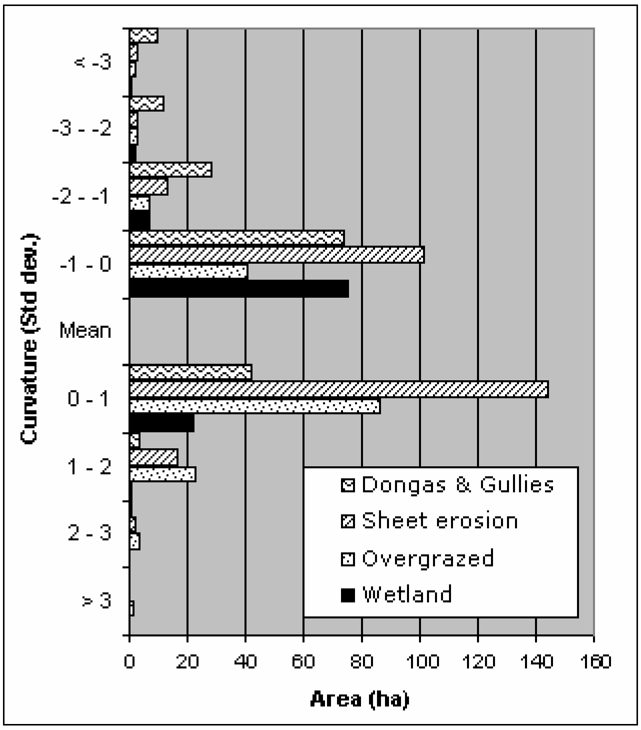

Figure 4.3: Distribution of erosion hazards, degraded grassland and wetland over the curvature classes

Although none existed, the mean theoretically implied absolute flat areas. Classes containing negative or positive values resembled the more concave or convex parts of the landscape, respectively. The first positive deviation (slightly convex slopes) was associated with high erosion risk since prolonged land mismanagement (mainly overgrazing) accelerated sheet erosion as indicated. A few high altitude bogs or marshy areas also occurred in this curvature class. In fact, some of the associated donga formations were attributed to past wetland draining practices. In response, conservation received at least medium potential and the class rated the least (medium) potential with regards to the communal use objective. Yet, assuming freely drained soils are predominant and runoff velocities are still relatively low, it remained highly favourable for agriculture and forestry practices, if compared to the much more convex slopes. When approaching the increasingly steeply curved sections in the landscape a drastic decrease in potential for the agriculture, forestry and built-up objectives applied. This was particularly true for concave slopes.

As expected (and also indicated in Figure 4.3), most wetlands fell within the first negative deviation (i.e. slightly concave slopes). The highest incidence of dongas was also found in this class, and dominated the increasingly concave classes as well. Although concave areas could benefit from sediment depositions and thus imply deeper soils, it can also mean waterlogged soils in other cases. Therefore, it displayed a high potential for conservation and communal uses, but only medium potential for forestry, agriculture and settlements. Sediment delivered from the end of the convex slope is often substantial, especially where sheet erosion is present in the landscape, as was the case here. Sheet erosion featured second most in the first negative deviation, again partly due to overgrazing. Nonetheless, runoff is least on the concave slope, where steepness is greatest, that even vegetation could at times re-establish itself. This could, although rated lower, be advantageous for agroforestry at some places. Appendix G elaborates in these relationships between land cover/use, slope shapes, and erosion risk for better understanding. A large-scale erosion zone in a section of the actual landscape, as located in the study area, appears with the accompanying discussion. Still, it was hoped that the relatively high conservation potential of these curved areas throughout the micro-catchment would counterbalance the generally high grazing potential should future herding be better managed. No development was allowed beyond the third deviation in either direction.

Developmental progress, in forestry and agriculture in particular, would naturally depend on the productivity of the soils present in the study area. Terrence, Foster & Renard (2002:4) defined soil productivity as “the capacity of a soil, in its normal environment, to produce a particular plant or sequence of plants under a specific management system”. Fertility is, according to the same authors, “the capacity of a soil to provide the quantities and balances of elements and compounds necessary for plant development”. The actual soil data in this case was limited to discrete variables in the form of land type classes and their associated, generalised soil form descriptions. On the one hand, red-yellow apedal, freely drained soils had the highest potential for agriculture and forestry. Soils dominated by Glenrosa and Mispah forms (yet still with spots of acceptable soil types) were rated medium for agriculture owing to foreseeable tilling or soil depth problems. Since silviculture would preferably not involve any tilling in this case though, such land types were rated slightly higher in potential for forestry activities. On the other hand, such rocky subsoil would enjoy the highest rating for the remaining objectives, viz. built-up, conservation, and communal use. Since soils more suitable for cultivation or planting would rather be allocated as such, only a medium rating for settlement applied in those cases, but conservation and communal use remained highly rated. The discrete allocations of soil suitability related to both curvature and land type in this section are summarised in Table 4.4 per land use objective.

Table 4.4: Standardised suitability ratings for soil factors

Factors	**LUO**	**Potential Rating/ Image Value**					
		0 (none)	**1 (very low)**	**2 (low)**	**3 (medium)**	**4 (high)**	**5 (very high)**
SOILS: Curvature (Z-units)	FOR AGR BLT	-6.654 – -1.010; 1.010 – 3.942	-1.010 – -0.674	-0.674 – -0.337; 0.674 – 1.010	-0.337 – 0	0.337 – 0.674	0; 0.337 – 0
	CSV COM	~	~	~	0 – 0.337	-0.673 – 0; 0.337 – 1.010	-6.654 – -0.673; 1.010 – 3.942
Land Type (Soil form)	FOR	~	~	~	~	Fa	Ac
	AGR				Fa	~	
	BLT				Ac		Fa
	CSV				~	Ac	
	COM						

LUO =Land Use Objective; FOR =Forestry; AGR =Agriculture; BLT =Built-up; CSV =Conservation; COM =Communal Use;
Ac =Red-yellow apedal, freely drained soils; Fa =Glenrosa and/or Mispah forms dominate.

4.1.4 *Standardised distance factors*

Distance thresholds the decision-making group did not determine earlier during the criteria selection phase, were refined or rationally set by the GIS expert. Some available practical guidelines assisted in this respect. All but one distance measure lacked zero ratings because no measurement or characteristic could exclude all development or practices for those variables. Forestry regulations and the risk of invasive species forced the decision to locate such forestry areas at least 80 meters from watercourses. All distance measurements were classified in equal intervals over the data range though. Distances to features for which two (or more) land uses competed were rated evenly, but in reverse order.

In summary, the class boundaries and standardised suitability ratings for all distance variables appears in Table 4.5 per land use objective. A simple reclassification was done on these images in ArcView to standardise the value ranges. All the decision-criteria were then subjected to a weighting procedure to gauge their relative importance with regards to the suitability assessment, or Step 5 of the research plan.

Table 4.5: Standardised suitability ratings for distance factors

Factors	**LUO**	**Potential Rating/ Image Value**					
		0 (none)	**1 (very low)**	**2 (low)**	**3 (medium)**	**4 (high)**	**5 (very high)**
DISTANCE TO:	BLT	~	≥ 500	375 – 499	250 – 374	125 – 249	0 – 124
Built-up & recreation (m)	COM		0 – 124	125 – 249	250 – 374	375 – 499	≥ 500
CBD/ Marketplace (km)	AGR BLT	~	~	≥ 12.0	8.0 – 11.9	4.0 – 7.9	0 – 3.9
Erosion hazards (m)	FOR AGR BLT	~	0 – 24	25 – 49	50 – 74	75 – 99	≥ 100
	CSV		≥ 100	75 – 99	50 – 74	25 – 49	0 – 24
Forestry office & nursery (km)	FOR	~	≥ 10.0	7.5 – 9.9	5.0 – 7.4	2.5 – 4.9	0 – 2.4
Major roads (m)	FOR AGR BLT	~	≥ 2000	1500 – 1999	1000 – 1499	500 – 999	0 – 499
	COM		0 – 499	500 – 999	1000 – 1499	1500 – 1999	≥ 2000
Old cropland (m)	COM	~	~	~	> 1000	500 – 999	0 – 499
Plantation & bushland (m)	FOR	~	≥ 2000	1500 – 1999	1000 – 1499	500 – 999	0 – 499
Productive cropland (m)	AGR	~	≥ 1000	750 – 999	500 – 749	250 – 499	0 – 249
Rivers (m)	FOR	0 – 79	80 – 159	160 – 239	240 – 319	320 – 399	≥ 400
Schools (m)	BLT	~	≥ 3000	2250 – 3000	1500 – 2249	750 – 1499	0 – 749
Wetlands (m)	FOR AGR BLT	~	0 – 49	50 – 99	100 – 149	150 – 199	≥ 200
	CSV		≥ 200	150 – 199	100 – 149	50 – 99	0 – 49

LUO =Land Use Objective; FOR =Forestry; AGR =Agriculture; BLT =Built-up; CSV =Conservation; COM =Communal Use.

4.2 Developing criteria weights

The fifth procedural step called for separate weights to be assigned to each criterion as a general measure of its importance during the impending MCE. The IDRISI WEIGHT module provided a pair-wise comparison matrix for this purpose, which produced the weights by following the logic provided by the AHP[41] as explained in Section 2.2.2. In this case the requisite local perspective from Step 2 was incorporated in the form of factor priorities, whilst the relative comparison values allowed the GIS-expert some room for finer calibration in this iterative model.

4.2.1 *The method*

During the second procedural step the decision-group members selected and prioritised the criteria, because the pair-wise comparisons required by Saaty’s judgement matrices (e.g. 201 in total in this case) could prove cumbersome and time-consuming. It might even affect the motivation of the participants (Steward et al. 1997) in question and thereby influence the results. For example, a study conducted at a landscape scale by Phua & Minowa (In press) recently using a GIS-based MCDM approach for forest conservation planning, confirmed that the decision makers or those involved in the weight assignment may face difficulty in giving weights on a pair-wise basis. On the other hand, in Mendoza & Prabhu's (2002) study in Zimbabwe MCDA was used as a decision-making tool to analyse and evaluate multiple criteria and indicators (C&I) in a similar participatory group decision-making situation. Feedback received from those participants indicated that the methods used (for extensive comparisons) were quite simple, easily grasped by participants, and the group decision-making process was transparent. Yet, where such important C&I evaluations warrants full participation in all instances, the decision criteria for this study were more generalised in nature. The approach in this study was therefore to not tax the decision-making group with the pair-wise comparisons exercise, but to only implement a simple prioritising procedure at the appropriate time. The need to evaluate (or compare) a large number of relatively complex concepts such as curvature or erosion risk, for example, all at once in the time available was thus largely avoided.

For each objective the WEIGHT-module begins by entering the number of factors and factor image names. All the necessary standardised raster images in ArcView were therefore converted to ASCII files, imported into IDRISI and converted from real to integer values. Since each factor was rated against every other factor in the weighting system by assigning it a ‘relative dominance

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[41] Weights are determined by normalising the eigenvector associated with the maximum eigenvalue of the (reciprocal) ratio matrix (Malczewski 1999). See also Appendix A for a technical description.

value' (Van der Merwe 1997), the criteria images per objective were entered in order of priority. Great care went into the pair-wise comparisons, which were quantified by using the linear scale proposed by Saaty (1980). Such a scale is a one-to-one mapping between the set of discrete linguistic choices available to the decision maker and a discrete set of numbers which represents the importance, or weight, of the previous linguistic choices (Triantaphyllou 2000). Since the factor on the horizontal axis was more important than the factor on the vertical axis in this case, the relative reciprocal values applied, i.e. values varying between 1 and 1/9 to the intersecting cell. The consistency check was stringently performed through machine logic during each run. Although dependent on the author's scientific perceptions and priorities this time around, one may argue it counter-balanced to some extent the impact of the inherent bias some members of the decision-making group may have displayed towards familiar factors. Besides, this phase is part of an iterative process according to the study design (Figure 1.5). Where the returned results show an obvious inconsistency or unexpected behaviour in the output data or image in the laboratory, the decision-maker (GIS expert) can readdress the problem. Within this framework, the fifth step was executed.

4.2.2 *Inspection of the factor priorities*

The participatory component or factor priorities assisting in the weighting were reviewed for inclusion in the weighting process and are summarised briefly per land use objective. The weights matrices appear in Appendix H.

4.2.2.1 Prioritised conservation factors

When the group prioritised the five criteria selected for conservation, the protection of wetlands and indigenous wooded areas was rated most important. Since land degradation issues featured strongly during deliberation, distance to wetlands and the proximity to erosion hazards followed as the second and third most important factors, respectively. Next lowest in priority was curvature to account for erosion risk, followed by land type last, due to its generalised nature in this case.

4.2.2.2 Prioritised forestry factors

In total, the twelve factors for the forestry objective were slightly more difficult to prioritise, but were agreed upon after some deliberation. The importance given to the first three factors mirrored those of conservation for similar reasons, i.e. land retention and to combat further land degradation. The retention of plantation, woodlots, and non-indigenous bushland was thus a critical component in terms of the forestry objective, but with less environmental impacts envisioned, at sensitive areas in particular. Small-scale plantations on degraded land or abandoned agricultural sites would have environmental benefits in some instances (IPCC 2000), but the key was to consider site-specific circumstances rather than make generalisations. In this context, the distance to rivers was rated the fourth most important factor. The next factor was considered to be climate (i.e. MAP). The spatial accuracy of the data, and its usefulness in the assessment process, had to be considered when prioritising the decision criteria. For instance, the MAP criterion may be the more critical variable for a particular land use objective, as is the case here. Yet, an interpolated MAP value at a particular cell would inherently carry a greater margin of error than compared to, for example, a relatively straightforward accurate measurement such as a short Euclidean distance to a river. In this instance though, although derived from slope, curvature offered more important information with regards to forest development, particularly on relatively steep slopes. Because curvature also related to soil suitability in terms of runoff estimates, soil development, and erosion patterns, it was placed sixth in priority, followed by slope. Aspect was regarded more important than land type – here rated ninth – because of the latter’s generalisation. The three least important factors were all distance based. Distance to roads was rated more important than distance to plantations and bushland for logistical reasons, leaving the proximity to the forestry office as the factor with the lowest priority due to its simplistic dimensions.

4.2.2.3 Prioritised communal use factors

The six factors pertaining to communal use were ranked in order of importance without too much difficulty. The superior (negative) correlation that the distance factor to old cropland displayed (as the preferred grazing area) made it the first priority. The links between bad rangeland management and erosion with slope components provided the rationale to place slope and curvature second and third in priority, respectively. Following in lower order were distance to built-up and distance to roads. Although of diminished importance, they still played their respective role in consolidating the more remote pastures. As under the conservation objective, land type was once more rated the least important criterion.

4.2.2.4 Prioritised agriculture factors

Prioritising the eleven factors in this instance differed noticeably from the other objectives in terms of its retention as a land use, mainly as a result of the poor soil productivity levels and performance of recent crops. Calls for urgent wetland rehabilitation and conservation, as well as erosion control measures resulted in the distance to wetlands and erosion zones being rated highest and second highest in priority, respectively. Then only came the retention of productive cropland. Because of this lower importance rating very badly situated, yet productive cropland in the current landscape could be isolated and excluded to some extent. Slope and curvature was rated next in fourth and fifth positions because they were, as under the communal use objective, directly related to erosion risk. MAP was sensibly rated sixth in importance to ensure sufficient moisture is available for healthy plant growth. This principle also extended to aspect, which was rated the seventh most important factor, but in terms of satisfactory light exposure. As crop farming would accept shallower soils than say forestry, and involve tilling in most cases, the land type factor was rated more important in comparison, in eighth place. Considering current successfully farmed land (already assumed to be best suited for such purposes), distance to productive cropland was the logical next lower ranking factor in terms of importance. Still, the agricultural allocation should at the same time not correlate too strongly with rural clusters. Since productive cropland is in this case partly made up of small fields normally associated with subsistence farming, the lower importance ranking of this distance factor helped to dissociate it to some degree from such inhabited areas. It implies that larger-scale commercial farming is also stimulated elsewhere, further away from built-up land. The economic reasoning behind possible agricultural intensification was only broad enough though to justify the remaining distance factors the two least important berths. In this instance, the distance to the (theoretic) marketplace was rated lower than to existing transport routes, the latter often in poor condition.

4.2.2.5 Prioritised built-up factors

Eleven factors were available for the group to prioritise for the built-up objective. Once more the retention of land use, in the form of present built-up areas, was the most important factor, followed by the proximity to wetland and erosion hazards. Distance to official educational facilities and built-up areas that included sports fields, rated fourth and fifth most important respectively, was imperative in light of the poor public transport and infrastructure available to locals, young scholars in particular. Slope ended up being the sixth most important factor after considering the physical difficulties steep slopes pose towards this kind of development. Distance to roads was the seventh priority, its lower status justified in this instance due to its strong correlation with current settlements, the distance to which was already prioritised (fourth and fifth). However, smaller settlements further removed from the more defined rural clusters, but still in close proximity to a road, would still benefit in terms of probable development progress. Since a premium was also set on the amount of sunshine receivable, aspect was rated eight in importance. Soil suitability as gauged by curvature and land type in this case was rated third and second least important respectively due to their diminished role in site selection when building the basic rural structures. The proximity to the town centre in Mount Frere remained as the least important factor, mainly because distances were theoretically taken ‘as the crow flies’. Thus these distances could differ substantially from road distances actually travelled, especially to and from the outer reaches of the study area.

4.2.3 *The results*

The basic priority ratings and final calculated weights for all factor group variables per land use objective are summarised in Table 4.6, including the consistency ratio in each final run. Those obtained per objective in this case proved to be in an acceptable range (i.e. CR < 0.10). The weights per objective sum to one, as is required by the weighted linear combination procedure. The complete pair-wise comparison matrixes are reported in Appendix H. The decision factors are listed in order of importance under each land use objective and the perceived priorities are captured in the proportional weights through the assigned ‘dominance’ values. The reciprocals of the lower triangular half need not be filled in because the matrix is symmetrical. As the penultimate procedural step in this study, MCE was then applied.

Table 4.6: Relative weighting of decision criteria per objective

CRITERIA	**LAND USE OBJECTIVES**									
	CSV		**FOR**		**COM**		**AGR**		**BLT**	
	Priority	Weight	***Priority***	Weight	***Priority***	Weight	***Priority***	Weight	***Priority***	Weight
Land use retention	*1*	0.4551	*1*	0.2391	–		*3*	0.1458	*1*	0.2504
Climate:										
MAP	–		*5*	0.0841	–		*6*	0.0617	–	
Topography:										
Aspect	–		*8*	0.0396	–		*7*	0.0421	*8*	0.0361
Slope	–		*7*	0.0480	*2*	0.2719	*4*	0.1020	*6*	0.0650
Soils:										
Curvature	*4*	0.0742	*6*	0.0626	*3*	0.1579	*5*	0.0821	*9*	0.0256
Land type/ Soil form	*5*	0.0474	*9*	0.0282	*6*	0.0340	*8*	0.0335	*10*	0.0198
Distance to:										
Built-up areas	–		–		*4*	0.0839	–		*5*	0.0812
CBD/ Marketplace	–		–		–		*11*	0.0147	*11*	0.0153
Erosion hazards	*3*	0.1601	*3*	0.1560	–		*2*	0.1996	*3*	0.1541
Forestry office	–		*12*	0.0128	–		–		–	
Roads	–		*10*	0.0213	*5*	0.0494	*10*	0.0188	*7*	0.0479
Old cropland	–		–		*1*	0.4028	–		–	
Plantation & bush	–		*11*	0.0161	–		–		–	
Productive cropland	–		–		–		*9*	0.0261	–	
Rivers	–		*4*	0.1189	–		–		–	
Schools	–		–		–		–		*4*	0.1120
Wetland	*2*	0.2632	*2*	0.1733	–		*1*	0.2737	*2*	0.1926
Sum:		1.000		1.000		1.000		1.000		1.000
Consistency ratio:		0.02		0.05		0.02		0.04		0.04

CSV =Conservation; FOR =Forestry; COM =Communal Use; AGR =Agriculture; BLT =Built-up.
Priority = Basic order of importance as judged by decision-makers; Weight = Calculated relative weight.

4.3 Application of multi-criteria analysis

The factors and constraints were, by running the MCE-module in IDRISI, combined in weighted linear combinations. By repeating Step 6 of the research plan separately for each of the objectives, five suitability maps with value ranges per cell matching that of the standardised factor maps were compiled. Once more a value range of 0 to 5 applied (i.e. from totally unsuitable to maximum suitability), and the results are shown in Figure 4.4. As desired, most of the micro-catchment displays a small degree of suitability for conservation (Figure 4.4 i) where not constrained. Yet, as suitability correctly increases with areas strongly associated with erosion risk, indigenous vegetation and wetland respectively, it also implies corresponding conservation practices/controls of increasing magnitude and intensity, but compatible with the financial and human resources on hand. For example, Hugo (2004) states that severely donga-ridden landscapes (high suitability) can be restored to their original condition more easily with localised erosion control than can areas laid waste by sheet wash (low suitability).

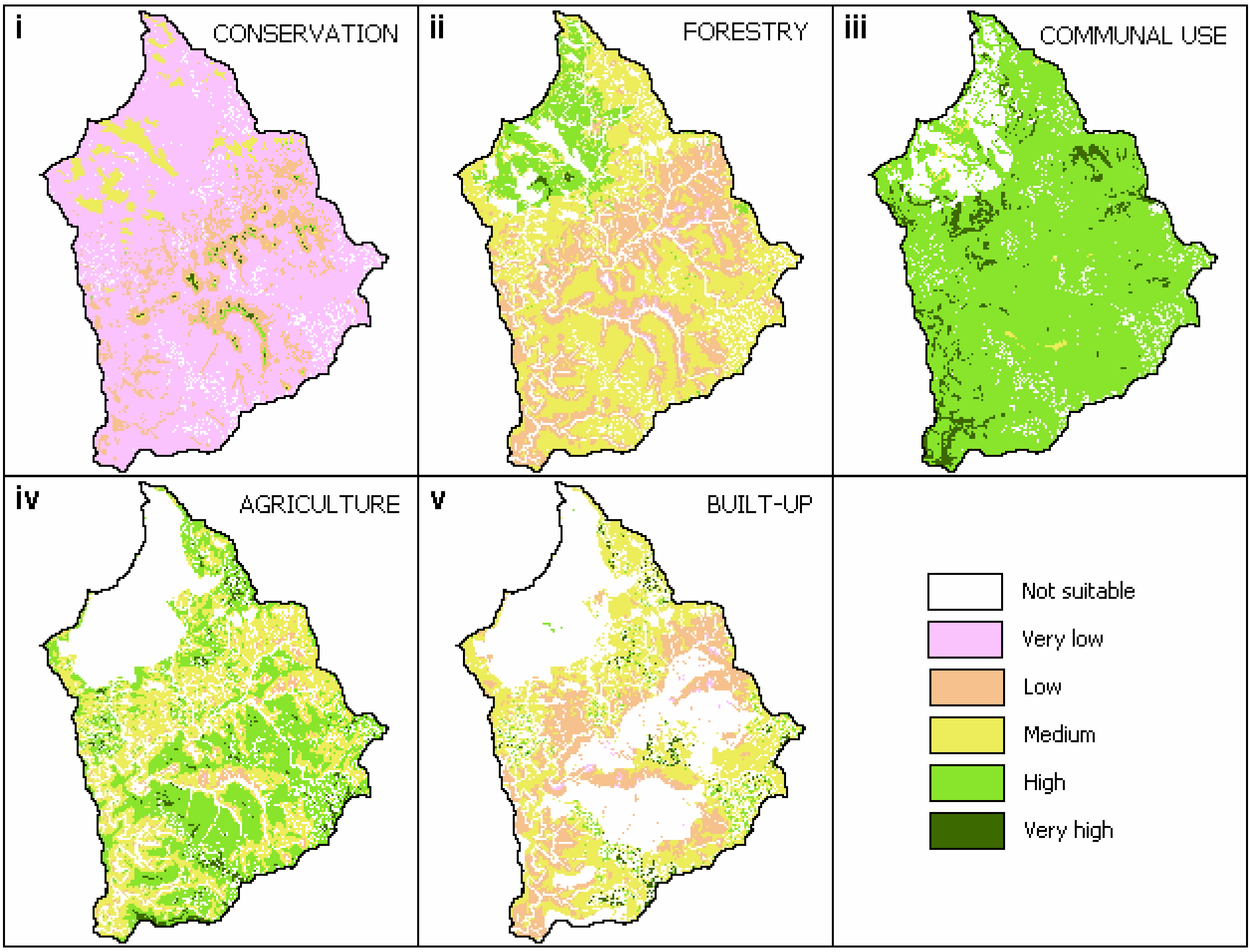

Figure 4.4: Suitability maps for each land use objective

Current wetland was sufficiently enhanced by the strong positive correlation with conservation to receive the highest suitability class as indicated. Forestry (Figure 4.4 ii) mustered only a few very high suitability cells (including those within the existing plantation boundary). Although one could argue that this is marginal land in the first place, this result is also due to the strict slope restraints in operation because the establishment of woodlots was being considered and not conventional plantation forestry as such. The Amanzamnyama plantation nevertheless displays high suitability in general, excepting constrained features/factors. Most wattle stands and other mixed jungle were effectively incorporated in areas of high suitability for forestry, but watercourses were effectively avoided.

As expected, the communal use objective (Figure 4.4 iii) received high suitability over most of the watershed, mainly as rangeland, but effectively excludes infrastructure, settlements, and plantations or relatively large woodlots. Medium suitability areas in the plantation extent correlates well in terms of increased access control, whereas some small ravines associated with indigenous vegetation correctly assumes high suitability in terms of its important communal use value. Agriculture (Figure 4.4 iv) returned a variety of suitability classes over the study area, and most high suitability cells were well concentrated around existing productive land of the same suitability (or even very high in a few instances). The effect of the constraints, viz. the Amanzamnyama plantation, as well as other sensitive or built-up areas unavailable for cultivation, is clear in this instance. Nonetheless, the more suitable farmland was still relatively closely associated with built-up areas to link with care-taking duties and labour availability.

The built-up areas (Figure 4.4 v) remained sufficiently concentrated to restrict fragmentation and intrusion, as indicated by the very high to high suitability ratings for existing settlements and close association with important transportation routes. Again, constraints excluded wooded areas and productive cropland, as well as wetlands, riparian zones and rocks. All that remained for the final procedural step was to consolidate these five land use suitability maps into one final land use allocation solution by implementing MODM that takes into account the complementary and conflicting relations involved.

4.4 Multi-objective decision-making for final allocation

In the seventh and final step the MODM procedure was applied to generate the idealised land use pattern. After the land use suitability images were subjected to a ranking procedure in order to standardise them and prioritise individual cells, they were entered with their relative weights and area targets in an iterative process out of which the final land use allocation solution and map(s) were produced.

4.4.1 *The principle*

The diagrams in Figure 4.5 best illustrate the logic of the MODM process performed by the GIS-specialist on the IDRISI platform. Eastman et al. (1995) suggests that all the cells making up the suitability maps may be thought of as an axis in multi-dimensional space, and can thus be located within this decision space according to its suitability level on each of the land use objectives. The diagrams show an example where only two objectives are involved. To find the 'best' land for any objective, a decision line moves down from the top of that objective's suitability axis until the area targets are fully met. This partitions the decision space in four regions as indicated in Figure 4.5A. A simple partitioning of the affected cells is utilised to resolve the conflict zone(s). Here the decision space is also partitioned into two further regions as indicated in Figure 4.5B, viz. those closer to the ideal point for the first objective and those closer to that of the second objective. The ideal point represents the best possible case, i.e. a cell that is maximally suited for one objective and minimally suited for anything else.

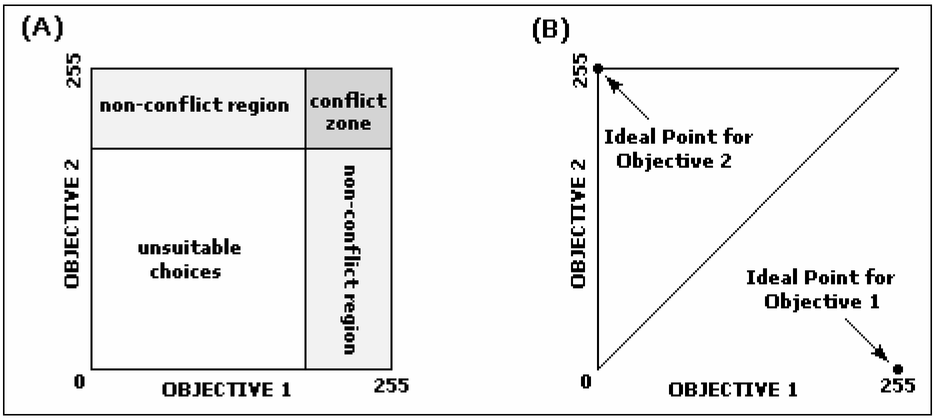

Figure 4.5 Conflict resolution in the MODM decision space when using IDRISI(Source: Eastman et al. 1995:65)

With goal programming (in hectares), this iterative process lowers the decision line for both objectives during each cycle in order to gain more territory until the area targets are met. The example assumes equal weighting of the two objectives in question. Unequal weighting would be reflected by the change in angle of this dividing line from 45 degrees. In order to handle conflict resolution of competing objectives and to make the single-objective suitability maps comparable in the MODM procedure, they each first had to be standardised.

4.4.2 *Image ranking*

The ranking system involved the matching of the histograms for the suitability maps, two at a time. With the IDRISI RANK-module, a very strict histogram equalisation was produced. An added advantage was that the number of classes in the output was equal to the number of input cells. RANK also permits the use of a secondary sort of procedure for the ranking of ties. The sort order of the secondary ranks should be chosen with direct reference to the decision problem at hand. In the case of conflicting objectives (e.g. agriculture and forestry), ties are ranked in the reverse order of their rank position on the second objective. In other words, the secondary ranks are opposite to the order of the primary ranks. At the same time rank position is forced to be consistent with the underlying logic of the minimum distance to ideal point procedure diagrammed in Figure 4.5 B. As a result, the best choices for any objective will be cells that are strongly suitable for the objective in question and strongly unsuitable for the other objectives. In cases where objectives are complementary (e.g. forestry and built-up), it would be better to make the secondary sort order identical to that used for the primary ranks. The primary and secondary ranking order of the competing objectives for this study, including their relationships, are listed in Table 4.7.

Table 4.7: Primary and secondary ranking order of competing objectives

Primary Objective	**Primary Ranking**	**Secondary Objective**	**Secondary Ranking**	**Relationship Type**
Conservation	Descending	Agriculture	Ascending	Competing
Forestry	Descending	Built-up	Descending	Complementary
Communal use	Descending	Agriculture	Ascending	Competing
Agriculture	Descending	Forestry	Ascending	Competing
Built-up	Descending	Agriculture	Descending	Complementary

Conservation and communal use competed with agriculture, and in turn, agriculture competed with forestry. Forestry on the other hand was complementary towards built-up areas since we saw earlier it was expected of them to be in close proximity to each other. The same principle explains the complementary relationship found between settlements and agriculture. Next was the actual MODM performed in IDRISI's multi objective land allocation (MOLA) module.

4.4.3 *The final allocation*

The MOLA interface needed only: i) the names of the objectives, ii) their relative weights, iii) the area targets, iv) names of the ranked suitability images for each. The first three inputs were derived from Tables 2.2 and 2.3 as part of the participatory decision-making results. MOLA then iteratively reclassified the ranked suitability images to perform a first stage allocation, checks for conflicts, and then allocated conflicts based on the minimum-distance-to-ideal-point rule using the weighted ranks. This process then continued until a solution was achieved. In this way it is ensured that conflict resolution would give precedence to existing uses followed by the introduction of areas destined for conservation activities, then agroforestry/woodlot practices, rangeland, cropland and so on until the last remaining suitable land ultimately ends up in the reserved objective. This is to experimentally show where the most marginal of land is located once the selected uses had been fully allocated. Since the tolerance level for the final allocation was set at zero, the area goals of all objectives were completely achieved, after several iterations. The future proportional land use distribution and the final optimum land allocation map are displayed in Figure 4.6.

The distribution of the five land uses and those reserved for roads as indicated in the pie chart indicate the extent the area goals (Table 2.2) was met. In the conservation areas all indigenous forests and bushland are adequately included and the imperative wetland rehabilitation is well catered for. ‘Converted’ invader jungle (to woodlot) and plantation trees are situated well away from the riparian zones, which are also assumed cleared of exotics. Areas in urgent need of erosion control activities are clearly demarcated, which in turn aids in managing herding decisions and grazing control measures.

Forestry plantations are completely maintained, including the mixed bushland/wattle jungles targeted for proper management retention. Much of the forestry areas are effectively distributed in large enough patches to allow for the envisioned woodlots of economical proportions. Some of these would more than likely satisfy the local fuelwood demand and be in close proximity.
Elsewhere, agroforestry activities were blended into the landscape satisfactorily, for example, the area slightly to the northeast of the little village (most recently developed on old cropland) on the western boundary of the watershed. Moreover, two important findings related to Baskent’s (1997) study and to forest management could be highlighted here. Spatial structure of forest patches, defined by both spatial configuration (e.g. shape, size, and relative arrangement) and aspatial characteristics (e.g. composition) of patches and interconnections among them, affects ecological processes and organisms and, therefore, plays a vital role in determining values. This conforms to the principle of island biogeography theory in plantation planning i.e. natural areas, big or small, within plantations linked with one another by corridors or consolidated where possible (FIEC 1995). The resulting forestry areas on the map, in conjunction with indigenous forests and watercourses, correspond very well with this idea as they cut through settlements and mono-cultural land uses, viz. cropland and plantation.

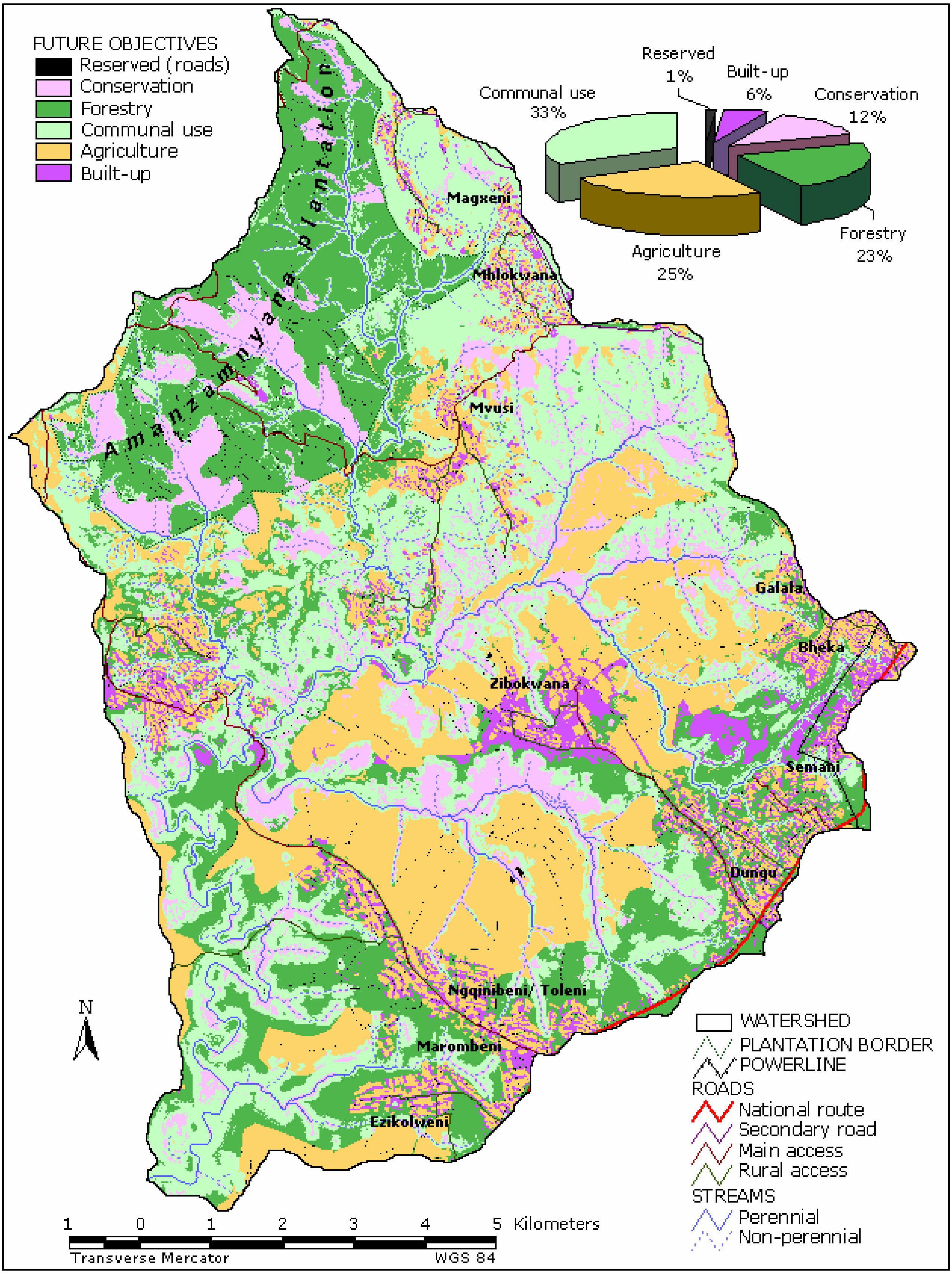

Figure 4.6: Idealised land use situation after MOLA

The communal use ended up well distributed over the micro-catchment as expected, and in many cases also contributed to the corridor effect, e.g. the veld buffers separating the wetlands from productive cropland. Similarly, the less steep, lower slopes were more readily available to grazing, as well as along most watercourses. Again, awareness towards areas displaying a high erosion risk is essential in this situation.

As for agriculture, the allocated areas on the map are now assumed to be the best productive cropland available, for both (increased) commercial and subsistence farming needs. Land parcels suitable for cultivation were functionally well clustered and retained most of the current productive areas as intended.

Other than the few relatively fragmented and smaller new built-up developments, two pertinent urban development nucleuses were returned in the final solution. One implied the expansion of an existing village/node (Zibokwana), the other a completely new development slightly to the west of Semani. Both were associated with an important road and thus easily accessible. Furthermore, these areas were also relatively close to basic and public services associated with Mount Frere situated just outside of the study area to the east. To some extent it illustrates controlled urban expansion along the national road running through the town. The transmission line did not feature as a decision criterion, but it is perfectly located in terms of the expanding urban areas, as well as the new potential development site as shown.

Finally, most of the reserved parcels were retained. Yet, the small patches above and below Zibokwana village in the cropland and riparian zone resemble the least suitable parcels for any of the other objectives and would be the first to be considered for alternative uses (if not communal use) in future follow-up evaluations. It could now be concluded that the objectives had captured the ‘best’ land for the land use practices associated with each.

CHAPTER 5 SYNTHESIS

A review of the steps taken and the results obtained at the completion of this basic natural resource allocation model was fundamental to reflect on whether the scientific research was carried out within design parameters set by the local community and environmental limitations were heeded. To those concerned the value or shortcomings of the study from both a theoretical and practical perspective are thus revealed and recommendations are offered where applicable.

5.1 Summary of processes and results

In order to address the unproductive land use and land mismanagement issues, which presently lead to further impoverishment and severe environmental degradation, two important study components had to be encapsulated once the study area in question was appropriately demarcated. In this case a land evaluation and decision-making model was selected consisting of seven main procedural steps, which incorporated spatial information and MCDM and MODM methodology at specific stages and GIS, but also allowed for effective community participation. The resource base and other spatial elements useful for land evaluation purposes and resource management decisions made up the first component and were subsequently sourced or digitised. In fully capturing the observed physical and biological landcover using GIS, it was possible to convert these to generalised land use. The second component involved the direct participation of three main stakeholder groups, which included the affected communities, relevant state officials, and independent advisors. This was later reduced to a single representative decision-making group consisting of ten individuals. The digital land information then facilitated the assessment of the current development state by decision-makers to arrive at five predetermined land use objectives, priorities, and area goals during a day long workshop. Surprisingly, the conservation objective, which directly correlated with water and soil issues, was perceived as being very important by stakeholders. Conversely, the most negative perceptions were associated with agriculture, which subsequently reduced its priority status.

In the context of geographical decision-making and the people-environment relationship, each objective indicated the directions of improvement of one or more attributes. From the available information the spatial decision factors were carefully selected per land use objective and prioritised towards progressive rural development. A range of criterion and constraints maps were prepared to this effect and the values or measurements demonstrated the suitability ratings in association with a particular land use objective over the entire study area. The model required that the factor attributes be standardised and each variable weighted in preparation for the MCE procedure. The resulting single-objective suitability images, with value ranges per cell matching that of the standardised factor maps, were further subjected to a standardising image ranking in order to handle conflict resolution of competing objectives. The MODM procedure produced the final land use allocation solution and map(s). Moreover, the effective incorporation of the local knowledge base and value judgements obtained from decision-making into the analysis made it possible to project the desired or ideal land use scenario. Figure 5.1 visually portrays these research processes.

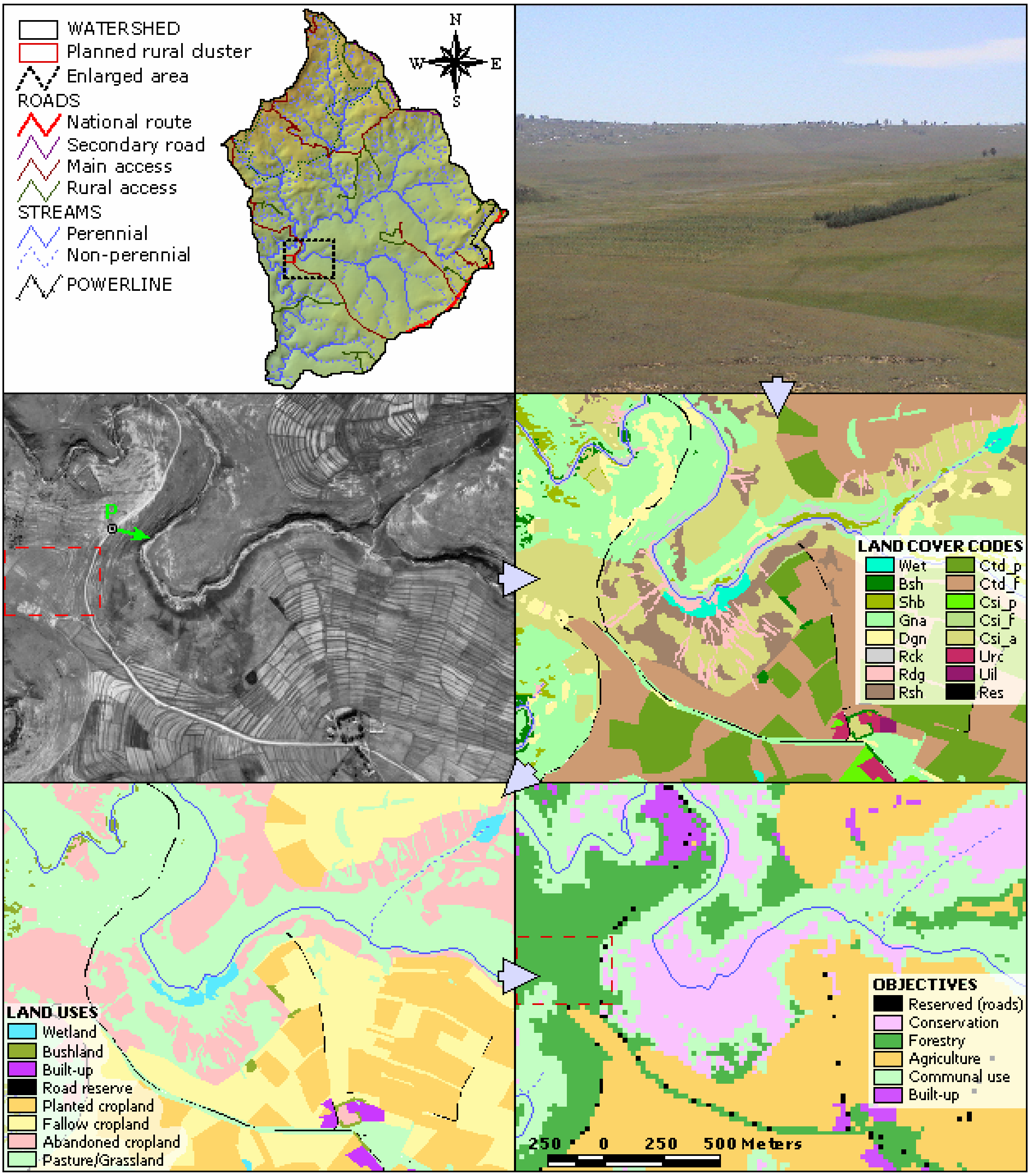

Figure 5.1: The flow of data analysis and returned images

It shows an enlarged part of the study area and, by following the arrows, the flow of data manipulation and analysis and images created for this study. The ‘P’ and arrow on the black and white image indicates the location and direction of the colour photograph. Technically this study was enabled by the available data sets, those digitised and created during the various phases and the advanced GIS used as Appendix I and Appendix J elaborate.

5.2 Appraisal of research results

When assessing the study results from practical and theoretical points of view some important observations need to be made and these follow next.

5.2.1 *Practical application value in local context*

Large-scale land use changes in this locality would be unacceptable in terms of the socio-economic and environmental fundamentals associated with the study region. Within the context of the reigning geographical strategy it thus essentially means examining the degree of retention of existing land use or determining whether the proportional contribution each of the existing land uses made towards the five selected objectives is acceptable in terms of land use change. The actual proportional contribution(s) each of the existing land uses made towards the idealised situation at the conclusion of this study are indicated in Figure 5.2.

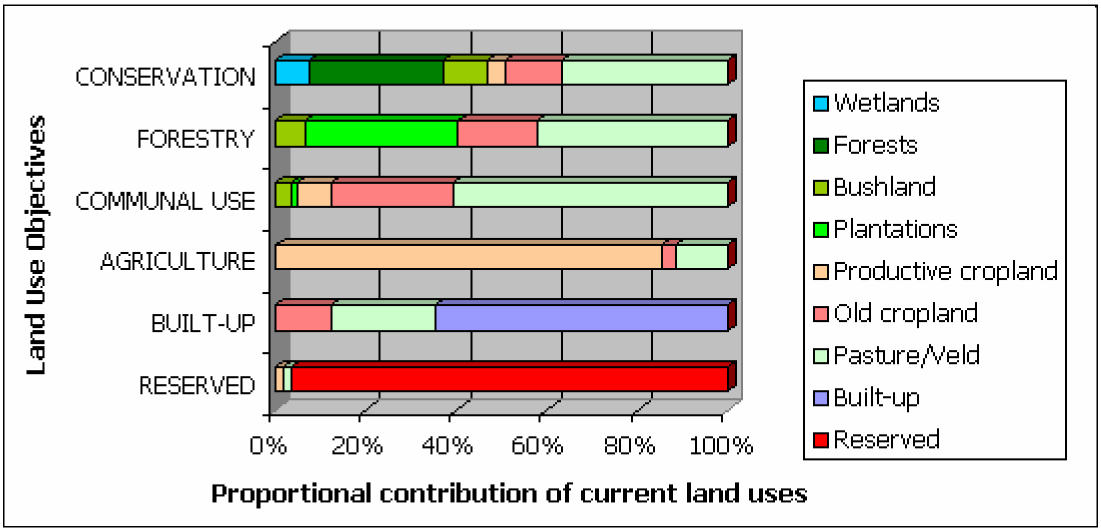

Figure 5.2: Proportional contribution of current land uses to each objective

As shown in the case of indigenous vegetation, wetlands, built-up areas, as well as the reserved objective, the desired retention of their existing uses is fully achieved. Nonetheless, as expected in terms of rural development, forestry would (in line with its higher priority) incorporate the most

(1804.7ha) land use change, followed by agriculture (355.1ha), and the built-up objective (237.5ha). Agroforestry practices or agriculture were inferior to other land uses in some instances, particularly when the technology was inappropriate or the accompanying policies not enabling. Yet, just over 95% of current plantations are retained for forestry (925.8ha) as desired, more so since the allocation to communal use (44.1ha) is slightly superficial when considering the concept of community forestry.

Some of the bushland contribution to forestry (179.4ha) represents the retained exotic jungles, viz. managed woodlots. Alternatively, indigenous bush is allocated to conservation (137.1ha) and the communal use allocation (146.0ha) implies alien vegetation clearing activities. With environmental sensitivity in mind it follows that conversion of present-day rangeland is considerably limited in respect of developmental progress. In fact, more veld is allocated to conservation (512.2ha) than the combined loss to settlement and agriculture (497.6ha). Almost 88% (2524.5ha) of present-day cultivated land would be retained for agriculture, and together with the newly allocated areas, would call for some forms of agricultural intensification. At the same time, badly situated productive agricultural land is also eliminated, ideally allocated to communal use or grazing (288.2ha), conservation (59.4ha), or even falling in the reserved category (2.2ha) in the worst cases. Any allocation to the latter three objectives does not necessarily represent any direct land use change though. As an existing land use class, old cropland provides for most of the objectives as expected, particularly contributing towards communal use (about 56% of all abandoned fields), followed by forestry (26%) and conservation (9%). The balance (173.1ha) is more or less evenly allocated between built-up and productive agricultural land. Therefore, a high degree of logical convergence between actual land use patterns (compare Figure 2.4) and the modelled allocation emphasised the envisaged planning potential of the methods used.

Judging by the practicality or functionality of the allocated objectives measured against current development initiatives, one should consider the extent of the planned rural cluster, shown in Figure 5.1. Current settlement development (i.e. marked out plots on old cropland) basically ended up as forestry land in the last frame. In fact, the cluster materialises next to the same road, but closer to the stream bank in the north and the school located in the other relatively new settlement to the northwest across the same stream. It would therefore make more sense to have the built-up area here as the results indicate because of its close proximity to water and educational facilities. Moreover, it does not occupy valuable land that is actually better suited for something more productive, such as planting trees in this case.

Enterprise development at local community level, based on tree- and forest products and linking forestry with other land-based activities in household production, was illustrated in this study. Noteworthy practical examples on this subject are the tree lane along the road, the convenient woodlot sizes and locations, as well as the windrows south of the wetland (in the centre of Figure 5.1) that will reduce runoff velocity from the agricultural land located higher up the hillside. Moreover, adequate strips of veld separate wetland and riparian zones from agricultural and forestry land, which in turn also avoid areas of high erosion risk.

Conservation wise, ecological corridors and wetland rehabilitation are well catered for as shown and might eventually lead to improved water quantity and quality. However, conversion of alien bush into managed woodlots remains to be given the full go-ahead from government agencies and environmentalists. The fact that investment in tree planting confers strong individual land rights implies that communal land tenure institutions have built-in rules to ensure the intensification of land use in areas where agroforestry has a comparative advantage (Otsuka & Place 2001). Land productivity was thus assumed to be at a maximum here, especially as indicated by the objectives that now occupy old abandoned cropland.

5.2.2 *Value from a theoretical perspective*

Community management of natural resources has assumed renewed importance in the last decade (De Janvry et al 2002) and, substantiated by interactive collaboration and collective action, gives the affected communities a new opportunity to improve their livelihood. A good understanding of communal tenure systems and land use patterns in these tribal lands dominated by subsistence farming was thus vital during this analysis. Both the socio-economic and biophysical appreciation of land resources should be encapsulated in the concept of resource management domains. In this case the collaboration strategies improved the overall quality of decisions, not least through exploration of new opinions, with the potential for win-win settlements. Using MCDA, we may not be able to operationalise ‘sustainable’ as an additional attribute, but we can estimate a) whether one alternative is ‘more sustainable’ than another, and we can know that b) critical levels of certain attributes of an ecosystem (ecological sustainability) or an economy will probably cause irreversible harm (Steward et al. 1997), e.g. in the form of soil erosion. The possibility that exists within MCDA to use ordinal, interval and ratio scale utility measurement, with full recognition of non-linearities, suited the problem at hand well. It increased its discriminatory powers, and improved the ‘trade-off’ capabilities of the approach with respect to land or resource allocation. This was also superbly proven by the ‘dominance’ values as implemented in the MCE using the

AHP approach. This study has therefore adequately demonstrated the successful application of a GIS-based multi-criteria spatial decision-making model to identify the optimally suitable areas for land use most likely to support sustainable development.

5.3 Recommendations

Common property (or un-priced) resources such as land, water, pastures, forest and wetlands have important economic values and are not infinitely substitutable. There needs to be an accounting system to assess depreciation of these natural resources and a mechanism to ensure their sustainable management, otherwise they are likely to be exploited to the point where the system is destroyed (Dalal-Clayton, Dent & Dubois 2003). Yet the effort and cost of data capturing and future monitoring normally rises sharply with increasing resolution. Full use of the available NLC information system must therefore be made, not only to eliminate the need for laborious digitising processes, but also to extend towards sensible rural land use planning. Budget and time constraints also, for the purpose of this study, limited the decision-making group to ten individuals. Ideally, it would be desirable to increase the number of participant (to at least 30) and to have some way of improving the incorporation and consistency of value judgments in future. To add even more value to the allocation process one could add an additional or final step to the research design that aims at maximising future land use potential. This can be achieved by effectively matching all the allocated agricultural and forestry sites with the optimal crop type or tree species available or specie-site matching. Nonetheless, this study had to make certain assumptions with regards to soil suitability or productivity. These have to be replaced with actual field data as soon as it is available, since soil variables play a vital role in both plant growth potential and erosion risk.

It will also make sense to have followed this study results with an impact study of these allocated land uses, particularly in terms of runoff or streamflow analysis. With GIS it is possible to route the movement of water and waterborne materials from the micro-watershed to full watershed to the rivers and downstream entities (Lyon 2001). By doing a full analysis in AVSWAT for instance, it would in fact evaluate whether the allocations made here were indeed optimal and sustainable (if correlated to the national Reserve concept, for example). Future developments in advanced GIS could enhance such land evaluations even further, even making it much more accessible and at a lower cost. The development of the spatial data transfer standard (SDTS) and the increasing availability of ‘open’ GIS toolboxes (such as IDRISI and GRASS[42]) have facilitated the development of tightly coupled GIS modelling systems. It is also acknowledged that farming

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[42] For further information, visit http://www.cecer.army.mil/grass/GRASS.main.html.

systems with high levels of societal and human assets are better able to innovate in the face of uncertainty (Pretty 2002), but further research on suitable forms of agricultural intensification in degraded landscapes should be undertaken. Improved cultivars, irrigation, organic and inorganic fertilization, management of soil acidity, green manure and cover crops in rotations, integrated pest management, double-cropping, and crop rotation (including reduction of bare fallow) are some of the recommended ways to increase crop yields (IPCC 2000). Normal practices like fertilisation and irrigation will however not easily find a place in such poverty stricken rural areas.

In conclusion, an overall appraisal of the work shows that he research achieved what it set out to doas the research aim – it demonstrates that MCE can successfully be applied in GIS to support land allocation decision making in a traditionally settled and degraded rural environment.

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APPENDICES

APPENDIX A: Notes on the Analytical Hierarchy Process
APPENDIX B: NLC land cover classification system
APPENDIX C: Land cover classification of the resource base
APPENDIX D: Conversion from land cover to land use classes
APPENDIX E: Rural development issues and concerns raised
APPENDIX F: Example factor and constraint images
APPENDIX G: Land use, hill slope, and erosion relationships
APPENDIX H: Pair-wise comparison matrixes
APPENDIX I: Technical design of the study
APPENDIX J: Sourced and created data layers and their properties

CHAPTER 6 APPENDIX A: NOTES ON THE ANALYTICAL HIERARCHY PROCESS

Many decision-making techniques attempt to determine the relative importance, or weight, of the objectives (alternatives) in terms of each criterion involved in a given MCDM problem. The AHP method is, according to Malczewski (1999:217-18), based on three principles: i) decomposition, ii) comparative judgement, and iii) synthesis of priorities. First, the AHP decomposes a complex MCDM problem into a system of hierarchies that captures the essential elements of the problem. The principle of comparative judgement requires assessment of pair-wise comparisons of the elements within a given level of the hierarchical structure, with respect to their parent in the next-higher level. The synthesis of priorities principle takes each of the derived ratio-scale local priorities in the various levels of the hierarchy and constructs a composite (global) set of priorities for the elements at the lowest level of the hierarchy, i.e. alternatives. Where comparative judgement is of concern, psychological experiments (Miller, 1956) have shown that the average individual cannot simultaneously compare more than seven objects (plus or minus two). Therefore, the linear scale required to quantify pairwise comparisons as proposed by Saaty (1980) are defined on the interval [9, 1/9], thus the available values for the pairwise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9}. The intensity of importance is reflected by these values, where 9 would imply absolute importance and decreasing downwards to equal importance (1). The highest value implies that the evidence favouring one activity over another is of the highest possible affirmation as opposed to two activities contributing equally to the objective. The reciprocals imply that if activity i has one of the above nonzero numbers assigned to it when compared to activity j, then j has the reciprocal value when compared with i.

After decomposition the AHP involves the processing of pair-wise comparisons to ultimately return the implied relative weights of importance of the compared items. To achieve the last part of the process Saaty's method makes use of eigenvalue theory. It deals with the structure of an m x n matrix (where m is the number of alternatives and n is the number of criteria). The decision matrix is constructed by using the relative importance of the alternatives in terms of each criterion. The vector (a_{i1}, a_{i2}, a_{i3}, …, a_{in}) for each i is the principle eigenvector of a n x n reciprocal matrix which is determined by pairwise comparisons of the impact of the m alternatives on the i-th criterion. The entry a_{ij} represents the relative value of alternative A_i when considering it in terms of a particular criterion. Thus, according to Malczewski (1999:10), where w_j is the weight of importance of the j-th criterion, the best alternative in the AHP maximisation case is indicated by the following:

$$\boxed{A_{AHP-score} = \max_i \sum_{j=1}^{n} a_{ij} w_j \,, \quad for\ i = 1, 2, 3, \ldots, m}$$

To determine the degree of consistency in the pair-wise comparisons, the consistency ratio (CR), which involves the maximum right eigenvalue, is also produced. Saaty indicated that matrices with CR ratings greater than 0.10 should be re-evaluated

Criticism of the AHP includes ‘the rank reversal problem’ (Belton & Gear 1983), problems with the pair-wise comparisons and 1-to-9 scale (Lootsma 1990; Goodwin & Wright 1998; Leskinen & Kangas 1998), and it being cumbersome and time-consuming (Steward et al. 1997). More recently, Leskinen, Kangas & Kangas (2003) argued that, in general, pair-wise comparisons data in ratio scale is more informative in MCDM than ordinal assessments, but the costs of the procedure in the form of time required to reach judgments, for example, could be high. Moreover, the increased amount of work can have negative impacts on the accuracy of ratio scale judgments. This demonstrates that the various theoretical and empirical results indicate that there is no single scale which can always be classified the ‘best’ scale or as the ‘worst’ scale for all cases.

CHAPTER 7 APPENDIX B: NLC LAND COVER CLASSIFICATION SYSTEM

The NLC classification system provides particularly reliable land cover (or use) data at medium to large scales. The National Land Cover 2000 project was jointly co-ordinated by the Council for Scientific and Industrial Research (CSIR) and Agricultural Research Council (ARC). The objective was to produce an up-to-date digital raster (30m pixel size) land-cover map for South Africa, Swaziland and Lesotho. The map extends for 10km into neighbouring Mozambique, Zimbabwe, Botswana and Namibia. The minimum mapping unit (MMU) size is 1ha. The NLC 2000 standardized classification scheme definitions and legend have been used at all times to ensure mapping consistency. Each 1 x 1 degree unit (latitude/longitude) will be independently validated with field data. Mapping was based directly on supplied multi-temporal (two dates) Landsat ETM images. Consistent mapping and proper edge matching will ensure a seamless map.

The Illustrated Field Guide 2000 (Working Document) was used during fieldwork to verify classes found in the watershed/study area. Tabulated below is a highly condensed version of the NLC Field Guide depicting only those land cover classes and descriptions applied in this study. The ‘CODE’ field represents the author’s unique land cover code used during analysis.

CLASS	CODE	CATEGORY	DESCRIPTION
01	Fst	FOREST (INDIGENOUS)	Tree canopy > 70 %. A multi-strata community, with interlocking canopies, composed of canopy, sub-canopy, and shrub & herb layers. Canopy mainly self-supporting, single stemmed, woody plants > 5 metres in height. Essentially indigenous species, natural or semi-natural conditions (may include some areas of self-seeded exotic species). Excludes planted forests (and woodlots).
03	Bsh	THICKET, BUSHLAND, BUSH CLUMPS, HIGH FYNBOS	Tall, woody, self-supporting, single or multi-stemmed plants (branching at or near the ground), with, in most cases no clearly definable structure. Total canopy cover > 10%, with canopy heights between 2 – 5 metres. Essentially indigenous species, natural or semi-natural conditions (may include some areas of self-seeded exotic species, e.g. riparian zones). Presence of alien exotic species can be modelled spatially using broad principles of unlikely structural / temporal occurrences within a given vegetation biome or region. Includes dense bush encroachment.
04	Shb	SHRUBLAND AND LOW FYNBOS	Communities dominated by low, woody, self supporting, multi-stemmed plants, branching at or near the ground, between 0.2 and 2 m in height. Total tree cover < 0.1. Typical examples are low Fynbos, Karoo and Lesotho (alpine) communities.
06	Gna	NATURAL GRASSLAND	Grassland with < 10% tree and/or shrub canopy cover, and >0.1% total vegetation cover. Dominated by grass-like, non-woody, rooted herbaceous plants. Essentially indigenous species, natural or semi-natural conditions.
08	Feu	FOREST PLANTATIONS: (EUCALYPTUS SPP)	Systematically planted, man-managed tree resources, composed of primarily exotic species (including hybrids). Includes both young & mature plantations established for commercial timber production, seedling trials and woodlot / windbreaks of sufficient size to be identifiable on satellite imagery. Excludes all NTFP's e.g. tea, sisal, citrus, nut crops etc.
09	Fpi	FOREST PLANTATIONS: (PINE SPP)	
10	Fac	FOREST PLANTATIONS: (ACACIA SPP)	
11	Fmx	FOREST PLANTATIONS: (OTHER/MIXED SPP)	
12	Fcf	FOREST PLANTATIONS: (CLEARFELLED)	
13	Wat	WATER BODIES	Areas of (generally permanent) open water. Includes both natural & man-made water bodies, which are either static or flowing, and fresh, brackish and salt water conditions, rivers, major reservoirs, farm-level irrigation dams, permanent pans, lakes & lagoons.
14	Wet	WETLANDS	Natural or artificial areas where the water level is permanently or temporarily at (or very near) the land surface, typically covered in either herbaceous or woody vegetation cover. Includes fresh, brackish & salt-water conditions. E.g. pans (with non-permanent water cover), & reed-marsh or papyrus-swamp.
15	Rck	BARE ROCK AND SOIL (NATURAL)	Natural areas of exposed sand, soil or rock with no, or very little vegetation cover during any time of the year, (excluding agricultural fields with no crop cover, and open cast mines and quarries). E.g. rock outcrops, beach sand, & dry riverbed material.
16	Rdg	BARE ROCK AND SOIL (EROSION : DONGAS / GULLIES)	Non-vegetated areas (or areas of very little vegetation cover in comparison to the surrounding natural vegetation) that are primarily the result of current gully erosion processes. Typically located in association with areas of poor grassland cover along existing streamlines and / or on slightly steeper slopes than sheet erosion areas (i.e. greater than 6 degree slope). In some areas the full extent of donga activity may be obscured by either overhanging adjacent bushes, encroaching thorn bush, or, in the case of more stable dongas, by bush or grass cover along the actual streamline.
17	Rsh	BARE ROCK AND SOIL (EROSION : SHEET)	Non-vegetated areas (or areas of very little vegetation cover in comparison to the surrounding natural vegetation), that are primarily the result of current sheet erosion processes. Associated with areas of severe donga erosion and / or poor grassland cover (i.e. low image NDVI rating). In some areas the full extent of this process may be obscured by encroaching bush. Typically located on slopes ≥ 6 degrees.
22	Dgn	DEGRADED NATURAL GRASSLAND	Permanent or near permanent, man-induced areas of very low vegetation cover (i.e. removal of tree, bush, or herbaceous cover) in comparison to the surrounding natural vegetation cover. Associated with subsistence level agriculture and rural population centres, where overgrazing of livestock and / or wood-resource removal has been locally excessive. Often associated with severe soil erosion problems.

CLASS	CODE	CATEGORY	DESCRIPTION
24	Cpd	CULTIVATED, PERMANENT, COMMERCIAL, DRYLAND	Land ploughed and / or prepared for raising crops (excluding timber production). Unless otherwise stated, includes areas currently under crop, fallow land & land being prepared for planting. Class boundaries are broadly defined to encompass the main areas of agricultural activity, and are not defined on exact field boundaries. As such all sub-classes may include small inter-field cover types (e.g. hedges, grass strips, small windbreaks), as well as farm infrastructure. Several sub-classes are defined, based on the following parameters: **Commercial**: characterised by large, uniform, well-managed field units (i.e. ± 50 ha), with the aim of supplying both regional, national and export markets. Often highly mechanised. **Semi-Commercial**: characterised by small - medium sized field units (i.e. ± 10 ha), within an intensively cultivated site, often in close proximity to rural population centres. Typically based on multi-cropping activities where annual (i.e. temporary crops) are produced for local markets. Can be irrigated by either mechanical means or gravity-fed channels and furrows. Medium - low levels of mechanisation. **Subsistence**: characterised by numerous small field units (less than ± 10 ha) in close proximity to rural population centres. Field units can either be grouped either intensive or widely spaced, depending on the extent of the area under cultivation and the proximity to rural dwellings and grazing areas. Includes both rain fed and irrigated (i.e. mechanical or gravity-fed), multi-cropping of annuals, for either individual or local (i.e. village) markets. May include fallow and 'old fields', and some inter-field grazing areas (which are often classified as degraded). **Permanent Crops**: lands cultivated with crops that occupy the area for long periods and are not re-planted after harvest. Examples would include sugar cane and citrus orchards. Note in the case of sugar cane, the growing season is typically 15 - 18 months per ratoon (i.e. harvest), with 2 - 3 ratoons possible before re-planting. Sugar cane is mapped as a separate crop type, and includes both large and small-scale commercial activities, as well as fallow (i.e. burnt / cleared) areas. **Temporary Crops**: land under temporary crops (i.e. annuals) that are harvested at the completion of the growing season, and that will remain idle until re-planted. In general this refers to maize and soya bean cultivation within the Pongola catchment, although cotton is locally dominant amongst the larger commercial sugar cane plantation areas. **Irrigated / Non-Irrigated**: major irrigation schemes (i.e. areas supplied with water for agricultural purposes by means of pipes, overhead sprinklers, ditches or streams), and are often characterized.
26	Cti	CULTIVATED, TEMPORARY, COMMERCIAL, IRRIGATED	
27	Ctd	CULTIVATED, TEMPORARY, COMMERCIAL, DRYLAND	
28	Csi	CULTIVATED, TEMPORARY, SUBSISTENCE, DRYLAND	

CLASS	CODE	CATEGORY	DESCRIPTION
30	Urb	URBAN / BUILT-UP (RESIDENTIAL)	A generic urban class, essentially comprising all formal built-up areas, in which people reside on a permanent or near-permanent basis, identifiable by the high density of residential and associated infrastructure. Includes both towns, villages, and where applicable, the central nucleus of more open, rural clusters. This class should be used if it is not possible to identify more industrial and transportation land-uses. Low-density smallholdings frequently located on the urban / peri-urban fringe should be mapped as a separate smallholding sub-class, subdivided by the appropriate (level I) background vegetation type. If visible, individual farm units are to be mapped as isolated urban / built-up units (if no other class is applicable). Specific urban / built-up sub-classes as listed below – in such cases it could include residential, or commercial areas.
31	Urc	URBAN / BUILT-UP (RURAL CLUSTER)	Areas of clustered rural dwellings whose structural density is too low to be classified as a formal village, but are of sufficient level to be easily identifiable as such on satellite imagery. Small scale cultivation / garden plots often form a major spatial component, and are located amongst the residential structures.
43	Ucm	URBAN/ BUILT-UP (COMMERCIAL, MERCANTILE)	Non-residential areas used primarily for the conduct of commerce and other mercantile business, typically located in the central business district (CBD). Often consisting of a concentration of multi-level buildings, but also includes small commercial zones (i.e. spaza shops) within former black townships.
44	Uce	URBAN/ BUILT-UP (COMMERCIAL, EDUCATION, HEALTH, IT)	Non-residential, non-industrial sites or complexes associated with educational (i.e. schools, universities), business development centres such as industrial ‘techno-parks’, and / or social services (i.e. hospitals), often consisting of a concentration of multi-level buildings (Note: only mapped if clearly identifiable, otherwise included within ‘commercial / mercantile’ or ‘suburban’ category.
46	Uil	URBAN/ BUILT-UP (INDUSTRIAL/ TRANSPORT: LIGHT)	Non-residential areas with major technology, manufacturing or transport related infrastructure. Examples would include light manufacturing units, warehouse dominated business development centres, and small airports (i.e. Lanseria). Also includes similar structures such as farm-based pig and battery hen breeding units.
48	Msu	MINES & QUARRIES (SURFACE-BASED MINING)	Active or non-active surface-based mining activities, both hard rock or sand quarry extraction sites & opencast mining sites i.e. coal. Includes all associated surface infrastructure.

APPENDIX C: LAND COVER CLASSIFICATION OF THE RESOURCE BASE

Land cover had to be related to the unique nature of the study area in terms of land tenure and land use patterns. One should therefore not confuse the terms ‘land cover’ with ‘land use’. Land cover is the observed physical and biological cover of the earth’s land, as vegetation or man-made features (FAO 1997). In contrast, land use is the total of arrangements, activities, and inputs that people undertake in a certain land cover type (FAO/UNEP 1999). Features classified as natural grassland could for example be associated with various uses, e.g. sports fields, seldom used kraals, remote gravesites, or open sites clearly destined (marked out) for newly planned settlement. Since working with grey-scale images derived from low-altitude aerial photographs, several methods were applied to aid interpretation of the land cover features found in the images for classification purposes. These elements of interpretation supplied information on features that are basically independent assessments of each characteristic. These elements may include characteristics such as: tone, shape, size, texture, pattern, shadow, and associations (Lyon 2001). Rock, bare (eroded or ploughed) soil, road surfaces and the like often appear light-toned. Conversely, vegetation is normally relatively dark-toned due to the low relative reflectance of green plant material compared to bare soil or rock. Therefore the relative ease with which planted and unplanted cropland could be separated. Even between vegetation types themselves, one can use tone to distinguish say, between two commercial tree species with different branching behaviour (e.g. pine stands would appear slightly darker than gum stands). Where shape refers to the exterior configuration of materials or features, size relates to the absolute or relative dimensions of the object or feature. In this case the applicability of these two elements in classifying the subsistence type farming found here is easy to grasp. A faint variation in tone and colour caused by a mixture of materials on a given site reflects its texture. This allows one to distinguish between shrubs and grassland for example. Pattern, on the other hand, is the regular or irregular distribution of relatively large features on the earth’s surface. This element was very useful in wetland landscape characterisation, for instance. Shadows may help identify a feature as to its type by providing additional or important shape and size information, but can obscure (hide) detail too. Fortunately the quality of the images used here was enhanced through atmospheric correction. As for the last element of interpretation, the ‘association’ of a feature is the other characteristic or clue that is found together (in association) with the feature of interest. For example, a stream could be identified by its shape easily, but many associations with it can be found, which may include bridges, floodplains and sandbanks at the waters edge, streamside vegetation, branching behaviour, places of low relative elevation, and the like. Figure C shows the resulting land cover map.

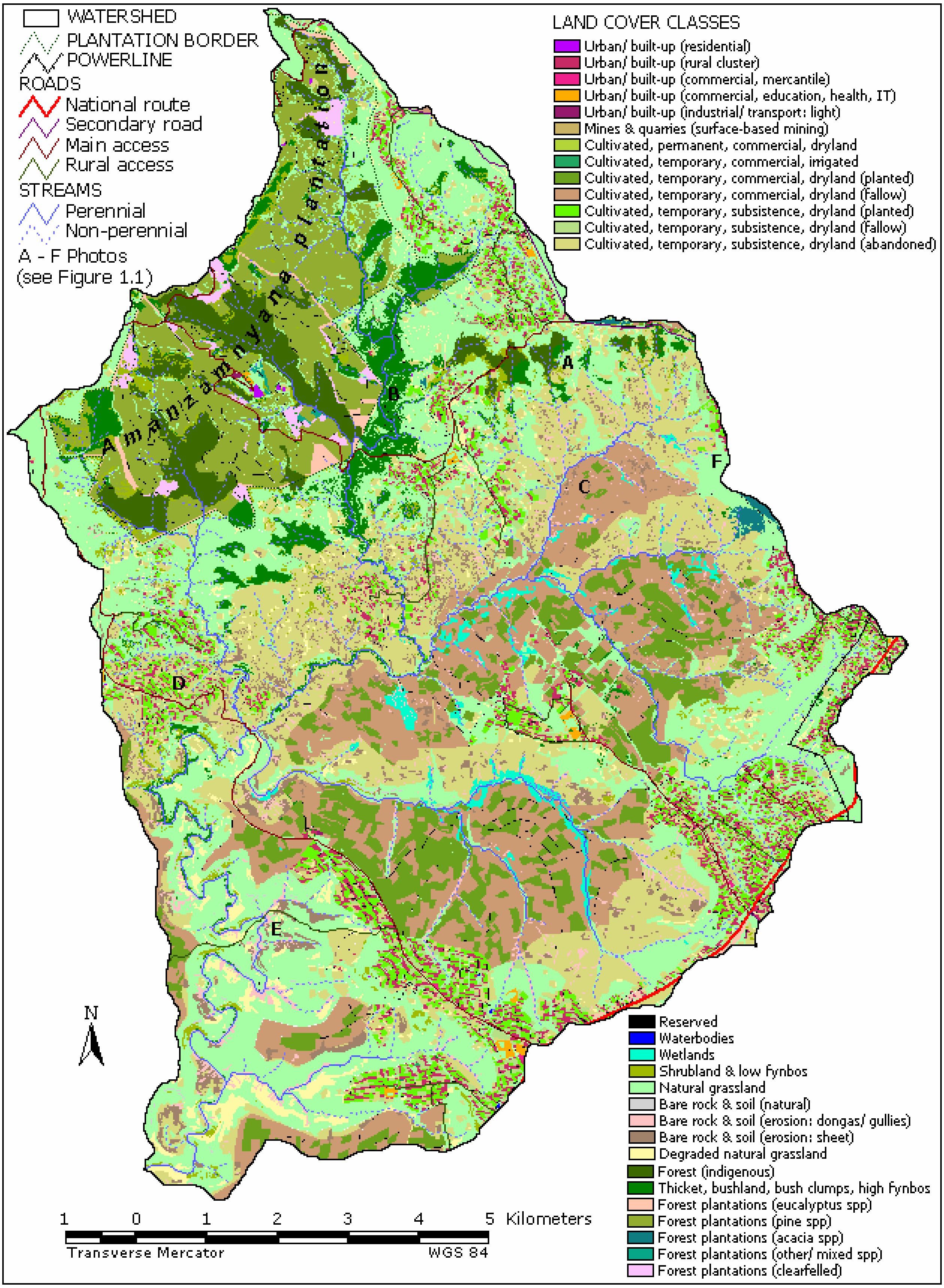

Figure C: Land cover map of micro-catchment

For orientation purposes other important infrastructure and features are overlaid. For the sake of interest, the letters A to F on the map indicates the location of the landscape scenes depicted in Figure 1.1 earlier in this document.

From a normal resource management point of view, forests were noted as either indigenous or mixed. A significant number of important and useful indigenous trees, in terms of timber, medicinal or cultural value, were in fact identified and recorded in the process. Mixed means the forest is partly infested, usually at the fringes, by a variety of exotic invader trees, such as *Eucalyptus* spp. To aid the classification of the plantation forests (as land cover units) in terms of species composition, clearfelled compartments, and other uses, the obtained Amanzamnyama plantation data was utilised. In addition, and this applied to all classes, any land cover unit found within the plantation border was flagged as being part thereof. Other smaller gum and wattle plantings were also encountered elsewhere in the area though, and classified accordingly. The bushland sub-classes were equally specific, particularly with regards to wattle infestations (indigenous; indigenous+ wattle; wattle only; mix; unknown). Although such wooded areas could perhaps have been classified as woodland in a few cases, the bushland class definition was found more applicable for the purpose of this study since these wattle and mixed bush could play a significant role in the future forestry objectives. Hedges, small windrows and all other similar small clumps of trees/bush and single large trees (related to human activity) were noted as being planted (as opposed to naturally dispersed). Cases where newly planned settlements were to occupy bushland areas to some extent were recorded as such, but remained classified as bushland.

The status of all wetlands encountered was classified as being in fine condition to drained and/ or severely degraded. Hugo (2004:255) defines wetlands as “areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support an abundance of vegetation typically adapted for life in saturated soil conditions”. Wetlands were detected by visits to the field, from aerial photographs or from satellite remote sensing imagery or other techniques. Interpreting imagery from black and white aerial photographs in the most sophisticated of applications, the author used not only the tone or colour in the photograph, but also landscape position, land slope, the appearance of vegetation, and local knowledge to distinguish wetland from uplands. Nonetheless, a wetland inventory should be done in a manner that matches the needs of the community, and the financial and human resources that are available. Other water bodies such as small man-made dams or natural pools were documented as such. All exposed rock and soil in drainage lines were noted as floodplains, to distinguish it from other rock features, natural (e.g. ridges/ cliffs) and man-made (e.g. rock piles next to cropland). Where built-up areas (mainly rural clusters) were concerned, records were made of all schools (primary and secondary), as well as the exact CBD of Mount Frere (to include the marketplace, health and welfare concerns, and police presence). Municipal water reservoirs and urban graveyards were added to the urban class.

Since the micro-catchment lies in the Grassland Biome, particular note was made of the status of the *grassveld*[43]. Erosion features over the entire watershed were carefully recorded as such. Where sheet and donga[44] erosion was visible in the landscape, the researcher attempted to capture the likely cause(s) thereof (e.g. natural, harmful agricultural techniques, overgrazing, sod removal, and old tracks), as well as its severity. Features classified as natural grassland, but noted for its use or cultural value, included sports fields, seldom used kraals, and remote gravesites. This category also included sites currently zoned under a built-up class, but which are still open veld, or sites clearly destined (marked out) for newly planned settlements. In fact, no sports field was of the improved grassland type as often found; rather, in many cases they could have easily been classified as degraded, but was not. This action ensures their retention and makes them unavailable for other uses associated with open veld, in this case sport (usually soccer). Features classified as degraded grassland included often used kraals, timber tracks, old contouring lines, places where soil sods are mined (for hut building), as well as overgrazed to severely overgrazed veld. Land previously part of some sort of household or settlement, but which has since been abandoned, was classified as degraded veld. The firebelts surrounding the Amanzamnyama plantation (about 25 hectares in total), viz. strips of land cleared of most of its vegetation cover, was also viewed as being degraded.

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[43] Veld (or veldt) is a local generic term for shrubby grassland.

[44] Gullies are locally known as donga's, thus it refers to gullying.

APPENDIX D: CONVERSION FROM LAND COVER TO LAND USE CLASSES

#	National Land Cover Description	Area (Ha)	%		Land Use	LU-Class	Total (Ha)	%
1	Water bodies	0.8	0.01	⇨	WATER BODIES & WETLAND	1	107.2	0.9
2	Wetlands	106.4	0.91					
3	Forest (indigenous)	414.0	3.53	⇨	INDIGENOUS FOREST	2	414.0	3.5
4	Thicket, bushland, bush clumps, high fynbos	473.4	4.04	⇨	BUSHLAND	3	473.4	4.0
5	Urban/ built-up (residential)	3.6	0.03	⇨	BUILT-UP & ROADS	4	549.5	4.7
6	Urban/ built-up (rural cluster)	401.2	3.42					
7	Urban/ built-up (commercial, mercantile)	1.6	0.01					
8	URBAN/ BUILT-UP (COMMERCIAL, EDUCATION, HEALTH, IT)	19.9	0.17					
9	Urban/ built-up (industrial/ transport: light)	2.5	0.02					
10	Mines & quarries (surface-based mining)	2.6	0.02					
11	*Reserved*[*]	*118.1*	*1.01*					
12	Forest plantations (eucalyptus spp)	61	0.52	⇨	PLANTATION	5	970.1	8.0
13	Forest plantations (pine spp)	813.3	6.94					
14	Forest plantations (acacia spp)	23.2	0.20					
15	Forest plantations (other/ mixed spp)	5.3	0.05					
16	Forest plantations (clearfelled)	67.3	0.57					
17	Cultivated, permanent, commercial, dryland	0.5	0.00	⇨	PRODUCTIVE CROPLAND (DRYLAND)	6	2874.3	24.5
18	Cultivated, temporary, commercial, irrigated	0.3	0.00					
19	Cultivated, temporary, commercial, dryland (planted)[**]	748.2	6.38					
20	*Cultivated, temporary, commercial, dryland (fallow)*[*]	*1408.1*	*12.00*					
21	Cultivated, temporary, subsistence, dryland (planted)[**]	439.8	3.75					
22	*Cultivated, temporary, subsistence, dryland (fallow)*[*]	*277.4*	*2.37*					
23	*Cultivated, temporary, subsistence, dryland (abandoned)*[*]	*1859.5*	*15.90*	⇨	OLD CROPLAND	7	1859.5	15.9
24	Shrubland & low fynbos	231.4	1.97	⇨	PASTURE / GRASSLAND	8	4470.9	38.2
25	Natural grassland	3379.5	28.80					
26	Bare rock & soil (natural)	99.9	0.85					
27	Bare rock & soil (erosion: dongas/ gullies)	169	1.44					
28	Bare rock & soil (erosion: sheet)	283.1	2.42					
29	Degraded natural grassland	308	2.63					
	TOTAL:	**11718.8**	**100**				**11718.8**	**100**

[*] Added land cover classes; [**] Refined land cover classes

APPENDIX E: RURAL DEVELOPMENT ISSUES AND CONCERNS RAISED

Local Issues and Concerns	Source		
	Communities	Officials	Planners
ECONOMIC: Inefficient road infrastructure	✓	✓	✓
Irresolute relationship between timber companies and small scale growers	✓	✓	✓
Complex or ineffective development policies and administration	✓		✓
Long distance to pension payout points	✓	✓	
More black economic empowerment	✓	✓	✓
High cost of basic goods and commodities	✓		
High cost of education	✓		
Lack of proper, affordable housing	✓	✓	
Lack of work and income (poverty)	✓	✓	✓
Low quality livestock	✓		
Limited access to financial instruments	✓		✓
Limited access to technology	✓		✓
Nepotism	✓	✓	
Poor quality seed and crops	✓		
Proper sharing of benefits within the community (access to land, funds and profits)	✓		✓
Stock theft	✓		
ENVIRONMENTAL: **Lack of woody vegetation and forests**	✓		✓
Low soil potential and loss of topsoil (erosion)	✓	✓	
Negative effects of drought **and fires**	✓		
Shortage and poor quality rangeland (pasture)	✓		
Shortage and poor quality of domestic water	✓	✓	
SOCIAL: **Health and welfare problems**	✓	✓	✓
Illiteracy among grownups	✓	✓	✓
Lack of basic services and delivery	✓	✓	✓
Lack of public transport (children and older people in particular)	✓		
Lack of females in decision-making	✓	✓	✓
Poor condition of educational facilities	✓	✓	
Time spent to gather water and firewood	✓		
Uncertain security of tenure	✓	✓	✓

Note: In modelling, only the bold printed items were selected for direct or indirect representation.

APPENDIX F: EXAMPLE FACTOR AND CONSTRAINT IMAGES

When the surface features were captured and manipulated, together with some of the sourced data, the mapping extent was set at approximately one kilometre from the initial anticipated watershed boundary, except to the east where it was extended to almost two kilometres (refer to Figure 1.4). This was done for specific reasons. Other than for mainly saving on digitising effort (time), it was also meant to include Mount Frere for orientation purposes and spatial relevance *viz.* the possible role of the town’s infrastructure (post office, marketplace, school, etc.) in the envisioned decision-making process. Additionally, more reliable results are returned after analysis. This is particularly true where surface interpolation methods from point data are involved, as in this study. For instance, creating a continuous surface from points containing altitude or mean annual precipitation (MAP) values, it naturally follows that the more points are included, the better the simulation. Similarly, the exclusion of a single point may yield unreliable results in a different way later. For instance if a future decision criterion happens to be a distance related factor, e.g. kilometres from a school, the ‘sphere of influence’ (or correlation with future land use objectives) of an excluded school located just outside the study area perimeter is ignored in spite of its close proximity. It follows that this slightly larger extent was then ‘cut’ with the actual (smaller) calculated study area extent as shown by the example factor images in Figure F.

Figure F(i) shows the climatic factor, i.e. suitability in terms of MAP for forestry and agriculture. Positively correlated with both land uses, it implied that for good plant growth higher annual precipitation was more desirable and rated higher accordingly. As for topographical factors, these two land uses, as well as buildings, avoided areas with higher slope values as far as possible. Figure F(ii) illustrates this as it applied to the forestry objective. Accessing suitability in terms of aspect is shown in Figure F(iii) as related to the agriculture and built-up objectives. Both were positively correlated to maximise exposure to sunlight, thus favouring north-facing slopes most. The same suitability shown here, but in reverse order, would describe aspect’s negative correlation with the forestry objective as argued. Curvature described the physical characteristics of the micro-catchment in more detail in terms of surface steepness. In Figure F(iv), its effect on soil suitability for crop and tree planting, as well as building activities, is clear seeing that steeply curved areas (often erosion prone or biologically diverse) were effectively excluded or awarded the lowest suitability rating. Alternatively, the flatter, less curved sections in the micro-catchment were associated with better soil development and subsequently rated much higher. Yet, in the case of agriculture for example, land types associated with Mispah or Glenrosa soil forms (thin soil layer on a rocky substrate) were rated medium, even on flat terrain.

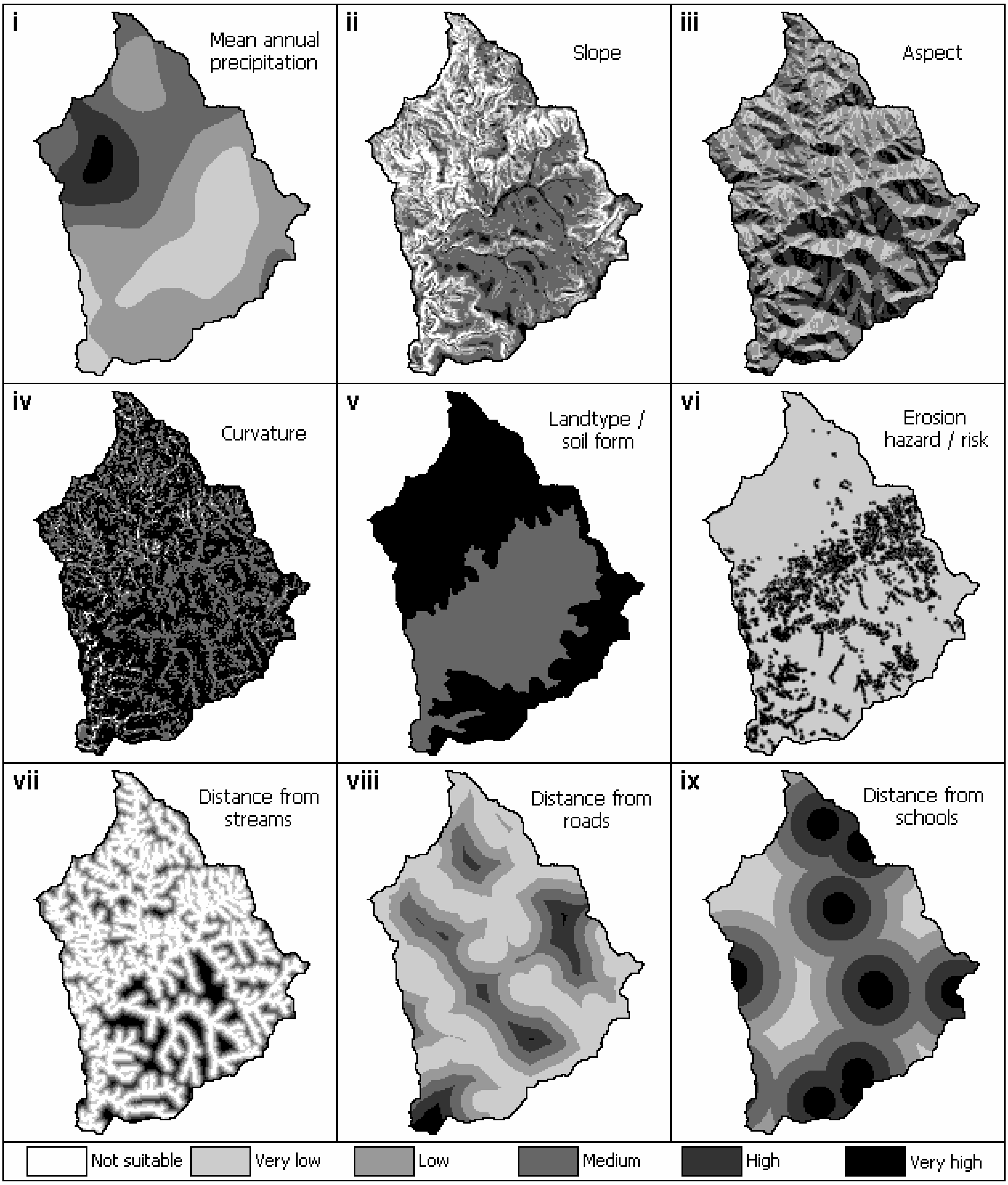

Figure F i-ix: Selection of suitability maps as derived from various factors

Figure F(v) shows this in the central part of the study area, though the surrounding part (generally associated with the red-yellow apedal, freely drained soils) was completely suitable. The rest of the images relates to a few distance factors. As illustrated in Figure F(vi), areas of high erosion risk were effectively protected for conservation efforts by being negatively correlated with the distance to erosion hazards. The inverse will apply to those land uses that could aggravate these environmental degradation processes. Buffering watercourses against the same land uses also made sense in this regard. Suitability as influenced by the distance to rivers in the case of forestry (a positive correlation) can be seen in Figure F(vii). The distance to selected roads in the case of communal use was positively correlated as shown in Figure F(viii) and consolidated rangeland in the more remote parts of the study area as planned. The inverse (negatively correlated) will apply to crop and tree cultivation, as well as built-up land. Supporting this trend, the built-up objective was negatively correlated with distance to schools. Since most of the larger rural clusters contain some sort of official educational facility, this ensured the development of existing nodes and small travelling distances for schoolgoing children, as illustrated by Figure F(ix).

APPENDIX G: LAND USE, HILL SLOPE, AND EROSION RELATIONSHIPS

The interaction between land use, erosion processes, and slope components becomes clearer when comparing frames A-B in Figure G.

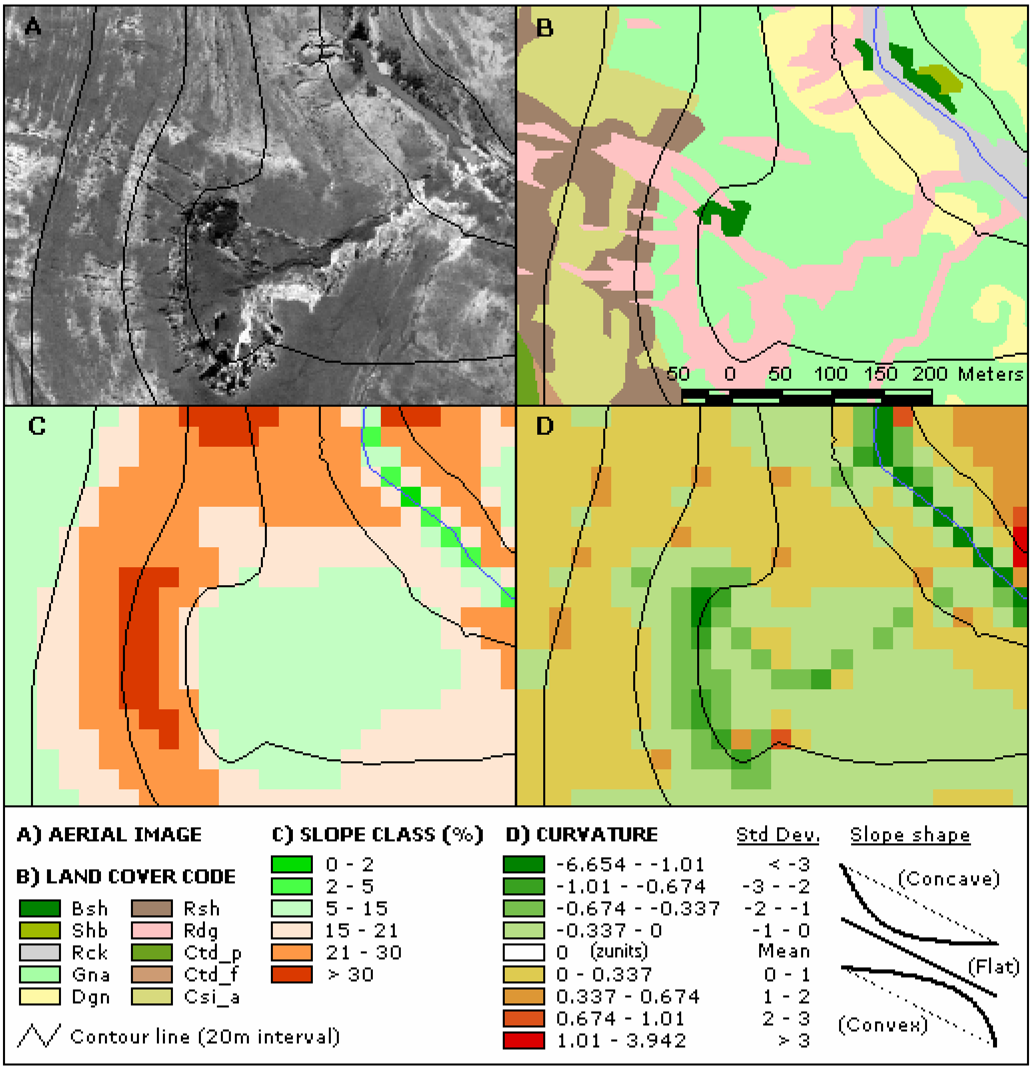

Figure G: The relationships between land cover/ use, erosion, and hill slope

Contour lines at 20m intervals are overlaid to aid the interpretation of the area shown. Frame A contains an aerial (photo-image) viewpoint of a small section in the micro-catchment that effectively displays most of the concepts involved and correlations in this case. Frame B indicates the land cover (or codes; see Appendix B) of the very same location. Frames C and D show the matching (standardised) factor images representing the slope classes and curvature classes, respectively. The slope shape diagrams that correspond with the curvature classes were added for additional clarity. Prominent are the large permanently incised gully and its central deposition zone in the middle of the area, the abandoned cropland on the left with signs of severe sheet erosion, and donga formations below it. The landscape was more than likely a marshy area before, but has been much altered since then. The duplex soil behaviour is clearly visible in the main central drainage/erosion channel. Permanent, incised gullies form in concentrated flow areas by headcuts advancing upstream. In addition, permanent incised gullies are eroded by laterally retreating sidewalls where the process is cyclical. Erosion in such permanent, incised gullies is episodic, varying from year to year. Runoff is least on the steep concave slope, where vegetation could at times re-establish itself. For example, vegetation got established on the slumped material in the large central gully, protecting this material from removal by flow. The weight of the slumped soil stabilises the base of the sidewall, preventing further slumping into the gully. High flow from an infrequent but high-magnitude runoff event can breach the protection provided by the vegetation at the base of the gully sidewall, remove the slumped soil, and destabilise the gully sidewall once again. The gully is now susceptible to erosion by much smaller runoff events than would have been the case had the highly erosive, destabilising runoff event not occurred. It follows that if slope steepness increases, the increase in erosion is linear with the increase in steepness (Hudson 1995). Thus a uniform slope, such as represented by the old cropland high up on the western slope in Figure G, loses more soil than a concave slope but less than a convex slope. The reason is that the greatest volume and velocity of the runoff that occurs at the bottom of the slope, operates on the steepest part of the convex slope but on the flattest part of the concave slope. The headcuts and the sidewalls of the large permanently incised gully, as well as the other erosion and sediment deposition processes, correlate with the slope and curvature classes.

Deposition occurs on a slope where the amount of sediment available for transport becomes greater than transport capacity (Terrence, Foster & Renard 2002). Sediment available for transport at a location on a slope is related to the amount of sediment produced by erosion on the upper part of the slope. If the steepness of a concave slope is sufficiently flat at the lower end as in this scene, much deposition can occur, which at times greatly reduces sediment delivery at the end of the slope. If however this is not the case and the slope is more uniformly convex as on the upper western part of the hillside, runoff is greater (aided by overgrazing), dongas are more prone to develop, and sedimentation loads could be large, particularly following an intense destabilising runoff event. Moreover, at the point where the large permanent gully joins the stream, the lighter water discoloration indicates the amount of sediment deposition (stream-flow is from top-to-bottom). The high erosion risk explains why it was rated as being of only medium suitability for communal use (grazing), for example. These findings therefore influenced the distance classes to erosion hazards and wetlands factors.

APPENDIX H: PAIR-WISE COMPARISON MATRICES

CONSERVATION FACTORS	**1**	**2**	**3**	**4**	**5**	**Weight**
1) Land use retention	1					0.4551
2) Distance to wetland	1/2	1				0.2632
3) Proximity to erosion hazards	1/4	1/2	1			0.1601
4) Curvature	1/5	1/4	1/3	1		0.0742
5) Land type / Soil form	1/7	1/5	1/4	1/2	1	0.0474
Consistency ratio = 0.02						1.000

FORESTRY FACTORS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**Weight**
1) Land use retention	1												0.2391
2) Distance to wetland	1/2	1											0.1733
3) Proximity to erosion hazards	1/3	1/2	1										0.1560
4) Distance to rivers	1/3	1/2	1/2	1									0.1189
5) Mean annual precipitation	1/4	1/3	1/3	1/2	1								0.0841
6) Curvature	1/4	1/3	1/4	1/3	1/2	1							0.0626
7) Slope	1/5	1/4	1/5	1/4	1/3	1/2	1						0.0480
8) Aspect	1/6	1/5	1/5	1/4	1/3	1/2	1/2	1					0.0396
9) Land type / Soil form	1/7	1/6	1/6	1/5	1/4	1/3	1/3	1/2	1				0.0282
10) Distance to roads	1/7	1/7	1/6	1/6	1/5	1/4	1/3	1/3	1/2	1			0.0213
11) Distance to plantation & bush	1/8	1/8	1/7	1/6	1/5	1/5	1/4	1/4	1/3	1/2	1		0.0161
12) Proximity to forestry office	1/9	1/8	1/7	1/7	1/6	1/6	1/5	1/5	1/4	1/3	1/2	1	0.0128
Consistency ratio = 0.05													1.000

COMMUNAL USE FACTORS	**1**	**2**	**3**	**4**	**5**	**6**	**Weight**
1) Proximity to old cropland	1						0.4028
2) Slope	1/2	1					0.2719
3) Curvature	1/3	1/2	1				0.1579
4) Distance to built-up areas	1/5	1/4	1/2	1			0.0839
5) Distance to roads	1/7	1/6	1/4	1/2	1		0.0494
6) Land type / Soil form	1/8	1/7	1/5	1/3	1/2	1	0.0340
Consistency ratio = 0.02							1.000

AGRICULTURE FACTORS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Weight**
1) Distance to wetland	1											0.2737
2) Proximity to erosion hazards	1/2	1										0.1996
3) Land use retention	1/3	1/2	1									0.1458
4) Slope	1/4	1/3	1/2	1								0.1020
5) Curvature	1/5	1/4	1/3	1/2	1							0.0821
6) Mean annual precipitation	1/5	1/4	1/3	1/2	1/2	1						0.0617
7) Aspect	1/6	1/5	1/4	1/3	1/3	1/2	1					0.0421
8) Land type / Soil form	1/7	1/6	1/5	1/4	1/4	1/3	1/2	1				0.0335
9) Proximity to productive cropland	1/7	1/6	1/6	1/5	1/4	1/3	1/2	1/2	1			0.0261
10) Distance to roads	1/8	1/7	1/7	1/6	1/5	1/4	1/3	1/3	1/2	1		0.0188
11) Proximity to CBD/ Marketplace	1/9	1/8	1/7	1/6	1/6	1/5	1/4	1/4	1/3	1/2	1	0.0147
Consistency ratio = 0.04												1.000

BUILT-UP FACTORS	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Weight**
1) Land use retention	1											0.2504
2) Distance to wetland	1/2	1										0.1926
3) Proximity to erosion hazards	1/2	1/2	1									0.1541
4) Distance to schools	1/3	1/3	1/2	1								0.1120
5) Distance to built-up areas	1/4	1/3	1/3	1/2	1							0.0812
6) Slope	1/5	1/3	1/3	1/3	1/2	1						0.0650
7) Distance to roads	1/6	1/4	1/4	1/3	1/2	1/2	1					0.0479
8) Aspect	1/6	1/5	1/5	1/4	1/3	1/3	1/2	1				0.0361
9) Curvature	1/7	1/5	1/6	1/5	1/4	1/4	1/3	1/2	1			0.0256
10) Land type / Soil form	1/8	1/6	1/6	1/5	1/5	1/4	1/3	1/3		1		0.0198
11) Proximity to CBD/ Marketplace	1/9	1/7	1/7	1/6	1/6	1/5	1/4	1/4	1/3	1/2	1	0.0153
Consistency ratio = 0.04												1.000

APPENDIX I: TECHNICAL DESIGN OF THE STUDY

The procedures of this study are illustrated by means of the flow diagram in Figure I. For more information on each image shown, one can match each image by name in Appendix J, which list all these and other sourced data sets used or created in this study. Whereas the MCE and MOLA processes were executed in IDRISI (14.2), most of the preparation and manipulation of data were performed in ArcView (3.x) and its associated extensions.

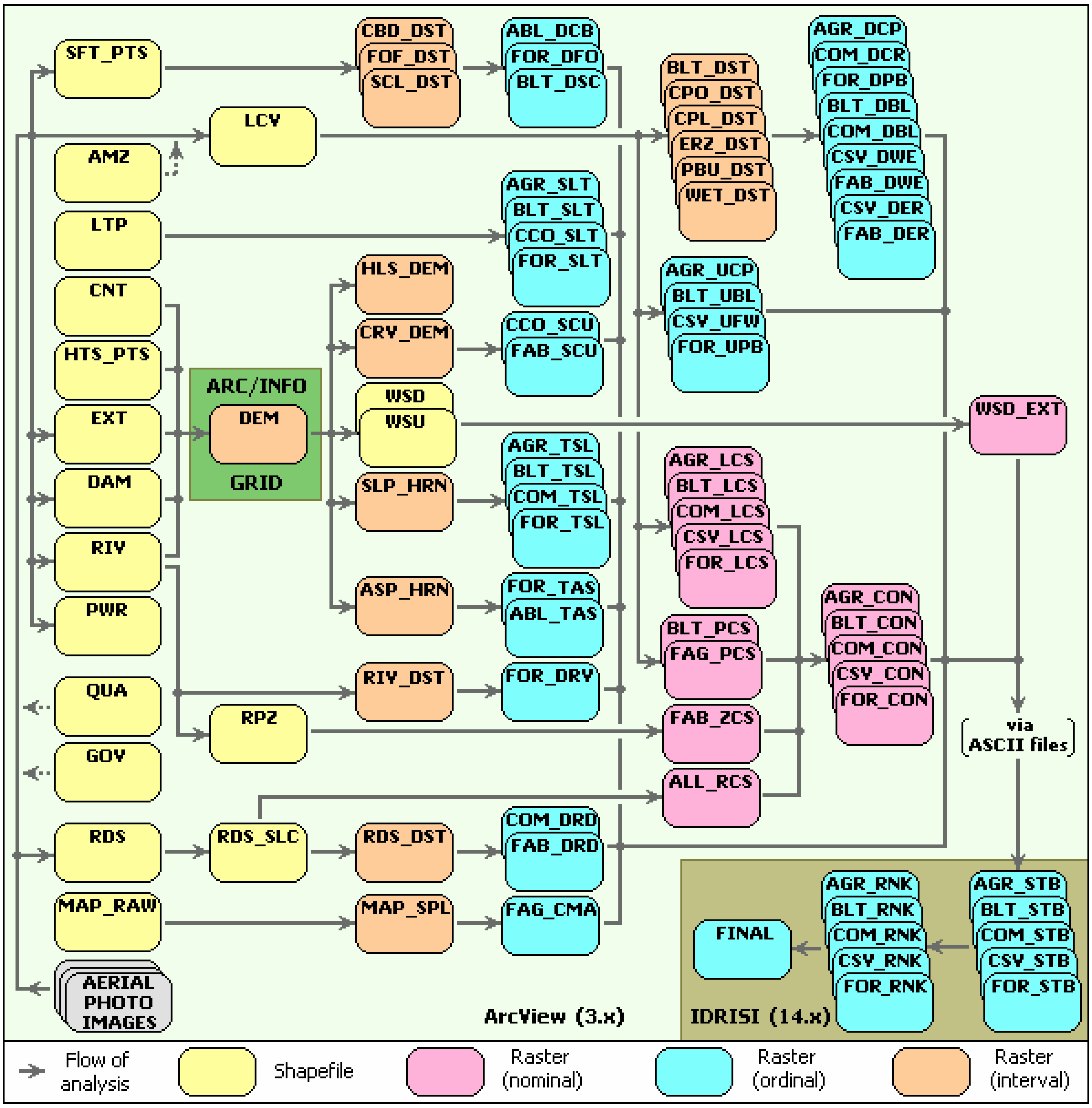

Figure I: The technical design of the study

APPENDIX J: SOURCED AND CREATED DATA LAYERS AND THEIR PROPERTIES

PAGE	IMAGE NAME	TYPE	DESCRIPTION	CATEGORIES/ CLASSES/ VALUES	SOURCE
74	ABL_DCB	Raster	Standardised suitability for agriculture & built-up in terms of distance to the CBD	2, 3, 4, 5	Manipulated point data
70	ABL_TAS	Raster	Standardised suitability for agriculture & built-up in terms of aspect	1, 2, 3, 4, 5	Derived from DEM
67	AGR_CON	Raster	Merged constraints for agriculture	0, 1	Manipulated spatial data
74	AGR_DCP	Raster	Standardised suitability for agriculture in terms of distance to productive cropland	1, 2, 3, 4, 5	Manipulated land cover data
67	AGR_LCS	Raster	Standardised land use constraint image for agriculture	0, 1	Manipulated land cover data
82	AGR_RNK	Raster	Standardised/ Ranked suitability image for agriculture	Calculated interval values	Single-objective suitability images
73	AGR_SLT	Raster	Standardised suitability for agriculture in terms of land type	3, 5	Manipulated land type data
79	AGR_STB	Raster	Suitability image for agriculture	0, 1, 2, 3, 4, 5	Standardised criteria images
70	AGR_TSL	Raster	Standardised suitability for agriculture in terms of slope	0, 2, 3, 4, 5	Derived from DEM
67	AGR_UCP	Raster	Standardised land use retention image for agriculture	0, 5	Manipulated land cover data
27	ALL_RCS	Raster	All road (buffer) surface cells	0, 1	Manipulated roads data
14	AMZ	Polygon	Amanzamnyama plantation	– Layer – Feature > Indigenous forest > Compartment ID – Species > Pinus spp > *Eucalyptus fastigata* > *Eucalyptus grandis* > Other/Mixed– Status > Planted > Temporary unplanted > Clearfelled > Open	Fractal Forest Africa
14	AERIAL PHOTO IMAGES	Digital	Scanned black & white aerial photographs	Real world	Fractal Forest Africa
65	ASP_HRN	Raster	Aspect image	Calculated interval measurements (Degrees)	Derived from DEM
67	BLT_CON	Raster	Merged constraints for built-up	0, 1	Manipulated spatial data

PAGE	IMAGE NAME	TYPE	DESCRIPTION	CATEGORIES/ CLASSES/ VALUES	SOURCE
74	BLT_DBL	Raster	Standardised suitability for built-up in terms of distance to built-up	1, 2, 3, 4, 5	Manipulated land cover data
74	BLT_DSC	Raster	Standardised suitability for built-up in terms of distance to schools	1, 2, 3, 4, 5	Manipulated point data
65	BLT_DST	Raster	Distance surface representing the proximity to built-up	Calculated interval measurements (m)	Manipulated land cover data
67	BLT_LCS	Raster	Standardised land use constraint image for built-up	0, 1	Manipulated land cover data
67	BLT_PCS	Raster	Standardised ecological constraint image for built-up to protect sensitive areas	0, 1	Manipulated land cover data
82	BLT_RNK	Raster	Standardised/ Ranked suitability image for built-up	Calculated interval values	Single-objective suitability images
73	BLT_SLT	Raster	Standardised suitability for built-up in terms of land type	3, 5	Manipulated land type data
79	BLT_STB	Raster	Suitability image for built-up	0, 1, 2, 3, 4, 5	Standardised criteria images
70	BLT_TSL	Raster	Standardised suitability for built-up in terms of slope	0, 1, 3, 5	Derived from DEM
67	BLT_UBL	Raster	Standardised land and use retention image for built-up	0, 5	Manipulated land cover data
65	CBD_DST	Raster	Distance surface representing the proximity to the CBD of each cell	Calculated interval measurements (km)	Manipulated point data
73	CCO_SCU	Raster	Standardised suitability for communal use & conservation in terms of curvature	3, 4, 5	Derived from DEM
73	CCO_SLT	Raster	Standardised suitability for communal use & conservation in terms of land type	4, 5	Manipulated land type data
14	CNT	Line	Contours	– Layer – Height (m) {20m interval}	Chief Dir. of Surveys and Mapping (Cape Town)
67	COM_CON	Raster	Merged constraints for communal use	0, 1	Manipulated spatial data
74	COM_DBL	Raster	Standardised suitability for communal use in terms of distance to built-up	1, 2, 3, 4, 5	Manipulated land cover data
74	COM_DCR	Raster	Standardised suitability for communal use in terms of distance to old cropland	3, 4, 5	Manipulated land cover data
74	COM_DRD	Raster	Standardised suitability for communal use in terms of distance to major roads	1, 2, 3, 4, 5	Manipulated road data
67	COM_LCS	Raster	Standardised land use constraint image for communal use	0, 1	Manipulated land cover data
82	COM_RNK	Raster	Standardised/ Ranked suitability image for communal use	Calculated interval values	Single-objective suitability images
79	COM_STB	Raster	Suitability image for communal use	0, 1, 2, 3, 4, 5	Standardised criteria images
70	COM_TSL	Raster	Standardised suitability for communal use in terms of slope	3, 4, 5	Derived from DEM

PAGE	IMAGE NAME	TYPE	DESCRIPTION	CATEGORIES/ CLASSES/ VALUES	SOURCE
65	CPL_DST	Raster	Distance surface representing the proximity to productive cropland	Calculated interval measurements (m)	Manipulated land cover data
65	CPO_DST	Raster	Distance surface representing the proximity to abandoned cropland	Calculated interval measurements (m)	Manipulated land cover data
67	CSV_CON	Raster	Merged constraints for conservation	0, 1	Manipulated spatial data
74	CSV_DER	Raster	Standardised suitability for conservation in terms of distance to erosion hazards	1, 2, 3, 4, 5	Manipulated land cover data
74	CSV_DWE	Raster	Standardised suitability for conservation in terms of distance to wetland	1, 2, 3, 4, 5	Manipulated land cover data
67	CSV_LCS	Raster	Standardised land use constraint image for conservation	0, 1	Manipulated land cover data
82	CSV_RNK	Raster	Standardised/ Ranked suitability image for conservation	Calculated interval values	Single-objective suitability images
79	CSV_STB	Raster	Suitability image for conservation	0, 1, 2, 3, 4, 5	Standardised criteria images
67	CSV_UFW	Raster	Standardised land and use retention image for conservation	0, 5	Manipulated land cover data
14	DAM	Polygon	Dams / Waterbodies	– Layer – Feature > Man-made > Natural	Digitised from aerial photo images
14	DEM	Raster	Digital elevation model	Calculated interval measurements (m)	Manipulated spatial data
65	ERZ_DST	Raster	Distance surface representing the proximity to erosion hazards	Calculated interval measurements (m)	Manipulated land cover data
14	EXT	Polygon	Area of interest	– Layer	Digitised from aerial photo images
74	FAB_DER	Raster	Standardised suitability for forestry, agriculture & built-up in terms of distance to erosion hazards	1, 2, 3, 4, 5	Manipulated land cover data
74	FAB_DRD	Raster	Standardised suitability for forestry, agriculture & built-up in terms of distance to major roads	1, 2, 3, 4, 5	Manipulated road data
74	FAB_DWE	Raster	Standardised suitability for forestry, agriculture & built-up in terms of distance to wetland	1, 2, 3, 4, 5	Manipulated land cover data
73	FAB_SCU	Raster	Standardised suitability for forestry, agriculture & built-up in terms of curvature	0, 1, 2, 3, 4, 5	Derived from DEM
67	FAB_ZCS	Raster	Standardised constraint image for forestry, agriculture & built-up to protect riparian zones	0, 1	Manipulated spatial data
68	FAG_CMA	Raster	Standardised suitability for forestry & agriculture in terms of MAP	1, 2, 3, 4, 5	Manipulated climatic data
67	FAG_PCS	Raster	Standardised ecological constraint image for forestry, agriculture & built-up to protect sensitive areas	0, 1	Manipulated land cover data

PAGE	IMAGE NAME	TYPE	DESCRIPTION	CATEGORIES/ CLASSES/ VALUES	SOURCE
83	FINAL	Raster	Final land use allocation theme	Land use codes	Standardised single-objective suitability images
65	FOF_DST	Raster	Surface representing the distance to the forestry office of each cell	Calculated interval measurements (km)	Manipulated point data
67	FOR_CON	Raster	Merged constraints for forestry	0, 1	Manipulated spatial data
74	FOR_DFO	Raster	Standardised suitability for forestry in terms of distance to the forestry office	1, 2, 3, 4, 5	Manipulated point data
74	FOR_DPB	Raster	Standardised suitability for forestry in terms of distance to plantation & bushland	1, 2, 3, 4, 5	Manipulated land cover data
74	FOR_DRV	Raster	Standardised suitability for forestry in terms of distance to rivers	0, 1, 2, 3, 4, 5	Manipulated river data
67	FOR_LCS	Raster	Standardised land use constraint image for forestry	0, 1	Manipulated land cover data
82	FOR_RNK	Raster	Standardised/ Ranked suitability image for forestry	Calculated interval values	Single-objective suitability images
73	FOR_SLT	Raster	Standardised suitability for forestry in terms of land type	4, 5	Manipulated land type data
79	FOR_STB	Raster	Suitability image for forestry	0, 1, 2, 3, 4, 5	Standardised criteria images
70	FOR_TAS	Raster	Standardised suitability for forestry in terms of aspect	1, 2, 3, 4, 5	Derived from DEM
70	FOR_TSL	Raster	Standardised suitability for forestry in terms of slope	0, 1, 2, 3, 4, 5	Derived from DEM
67	FOR_UPB	Raster	Land use retention image for forestry	0, 5	Manipulated land cover data
14	GOV	Polygon	District / Municipal borders	– Layer – District name – Municipal name – Ward no	Municipal Demarcation Board (Pretoria)
14	HLS_DEM	Raster	Hillshade image	Calculated illumination values	Derived from DEM
14	HTS_PTS	Point	Altitude	– Layer – Height (m)	Chief Dir. of Surveys and Mapping (Cape Town)
28	LCV	Polygon	Land cover	– Layer – Land cover code – Description/ Notes	Digitised from aerial photo images
14	LTP	Polygon	Land Type	– Layer – Soil pattern – Description (Soil form)	Agricultural Research Council (Pretoria)
14	MAP_RAW	Point	Mean annual precipitation	– Layer – MAP (mm)	Agricultural Research Council (Pretoria)
64	MAP_SPL	Raster	Mean annual precipitation map after regularized splining	Calculated interval measurements (mm)	Interpolated climatic data
65	PBU_DST	Raster	Distance surface representing the proximity to plantations & bushland	Calculated interval measurements (m)	Manipulated land cover data

PAGE	IMAGE NAME	TYPE	DESCRIPTION	CATEGORIES/ CLASSES/ VALUES	SOURCE
14	PWR	Line	Transmission/ Power lines	– Layer	Digitised from aerial photo images
14	QUA	Polygon	Quaternary catchments	– Layer – Quaternary catchment no	University of Stellenbosch
14	RDS	Line	Roads	– Layer – Feature > National route > Secondary road > Forestry road > Main access > Rural access > Tracks – Surface > Tarred > Gravel > DIRT > Grass – Road buffer distance (m)	Digitised from aerial photo images
65	RDS_DST	Raster	Distance surface representing the proximity to roads of each cell	Calculated interval measurements (m)	Manipulated spatial data
27	RDS_SLC	Line	Buffered important transportation routes	– Layer	Manipulated roads data
14	RIV	Line	Drainage features	– Layer – Feature > River > PERENNIAL STREAM > Non-perennial stream > Furrow > Donga – Riparian buffer distance (m)	Digitised from aerial photo images
65	RIV_DST	Raster	Distance surface representing the proximity to rivers of each cell	Calculated interval measurements (m)	Manipulated spatial data
64	RPZ	Polygon	Stream buffers representing riparian zones	– Layer	Manipulated river data
65	SCL_DST	Raster	Distance surface representing the proximity to schools of each cell	Calculated interval measurements (m)	Manipulated spatial data
14	SFT_PTS	Point	Special man-made features	– Layer – Feature > Town centre (CBD) > Climate station > FORESTRY OFFICE > School	Digitised from aerial photo images
65	SLP_HRN	Raster	Slope surface of the watershed	Calculated interval measurements (%)	Derived from DEM
65	WET_DST	Raster	Distance surface representing the proximity to wetland of each cell	Calculated interval measurements (m)	Manipulated spatial data

PAGE	IMAGE NAME	TYPE	DESCRIPTION	CATEGORIES/ CLASSES/ VALUES	SOURCE
14	WSD	Polygon	Study area/ Watershed	– Layer – Feature > Area (ha)	Derived from DEM
14	WSD_EXT	Raster	Watershed extent	0, 1	Derived from DEM
14	WSU	Polygon	Sub-catchments of watershed	– Layer – Feature > Sub-catchment no > Area (ha)	Derived from DEM