LANDSCAPE FUNCTION ANALYSIS AND ECOLOGICAL MANAGEMENT OF AN AGRICULTURAL LANDSCAPE

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Thesis presented in partial fulfilment of the requirements for the degree of Master of Natural Sciences at the University of Stellenbosch

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AUTHOR'S 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: …………………………………………….

ABSTRACT

In the past, development was allowed in agricultural areas which would not be acceptable under current planning policy. There is a growing need to develop and maintain highly productive and ecologically stable agricultural systems. One approach to encourage better land management and utilisation is the international certification of a farm's production practices. Requirements for certification include environmentally sound practices and the establishment of a conservation management plan. These requirements are often not fully serviced and Geographical Information Systems (GIS) provides a tool with which to effectively address them. Careful thought, planning and a proven basis for proposed actions are required to manage the environment effectively.

The study area is a farming area of $104km^2$ in the Koue Bokkeveld region of the Western Cape, South Africa. The aim of the study was to assess agricultural landscape functioning and provide scientifically based guidelines for management of the agricultural landscape. Data sources consisted of digital aerial photographs and a digital elevation model (DEM) of the study area. The land cover was digitized from the digital aerial photographs. The calculation of landscape metrics using the Patch Analyst extension in ArcView 3.3 allowed for an investigation of the land cover pattern and how this might affect the natural flora and fauna of the landscape.

The topographical analysis was carried out using ArcGIS 8 and ArcView 3.3. Slope, plan curvature and profile curvature were used to delineate landform elements. With watersheds delineated, this allowed for a broad-scale investigation of the process-controlling effect of topography, especially with regards to the movement of water over the landscape. Using the land cover analysis an ecological network of natural habitat linkages was identified. General principles and guidelines for management of the agricultural landscape were compiled from literature. Specific recommendations were then made for management of the study area using the information gathered from literature and data analysis.

From the landscape metrics it is evident that the natural vegetation in the developed portion of the study area is highly fragmented. The landform elements identify areas of accumulation and deflection of water and associated materials. These correlate well with the drainage lines created from the DEM and the dams and wetlands from the land cover theme. Practical recommendations with regards to optimum management of the study area are made. Core areas of pristine vegetation, large natural vegetation patches and wetlands are areas which should be protected. The maintenance of connectivity in the landscape is vital for

conservation and areas where significant linkages are present are highlighted. It is recommended that a set of operational rules be formulated and enforced to prevent disturbance of important conservation areas.

The land cover theme sets the stage for an evaluation of land cover change in the future. An investigation into the flora and fauna present in the disturbed and pristine areas would be of value. The landscape is a complex, highly integrated system which is the result of both human and natural processes. Growing demands are being placed on science for instant solutions to conservation issues. The challenge lies in taking concepts developed by the research community and making them accessible and useful to landscape managers.

OPSOMMING

In die verlede was ontwikkeling in landbou gebiede toegelaat wat nie onder huidige beplanningsbeleid aanvaarbaar sal wees nie. Daar is 'n groeiende behoefte om produktiewe en ekologies stabiele landbou sisteme te ontwikkel en te onderhou. Een benadering om beter land bestuur en -gebruik te bevorder is die internasionale sertifisering van 'n plaas se produksie praktyke. Vereistes vir sertifisering sluit omgewings-vriendelike praktyke en die skepping van 'n bewaringsbestuursplan in. Hierdie vereistes is nie altyd volledig uitgevoer nie en geografiese inligtings stelsels (GIS) kan dit verbeter. Versigtige oorweging, beplanning en 'n geldige basis vir voorgestelde optredes is 'n vereiste om die omgewing doeltreffend te bestuur.

Die studie gebied is 'n landbou gebied van 104km^2 in die Koue Bokkeveld streek van die Wes-Kaap, Suid-Afrika. Die doel van die studie was om die werking van die landbou landskap te bestudeer en wetenskaplik gebaseerde riglyne vir die bestuur daarvan te verskaf. Data bronne het uit digitale lugfotos en 'n digitale elevasie model (DEM) van die studie gebied bestaan. Die grondgebruik tema is van die digitale lugfotos geskep. Die berekening van landskap indekse met die 'Patch Analyst extension' in ArcView 3.3 het die ondersoek van die grondgebruik patroon toegelaat en ook bepaling van hoe dit die flora en fauna van die landskap sou kon beïnvloed.

Die topografiese analise is met ArcGIS 8 en ArcView 3.3 gedoen. Helling, plan kromming en profiel kromming is gebruik om landvorm elemente te skep. Met waterskeidings geskep, was 'n grootskaal studie van die proses-beherende effek van topografie, veral met betrekking tot die beweging van water oor die landskap, moontlik. 'n Ekologiese netwerk van natuurlike habitat skakels is met behulp van die grondgebruik analise geïdentifiseer. Algemene beginsels en riglyne vir die bestuur van landbou landskappe is uit literatuur saamgestel. Spesifieke aanbevelings vir die bestuur van die studiegebied is met behulp van literatuur en data-analise gemaak.

Die landskap indekse maak dit duidelik dat die natuurlike plantegroei in die ontwikkelde deel van die studiegebied hoogs gefragmenteer is. Die landvorm elemente het gebiede van akkumulasie en defleksie van water en verwante stowwe geïdentifiseer. Hierdie stem goed ooreen met die dreineringslyne vanaf die DEM geskep en die damme en vleie van die grondgebruik tema. Praktiese voorstelle vir die optimum bestuur van die studiegebied is gemaak. Kerngebiede van oorspronklike plantegroei is geïdentifiseer. Hierdie kerngebiede, saam met groot natuurlike plantegroei fragmente en vleie, is gebiede wat beskerm moet word. Die onderhoud van konnektiwiteit in die landskap is noodsaaklik vir bewaring en gebiede

waar belangrike skakels voorkom is uitgewys. ’n Stel reëls om verdere versteuring van belangrike bewaringsgebiede te verhoed, word voorgestel.

Die grondgebruik tema kan vir monitering van verandering in die toekoms gebruik word. ’n Studie van die flora en fauna in versteurde en oorspronklike gebiede sal van waarde wees. Die landskap is ’n komplekse, hoogs geïntegreerde sisteem wat die resultaat van beide menslike en natuurlike prosesse is. Groeiende eise word op die wetenskap geplaas vir onmiddellike oplossings van bewaringskwessies. Die uitdaging is om konsepte wat deur die navorsingsgemeenskap ontwikkel is, toeganklik en bruikbaar te maak vir bestuurders van die landskap.

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CONTENTS

Page

5 ECOLOGY-BASED GUIDELINES FOR MANAGEMENT OF THE AGRICULTURAL LANDSCAPE

6 TOWARDS CREATING A SUSTAINABLE LANDSCAPE

TABLES

Page

FIGURES

CHAPTER 1: SETTING THE SCENE FOR RESEARCH ON THE AGRICULTURAL LANDSCAPE

1.1 The need for research on the agricultural landscape

Agriculture provides food for the world's growing population, while at the same time being the leading cause of destruction of native vegetation and loss of biodiversity (Saunders, Hobbs & Erlich 1993). In the past a great deal of development in South Africa was allowed in agricultural areas which would not be acceptable under current planning policy. Prime examples include extensive clearing of natural vegetation, straightening of river courses, drainage of wetlands and pollution of ground water. The current generation is increasingly unable to pass on productive land or a rich wildlife resource to future generations (Fry & Main 1993).

There is a growing need to develop and maintain highly productive, yet ecologically stable agricultural systems (Ares, Bertiller & del Valle 2001). One approach to encourage better management and utilisation of land is that of international certification of a unit or farm's production practices. This often leads to better marketing opportunities and therefore acts as a good practice incentive. EurepGAP is one such certification scheme for which requirements include environmentally sound practices and the establishment of a conservation management plan (EurepGAP 2001). These environmental requirements are mostly poorly-serviced and Geographical Information Systems (GIS) provide a tool with which to address its implementation more effectively.

Managing the agricultural landscape for conservation does not involve simply planting a few rare plants here and there. As Bennett (2003:153) states: "Effective conservation of natural environments and their wildlife can not be achieved by short-term reactions to an ongoing series of crises in land management and land use planning…". We cannot wait for crises to occur before taking steps to protect the environment. Careful thought, planning and a proven basis for proposed actions are required to manage the environment effectively (Dale & Haeuber 2001). An improved knowledge of landscape function aids in better management. This paper attempts to lay a basic foundation for managing the agricultural landscape in an environmentally sound manner and to do so using the tools provided by the disciplines of landscape ecology and geography.

1.2 Conceptual foundation for agricultural landscape research

With the conceptual backgrounds of landscape ecology and geography a unique perspective is provided which allows for wise management of the agricultural landscape. There are various definitions of the term landscape. From the beginning the understanding of the term has related to "…the perception, observation and view of the environment as the living space of man" (Klink et al 2002:1). Jorge & Garcia (1997:35) see landscape as referring to a "...mosaic of heterogeneous vegetation types, shapes and land uses." Forman & Godron's (1986) definition of landscape as an area composed of a mosaic of interacting ecosystems or habitat patches is the view adopted for this study. The concept of landscape is complex and its all-encompassing nature has been realized in many geographical and ecological studies (Naveh 1991; Antrop 1997). Bastian (2001) is of the opinion that as environmental problems increasingly come to the fore, the landscape should be regarded as a complex, highly integrated system which is the result of both human and natural processes.

Agricultural landscapes are multifunctional landscapes requiring research and management approaches which cross traditional subject boundaries. Landscape ecology has emerged as a field incorporating this inter-disciplinary perspective (Fry 2001). The term landscape ecology was first coined by Carl Troll (Turner 1989), who saw the discipline as the union of geography and ecology. It has subsequently evolved into a diverse field with varying applications. Wiens (2002) describes landscape ecology as an interdisciplinary subject concerned with the structure and function of ecological communities in spatial landscapes. The study of landscape structure, function and change is central to landscape ecology (Turner 1989; Forman 1997; Hobbs 1997). Structure refers to the spatial relationship between elements, while function refers to the interaction between elements and change to the alteration in structure and function over time (Hobbs 1997).

Landscape ecology provides a unified theory of earth functioning by linking together the patterns and processes in the real world (Farina 2000). According to Collinge (1996:59): "An integrated view of the spatial characteristics of habitat fragments and their ecological consequences improves our ability to predict the outcomes of and to design particular patterns of land conversion." Wiens (2002) sees the overarching principle of landscape ecology as the fact that the spatial configuration of landscapes can have important effects on a wide variety of ecological processes. Most agricultural landscapes are a mosaic of farmers' fields, semi-natural habitats, human infrastructures and occasional natural habitats (Marshall & Moonen 2002) and therefore can be researched effectively within the framework of landscape ecology.

Aspinall (2001) highlights the need to couple ecological science with spatial concepts and methods. Landscape ecology provides the conceptual framework to do so and GIS the mechanism by which this can be achieved. Burrough & McDonnell (1998:11) define GIS as "…a powerful set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world". There is a need to move beyond broad scientific principles to actual implementation and application of principles. This study aims to do this by using landscape ecology as a conceptual foundation and GIS as the toolbox.

1.3 Research aims and objectives

The research aim is to assess the functioning of an agricultural landscape and provide scientifically-based guidelines for the management thereof.

The main objectives of the study are as follows:

- Quantify land cover pattern and assess landscape function using landscape metrics;
- Calculate topographic attributes and assess landscape function using a digital elevation model (DEM);
- Identify existing and possible ecological networks in the study area;
- Compile from the literature ecological guidelines for managing the agricultural landscape;
- Compile practical recommendations for improved environmental management of the study area.

The research will assist in the environmental requirements for international certification of a farm's production being serviced and illustrate what can be achieved with the aid of GIS. The EurepGAP requirements for certification are laid out in Table 1.1 and lay the foundation for farm production that is environmentally sound. The research will aid in a better understanding by farmers of the impact of their activities on the environment, as well as how they can enhance the environment with regards to the flora and fauna as recommended in Issue 1 (Table 1.1). The recommendations for environmental management of the study area will contribute to the wildlife and conservation policy discussed in Issue 2, especially the formulation of a conservation management plan. They will also incorporate the recommendations concerning unproductive sites mentioned in Issue 3. As highlighted in the literature (Hobbs 1997; Wilson & Gallant 2000), it is no easy task to investigate landscape function and this study will therefore aim to show what can be done within a geographical perspective.

1.4 The study area

The study area lies in a farming district in the Koue Bokkeveld region of the Western Cape, South Africa (Figure 1.1). It lies north of Ceres and covers a rectangular area of 104km^2, lying between 19°27'0"E and 19°21'9"E and 33°3'0"S and 33°9'0"S. Perennial and annual crops are farmed in the lower-lying areas, with natural vegetation occurring in the higher-lying areas. The natural vegetation

Table 1.1 Environmental requirements for EurepGAP

EurepGAP General Regulations: Environmental Issues
1: Impact of farming on the environment
Recommended: Farmers should understand and assess the impact their farming activities have on the environment and consider how they can enhance the environment for the benefit of the local community and flora and fauna
2: Wildlife and conservation policy
Encouraged: A key aim must be the enhancement of environmental biodiversity on the farm through a conservation management plan. This could be a regional activity rather than an individual one.
Recommended: Each grower should have a management of wildlife and conservation policy plan on their property. This policy should be compatible with sustainable commercial agricultural production and minimise-environmental impact of the agricultural activity. Key elements of this plan should be to: • Conduct a baseline audit to understand existing animal and plant diversity on the farm; • Take action to avoid damage and deterioration of habitats; • Create an action plan to enhance habitats and increase biodiversity on the farm.
3: Unproductive sites
Recommended: Consideration should be given to the conversion of unproductive sites (e.g. low lying wet areas, woodlands, headland strip or areas of impoverished soil) to conservation areas for the encouragement of natural flora and fauna.

Source: EurepGAP 2001.

consists predominantly of fynbos belonging to the Cape Floral Kingdom. Figure 1.2 provides an aerial perspective using digital aerial photographs of the study area. It shows the various cultivated areas interspersed with large irrigation dams used to store winter run-off for use during the long dry summer.

1.5 Data sources, research design and report structure

Digital orthorectified and georeferenced colour aerial photographs for 2002 at a 1:10 000 scale (Figure 1.2) and 0.85m square pixel size were obtained from the Department of Water Affairs and Forestry. The DEM of the area was obtained from the Centre for Geographical Analysis, University of Stellenbosch. The DEM has a 20m resolution. The research design and report structure are laid out in Figure 1.3. The land cover was digitized from the digital aerial photographs.

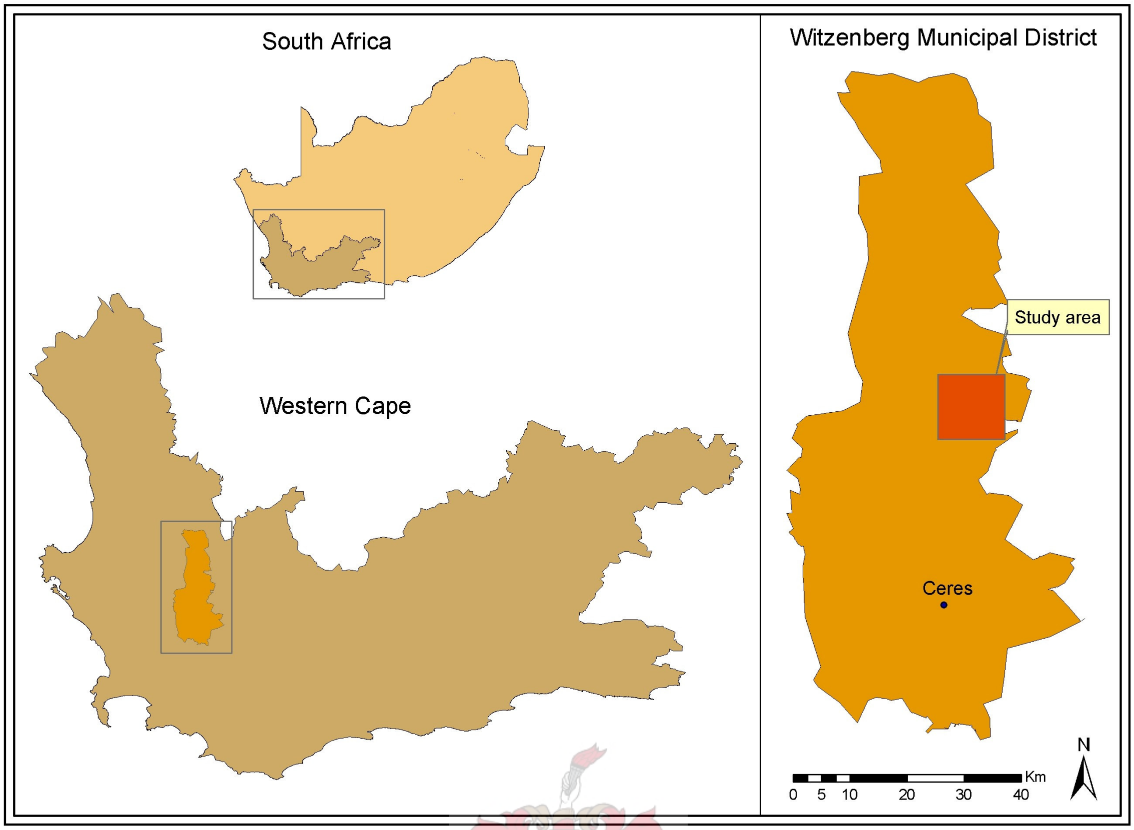


Figure 1.1 Location of study area

Figure 1.2 Aerial perspective of study area

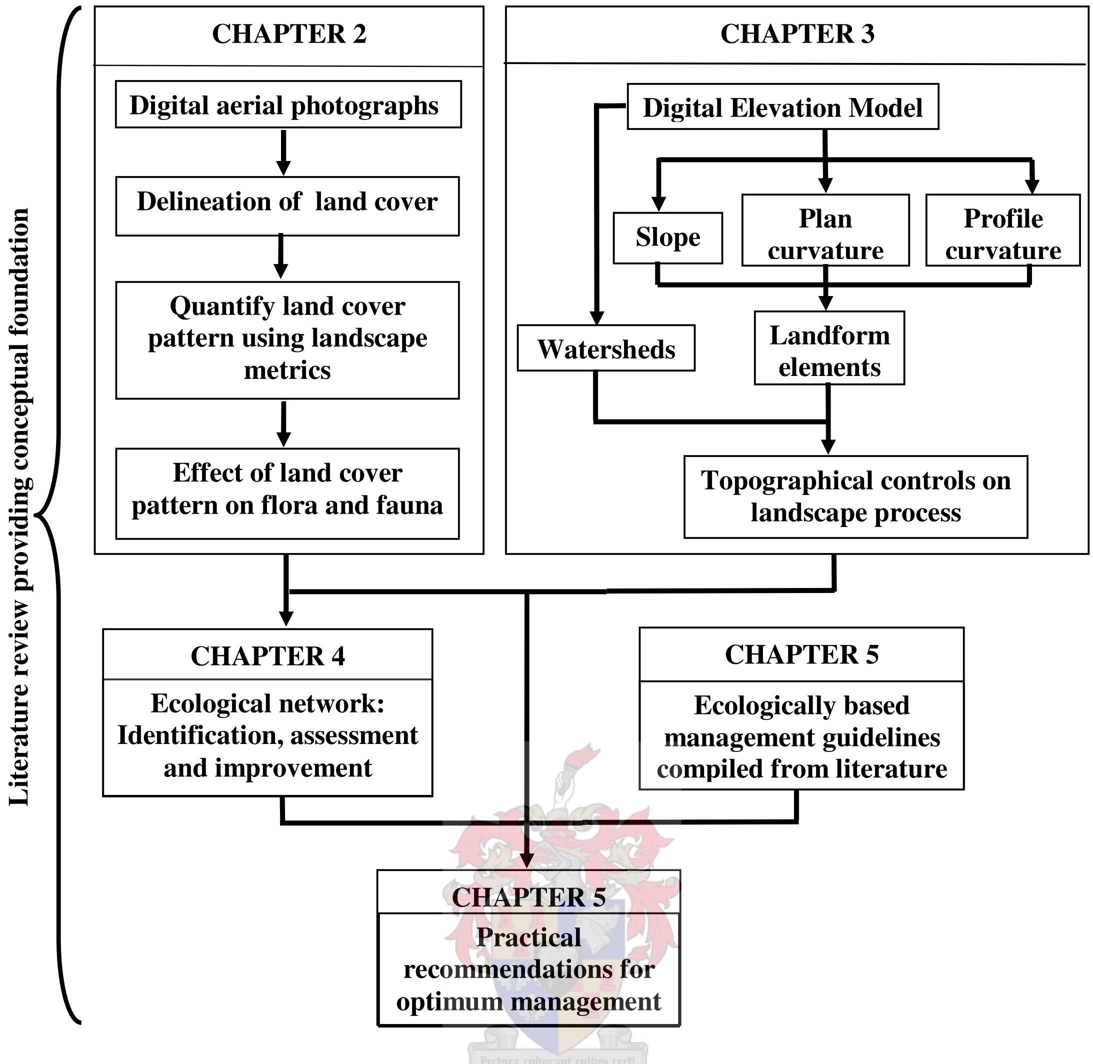


Figure 1.3 Research design and report structure

The calculation of landscape metrics using the Patch Analyst extension (Elkie, Rempel & Carr 1999) in ArcView 3.3 allowed for an investigation of the land cover pattern and how this affects the flora and fauna of the landscape, especially with regards to the degree of natural vegetation fragmentation. These results are reported in Chapter 2. The topographical analysis, reported in Chapter 3, was carried out using ArcGIS 8 and ArcView 3.3. The DEMAT extension (Behrens 2000) was used to calculate slope, plan curvature and profile curvature. These topographic attributes were then used to delineate landform elements.

The ArcHydro extension was used to delineate watersheds. This allowed for a broad-scale investigation of the process-controlling effect of topography, especially with regards to the movement of water over the landscape. Using the land cover analysis an ecological network of natural habitat linkages was identified in Chapter 4. General principles and guidelines for management of the agricultural landscape were compiled from literature and summarized in

Chapter 5. Specific recommendations were then made for management of the study area using the information gathered from literature and data analysis and are laid out in Chapter 5. Chapter 6 provides a summary and evaluation of the research carried out, as well as recommendations for further research.

CHAPTER 2: LAND COVER ANALYSIS AS AN INDICATOR OF LANDSCAPE PROCESS

Landscape ecology provides the view of the landscape as a mosaic of interacting ecosystems or habitat patches (Young & Sanzone 2003) with all ecological processes responding, at least in part, to this landscape mosaic (Turner 1989; Forman 1995). The size, shape and spatial relationships of land cover types influence the dynamics of populations, communities and ecosystems (Dale et al. 2001). Firstly the creation of the land cover theme is discussed. This is followed by an overview of landscape metrics and their application on the land cover of the study area.

2.1 Definition and delineation of land cover categories

For analytical purposes, the study area ($104km^2$) was divided into a largely developed ($44km^2$) and totally undeveloped ($60km^2$) area.

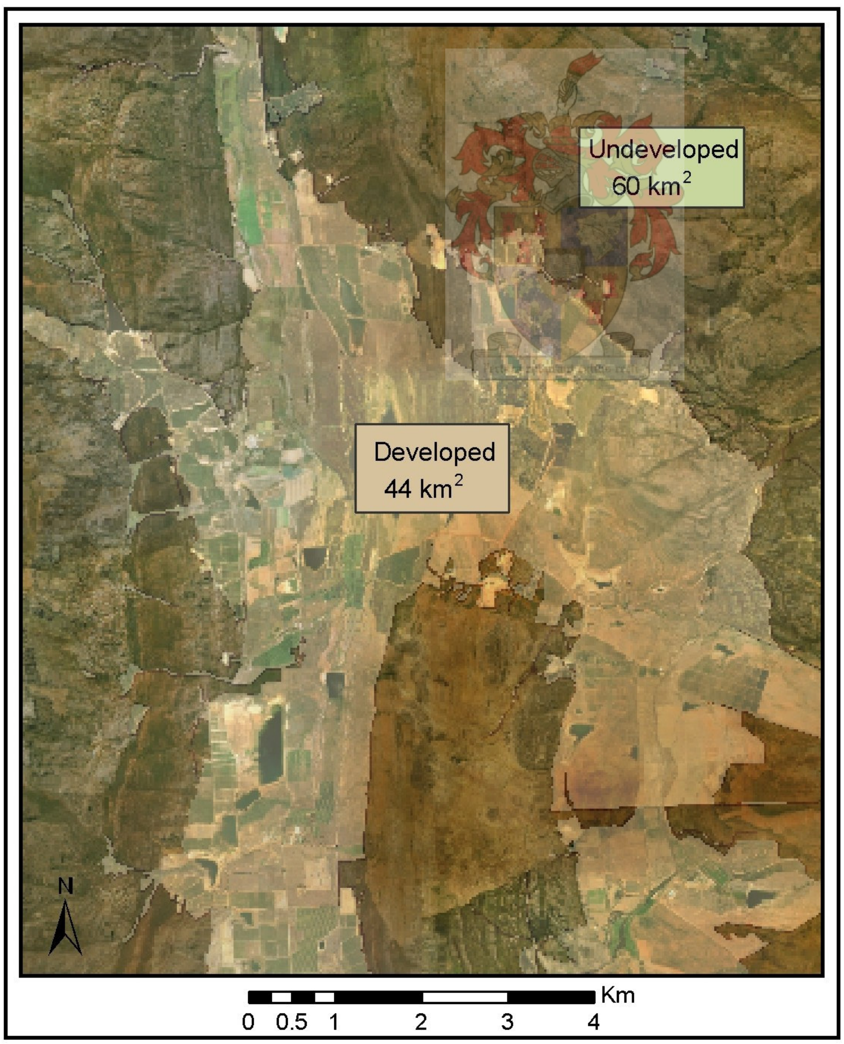


Figure 2.1 Developed and undeveloped portions of the study area

Table 2.1 provides the land cover classes that were digitized from the digital aerial photographs. The map was then verified by field visits, after which the alterations to reflect change between 2002 and 2004 were made.

Table 2.1 Land cover classes

Number	Land cover name	Number	Land cover name
1	Natural vegetation	6	Perennial agriculture
2	Tree stands	7	Built-up areas
3	Wetlands/Canals/Streams	8	Clearances/Excavations
4	Dams	9	Tar road
5	Annual agriculture	10	Gravel Road

Figure 2.2 shows the final land cover theme with the digital aerial photographs as a semi-transparent background. The two classes of roads were grouped into a single road class.

Within the context of landscape ecology the land cover can be viewed using the patch-corridor-matrix model (McGarigal, Berry & Buckley 2004). The landscape is seen as made up of patches, corridors and a matrix. The matrix is the background cover type in a landscape and is characterized by extensive cover and high connectivity. Patches are defined as non-linear surface areas which differ in appearance from their surroundings (Forman 1995). Corridors are seen as linear portions of the landscape which differ from the surrounding environment on both sides (Ingegnoli 2002). Corridors usually link two patches of the same type as the corridor. They can serve as landscape linkages which provide habitat and allow for movement between patches (Turner, Gardner & O'Neill 2001) and are further discussed in Chapter 5.

When examining the land cover of the study area, the natural vegetation can be considered as the matrix, as this is what was originally present in the landscape. Natural vegetation makes up 71% of the entire study area and 31% of the developed portion. Tree stands, dams, built-up areas, excavations/clearances, wetlands/streams/canals and individual perennial and annual agriculture fields can be seen as patches. The roads and some parts of the wetlands/streams/canals, tree stands and natural vegetation can be classified as corridors. The land cover extract in Figure 2.3 provides examples of patches, corridors and the matrix of the study area.

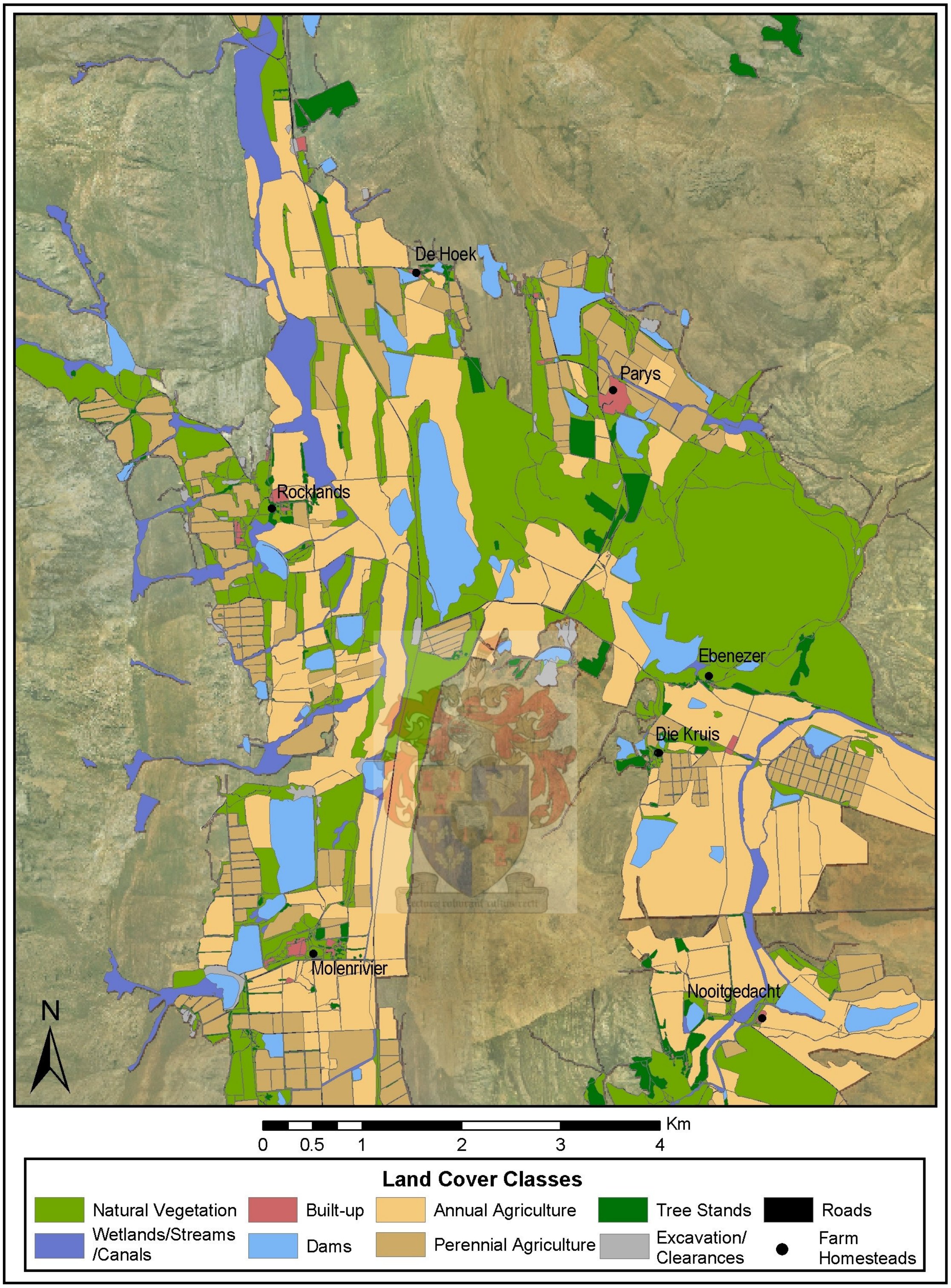


Figure 2.2 Land cover of the study area

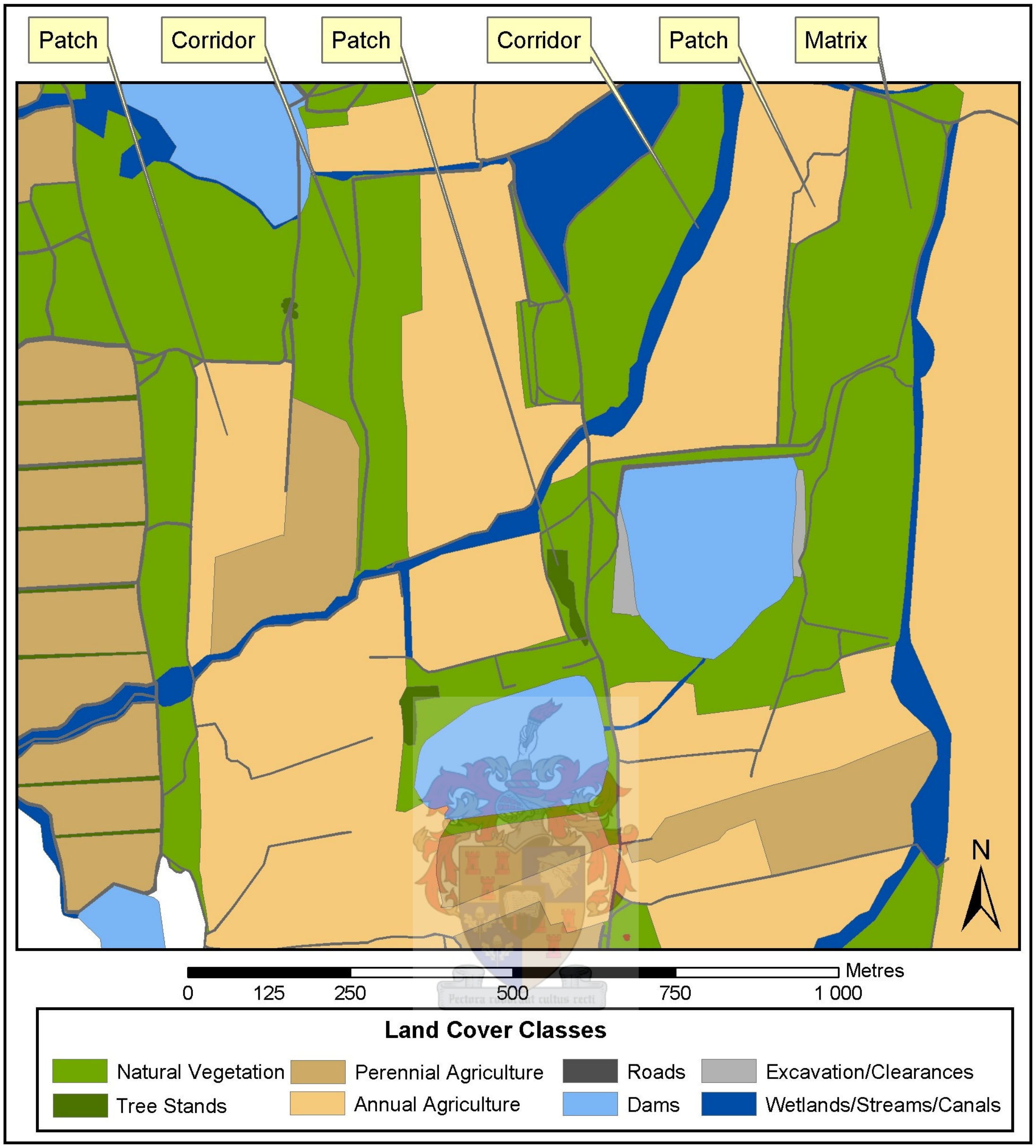


Figure 2.3 Patch-corridor-matrix model applied to the study area

Agricultural patches and the natural vegetation matrix fragments are indicated. Two corridors (roads and wetlands/streams/canals) are pointed out. Viewed from an ecological perspective, the road corridor can be seen as a barrier and source of negative influence on landscape functioning, while the wetland is a source of positive influence, providing habitat and carrying out ecological functions.

2.2 Quantifying landscape pattern with the aid of landscape metrics

Landscape metrics can be used to quantify landscape pattern (McGarigal, Berry & Buckley 2004). Once the structure is quantified it can be related to the processes occurring in the landscape. A theoretical overview of landscape metrics is provided next, after which they are applied to the study area.

2.2.1 Overview of landscape metrics and their relation to landscape process

Landscape metrics can be seen as measures that characterize the geometric and spatial properties of a patch or a mosaic of patches (Fortin 1999). Metrics and the quantification of landscape structure which they provide are seen as a prerequisite to studying landscape function and change (Haines-Young & Chopping 1996). The two components of landscape structure are composition and configuration. *Composition* deals with characteristics such as the number and proportion of patch/class types with no reference to spatial attributes. Composition metrics are only applicable at the landscape level where the pattern of the entire landscape mosaic can be quantified and are especially useful when comparing landscape metrics of different areas. *Configuration* concerns itself with spatial characteristics, such as metrics quantifying patch shape complexity (Leitao & Ahern 2002; McGarigal, Berry & Buckley 2004).

There are three decreasing levels of detail at which metrics can be calculated – patch, class and landscape. Patch metrics characterize the spatial characteristics and context of a single patch or group of patches. Class metrics can be interpreted as fragmentation metrics as they measure the configuration of a particular patch type (McGarigal, Berry & Buckley 2004). Landscape-level metrics can be interpreted broadly as landscape heterogeneity metrics that measure the overall landscape pattern. They are useful for comparing landscapes over time or in different areas.

Numerous metrics have been developed to analyse the landscape structure and are often correlated amongst themselves (Leitao & Ahern 2002). Studies have been carried out with the aim of identifying a core set of metrics (Haines-Young & Chopping 1996; Jorge & Garcia 1997; Giles & Trani 1999; Leitao & Ahern 2002). Haines-Young & Chopping (1996) summarized the basic categories of metrics as area, edge, shape, core area, nearest-neighbour, interspersion, and diversity and contagion metrics. Table 2.2 provides the descriptions of those metrics that have been calculated in this study. These are considered sufficient for a basic assessment of land cover pattern.

The choice of categories when delineating landscape pattern is critical (Turner, Gardner & O'Neill 2001) and all categories can be considered as an aggregate of a more detailed set of

Table 2.2 Landscape metrics description

Category	Metric	Description	Units
Area metrics	Landscape area (TLA)	Area of total landscape	ha
	Class area (CA)	Sum of area of all patches belonging to a given class	ha
Patch abundance and size metrics	Number of patches (NumP)	Total number of patches of each class	# patches
	Mean patch size	Average patch size for each class: $\frac{CA}{NumP}$	ha
	Patch density	Number of patches in each class divided by total landscape area: $\frac{NumP}{TLA}$	# patches /km^2
Edge metrics	Total edge (TE)	Sum of perimeter length of all patches in each class	km
	Edge density	Amount of edge relative to landscape area: $\frac{TE}{TLA}$	m/ha
	Mean patch edge	Average length of edge per patch: $\frac{TE}{NumP}$	m
Shape metrics	Mean perimeter-area ratio	Sum of each patch's perimeter/area ratio divided by number of patches	m/ha
	Shape index	Sum of each patch's perimeter divided by the square root of the patch area for each class	Index
	Mean shape index	Shape index divided by number of patches	Index

Source: Haines-Young & Chopping 1996; Elkie, Rempel & Carr 1999.

subcategories (Croissant 2004). For example, in this study perennial and annual agriculture are subcategories of agriculture. Each decision in the mapping process affects the analysis of spatial structure and the end product is only as good as the data on which analysis is to be based (Gustafson 1998; Turner, Gardner & O'Neill 2001).

The process of delineating land cover and the chosen land cover classes can therefore have a profound effect on the calculation of landscape metrics, as they are the input data for metrics. With regard to the land cover classes chosen in this study, the basic classification is suitable for providing an overview of landscape pattern. Some of the areas delineated as annual agriculture have been left to lie fallow, but the probability that they will be cultivated in the future is high and therefore they have not been designated as natural vegetation. Wetlands, streams and canals were not separated into different classes, but amalgamated into the single aquatic class.

The edge effect is an important phenomenon to consider when using landscape metrics. The edge is the portion of the patch/corridor/habitat near its perimeter where the environmental conditions may differ from those of the interior (Forman 1995). The edge effect influences the environment at the edge of the fragment and can permeate a habitat remnant for tens of meters (Haila, Saunders & Hobbs 1993). Physical changes associated with the creation of an edge can have profound effects on ecological processes (Debinski & Holt 2000). Larger patches, dependent on shape, have a greater amount of interior habitat and less edge habitat than smaller patches. Certain species will flourish at the edge of patches, while other species need a certain amount of interior patch habitat to survive (McGarigal, Berry & Buckley 2004). A highly fragmented landscape has more edge habitat than interior habitat, to the detriment of interior species. The edge effect is one of the reasons why the effects of natural vegetation fragmentation are so severe. Roads are often a major source of habitat fragmentation. Fragmentation is discussed further in Section 2.3 and the edge effect in Section 4.4.5.

2.2.2 Calculation of landscape metrics

Metrics were calculated for the developed portion of the landscape (Figure 2.1), which makes up 42% of the full study area. Metrics have been calculated at the class scale, which allows for a comparison of the land cover classes. Natural vegetation is of chief significance and its spatial pattern is focused upon in the discussion of the landscape metrics results.

2.2.2.1 Area metrics

The total landscape area for the developed portion of the study area is 44km^2. The proportional abundance of each land cover class was calculated. Figure 2.4 provides a graph of the land cover classes and the area covered by each class. Agriculture is the dominant land cover class making up nearly half of the landscape, with annual agriculture and perennial agriculture covering 34% and 13% respectively. Natural vegetation covers 31% of the developed portion of the landscape, leaving 22% to the other 6 classes.

2.2.2.2 Patch abundance and patch size metrics

Patch number, patch density and patch size metrics provide an indication of the degree of fragmentation in the landscape when viewed as a whole. The number of patches per class

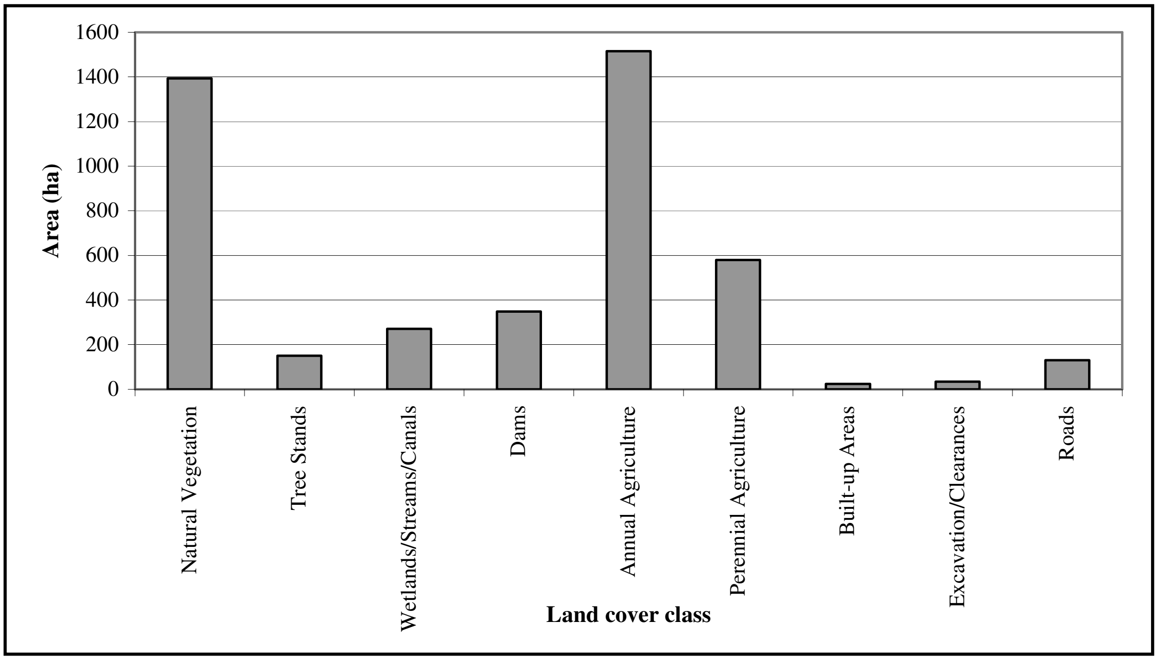


Figure 2.4 Area covered by each land cover class in the developed portion of the study area

provides a simple measure of the extent of subdivision or fragmentation of each patch type. The density and number of patches are similar measures and indicators of the spatial heterogeneity of the landscape (Berry 1999). Mean patch size is an average condition and is best interpreted with total class area, patch density and patch size variability. A class with a smaller mean patch size can be considered as more fragmented than a class with a larger mean patch size. A large number of patches, a high patch density and small patch sizes in a class could therefore indicate a high degree of fragmentation (McGarigal, Berry & Buckley 2004).

Patch size plays an important role in functioning of the landscape and determines the amount of resources available for species (Blaschke & Dragut 2003). Larger patches are generally superior to smaller patches when it comes to ecological considerations (Section 5.2.1). They contain more local environmental variability and are generally more heterogeneous due to a greater variety of soil and habitat types, as well as greater topographic variation. Larger patches have a greater proportion of interior habitat as opposed to edge habitat (Collinge 1996) and are therefore less prone to edge effects. Smaller, more isolated patches support fewer species than larger, less isolated patches (Debinski & Holt 2000). The largest habitat patches in the landscape can therefore represent potentially significant core areas for biodiversity (Leitao & Ahern 2002).

Figure 2.5 shows the mean patch size for each class, as well as the total area covered by each class.

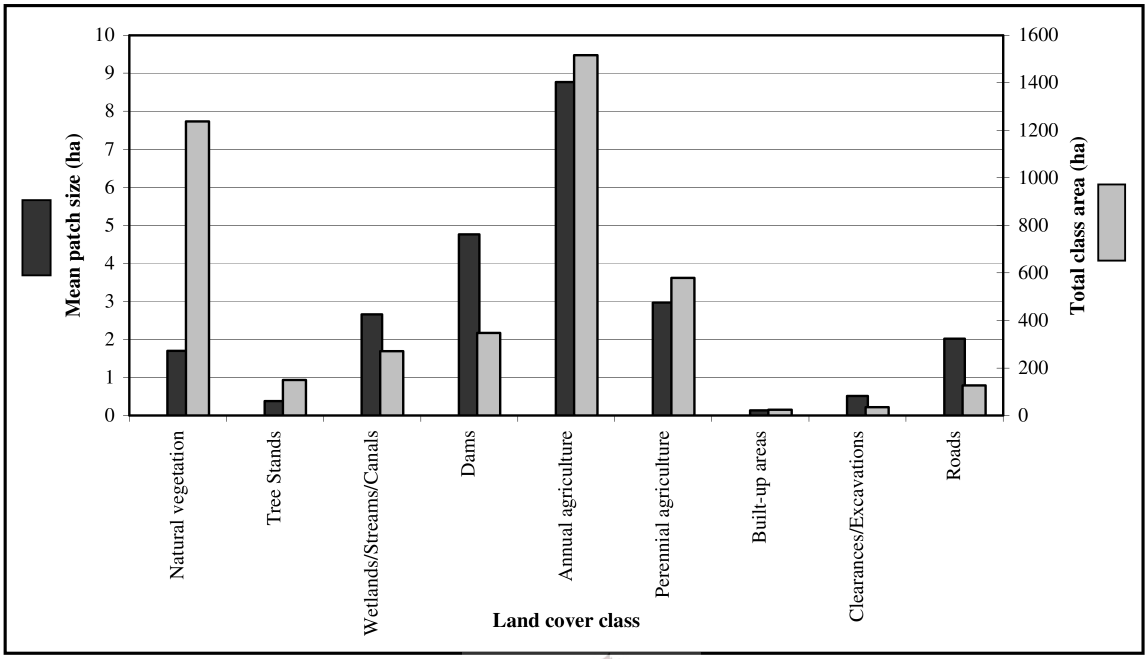


Figure 2.5 Mean patch size for each land cover class

Natural vegetation has the highest number of patches and patch density (Table 2.3), with a low mean patch size.

Table 2.3 Patch abundance metrics for each land cover class

Land cover class	Number of patches	Patch density (# patches /km^2)	Land cover class	Number of patches	Patch density (# patches /km^2)
Natural Vegetation	731	16	Built-up Areas	171	4
Tree Stands	396	9	Wetlands/Streams/Canals	102	2
Perennial Agriculture	195	4	Dams	73	2
Annual Agriculture	175	4	Excavation/ Clearances	67	2
			Roads	43	1

This shows a high degree of fragmentation, especially when considering that natural vegetation covers 31% of the developed portion of the landscape. This is seen in Figure 2.5 where natural vegetation clearly differs from the rest of the land cover classes. Natural vegetation is therefore more prone to negative edge effects and loss of habitat integrity. Tree stands also show a similar trend, but not as pronounced. This is due to the fact that most trees in the landscape occur singly or as linear elements in the agricultural areas where they have been planted as windbreaks. Annual agriculture has the largest mean patch size and a low patch density, showing a low degree of fragmentation and a tending towards monoculture. Due to their structural connectivity and small area coverage, roads have a low patch density and number of patches.

2.2.2.3 Patch shape metrics

Shape metrics quantify the landscape configuration in terms of patch shape complexity. Patch shape refers to the two-dimensional form of a given area as determined by its perimeter. Shape is a difficult feature to capture in a metric and shape metrics generally index overall shape complexity rather than assign a value to each unique shape (McGarigal, Berry & Buckley 2004). Most of the shape metrics are based on perimeter-area relationships. The perimeter-area ratio is the most basic shape metric and is higher for more complex shapes. The shape index measures the complexity of patch shape compared to a standard shape of the same size. The mean shape index represents the average shape complexity for each class. The index is equal to one when the patch is square and increases as the patch shape becomes more irregular. Area-weighted mean shape determines patch complexity independent of its size and therefore provides a better interpretation of shape complexity.

A primary significance of shape in determining the nature of patches in a landscape seems to be related to the edge effect (McGarigal, Berry & Buckley 2004). The geometric shape of the patch influences the extent to which edge effects pervade the edge interior. Patches can have the same area but have varying amounts of edge depending on their shape (Blaschke & Dragut 2003). A circular shape will have the least edge habitat, while a long narrow shape will have much more edge habitat. Fragments with highly irregular, convoluted boundaries will have a greater exchange of nutrients, materials and organisms with adjacent habitats than will those with less convoluted boundaries. Patch size and shape can be seen as interacting to influence the amount of interior area remaining in a particular habitat fragment (McGarigal, Berry & Buckley 2004). Human activities often simplify the more complex shapes that can be found in nature (O'Connor, Neville & Bennett 1999). The shapes of natural patches are usually curved or irregular in contrast to patches created due to human influence. These generally have straight boundaries and are often rectilinear in shape (Forman & Godron 1986).

In the study area (Table 2.4) roads and wetlands/streams/canals show the highest degree of shape complexity.

Table 2.4 Patch shape metrics for each land cover class

Land cover class	**Mean perimeter area ratio[1] (m/ha)**	**Mean shape index[2]**	**Area-weighted mean shape index[3]**
Roads	74.99	9.95	151.42
Wetlands/Streams/Canals	2.02	3.90	3.99
Natural Vegetation	8.72	2.15	2.24
Tree Stands	2.99	2.18	1.87
Annual Agriculture	1.97	1.68	1.80
Excavation/Clearances	0.78	1.73	1.71
Built-up Areas	2.93	1.33	1.50
Perennial Agriculture	19.30	1.66	1.44
Dams	54.40	2.58	1.42

1. Sum of each patch's perimeter/area ratio divided by the number of patches

2. Sum of each patch's perimeter divided by the square root of patch area for each class

3. Average perimeter-area ratio for a class, weighted by the size of its patches

Roads have the highest mean shape index. This is to be expected as roads are linear elements and have a proportionally large influence on neighbouring habitat. They are a major cause of natural habitat fragmentation. The wetlands/streams/canals have a high complexity due to their linearity. The natural vegetation patches are more complex in shape than the remaining classes, but are not as high due to their irregular-edged fragmentation by the man-made elements of the landscape. Roads, dams, natural vegetation and perennial agriculture all have a high mean perimeter-area ratio and therefore experience more interaction with adjacent habitats than the other land cover classes.

2.2.2.4 Edge metrics

The total length of edge for each class is an important metric, as the more edge that is present, the more edge effects that occur. Edge density is calculated by dividing the total edge of each class by the area covered by the class. With increasing edge there will be a greater amount of surface in contact with adjacent patches (Blaschke & Dragut 2003). Table 2.5 shows the mean patch edge and edge density for each class and Figure 2.6 shows the total edge along with total class area. Roads have the highest total edge length and edge density due to their linearity. The disproportionate relation between the amount of edge and the area they cover is

Table 2.5 Edge metrics for each land cover class

Land cover class	Mean patch edge (m/patch)	Edge density (m/ha)	Land cover class	Mean patch edge (m/patch)	Edge density (m/ha)
Roads	9990.34	146.79	Perennial Agriculture	767.87	34.92
Natural Vegetation	88.43	522.28	Tree stands	309.52	28.51
Annual Agriculture	56.59	1402.44	Dams	793.61	13.51
Wetlands/ Canals/ Streams	37.76	1587.18	Built-up areas	113.45	4.52
			Excavation/ Clearances	336.49	5.26

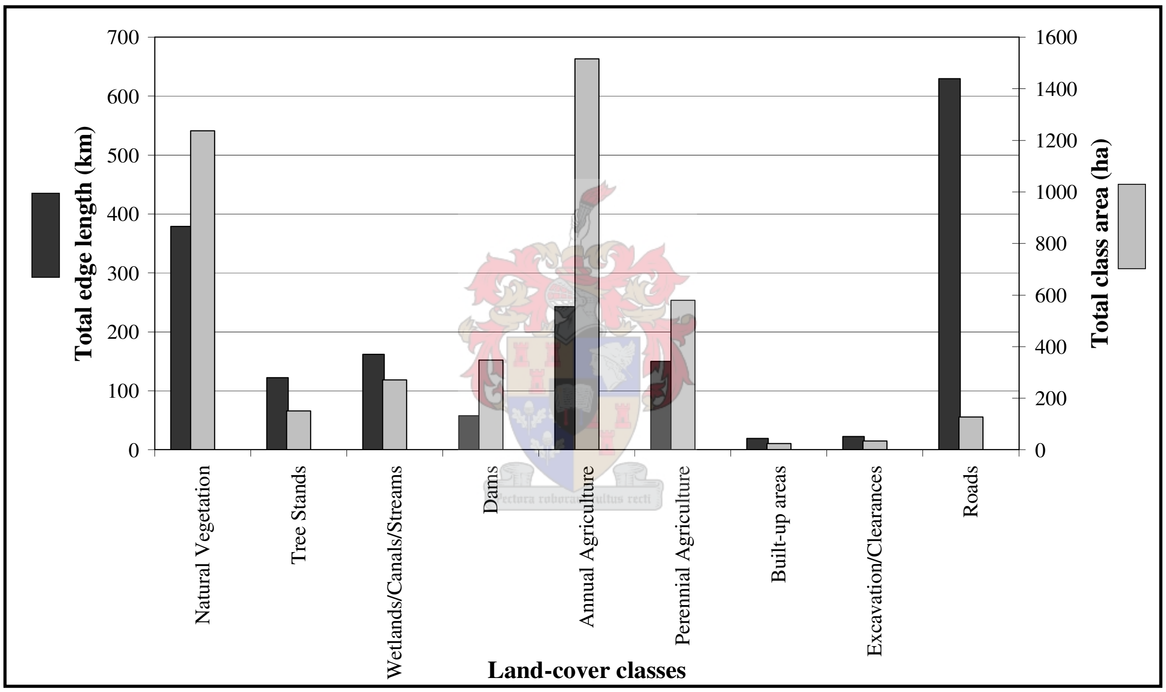


Figure 2.6 Total edge length metrics for each land cover class

seen in Figure 2.6. This emphasizes the large influence that roads can exert on the neighbouring habitat. Natural vegetation has the second highest total edge length and edge density. This is related to the fact that it has the larger number of patches and a small mean patch size in relation to the proportion of the landscape that it occupies. The natural vegetation in the landscape is therefore quite prone to the edge effect and negative influences from the surrounding land uses. In contrast, annual agriculture has much less edge in proportion to the area which it covers, contributing to negative monocultural habitat sterility.

2.3 Overall fragmentation and connectivity of the landscape

Habitat fragmentation has been called the most serious threat to biodiversity and the primary cause of the present extinction crisis (Ingegnoli 2002; Noss 1991). Fragmentation and loss of habitats in developed landscapes is not a random process. Clearing, cultivation and pastoral land use are biased toward those areas that have the most fertile soils or are the most accessible (Bennett 2003). This has been seen in South Africa, where 85% of the South Coast renosterveld of the Western Cape has been replaced by agriculture and the remaining areas are small fragments scattered throughout the agricultural landscape (Kemper, Cowling & Richardson 1999).

Fragmentation has three major effects: reduction in habitat patch size, increase in exposure to external disturbances and increased isolation of habitat patches (Leitao & Ahern 2002; Geneletti 2004). Fragmentation affects interspecific interactions and ecological processes (Debinski & Holt 2000) and almost always decreases habitat connectivity due to an increased isolation of habitat patches. This then constrains the spatial distribution and survival of species by making some areas accessible and others not (Forman 1995; Noss 1991). Current knowledge of precisely how fragmentation affects ecological processes is limited but ecological processes such as nutrient cycling and plant pollination are modified or disrupted by fragmentation. Fragmentation leads to a decline in biodiversity, stability and resilience of the ecosystem.

From the landscape metrics one can see that the natural vegetation is highly fragmented due to its small mean patch size, large patch density, large total edge and high number of patches. Chapters 4 and 5 further discuss steps which can be taken to improve connectivity and enhance the ecological functioning of the landscape. Figure 2.7 shows the natural land cover elements of the landscape, namely, tree stands, wetlands and natural vegetation, as well as the pristine vegetation. These elements can form the basis for the establishment of an interconnected ecological network and their preservation and maintenance are vital for a healthy agricultural landscape.

The natural vegetation in the developed portion of the study area is dominantly natural, but some disturbed patches do occur. In the undeveloped portion, pristine vegetation occurs, which has experienced very limited disturbance, mainly in the form of paths. In the western section grid-like north-south and east-west trending linear remnants of natural vegetation remain. This holds potential for re-establishing landscape connectivity. The lack of fair-sized

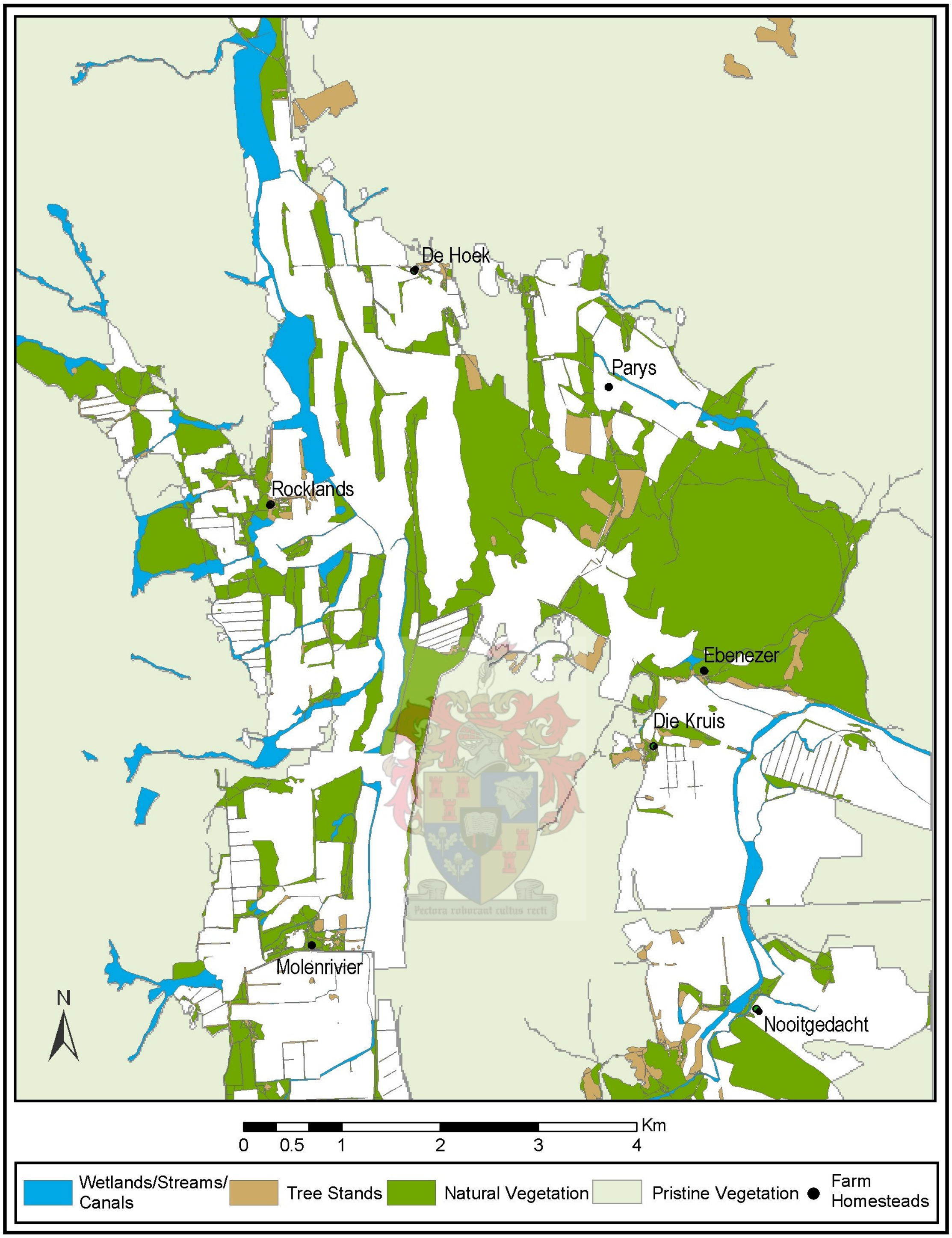


Figure 2.7 Natural land cover elements of the study area

natural habitat remnants is obvious, though. In the centre and towards the north-east more consolidated blocks of natural vegetation remain, although some blocks have been disturbed in the past but are now in slow recovery. The landscape metrics which were calculated in this chapter provide a baseline for future monitoring of the state of the study area. They were calculated for the developed portion of the study area. Chapter 3 investigates the topography of the full study area and how this can be used to investigate landscape function.

CHAPTER 3: TOPOGRAPHICAL ANALYSIS AS AN INDICATOR OF LANDSCAPE FUNCTION

Topography has a controlling effect on ecological processes occurring in the landscape and topographical analysis can therefore aid in a better understanding of landscape function. In this chapter an overview of topographic attributes and their relation to landscape function is given, followed by calculation of these attributes and the creation of a set of landform elements. Watersheds are also demarcated and discussed in context of the land cover and landform.

3.1 Topography as an aid to understanding landscape function

Terrain plays a fundamental role in modulating earth surface and atmospheric processes (Hutchinson & Gallant 2000). Relief forms the basis of a landscape's structure and plays a key role in ecosystems due to its structure-forming, process-regulating effect (Klink 2002). Relief can be seen as an ecologically indirect or regulating factor. The influence of relief takes effect via climate, soil formation, and the water and nutrient supply. Ingegnoli (2002) agrees that geomorphology is one of the factors that regulate landscape functions and has a strong ecological significance. Viglizzo et al (2004) carried out research on controls on ecological functions. Landform, climate and land quality were generally considered to be strong large-scale top-down environmental controls which determine geographic patterns of energy, nutrient and water flows and cycles. Topography can therefore be seen as controlling the distribution, redistribution and accumulation of water and energy in the landscape (Schmidt 2003; MacMillan, Jones & McNabb 2004).

3.2 Overview of topographic attributes and their relation to landscape function

Primary and secondary attributes can be derived from the DEM. Primary attributes are those computed directly from the DEM such as slope and aspect (first-order derivatives), and plan and profile curvature (second-order derivatives) (Wilson & Gallant 2000). Table 3.1 provides the most common primary attributes. Secondary attributes are derived from combinations of primary attributes. They often include simplified equations that represent the underlying physics of natural processes. The compound topographic index (CTI) and solar radiation are examples. The amount of solar radiation reaching an area is determined by aspect and slope gradient. The CTI is used to predict relative soil moisture values and describes the effects of topography on the location and size of areas of water accumulation in topographically complex landscapes. It determines the relative likelihood of saturation/wetness and takes into account the local slope geometry and specific catchment area of the landscape.

Table 3.1 Primary topographic attributes

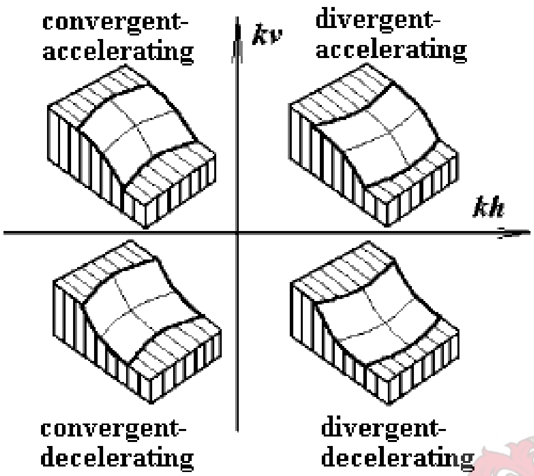
Attribute	Definition	Units/Measurement
Slope	Rate of change of elevation in direction of steepest descent	Percent or degrees
Aspect	Orientation of line of steepest descent	Degrees clockwise from north
Primary flow direction	Primary flow direction for water moving over the land surface	Cardinal or intermediate direction to the nearest neighbour with a maximum gradient
Plan curvature	Rate of change of slope in an across slope direction	Degrees per 100m
Profile curvature	Rate of change of slope in a down slope direction	Degrees per 100m

Sources: Irvin, Ventura & Slater 1997; Gallant & Wilson 2000.

Slope is the means by which gravity induces the flow of water and other materials and therefore affects the velocity of substance flows (Florinsky et al 2002). By affecting surface and subsurface flow velocity, slope influences soil-water content, erosion potential and soil formation (Gallant & Wilson 2000). As slope increases so does the intensity and frequency of the processes related to substance flows such as soil erosion. The degree of radiation exposure and temperature is also influenced by slope (Hoersch, Braun & Schmidt 2002). Relatively flat areas will be more exposed to the sun and have a higher temperature than south-facing slopes, but receive less radiation and have lower temperatures then north-facing slopes.

Slope aspect affects the direction of substance flows (Florinsky et al 2002) as well as the degree of radiation and therefore temperature (Hoersch, Braun & Schmidt 2002). In the southern hemisphere and therefore the study area, slopes facing north will have the most exposure to the sun and therefore a higher average temperature than slopes facing east and west, with south-facing slopes receiving the least radiation of all. As slope increases the influence of aspect on surface processes increases. Shadowing from other topographic features will also influence the effect of aspect on surface processes (Gallant & Wilson 2000).

Profile and plan curvature can be used to represent accumulation of material (Shary 2002), with each representing a different accumulation mechanism. Plan curvature measures topographic convergence and divergence and therefore the tendency of water to converge as it flows across the land. It affects exposure to wind, soil moisture and radiation (Hoersch, Braun & Schmidt 2002). Profile curvature is important for characterizing changes in flow velocity and sediment transport processes (Gallant & Wilson 2000) and can be used to highlight zones of enhanced erosion or deposition. Figure 3.1 illustrates the various combinations of profile and plan curvature that could occur. Kh represents horizontal (plan) curvature and kv vertical (profile) curvature.



Source: Shary 2002.

Figure 3.1 Troeh's land form classification based on horizontal curvature (kh) and vertical curvature (kv) signs

A convex profile is responsible for an acceleration of flow as slope increases downhill. A concave profile indicates a deceleration in flow as slope decreases downhill. Profile curvature influences soil moisture, as well as the intensity and frequency of natural processes (Hoersch, Braun & Schmidt 2002). Converging and decelerating (concave) forms are potential sites of higher soil moisture or relative accumulation due to water accumulation caused by the deceleration of flow and topographic convergence (Shary 2002; Schmidt 2003). Diverging and accelerating (convex) forms are sites of relative deflection.

3.3 Calculation of topographic attributes

By calculating the topographic attributes of slope, profile curvature and plan curvature, a better understanding of landscape function can be reached. These attributes also form the foundation for the calculation of landform elements.

3.3.1 Slope

Figure 3.2 shows the slope for the study area calculated from the DEM using the 3D Analyst in ArcGIS 8. Both normal and standard deviation classifications of slope are shown. The

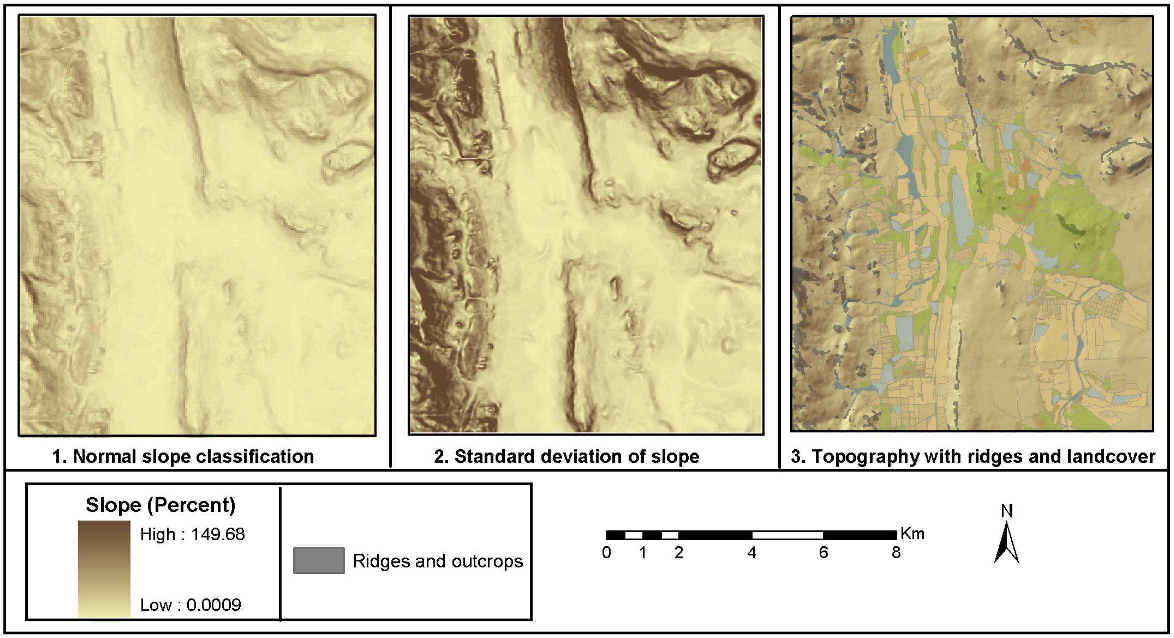


Figure 3.2 Slopes over the full study area

standard deviation allows areas with a sharp contrast in elevation or surface roughness such as rocky outcrops, ridges and cliff-lines to be identified. These areas can act as ecological barriers in the landscape, or ecologically unique areas. In the north and west of the study area relief is exceptionally sharp and pronounced. In the centre and south-east it is relatively flat. The steeper areas will have a higher flow velocity and therefore a higher intensity of soil erosion and other processes related to substance flows. The third map in Figure 3.2 shows the land cover theme, hill-shade of the DEM and those areas of high standard deviation where ridges and outcrops occur. A DEM with a finer resolution will be able to give a better idea of surface roughness of the landscape, especially in the lower-lying areas where most of the agricultural land cover is to be found. The lower lying areas have more exposure to the sun due to their low slope gradients and therefore experience higher temperatures.

3.3.2 Profile curvature and plan curvature

Profile and plan curvature were calculated using the DEMAT extension in ArcView 3.3 (Behrens 2000). Plan curvature allows for differentiation between converging or diverging landforms, while profile curvature allows for differentiation between convex and concave slopes (Gallant & Wilson 2000). A negative value represents topographic convergence, a positive value topographic divergence and a zero value flat surfaces (Figure 3.3). For profile curvature, a convex slope, where a deceleration in flow occurs, is represented by a positive value. A concave slope, where flow acceleration occurs, is represented by a negative value (Figure 3.3). Profile and plan curvature were combined to get an overall view of how the

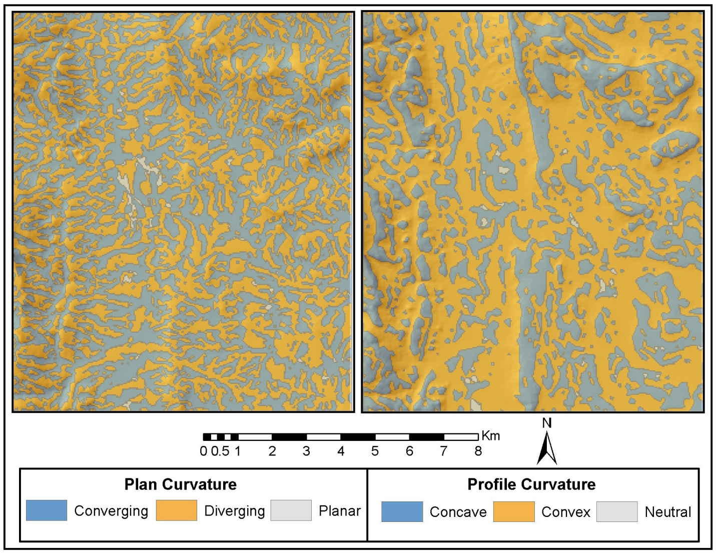


Figure 3.3 Profile and plan curvature of the study area

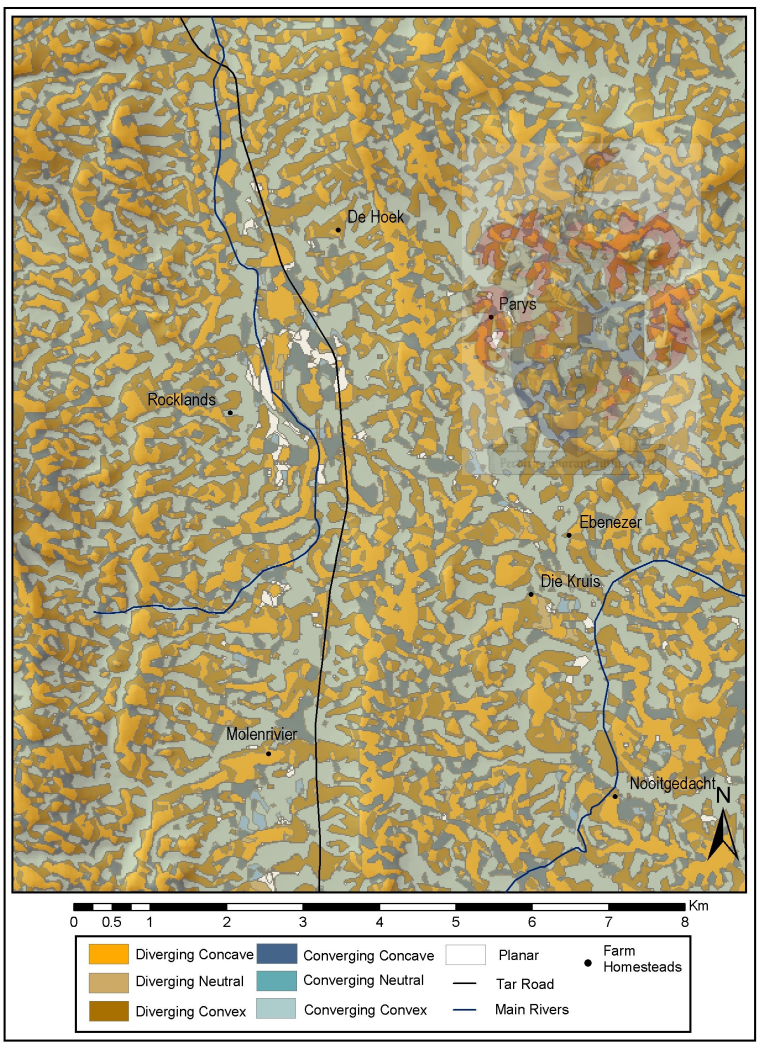


Figure 3.4 Combined curvature classification of the study area

curvature affects the accumulation and deflection of water and other materials in the landscape (Figure 3.4).

Converging and concave curvatures are potential sites of water accumulation, deposition and higher soil moisture due to the accumulation of water, while diverging and convex curvatures can be considered as areas where deflection of water occurs. The blue shades in Figure 3.4 represent areas of accumulation, while the orange shades represent areas of deflection. This combination of curvatures is used to calculate landform elements in the following section.

3.3.3 Landform elements calculated from topographic attributes

Landforms are natural terrain units which can be used to represent landscapes at various scales. They are a result of the interactions of physical, chemical and biological processes acting on the surface. Mathematically landform can be viewed as a continuous surface covering the earth (Dehn, Gartner & Dikau 2001). Much of the research dealing with classification of landform from DEMs has been related to soil surveying and soil-landscape studies (Irvin, Ventura & Slater 1997). This is due to the fact that the processes of erosion, geomorphology, soil function and hydrology are closely interlinked. Landforms can provide a physical framework for describing the environment and ecological processes and interactions occurring within the environment (MacMillan et al. 2000). In this study landform elements are used to aid in understanding processes in the landscape related to the transport of water and other materials.

Slope and plan and profile curvature are vital in any classification of landform units. The scale to which one can delineate landforms from a DEM is dependent upon the resolution of the DEM. Much of the research that has been carried out has been done on scales that are finer than the 20m resolution of the DEM available for use in this study (MacMillan et al. 2000; Hoersch, Braun & Schmidt 2002; MacMillan, Jones & McNabb 2004). The landform classification used in this study was adapted from the landform classification of MacMillan et al (2000) where slope and profile and plan curvature were used to classify 15 landform elements (the detail of which appears in Table A.1). These were then aggregated into 4 landform categories. This was the initial landform classification for their study and was based on Pennock's (2003) seven landform elements, also obtained using slope and profile and plan curvature. Pennock used four profile and gradient groups, which were then split on the basis of plan curvature into divergent and convergent elements.

Table 3.2 shows the classification used to map the landforms. The slope and combined curvature calculated in Sections 3.3.1 and 3.3.2 were used to create landform elements. Slope was classified into 3 classes shown in Figure 3.5. A majority filter was applied to both the

Table 3.2 Final landform element classification system for the study

Landform Code	Slope	Curvature: Profile	Curvature: Plan	Process Effect
1	0 -17%	Concave	Converging	Accumulation
2		Neutral		
3		Convex		
4		Concave	Diverging	Deflection
5		Neutral		
6		Convex		
7		Neutral	Planar	Neutral
8	17 - 42%	Concave	Converging	Accumulation
9		Convex		
10		Concave	Diverging	Deflection
11		Convex		
12	42 -150%	Concave	Converging	Accumulation
13		Convex		
14		Concave	Diverging	Deflection
15		Convex		

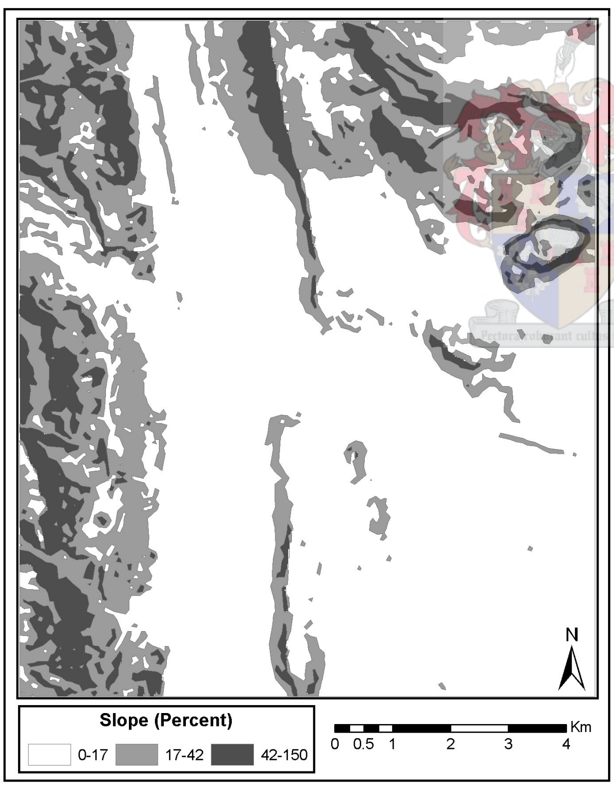


Figure 3.5 Slope classification for landform elements

slope and curvature to generalize the detail of the classes, before converting the raster files to vector format. Slope and curvature were then unioned and the final classification of 15 landforms was obtained. In the two higher slope areas there were minimal planar curvature elements, which were not included in the final classification.

Figure 3.6 shows the final landform classification. Landforms 1-3, 8-9 and 12-13 represent zones where accumulation can occur and landforms 4-6, 10-11 and 14-15 zones where deposition can occur. Landform 7 is planar and is therefore a neutral zone that covers only a small proportion of the study area. Landforms 12-15 (represented by darker shades), where slope gradient is high, will have a greater degree of erosion and water shedding due to increased flow velocity. Drainage lines were created from the DEM and when overlain on the landform classification, it was found that, as expected, the vast majority of the streams are found in converging landforms (the blue landform shades).

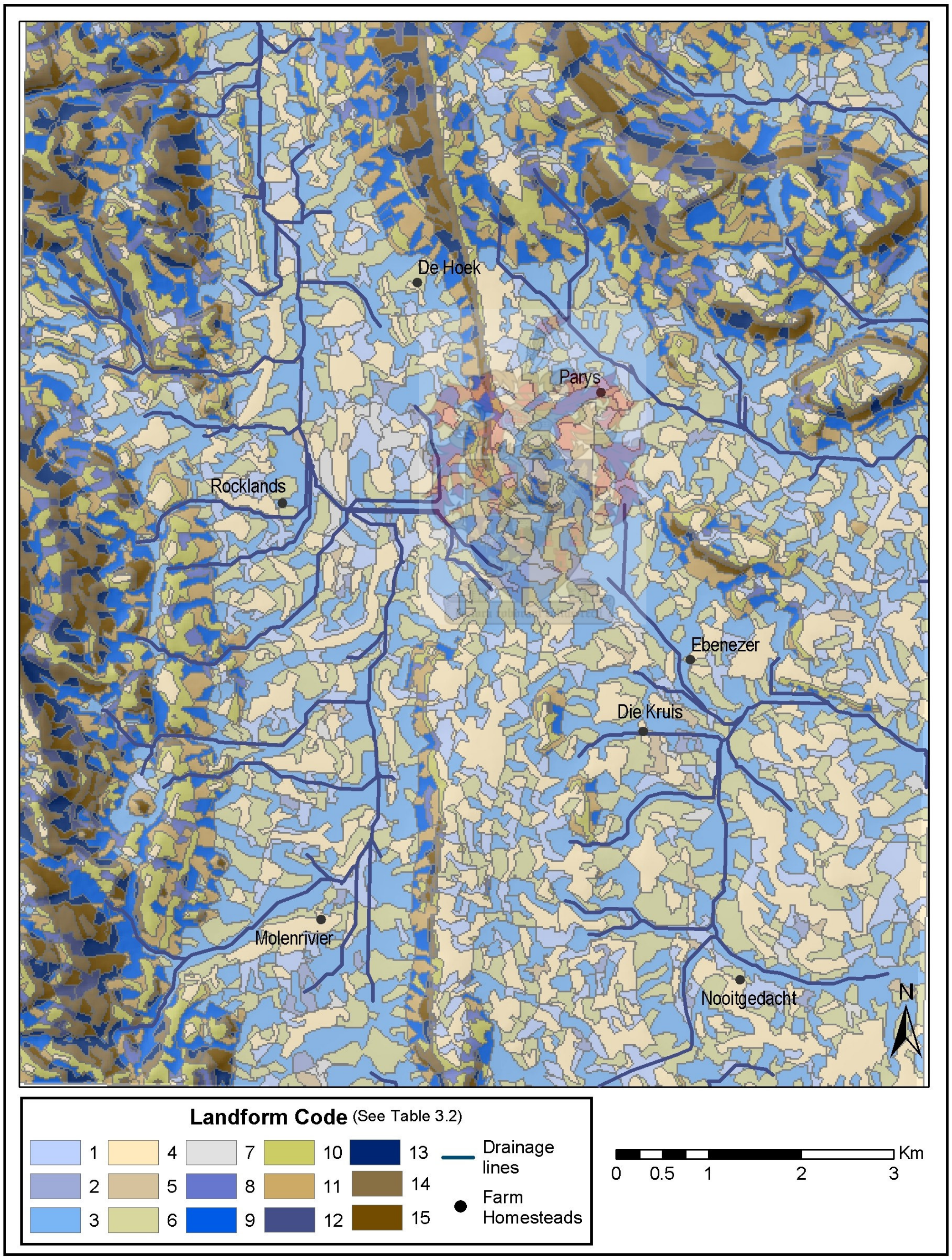


Figure 3.6 Landform elements

3.4 Watershed delineation

Drainage networks, streams and catchments or watersheds are important properties of real landscapes that can contribute to the understanding of material flows (Burrough & McDonnell 1998). A watershed can be defined as the up-slope area contributing flow to a given location. Watersheds are increasingly recognized as functional and optimal geographical areas that integrate a variety of processes and human impacts on landscapes (Aspinall & Pearson 2000). Drainage basins, catchments and sub-catchments are often used as fundamental management units. The approach of a nested series of water sub-catchments constructed within a larger catchment has proved of great use in dividing the landscape into functionally similar areas (Adinarayana & Rama Krishna 1995). Watersheds for the study were delineated using the Hydrological Modelling extension in ArcGIS 8 and are shown in Figure 3.7.

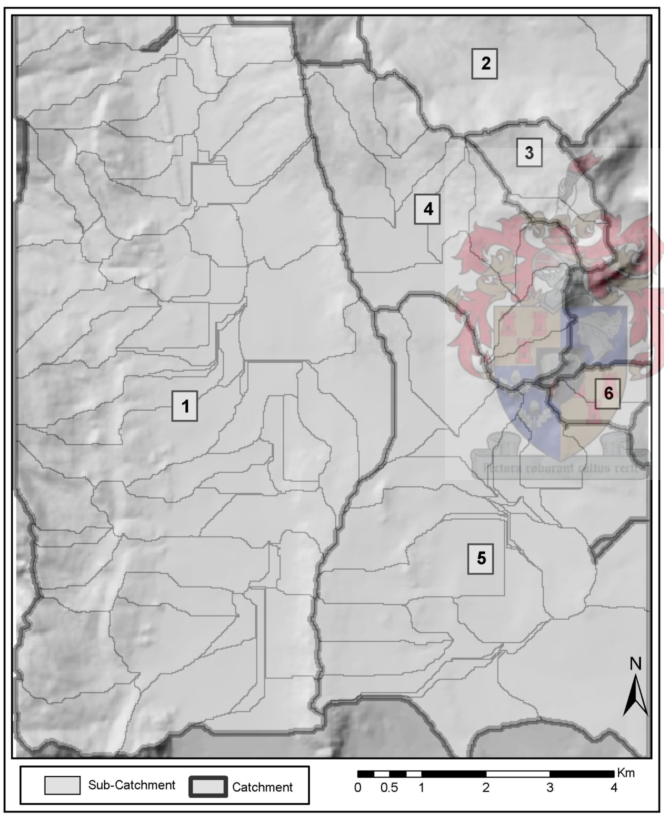


Figure 3.7 Catchments and sub-catchments

Six main catchments (1-6 in Figure 3.7) were identified with a number of sub-catchments. Due to the artificially rectangular study area boundary the catchments are incomplete in some areas. Catchment 1, defining runoff in the western section is by far the largest and forms the source for the Houdenbeks River flowing northwards out of the study area. The eastern section is mostly drained by the Kruis River sourced outside the study area in the south-west. Catchments 2-6 are tributaries producing runoff towards this main channel.

3.5 Land cover in context of landform elements and watersheds

Figure 3.8 shows the land cover and landform overlaid by the watersheds. The largest watershed is to the west, and the five smaller watersheds to the east. Catchments 2 and 3 occur in pristine vegetation. Catchment 5 is in a largely flat, cultivated area.

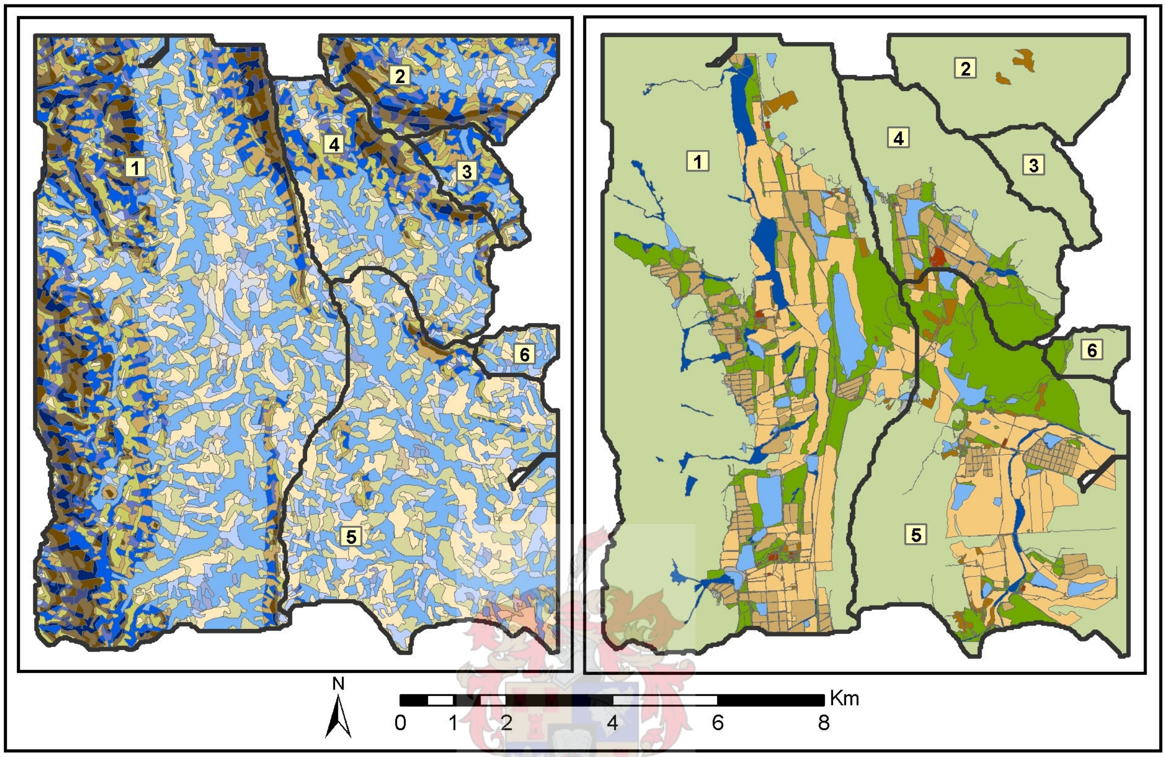


Figure 3.8 Landform elements and land cover in context of watersheds

Figure 3.9 shows all the water related areas of the landscape used in this study. The natural elements derived from the DEM include the accumulation zones derived from the landform elements, the watersheds and the drainage lines. The wetlands/canals/streams and dams in most cases represent modifications by man, with only some of the wetlands occurring in their original state. They all correlate well with one another spatially. Figure 3.10 shows the agricultural land uses in the context of the areas of water accumulation.

In this chapter, an overview of topographical and hydrological aspects of the study area was obtained. Chapter 4 focuses on improved management of the agricultural landscape through improving natural habitat connectivity.

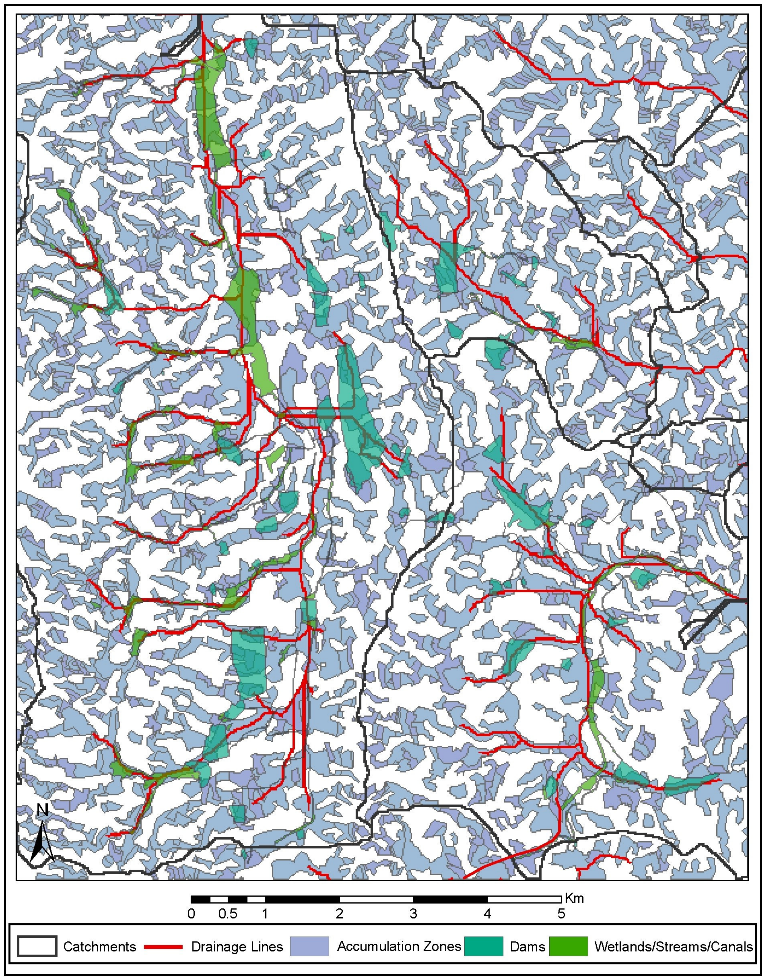


Figure 3.9 Areas in the landscape where water accumulation occurs

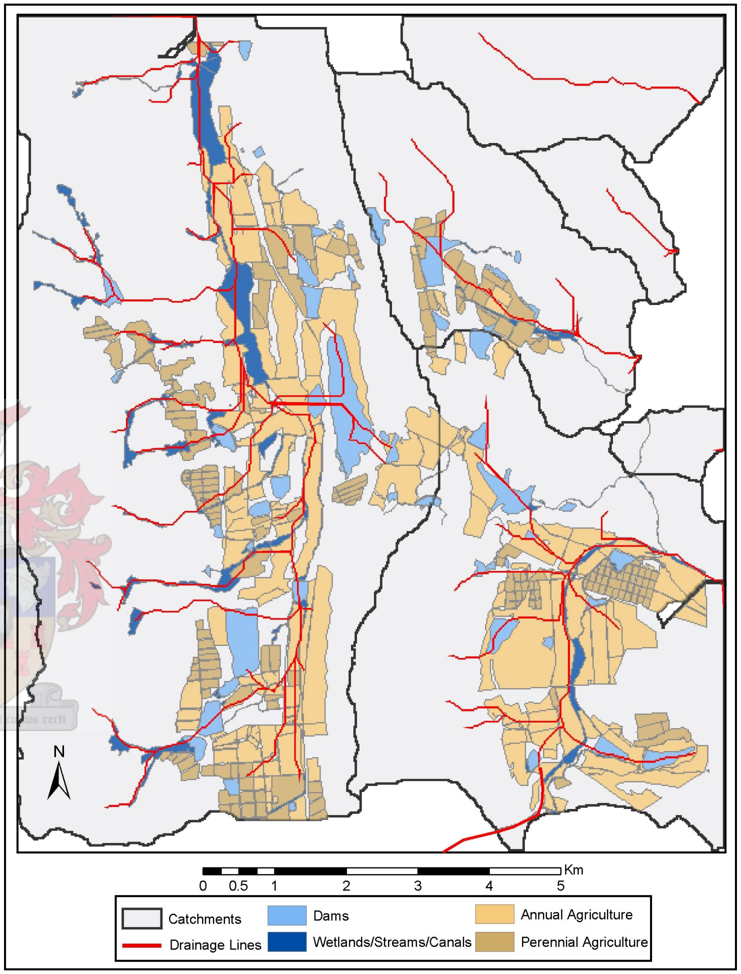


Figure 3.10 Agriculture in context of water accumulation areas

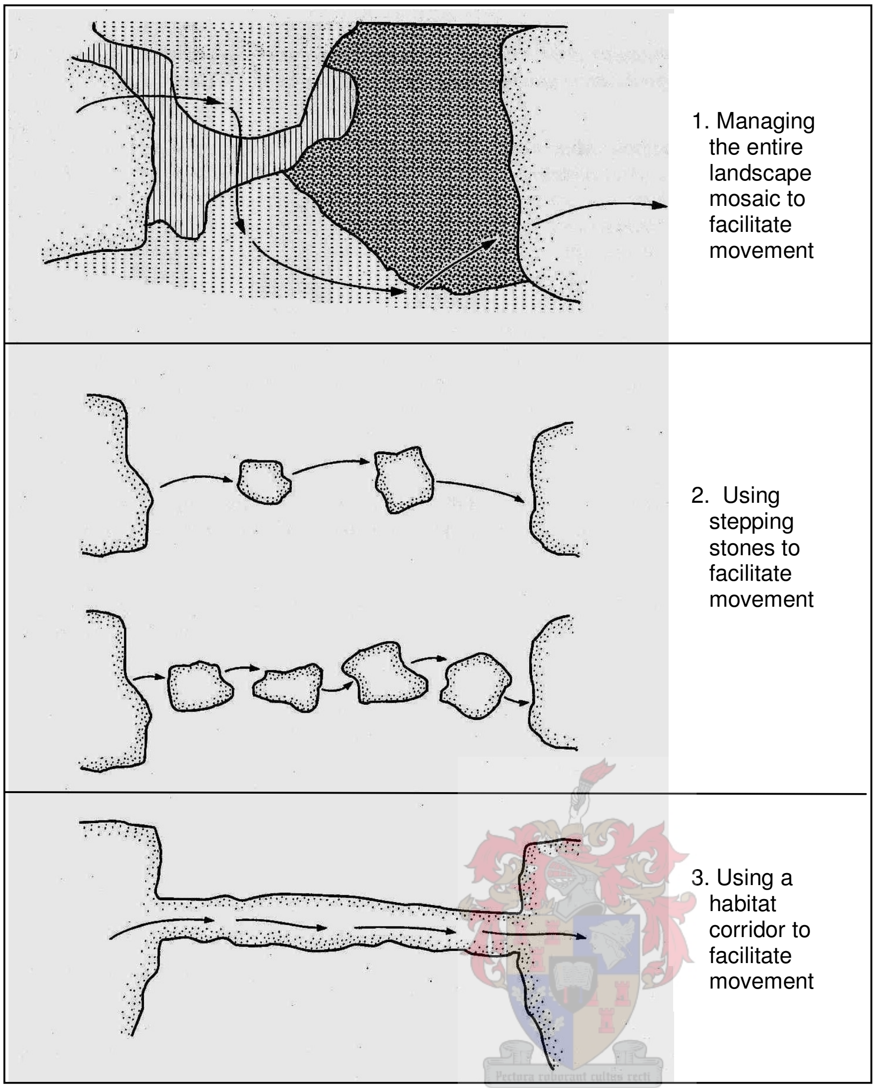
CHAPTER 4: ECOLOGICAL LINKAGES IN THE AGRICULTURAL LANDSCAPE

Bennett (2003) is of the opinion that a primary goal of conservation planning in developed regions should be the delineation of linked systems of habitat within the broader context of an integrated landscape approach to conservation. The main function of linkages is to increase the connectivity of the landscape. Landscape patterns that promote connectivity for species, communities and ecological processes are a key element in agricultural areas where natural vegetation is often fragmented. The types and functions of linkages are first discussed. This is followed by an overview of the design and management of linkages and the delineation of an ecological network for the study area.

4.1 Types of linkages

A linkage refers to an arrangement of habitat that enhances the movement of animals or the continuity of ecological processes through the landscape (Vos, Baveco & Grashof-Bokdam 2002). Bennett (2003) identifies two main approaches to achieving landscape connectivity: managing the entire landscape mosaic to facilitate movement or maintaining specific habitats that assist movement through an inhospitable environment. These specific habitats may be in the form of stepping-stones of various sizes and spacing or habitat corridors that provide a continuous connection of favoured habitat. Figure 4.1 provides an illustration of each approach. Whether stepping-stones or a habitat corridor should be used depends on the types of species for which the linkage is being designed. Stepping-stones of suitable habitat allow species to be able to make short movements through disturbed environments.

The term ‘corridor’ is often used in ways that can be contradictory and confusing (Hess & Fischer 2001). In this study, corridors are referred to as a type of linkage which aids in improving connectivity. Habitat corridors provide a continuous link of suitable habitat through an inhospitable environment (Bennett 2003) and can be defined structurally and functionally. The structural definition defines a corridor as a narrow/linear feature of vegetation or land which differs from the surrounding vegetation and connects at least two patches, which were once connected in historical time (Merriam & Saunders 1993; Forman 1995). The functional definition sees corridors as providing for the movement of flora and fauna from one area to another. Examples of habitat corridors include landscape linkages, remnant roadside vegetation, linear vegetation habitats and riparian vegetation. These are especially important as they can act as ecological elements in the agricultural landscape. They are each discussed in more detail below.



Source: Bennett 2003:51.

Figure 4.1 Approaches to achieving landscape connectivity

Landscape linkages provide major links through the environment at the landscape or regional scale. Broad tracts of natural habitat between conservation reserves and major river systems and the riparian zones accompanying them are examples of landscape linkages (Bennett 2003). The road reserve is the total strip of land that is reserved for transportation purposes (Bennett 1991) and roadside vegetation can be seen as the strip of vegetation between the road surface and the boundary of the road reserve. There is much concern about the detrimental effect of road systems, but their high level of structural connectivity may be advantageous for species that are able to use roadside habitats. The type and quality of habitats on roadsides varies greatly, but their value should not be underestimated (Carr, Fahrig & Pope 2002).

Fischer & Fischenich (2000:1) describe riparian vegetation as “long, linear strips of vegetation adjacent to streams, rivers, lakes, reservoirs and other inland aquatic systems that affect or are affected by the presence of water”. They occur as transitional areas between aquatic and upland terrestrial habitats and have been widely recognized as functionally unique and dynamic ecosystems, having become a major focus in landscape restoration and management. They typically comprise a small percentage of the landscape, often less than one percent, yet provide for a high number of wildlife species and perform a distinct number of ecological functions when compared to other habitats (Fischer & Fischenich 2000).

Hedgerows, fencerows and field margins are part of a diverse group of linear vegetated habitats that occur in rural environments worldwide (Bennett 2003). Hedgerows are linear strips of shrubs and small and sometimes large trees planted along boundaries of fields. Fencerows are not deliberately planned, but are narrow strips developed by regeneration and dispersal of plants in a neglected strip of land between fields. Other linear strips of vegetation such as shelterbelts, windbreaks, tree rows and plantations, which are planted for a variety of purposes, form part of this category (Fritz & Merriam 1996). These features share the characteristics of being linear in shape, frequently providing links between remaining natural and semi-natural habitats in rural environments and being closely associated with agricultural structure and composition strongly influenced by past and present agricultural land management (Bennett 2003).

4.2 Functions of linkages

Whether in the form of habitat corridors, stepping stone patches or habitat mosaics, all linkages are part of the landscape and contribute to its structure and function (Bennett 2003). It is well known that linkages can potentially assist movements of animals through inhospitable environments and provide habitat, but little consideration is given to the other ecological roles they play. Whether or not a linkage carries out a specific function or not depends on the structure and content of the linkage. There has been much discussion on the merit of corridors (Beier & Noss 1998; Haddad, Rosenberg & Noon 2000). Noss (1991) sees the successful use of corridors in wildlife management for over fifty years as verifying the utility of corridors as a conservation tool. Linkages are often set up as a magic solution to environmental problems. They are most definitely part of the solution but not the only solution. Just because a linear piece of habitat has the structure of a linkage does not necessarily mean it will carry out the functions of a linkage. Figure 4.2 illustrates the various functions that linkages can perform and is further discussed below.

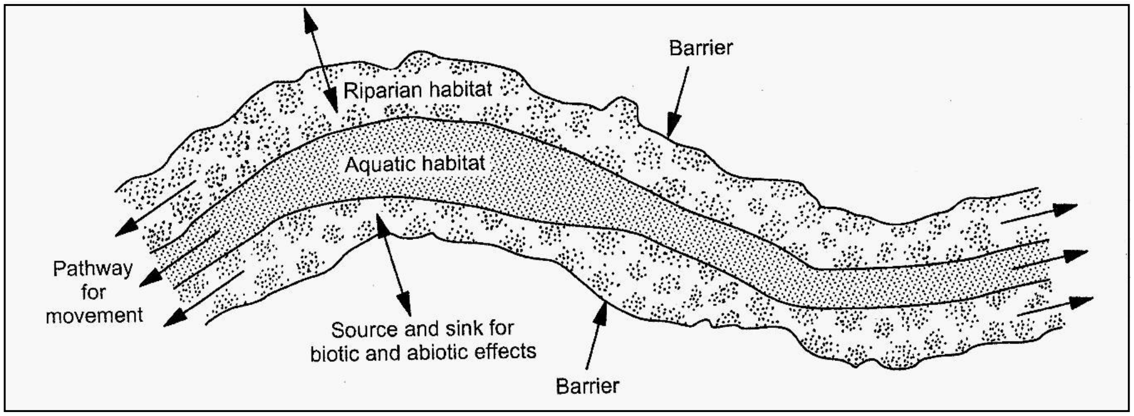


Figure 4.2 Functionality of a riparian zone Source: Bennett 2003:44.

Linkages can provide habitat for flora and fauna. A linkage providing habitat passively increases habitat connectivity (McGarigal, Berry & Buckley 2004). In a modified landscape, linkages such as riparian vegetation (Figure 4.2), hedgerows and forested strips are important and provide habitat for a wide range of plants and animals (Bennett 2003). If a linkage does not perform any other function the one thing that it does do is provide habitat (Recher 1993; Scougall, Majer & Hobbs 1993). Linkages serving as habitat make a direct contribution to the conservation of biodiversity and can be an important refuge for rare and threatened species (Bennett 2003).

Linkages can act as conduits for various species. Linkages facilitating movement actively increase habitat connectivity (McGarigal, Berry & Buckley 2004; Debinski & Holt 2000). This is the most common application of linkages. Increased connectivity assures regional survival of scattered and isolated populations (Merriam & Saunders 1993) and increased species richness (Debinski & Holt 2000). This is especially true in fragmented habitats, where the probability of local extinction of small populations is lessened (Collinge 1996; Wiens 2002). The riparian and aquatic habitat in Figure 4.2 illustrate habitat serving as pathways for movement.

Linkages can act as a filter or barrier. They prohibit or differentially impede the flow of energy, mineral nutrients and/or species across corridors (McGarigal, Berry & Buckley 2004). This can occur in a negative or positive manner. Disturbance corridors of human origin such as roads function as barriers in the landscape, while wetlands or riparian corridors filter out pesticides and fertilisers (Fischer & Fischenich 2000). Rows of trees can act as a barrier keeping out wind and thereby protect crops. In Figure 4.2 the riparian habitat serves as a filter and a barrier to certain species.

Linkages can function as sources or sinks of environmental and biotic effects. They can modify the inputs of energy, nutrients and/or species to the surrounding matrix (McGarigal, Berry & Buckley 2004). Roads can be a source of chemical and physical pollutants from cars and introduce invasive species into environments (Bennett 1991). Riparian vegetation can act as a sink that limits the flow of chemicals, nutrients and particulate matter into streams (Fischer & Fischenich 2000). A linear habitat can act as a source when animals in the habitat move out to forage in adjacent habitats and as a sink by providing shelter, nesting sites, or refuge for species in the surrounding environment. Figure 4.2 shows riparian habitat serving as a source and sink.

4.3 Linkages as ecological elements in the landscape

Much of the focus on linkages has been on their function as conduits for movement, with little thought to the other roles they can play. Bennett (2003) identified riparian vegetation, landscape links, forest linkages, roadside fragments and linear vegetation habitats as important ecological elements in the landscape. The last three are especially applicable in the agricultural landscape and their functions are highlighted below.

4.3.1 Riparian vegetation

The many functions provided by riparian vegetation are illustrated in Figure 4.2. Riparian habitats situated between crop fields and watercourses are vital for the maintenance of water and soil quality (De Snoo & de Wit 1998; Boutin, Jobin & Belanger 2003) and play an important role in reducing nutrient loading to streams in agricultural watersheds (Cey et al. 1999). Riparian zones provide stream bank stabilisation and downstream flood attenuation. The density and types of vegetation bordering streams and riverbanks are crucial elements, largely responsible for water-quality maintenance in areas with high agrochemical inputs (Blanchard & Lerch 2000; Schulz & Peall 2001). There is solid evidence that providing riparian buffers of sufficient width protects and improves water quality by intercepting nitrogen, potassium, sulphur and phosphate (Peterjohn & Correll 1984, Fischer & Fischenich 2000).

Riparian zones also provide habitat for a large variety of plant and animal species and can have a major effect on regional biological diversity (Bennett 2003). The presence of water and other riparian zone characteristics such as slope and soil create conditions for the support of plants and animals (Collinge 1996). Riparian zones shade aquatic habitats and provide organic matter such as leaves and woody debris that are critical for aquatic organisms (Fischer

& Fischenich 2000). The vegetation present influences the plant and animal species found in the riparian zone. Bird species abundance and richness were found to be greater in wooded and tall shrubby riparian zones in a study by Deschenes, Belanger & Giroux (2003). Maisonneuve & Rioux (2001) found that abundance of small mammals and herpetofauna increased with complexity of vegetation structure. Riparian zones have the potential to be habitat components that promote faunal movement, enhance gene flow and provide habitat, and can make a large contribution to maintaining indigenous species in modified landscapes (Bennett 2003).

4.3.2 Linear vegetation habitats

Linear vegetation habitats such as hedgerows have an important function in the landscape due to their relationship with other landscape components through the flow of wind, water, nutrients, energy and biota (Fritz & Merriam 1996). In France extensive clearing of hedgerow networks led to widespread ecological problems: soil erosion, flooding, wind damage and crop diseases (Baudry & Burel 1984). By influencing microclimatic conditions linear vegetation habitats exert a major influence on the rural environment. Wind speed and evaporation are reduced downwind, while daytime temperatures, soil moisture and atmospheric moisture are increased. Shading occurs in a narrow band next to the vegetation. The surface runoff and subsurface flow of water across agricultural land is slowed down and intercepted, and soil erosion potential is reduced (Burel & Baudry 1995).

Linear vegetation habitats provide important habitat for wildlife in rural areas (Burel & Baudry 1995). Their presence significantly increases the diversity of birds in farmland and sites with hedges, ditches or linear woods have more species than comparable areas of arable land. Boutin, Jobin & Belanger (2003) found that bird use of field margins was mostly related to the structural complexity and dimension of the vegetation. Linear vegetation habitats do not often provide habitat for rare species but by forming networks together with remnant natural habitat, they have a significant role in sustaining a broad range of wildlife species and enhancing biodiversity within rural environments (Bennett 2003).

Boutin, Jobin & Belanger (2003) came to the conclusion that conserving natural hedgerows, minimizing mechanical and chemical control of vegetation in field margins and planting a mix of deciduous and coniferous species in windbreaks represents an efficient conservation strategy from a wildlife and agronomic perspective. The ecological impacts of linear vegetation habitats can extend across large areas, far beyond the immediate environment of the linear vegetation. Their properties can be manipulated for ecological and agricultural benefits in rural environments by careful location, orientation and spacing of vegetation, and management of the vegetation (Forman 1995).

4.3.3 Roadside vegetation

Roadside vegetation can contribute substantially to the natural habitat in the landscape, as well as facilitating movement of fauna (Saunders & Hobbs 1991). Birds are the most conspicuous species of wildlife on the roadside and numerous studies have investigated them using roadside vegetation as habitat (Meunier, Verheyden & Jouventin 1999; Foppen, Chardon & Liefveld 2000; Bennett 2003; Schocat et al. 2005). Roadside avifauna are often dominated by common species dependent on the composition of roadside vegetation. The structure of the vegetation influences species richness and abundance more than the width of vegetation. Roadside verges can provide favourable habitat for birds if they provide a complementary habitat to dominant habitat in the landscape (Meunier, Verheyden & Jouventin 1999). Roadside vegetation also provides habitat for invertebrates and mammals (Keals & Majer 1991).

4.4 Optimal design and management of linkages: considerations and suggestions

In a disturbed landscape an ideal system of habitats to maintain landscape connectivity cannot be designed. The challenge is how to best manage remnant linkages that have survived in heavily disturbed landscapes, maximize landscape connectivity by using habitats retained primarily for other purposes and restore connectivity between vestiges of natural habitats that remain after development (Bennett 2003). Corridors should be viewed as one of a suite of strategies in planning projects aimed at habitat conservation or restoration. Whether corridors are effective or not depends on the degree of connectivity they can achieve (Merriam & Saunders 1993). One cannot assume that just by placing or identifying a corridor as a linkage in a landscape that it will perform all six functions. In some cases corridors provide a conservation/movement network, while in others they just provide additional habitat (Recher 1993). The function of providing habitat and increasing the effective size of fragments is enough on its own to warrant the existence of a corridor.

4.4.1 Biological purpose of the linkage

It is emphasized throughout the literature that in order for corridors and linkages in the landscape to be used effectively, they need to be designed and managed with a specific function in mind. Clearly identifying the purpose of a linkage is important. Common purposes are (Bennett 2003):

- Assisting the movement of wide-ranging/migrating animals through developed landscapes;
- Facilitating the dispersal of individual animals between isolated habitats or populations;
- Promoting effective continuity and gene flow between populations in two areas by supporting a resident population within the linkage;
- Promoting continuity of habitats, communities, ecological processes between large areas such as national parks and conservation reserves;
- Providing an opportunity for populations to shift in response to change and natural catastrophes;
- Providing habitat and continuity for wildlife in conjunction with other environmental and social benefits.

4.4.2 Ecology and behaviour of the species

Different species will perceive linkages differently according to the quality of habitat it can provide (Soule & Gilpin 1991). To effectively manage habitats and increase connectivity for a specific species a basic knowledge of the ecology of that species is required (Bennett 2003). The linkage can then be tailored for optimum use by the species.

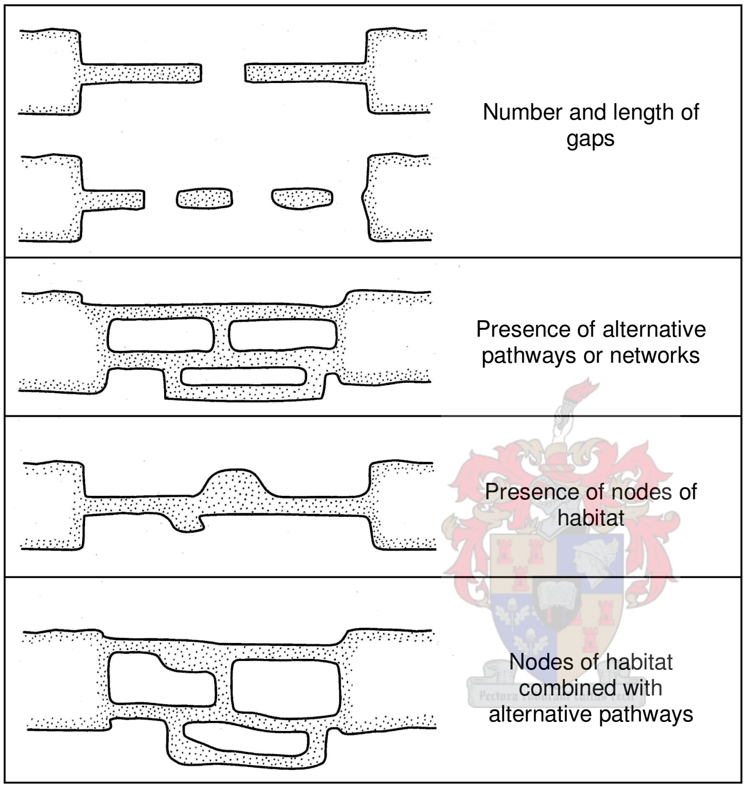
4.4.3 Quality of habitat

Animals do not recognize a linkage as a habitat linkage or a movement corridor. They see habitat and it is either suitable habitat or it is not (Bennett 2003). Habitat quality is determined by the availability and reliability of resources such as food, shelter, refuge from predators and nest sites (Bennett, Kimber & Ryan 2000) and is discussed in more detail in Section 5.2.3. Animals only moving through the linkage need adequate cover or refuge for the duration of movement and may use linkages that they otherwise would not find suitable to live in.

In order to maintain habitat quality, linkages should as much as possible be based on existing natural vegetation and not degraded or reconstructed vegetation. A high-quality habitat has a full diversity of vegetation, maintained by natural ecological processes. It is therefore vital to identify, retain and protect natural links still present in the landscape before they are lost. Where restoration of vegetation is required, priority should be given to restoration mimicking the natural environment. Restoring semi-natural vegetation or revegetating areas directly adjacent to natural vegetation can enhance the re-establishment of natural processes in new habitats (Bennett, Kimber & Ryan 2000). Linear habitats/linkages are very vulnerable to edge effects and a high level of management is required to maintain vegetation integrity.

4.4.4 Structural connectivity

Structural variables that influence the connectivity of a linkage include the number and length of gaps, the presence of alternative pathways or networks between suitable habitats and the presence of nodes of the habitat in the system. These variables are illustrated in Figure 4.3.



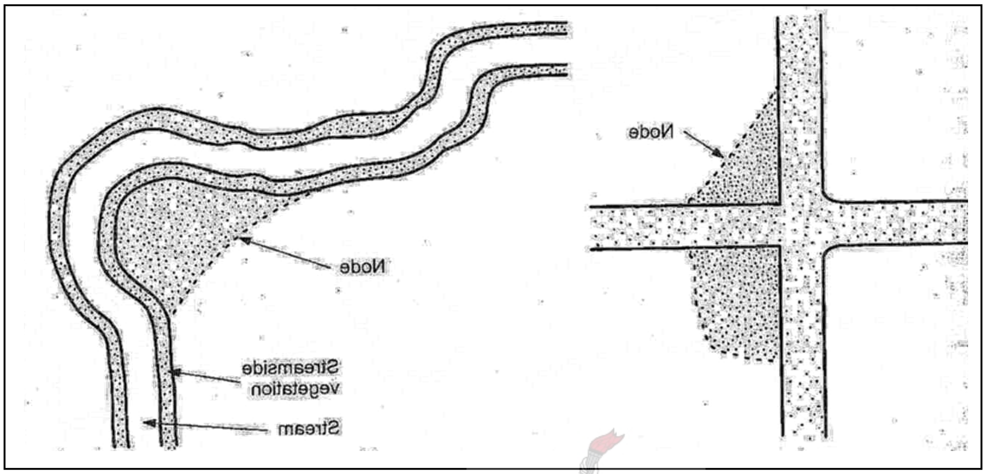
Source: Bennett 2003:129.

Figure 4.3 Factors influencing structural connectivity in an ecological linkage

The length of a linkage also influences effectiveness (Bennett 2003). As length increases:

- There is a reduced likelihood of single animals travelling through the linkage;
- There is an increased reliance on animals resident in the linkage to provide population continuity;
- The more important it becomes that the linkage provides habitat and food requirements for key species;
- There is a greater risk for animals moving through or living in the linkage of greater cumulative disturbance from adjacent habitats, e.g. predation;
- There is a greater vulnerability to sudden disturbance/catastrophe.

To counteract the risks associated with length a network of connecting habitats can be used to provide alternative pathways (Johnson 1998 in Fischer & Fischenich 2000). The width of linkages should be maximized to provide the largest possible habitat and to minimize external disturbance. Nodes of habitat can also be used to provide additional habitat and increase corridor effectiveness. Nodes at T and cross junctions in linear habitat networks are especially useful (Forman & Godron 1986) as illustrated in Figure 4.4.



Source: Bennett 2003:133.

Figure 4.4 Nodes as a measure to increase corridor effectiveness

Examples where this may be affected in the agricultural landscape would be road junctions, stream lines and meanders, field junctures and edges and outcrops disrupting continuous field cultivation.

4.4.5 Edge effects

Linkages have a high perimeter-area ratio and therefore are more prone to the edge effects described in Section 2.2.1. They include a range of physical and biological effects occurring along edges that can affect wildlife directly or indirectly through changes to habitats (Forman 1997). Microclimatic changes such as changes in solar radiation, incident light, humidity, temperature and wind speed, as well as changes in the composition and structure of plant communities occur at habitat edges (Bennett, Kimber & Ryan 2000). Changes can be expected at newly created edges following exposure from clearing. The changes to plant communities alter habitat and this benefits some species, while affecting others negatively. Species that are edge specialists or typical of disturbed lands can invade linkages and become predators, competitors or parasites of interior species (Wiens 1992). This is especially the case in linkages where the amount of edge is much greater than the edge habitat.

Besides the change in plant and animal species due to edge effects, edge habitats are prone to disturbance processes often due to activities in adjacent developed land. Examples include placement and over-extension of access tracks along edges, littering, dumping and burning of agricultural residue, and drift of fertilizers and chemicals from farmland. The extent to which edge effects extend should be considered in relation to the particular species or process being investigated (Forman 1997). The impact of edge disturbance processes is greatest where there is a sharp contrast between two types of habitat, e.g. forest/veld and farmland. Narrow habitat corridors within rural environments, such as streamside strips, hedgerows and roadside vegetation may effectively be entirely edge habitat.

4.4.6 Location of linkages

In heavily disturbed landscapes there is often no choice as to where linkages can be located. The challenge is to maintain connectivity of existing linkages or to maximize connectivity based on existing vegetation patterns. Linkages should not be established to link habitats separated by a natural barrier, but should maintain connectivity for habitats that were naturally continuous (Johnson 1998 in Fischer & Fischenich 2000; Vos, Baveco & Grashof-Bokdam 2002). In general, linkages should be located along, rather than across, environmental or topographic contours to ensure continuity of habitats for animals. Existing remnants of native vegetation can be viewed as a skeleton on which to build restoration (Bennett, Kimber & Ryan 2000). Those fragments that are of significant conservation importance should be identified and used as cornerstones of reconstruction (Lambeck & Saunders 1993).

Where possible, linkages should be located away from known sources of human disturbance such as human settlements and road systems. Designating buffer zones or establishing buffer vegetation can help to protect sensitive habitats in linkages (Vos, Baveco & Grashof-Bokdam 2002). Strips of natural planted vegetation adjacent to linkages can aid in protecting them from environmental change and other disturbance and also serve as a marker of the boundary of the linkage to limit incremental encroachment or clearing (Bennett 2003). Linkages can aid in maintaining ecological values and should be located so as to complement and enhance other resource conservation strategies.

4.4.7 Width of linkages

Maximizing the width of linkages aids greatly in increasing their effectiveness. An increase in width leads to a reduction of edge effects, a larger area and greater diversity of habitats and wildlife and an increase in the likelihood of rare species occurring. The wider a linkage, the more interior habitat there is in contrast to edge habitat. Studies have shown positive relationships between species richness of birds and width of linear habitats such as riparian vegetation, roadsides and hedgerows (Bennett 1991; Hussey 1991; Lynch & Saunders 1991). The relative composition of faunal assemblages in wide habitat corridors differs from that in narrow strips. A greater width increases the likelihood that species with requirements for large amounts of space or specialized feeding and habitat requirements will use the linkage.

The question 'How wide is wide enough?' is often asked. A linkage is wide enough when it maintains connectivity for the species for which it is intended (Vos, Baveco & Grashof-Bokdam 2002). The optimum width depends on the purpose and function of the linkage, the behavioural ecology and movements of the key species and the nature of surrounding landscape use (Bennett 2003). One measure that can be used is the distance over which edge effects affect the functioning of the linkage. If a linkage has a proportion of habitat free of disturbance twice that over which edge effects affect ecological processes, then the width is sufficient. If this cannot be determined, then the purpose of the linkage should be clearly defined and the principle 'the wider the better' should be applied. Optimum width varies greatly depending on the species using the linkage. Most existing and planned linkages are likely to be much less than the optimum width for long-term ecological function.

Table 4.1 provides recommended widths compiled from literature for the various functions of riparian corridors or buffers. Riparian buffers should be wider than 10m in order to provide water quality, stability and habitat. Widths of 100m or more are usually needed to ensure values related to wildlife habitat and use as migration corridors (Fischer & Fischenich 2000). Spackman & Hughes (1995) found that optimum riparian corridor width for species conservation depends upon the stream and the species of concern. South African land use regulations require 10m of stream bank to remain uncultivated, ensuring sufficient buffer width if complied with in agricultural practice.

4.5 Defining an ecological network for the study area

This section deals with the identification and management of an ecological network in the study area. As stated in Section 4.2, a network of linkages on their own do not make up a conservation or management plan and additional steps need to be taken. Further practical recommendations for general ecological management of the study area are laid out in Section 5.3.

Table 4.1 Recommended widths for riparian buffers.

Function	**Description**	**Recommended Width**
Water quality protection	Buffers, especially dense grassy or herbaceous buffers on gradual slopes, intercept overland runoff, trap sediments, remove pollutants and promote ground water recharge. For low to moderate slopes, most filtering occurs within the first 10m, but greater widths are necessary for steeper slopes, buffers comprised of mainly shrubs and trees, where soils have low permeability, or where nutrient loads are particularly high	5 to 30m
Riparian habitat	Buffers, particularly diverse stands of shrubs and trees, provide food and shelter for a wide variety of riparian and aquatic wildlife	30 to 500m +
Stream stabilization	Riparian vegetation moderates soil moisture conditions in stream banks, and roots provide tensile strength to the soil matrix, enhancing bank stability. Good erosion control may only require that the width of the bank be protected, unless there is active bank erosion, which will require a wide buffer. Excessive bank erosion may require additional bioengineering techniques	10 to 20m
Flood attenuation	Riparian buffers promote floodplain storage due to backwater effects, they intercept overland flow and increase travel time, resulting in reduced flood peaks	20 to 150m
Detrital input	Leaves, twigs and branches that fall from riparian forest canopies into the stream are an important source of nutrients and habitat	3 to 10m

Source: Fischer & Fischenich 2000.

4.5.1 Locating ecological network development areas

Figure 4.5 shows seven areas where existing or potential linkages would support an ecological network for the study area and therefore need to be consciously developed. The core area of relatively undisturbed vegetation is shown, as well as those areas where clearing or excavation has taken place, and which could make up part of the network once revegetated. The areas where connectivity needs to be maintained and can be improved are circled. The purpose of the ecological network will firstly be to provide habitat, and secondly to assist in the continuity of communities and ecological processes. The degree to which this is achieved will be determined to a large extent by the habitat quality of the network. Each of the seven areas is analysed in greater detail next and the structure of possible and existing linkages is discussed. Enlarged aerial views and the land cover pattern of each area is provided.

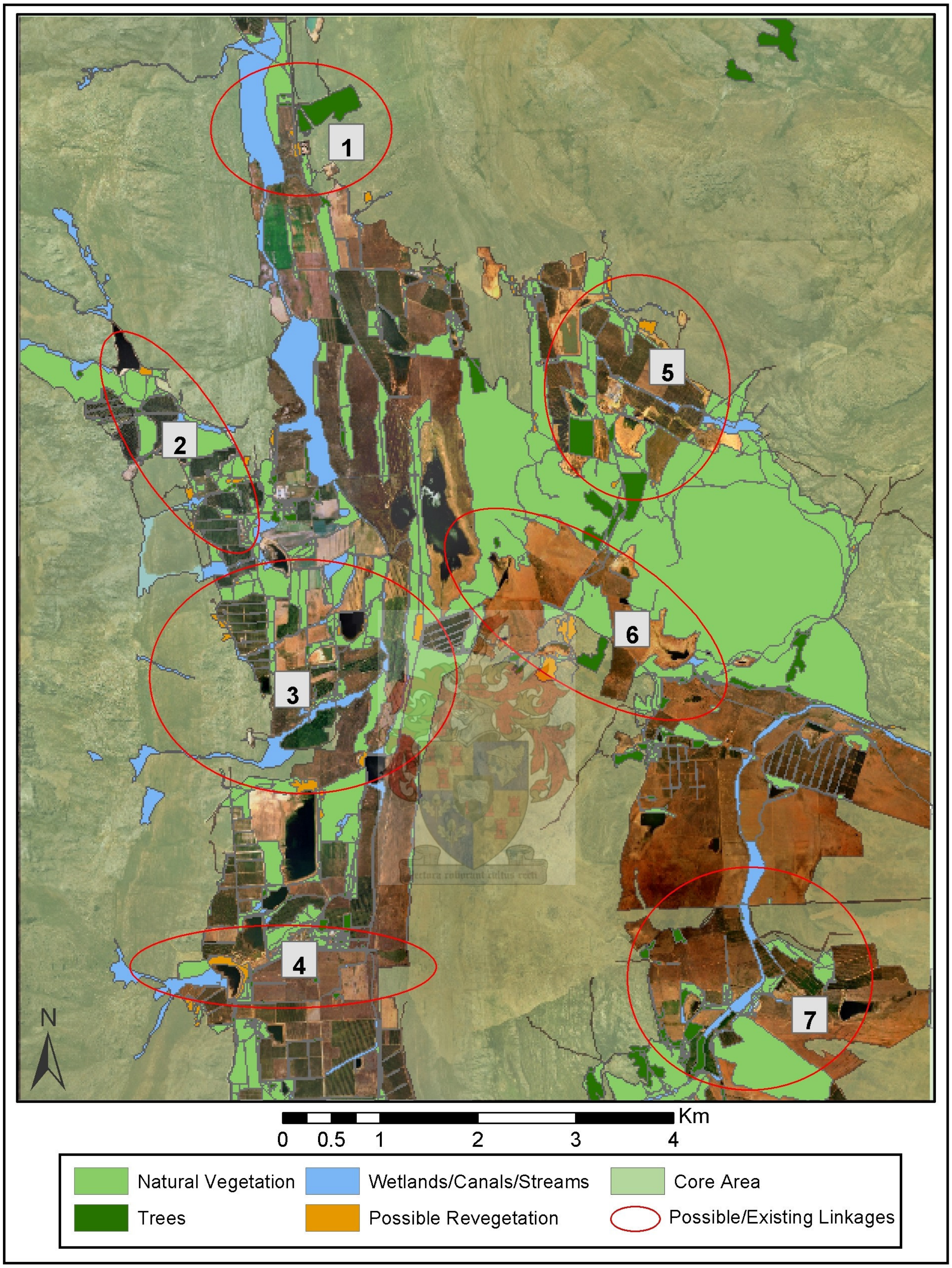


Figure 4.5 Potential linkages, ecological network components and areas for revegetation in the study area

4.5.2 Linkage area 1

In area 1, as displayed in Figure 4.6, the north-most linkage is the most important as it connects the western and eastern core areas of pristine vegetation.

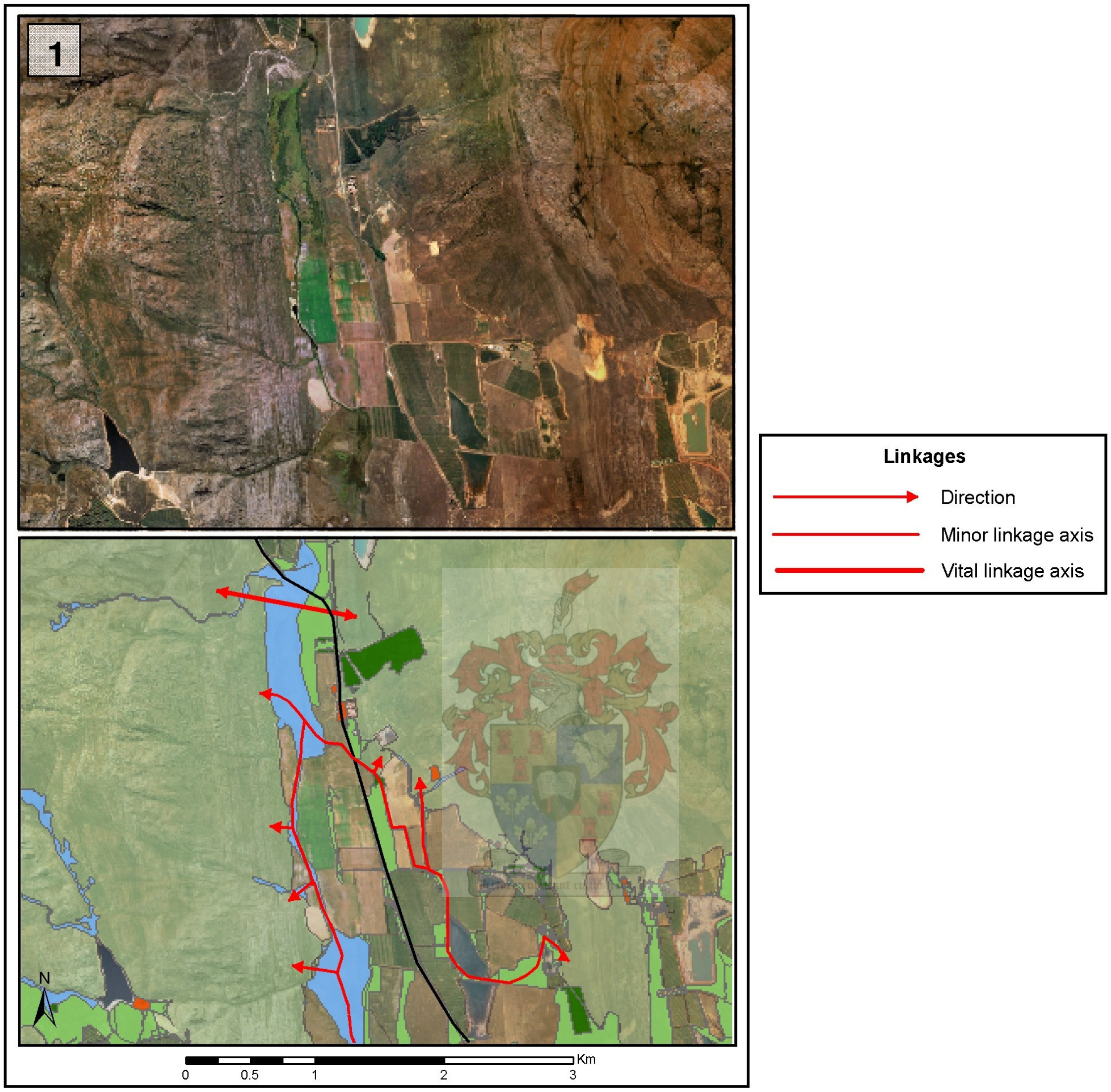


Figure 4.6 Linkage area 1

The large wetland and natural vegetation patch, which constitute this linkage, should be conserved. The tar road (black line in Figure 4.6) presents the only gap or barrier in the linkage and a crossing structure to aid in movement of animals over or under the road could be constructed. This has been done successfully to aid elk, deer and moose in crossing highways in Canada (Clevenger 2000). The other linkages in the area are relatively narrow and rely on the presence of vegetation strips adjacent to the wetlands and canals. This vegetation is often patchy and these areas therefore represent possible linkages where revegetation can increase connectivity.

4.5.3 Linkage area 2

In area 2, as displayed in Figure 4.7, there are a number of linkages and alternative pathways connecting natural vegetation patches which are of reasonable sizes.

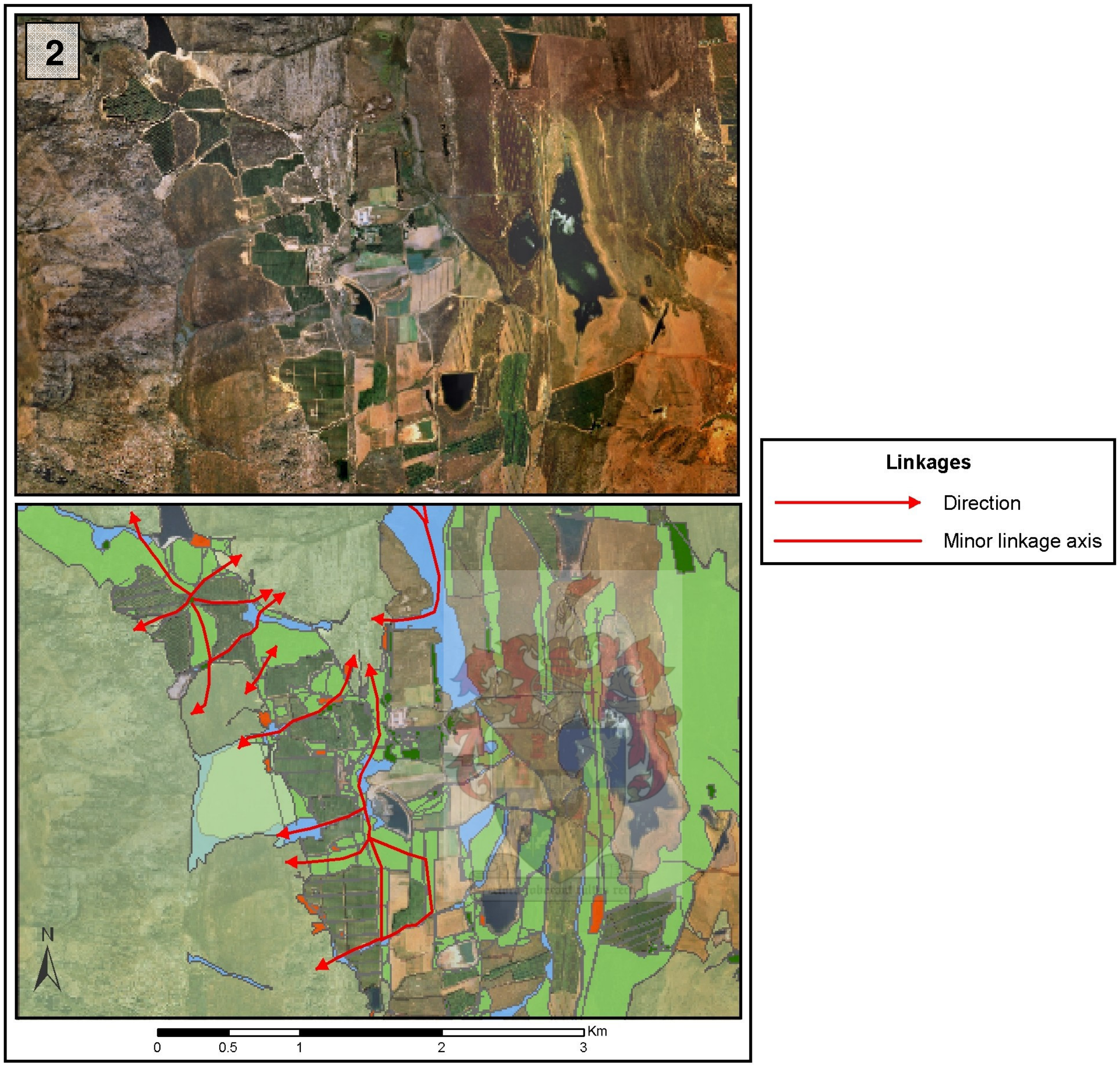


Figure 4.7 Linkage area 2

These patches of vegetation and wetlands are important and should be maintained, especially those patches close to the core areas of undisturbed vegetation, which act as buffers. There are a number of built-up areas in the centre of the area and these could affect the linkages which utilize the natural vegetation adjacent to them. There are a large number of clearances and excavations (highlighted in orange) where revegetation could take place. This would increase the habitat sizes and contribute positively to the functioning of linkages as habitat and conduits. The only gaps in the network of linkages are caused by dirt roads and tracks. These are not as detrimental as the tar road but could be a hindrance to the use of linkages by certain species.

4.5.4 Linkage area 3

The linkage network in area 3, as displayed in Figure 4.8, plays an important role in connectivity of the landscape as it connects the western and eastern core areas of pristine vegetation.

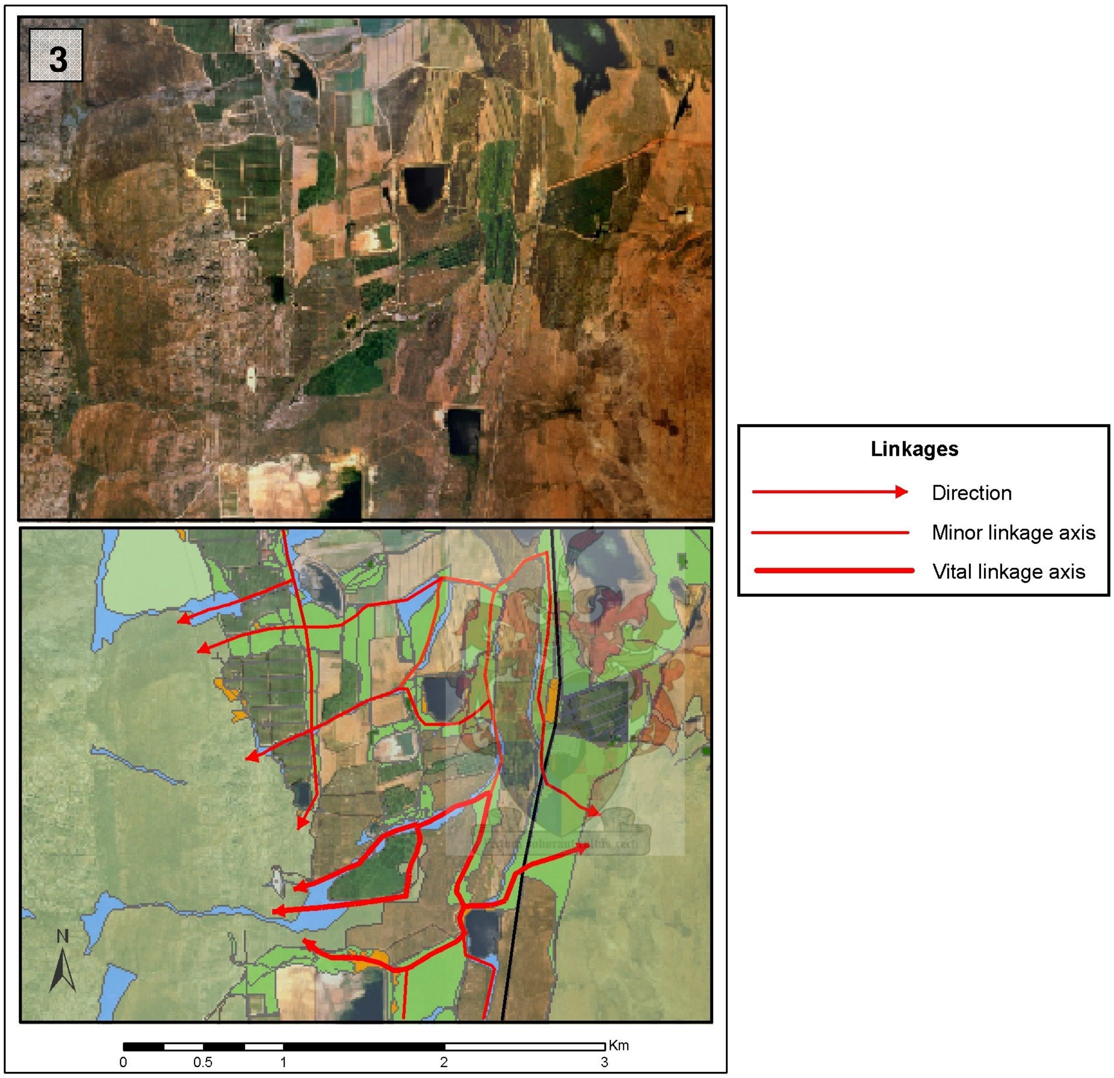


Figure 4.8 Linkage area 3

This area also contains a large number of medium-size natural vegetation patches, which should be conserved as far as possible. The linkages have a high structural connectivity, with a number of alternative pathways. The canals linking some of the natural vegetation patches require revegetation of riparian zones on their sides if they are to form part of the network. There are also two areas in the bottom linkage of the map where areas for revegetation are highlighted in orange. These areas could make an important contribution to increasing connectivity and closing gaps in the linkage if they were to be revegetated. The tar road (black line in Figure 4.8) presents a barrier for animal movement and, as in area 1, wildlife crossing structures would be beneficial.

4.5.5 Linkage area 4

Due to the importance of linkages improving connectivity between the eastern and western core areas, area 4, as displayed in Figure 4.9, was included.

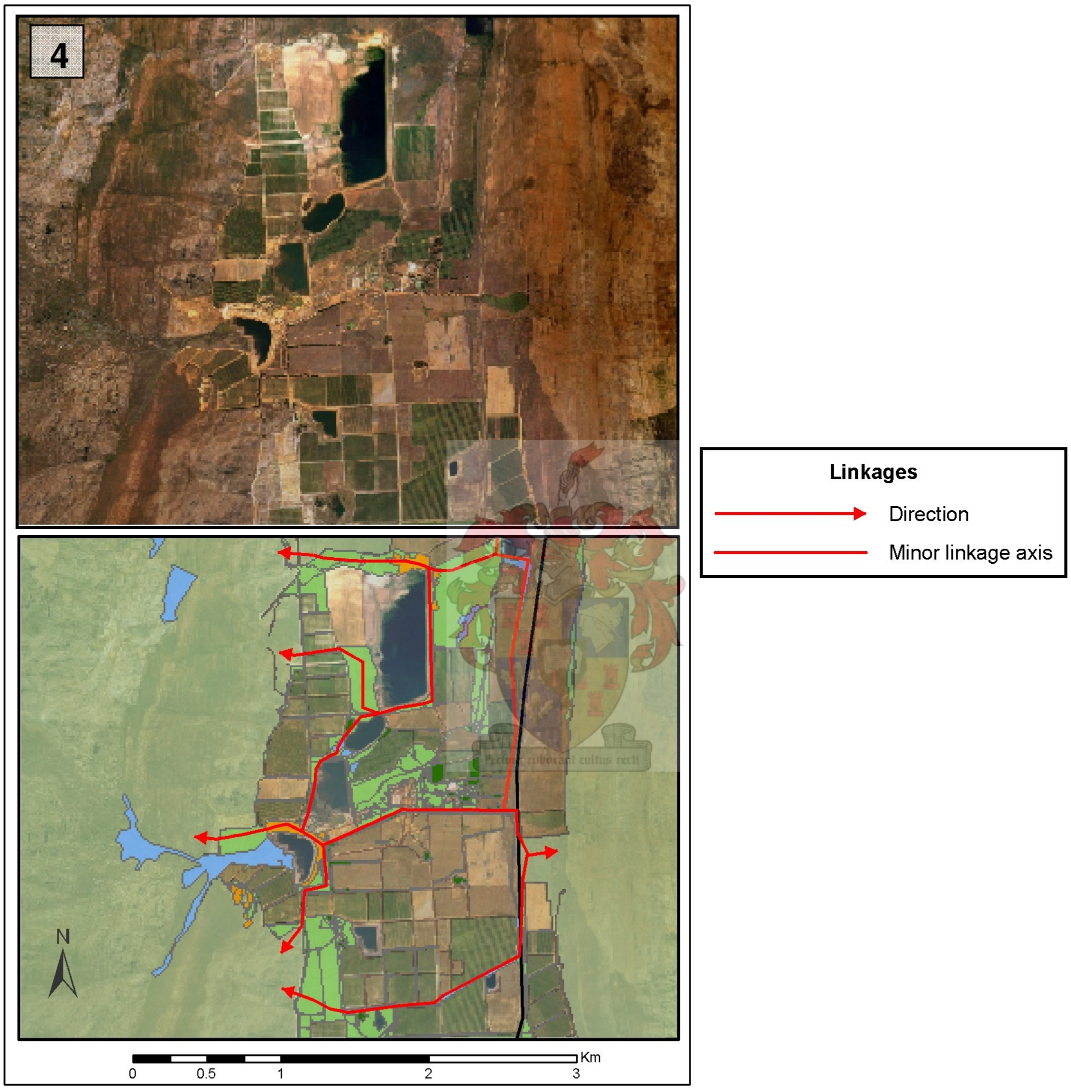


Figure 4.9 Linkage area 4

Here the structure is not as optimal as that of areas 1, 2 and 3. In order for it to function as a conduit and provide habitat, the canal forming the southernmost linkage would have to be revegetated. The middle east-west linkage runs past a built-up area and therefore may not be highly functional. There are also a few areas where the linkage consists of a row of trees, which may not be suitable and revegetation could aid in widening these areas. The large patch of vegetation in the north of the area is an important provider of habitat and should be conserved. Also, the four irrigation dams running diagonally to the north-west should consciously be enhanced as linkage nodes.

4.5.6 Linkage area 5

In area 5, as displayed Figure 4.10, the most important linkage is the one to the west.

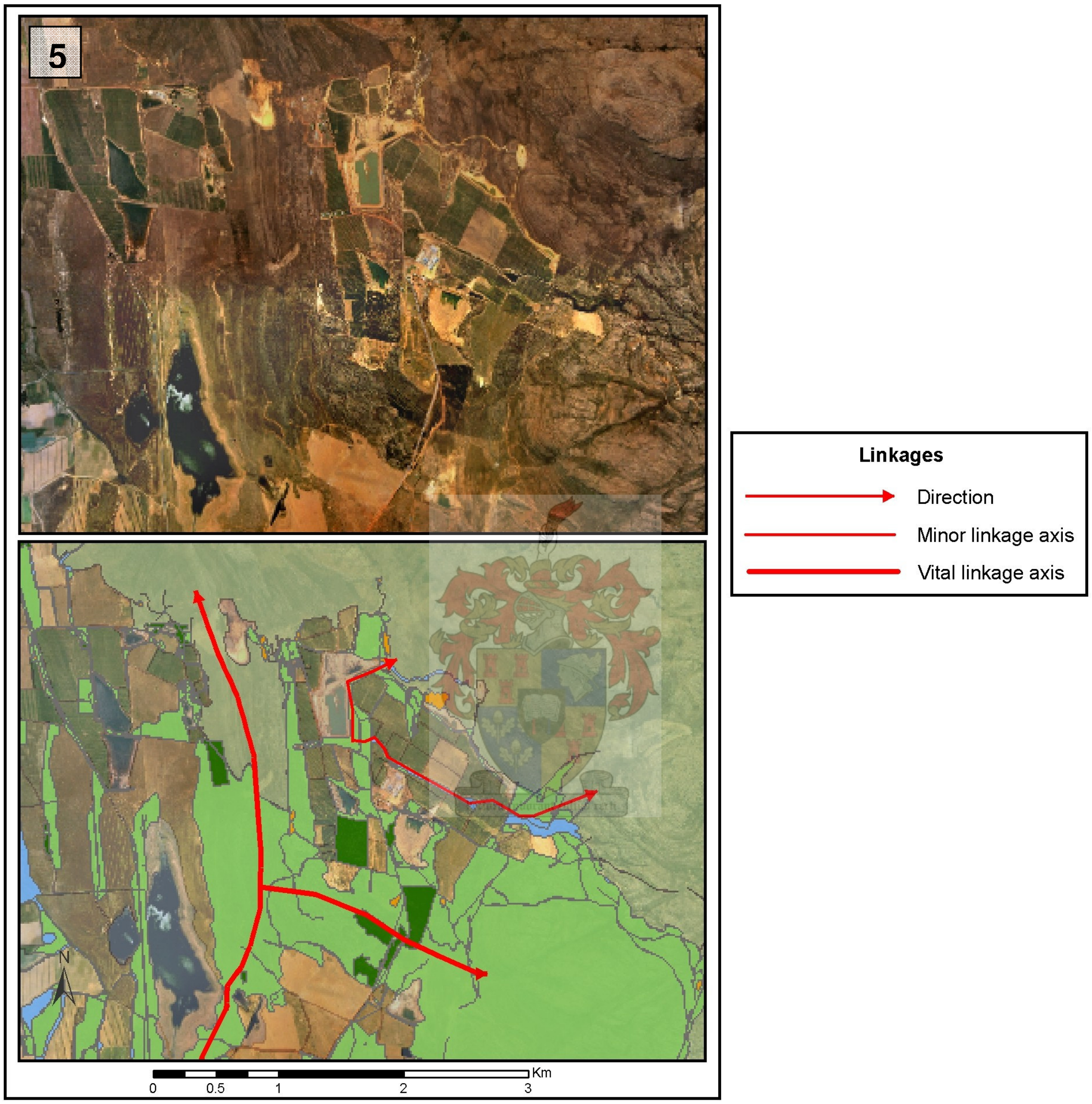


Figure 4.10 Linkage area 5

This represents a relatively wide linkage and connects with area 6 (Figure 4.11), linking the northern and southern core areas of pristine vegetation. It is narrowest at the southern extreme of the area shown and this part of the linkage should be protected from further disturbance. A buffer of natural vegetation on either side of the link could be functional. There is a large built-up area in the centre of this area and this could negatively influence the possible linkages occurring close to it. There is also a secondary tar road in centre, though not as heavily utilized as the tar road in areas 1, 3 and 4. It inhibits east-west movement, but a wildlife crossing structure here would not be recommended.

4.5.7 Linkage area 6

Of the three linkages shown in linkage area 6, as displayed in Figure 4.11, the westernmost linkage is most significant and was already highlighted in area 5.

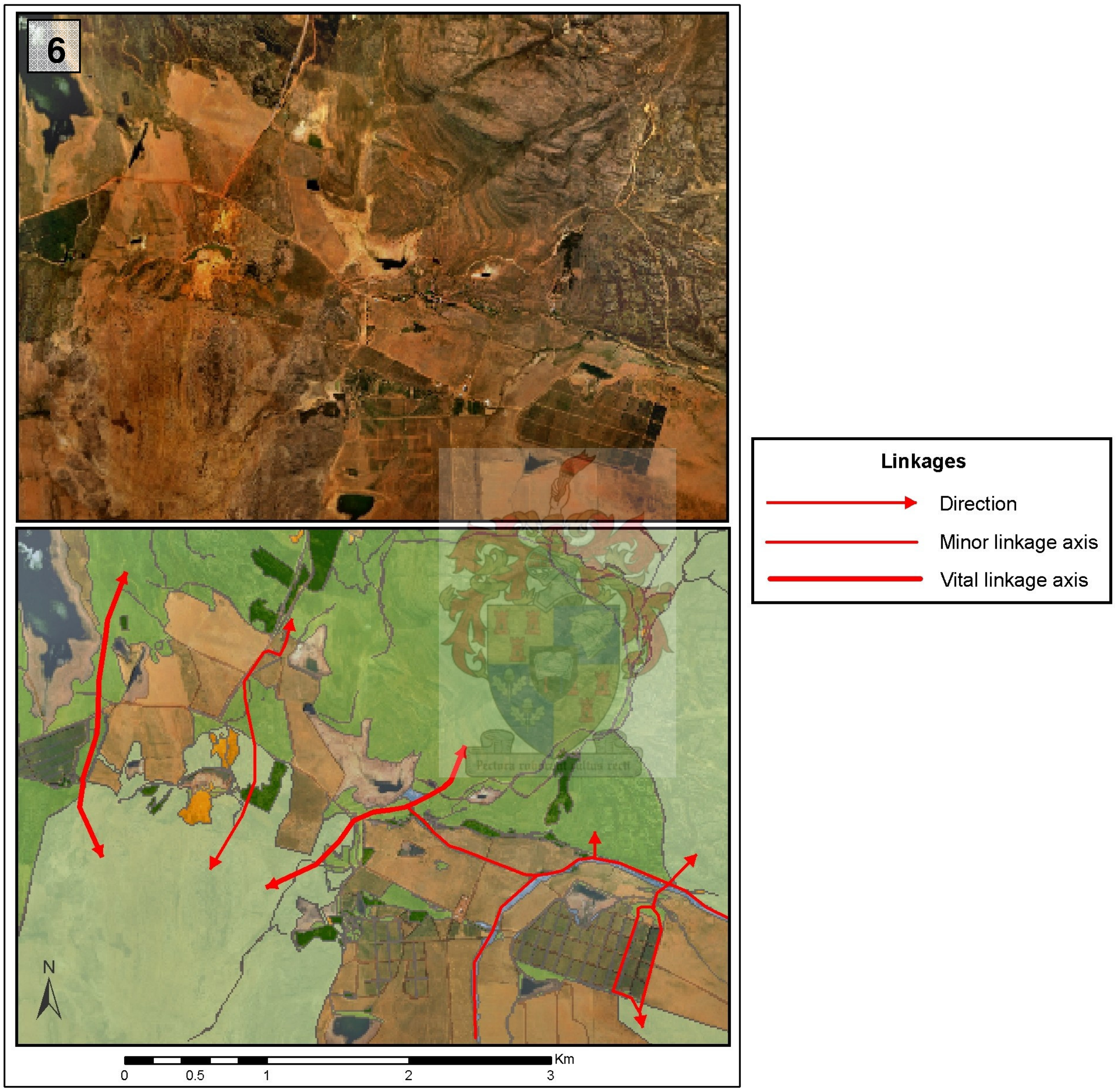


Figure 4.11 Linkage area 6

The natural vegetation making up this linkage should be protected by minimizing disturbance and maximizing habitat quality. The areas where clearances/excavations (highlighted in orange) could be revegetated could aid in increasing the area covered by natural vegetation. The linkage west of the centre linkage is tenuous, consisting of two strips of trees and a small vegetation fragment at the top of the linkage. Steps would have to be taken to improve connectivity in this area, building upon what already exists. The centre linkage is well structured, consists of adequately sized vegetation fragments and should therefore be protected and further enhanced along the line of the large new rebuilt dam. In the south-east of the area two potentially important linkages are found. The curved linkage running along the Kruis River has major potential for a fluvial linkage, although the flow pattern is erratic. The linkage running through the orchards could potentially connect the two core areas of endangered renosterveld vegetation. It would include the patch of renosterveld vegetation above the orchards.

4.5.8 Linkage area 7

The narrow east-west linkage in area 7, as displayed in Figure 4.12, is significant as there is a relatively small gap between the two core areas.

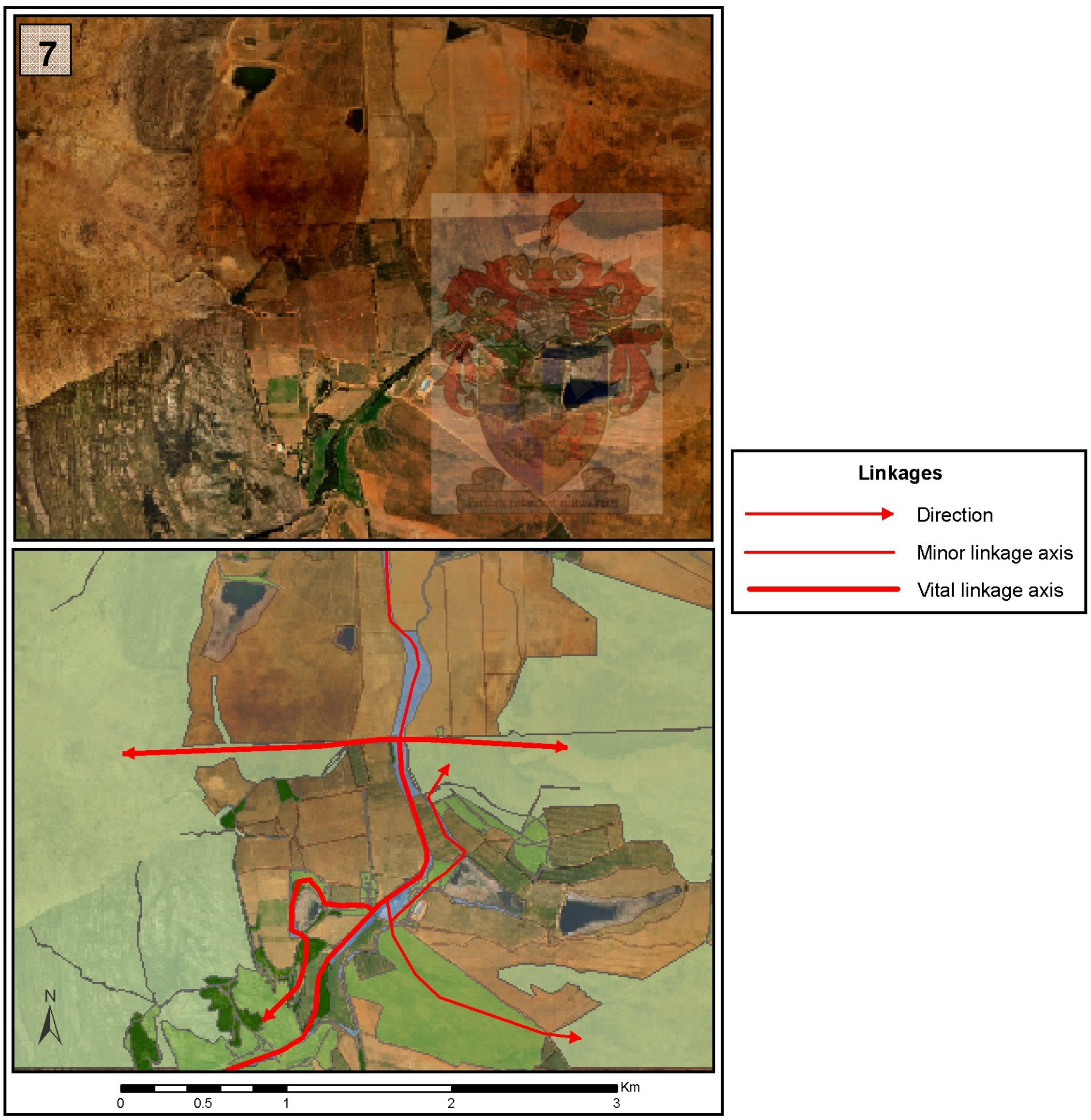


Figure 4.12 Linkage area 7

This gap is demarcated by a row of trees, with adjacent annual agriculture and could be buffered by natural vegetation on both sides to increase its effectiveness. Part of its importance stems from it's linkage of the conservation important renosterveld remnant in the east with the rest of the fynbos habitat. The other alternative pathways in the area are well structured and made up of wetlands, natural vegetation and trees of relatively adequate width. There are a number of dirt roads and tracks in the area which could act as a barrier to the movement of certain species. The central wetland connects to area 6 and provides a north-south linkage between core pristine vegetation areas. The Kruis River runs from south to north, continued from area 6, and is a potentially important fluvial linkage if adequate riparian vegetation is present.

4.5.9 The area-wide linkage network

Figure 4.13 shows the ecological network for the whole study area. Linkages are most effective in decreasing the rate of species loss due to fragmentation when connecting medium-sized fragments (Collinge 1996). The most important linkages are therefore those which are made up of the larger natural vegetation patches in the landscape. These are shown by the solid red lines. The wider the habitat in the linkage is, the greater the connectivity that is achieved by the linkage. The larger vegetation fragments should therefore be conserved as stated in the discussion of the various areas above. The presence of alternative pathways and networks is of importance. There are a number of alternative pathways in the ecological network and their general structure was discussed in the previous sections.

The length of linkages does not seem to pose a threat to connectivity in the landscape as the majority of the ecological network is of an acceptable length. Wetlands and canals provide the opportunity for linkages to be established and enhanced. Many of these areas have no adjacent vegetation and a buffer zone of vegetation could be beneficial to landscape functioning. Nodes of habitat can aid in increasing the use of linkages. Nodes at T- and cross-junctions are especially useful and could be applied in certain areas. The number and length of gaps should be minimized actively. The effect of a gap depends on the land cover found in the gap. Where there are roads, especially the primary tar road, structures to facilitate animal movement could be constructed. In constructing structures to aid in the crossing of animals, it might be important to first verify what species are present in the study area and could potentially make use of the crossing structures. Since species are dominantly small, bridge-like structures at drainage lines should suffice.

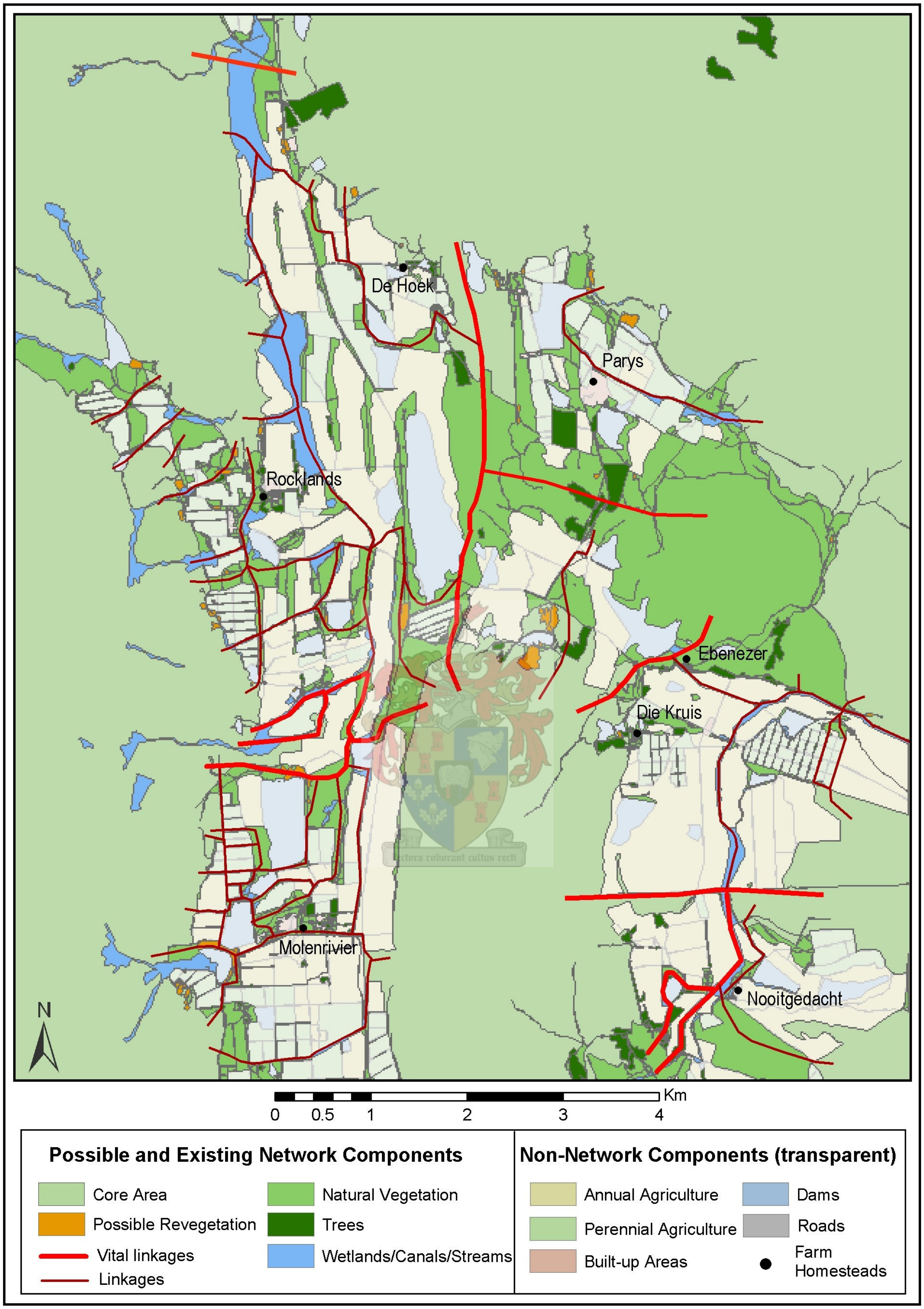


Figure 4.13 Ecological network for the study area

The natural vegetation fragments are exposed to various disturbance influences and are not in the same state as the pristine vegetation found in the core areas. It is therefore important to maximize the habitat quality of these fragments and to protect them from further anthropogenic influences. Maximizing habitat quality is one of the guidelines for managing the agricultural landscape which are discussed further below.

CHAPTER 5: ECOLOGY-BASED GUIDELINES FOR MANAGEMENT OF THE AGRICULTURAL LANDSCAPE

When managing the landscape for conservation it is important to remember that one cannot reconstruct the landscape to its original form, but one can aim to restore the functional and structural attributes of the degraded ecosystem (Recher 1993) and thereby create a healthy and self-regulating ecosystem (Saunders, Hobbs & Erlich 1993).

5.1 Resolving the agricultural-environmental dichotomy in agricultural landscape management

Agroecosystems are under the influence of natural processes and human action interacting in complex ways (Ares, Bertiller & del Valle 2001). In order to prevent long-term or broad-scale harmful ecological effects resulting from unwise land use choices, planning based on sound ecological principles is needed (Dale et al. 2001). Planning and management decisions for improving crop production, biodiversity, landscape and other environmental functions cannot be made outside the context of human needs and wishes (Fry 2001). The integration of diverse perspectives and approaches is one of the most significant obstacles to effective land management and policy (Haeuber & Dale 2001).

Farmers are under pressure to accomplish more than only the production of food (Fry & Main 1993) and become confused by the differing messages they receive expecting them to be protectors and enhancers of important landscapes and wildlife habitats, as well as creating landscapes which are of productive, recreational and aesthetic value (Fry 2001). Srivastava, Smith & Forno (1996) identify the common ground between environmentalists and the agricultural community as the fact that both conservation and development interests have a stake in the survival of natural habitats. Natural habitats harbour wild populations and near-relatives of numerous crops and livestock that contain genes for agricultural improvement. Sorting out conservation priorities and agricultural practicalities should be a priority even if they seem irreconcilable at times (Fry & Main 1993).

5.2 Ecology-based guidelines and principles for planning and management of the agricultural landscape

Broad guidelines and principles for planning and management of the agricultural landscape are provided here. In Section 5.3 the most important of these are revisited and specific recommendations with regards to management of the study area are made. Each guideline is discussed individually.

5.2.1 Conserve large areas of habitat

It is better to conserve a few larger fragments of natural vegetation than many smaller ones (Collinge 1996; Bennett 2003). Large areas of habitat are irreplaceable and required to maintain viable population sizes (Recher 1993) They have many vital ecological values and represent potentially significant core biodiversity areas (Dale et al 2001; Leitao & Ahern 2002). A large area of habitat will have a greater diversity of vegetation types, an increased richness of plant and animal species, an increased likelihood of rare or specialized habitats, and maintain ecological processes more effectively than a smaller habitat (Collinge 1996; Giles & Trani 1999; Bennett 2003). Large areas have a greater proportion of interior habitat which is unaffected by edge effects and do not loose species at the high rate that smaller fragments do (Collinge 1996; 1998). A larger area has increased sustainability of natural disturbance regimes and the maintenance of processes in fragmented landscapes is critically dependent on fragments of sufficient size (Bennett 2003). A patchwork of habitat types often maintains more organism types and a greater diversity of ecosystem processes than a large area of homogenous habitat (Dale et al 2001), but there is no substitute for large areas of natural habitat.

5.2.2 Expand the area of protected natural habitats

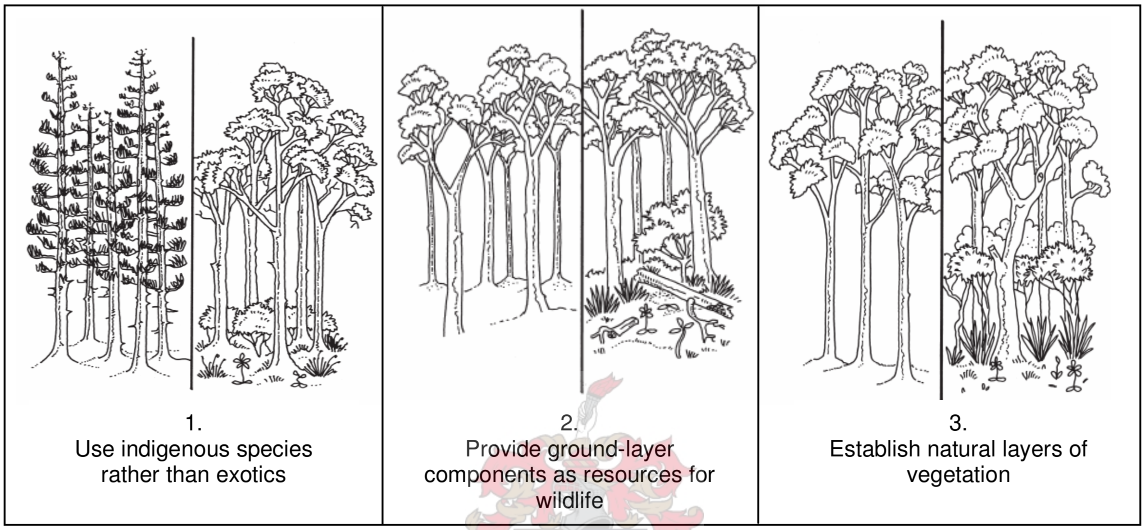
The benefits of large areas of habitat are expounded above. Expanding the area of natural habitats can increase habitat size and this is seen as one of the most effective ways in which land management can enhance wildlife values (Bennett, Kimber & Ryan 2000). This can be achieved by undertaking programmes to deliberately revegetate land adjacent to existing habitats. Revegetation is discussed in Section 5.2.7 below. Where habitats are cleared they should be regenerated or comparable new areas revegetated to minimize overall habitat loss (Bennett 2003).

5.2.3 Maximize the quality of existing habitats

Suitable habitat composition and quality within patches needs to be maintained (Freemark, Bert & Villard 2002). Habitat quality relates to a large extent to the resources that animals can obtain from the habitat (Bennett, Kimber & Ryan 2000). In order for diverse communities of flora and fauna to be present the habitat needs to provide resources for them. The following aspects of habitats can maximize habitat quality:

- A high diversity of vegetation types within habitat remnants is vital for long-term population persistence (Collinge 1996). The more complex the vegetation, the greater number of animal species it can sustain (Recher 1993; Bennett, Kimber & Ryan 2000).

- Different layers providing different types of foraging substrates, nesting locations and shelter for animal species should be present (Bennett, Kimber & Ryan 2000; Scougall, Majer & Hobbs 1993; Pagiola & Kellenberg 1997). This can be done by using plants that grow at different heights e.g. grasses, tall shrubs, low shrubs, ground cover (No. 3 in Figure 5.1).



Source: Bennett, Kimber & Ryan 2000.

Figure 5.1 Approaches to maximize habitat quality

- Long- and short-lived plants are important (Recher 1993) as different organisms are associated with different stages in the development of plant communities.
- Locally indigenous species (Lambeck & Saunders 1993; Bennett, Kimber & Ryan 2000) are more likely to provide natural habitat resources and healthy plant-animal interactions and ecological processes than aliens (No. 1 in Figure 5.1);
- Ground-layer components such as dead trees, logs, woody debris, leaf litter, lichens and mosses are important as they provide resources for wildlife and can play an important role in nutrient cycles (Recher 1993; Bennett, Kimber & Ryan 2000) (No. 2 in Figure 5.1).

5.2.4 Minimize the impacts from surrounding land uses

What is adjacent to natural vegetation can have a large impact on the vegetation. The effects of development on ecological processes should be avoided or compensated for (Dale et al. 2000). It is important to maintain a large enough habitat size so that there are areas in the vegetation fragments that retain untouched habitat. Habitat shape is important as discussed in Section 2.2.3 and certain shapes will contain more interior habitat than others. The impacts from surrounding land uses can be minimized by giving preference to blocks over strips when choosing remnants for protection (Recher 1993), keeping corridors and vegetation along watercourses as wide as possible (Recher 1993) and using buffer zones around conservation areas to minimize the impact of external influences (Bennett 2003).

5.2.5 Maintain and restore connectivity

Landscape connectivity improves the conservation potential of habitat (Bennett 2003). Natural vegetation occurring in the agricultural landscape is highly fragmented and the connectivity of natural habitats should be promoted in order to counter the effects of isolation. Landscape links between conservation reserves and large natural areas, combined with a network of habitat corridors connecting smaller areas of habitat can contribute to the healthy functioning of the landscape (Freemark, Bert & Villard 2002; Bennett 2003). The use of linkages assists in the movement of animals, continuity and maintenance of ecological processes and prevents the extinction of small populations in habitat fragments (Bennett 2003; Collinge 1998). The management and design of linkages are discussed in more detail in Section 4.4 Priority should be given to streams and watercourses as natural corridors (Bennett, Kimber & Ryan 2000).

5.2.6 Conserve vital habitats in the agricultural landscape

There are certain elements of the agricultural landscape that are indispensable and when they are negatively affected by anthropogenic influences, the functioning of the landscape is affected. Non-crop areas in the agricultural landscape are vital and enhance the selection of reproductive and foraging sites for birds, mammals and other species (Bowne, Peles & Barrett 1999; Foppen, Chardon & Lietveld 2000). Landscape components such as shelterbelts, tracks and open drainage are significant and provide refuges for 90% of farm-life as well as supplying ecological services (Fry & Main 1993). Rare landscape habitats provide critical habitats or ecological processes. They may cover a small proportion of the landscape, but their ecological significance is greater than suggested by their spatial extent (Dale et al 2001).

Scougall, Majer & Hobbs (1993) found that remnants of vegetation enhanced a wheat-belt landscape in several ways. They aided in the control of soil salinisation and erosion, provided shelter for livestock and a habitat for predators of pests. The retention of vegetation remnants is of considerable importance to conserve an agricultural region's flora, fauna and landscape representativeness. The natural vegetation left in an agricultural landscape is often in the form of linear or point elements such as road verges and margins of arable land. These natural and semi-natural habitats can enrich regional biodiversity considerably by providing habitat and pools of genetic diversity amidst increasingly mono-cultural landscapes (Baudry & Burel 1984; Duelli 1997; Pagiola & Kellenberg 1997).

Wetlands and bodies of water in general are low in spatial extent but high in contribution to the compositional and structural complexity of an ecoregion (Naiman & Decamps 1997). In the study area wetlands and canals make up 6% of the developed portion of the landscape (Figure 2.3). Watercourses and their associated vegetation are natural corridors linking catchments and following major bioclimatic gradients. Areas along drainage lines and wetlands tend to be nutrient-rich, productive and support a rich biota (Recher 1993). By protecting watercourses aquatic ecosystems are protected, water quality is improved, erosion is controlled and water temperature fluctuations are moderated (Recher 1993). See Section 4.3.1 for a more detailed discussion on the significance of riparian zones.

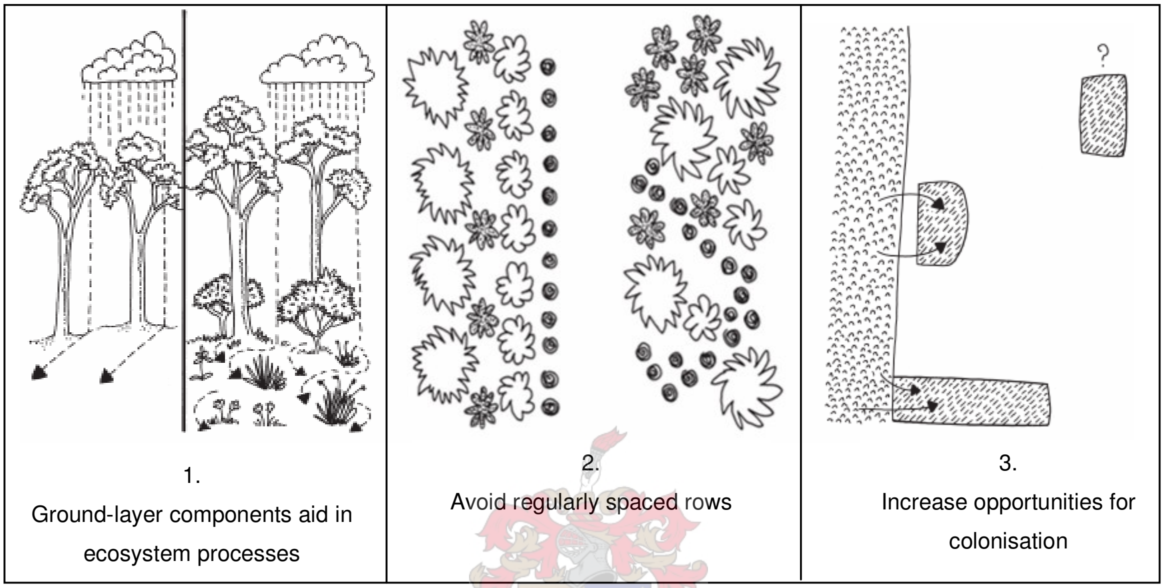
5.2.7 Revegetate unused/unproductive areas

Areas where vegetation has been cleared, where excavations have taken place and which are now standing derelict can be restored to natural/semi-natural vegetation. Such clearances cause loss of valuable habitat, isolation of populations in habitats, loss of key resources for food and shelter due to changes in remaining vegetation and allow exposure to introduced animals (Bennett, Kimber & Ryan 2000). Any increase in the amount of habitat in the landscape can make a contribution to the healthy functioning of the landscape. The EurepGAP environmental requirements (Table 1.1) recommend that unproductive sites be converted to conservation areas for the encouragement of natural flora and fauna. Revegetation can aid in reducing soil erosion, protecting water quality in streams, increase nature conservation values, provide protection for crops, restore severely degraded land such as quarries and enhance scenic quality and human amenity values (Bennett, Kimber & Ryan 2000).

Guidelines for revegetating unproductive areas relate to those for maximizing habitat quality laid out above (Section 5.2.3). These guidelines are not only applicable to unproductive sites, but also to any areas that are being revegetated as part of a conservation plan. When choosing areas to revegetate, it is important to remember that revegetation, once grown and if strategically placed, can become the backbone of a long-term revegetation plan (Lefroy, Hobbs & Scheltema 1993).

The following are important guidelines for revegetation:

- Ground-layer components such as ground vegetation and leaf litter are essential to natural functioning of ecosystems and aid in restoring ecosystem processes (Bennett, Kimber & Ryan 2000). Leaf litter and associated fungi, bacteria and small invertebrates aid in decomposition and nutrient recycling (No. 1 in Figure 5.2). They trap rainfall and assist its infiltration into the ground, prevent soil loss through erosion and contribute to soil formation.



Source: Bennett, Kimber & Ryan 2000.

Figure 5.2 Guidelines for revegetation

- The composition and structure of revegetated habitats needs to be managed by maintaining resources such as older trees and multiple layers of vegetation. Disturbance should be controlled (Bennett, Kimber & Ryan 2000). One method of doing this is by fencing the revegetated habitat.
- Plants should not be regularly spaced in rows (No. 2 in Figure 5.2). A natural patchiness can be maintained by using vegetation of different species, scattered thickets and small open clearings (Bennett, Kimber & Ryan 2000). Indigenous plants with different growth forms can be used.
- A single block of habitat should be planted in preference to several small ones. Multiple blocks that build onto each other over time should be planted. Larger habitat blocks support a greater number of species and populations and are especially important for sedentary species (Bennett, Kimber & Ryan 2000).
- To minimize the edge effect, broader areas should be planted in preference to narrow strips (Recher 1993; Bennett, Kimber & Ryan 2000) and those strips that are narrow can be widened by revegetation. Expanding field margins and road-side vegetation

strips (Fry & Main 1993) aids in revegetating farmland, provides refuge for insects and increases natural habitat.

- Revegetation should be positioned to increase opportunities for colonisation from other habitats (No. 3 in Figure 5.2). This depends on distance from existing populations, mobility of species and resistance to movement from intervening land uses (Bennett, Kimber & Ryan 2000).
- Blocks less than 2ha in size should not be planted. In blocks this size the number of species present is reduced, the size of populations is small and the fauna is dominated by generalist species. Blocks that are fairly small in size should be closely linked to larger blocks (Bennett, Kimber & Ryan 2000).
- Linear vegetation strips should be at least 20m wide. A width of 20-50m is preferred and 50-100m wide strips are ideal (Bennett, Kimber & Ryan 2000).

5.2.8 Avoid creating a monoculture landscape

When managing the agricultural landscape one should aim to create conditions that support a wide range of natural communities and ecological functions (Fry & Main 1993). A monoculture or uniform landscape should be avoided by creating a spatially and temporally varying mosaic of different plant and animal communities (Recher 1993). Diverse habitats provide more niches for plants and wildlife, as well as promoting more efficient nutrient use and creating microclimates that can help buffer crops from severe weather (Pagiola & Kellenberg 1997; Bennett, Kimber & Ryan 2000). One method of increasing diversity in the agricultural landscape is to create new linear features separating large fields (Fry & Main 1993). Examples of these are shelterbelts, tree rows, and other linear vegetation strips (Bennett, Kimber & Ryan 2000). This has the added benefit of increasing connectivity and the amount of natural habitat in the landscape and could provide other benefits. Representation of ecosystems is important at the landscape level. This is especially true in the agricultural landscape where fertile land has been used for agriculture (Bennett, Kimber & Ryan 2000) and there is therefore a misrepresentation of various ecosystem types. Foppen, Chardon & Lietveld (2000) emphasize the fact that even small and seemingly insignificant landscape elements can contribute to the viability of larger higher-quality patches.

5.3 Practical recommendations for optimal management of the study area

Protection and management of natural high-quality habitats are an essential basis for nature conservation (With 2002; Bennett 2003). Every step taken in the landscape has a consequence. The removal of a few patches of vegetation here and there can cause populations to become isolated and result in species loss occurring. There is widespread agreement that the highest priority for vegetation management in rural environments should be to identify, protect and manage existing remnants of natural vegetation (Bennett, Kimber & Ryan 2000). The importance of large patches of habitat are discussed in Section 5.2.1. Figure 5.3 shows the core areas of undisturbed vegetation and larger patches of disturbed natural vegetation which should be conserved. A buffer area of 150m into the core areas of pristine vegetation was created. This represents the zone of disturbance where the edge effect occurs and surrounding land uses influence habitat.

Wetlands are vital functional components in the landscape and should be protected. The two larger wetland areas at the north-western corner of Figure 6.1 are especially important due to their size. The maintenance and restoration of connectivity is vital. A concerted effort should be made to preserve the existing linkages identified in Section 4.5 and highlighted again in Figure 5.3. The core areas and connecting linkages are irreplaceable. These provide habitat corridors for movement of fauna and are of the utmost importance. Once a linkage is destroyed, it is no simple matter to restore connectivity. The two main rivers in the study area are illustrated by the broken red line in Figure 5.3. The Houdenbeks River lies in the north-west and the Kruis River in the south-east. These rivers have been victims of agri-development in the low-lying parts of the study area and can play a prominent role as riparian linkages if they are rehabilitated. A step which can be taken towards returning them to their natural functional state is the revegetation of their banks.

Habitat quality plays a large role in determining the effectiveness of a linkage. Renosterveld is found in the south-eastern part of the study area. It is a threatened habitat type which has been highly fragmented by agriculture in the Western Cape (Kemper, Cowling & Richardson 1999; Donaldson et al. 2002). Less than 15% of original renosterveld vegetation remains, and most of its habitat remnants are surrounded by agriculture (Donaldson et al 2002). Donaldson et al's (2002) research indicates that larger fragments of renosterveld need to be managed in a way that increases habitat heterogeneity and reduces shrub density. Small fragments may contain important population or threatened plant species, and it is important to ensure that nearby large fragments are retained as potential sources of pollinators. It is therefore vital to make a concerted effort to protect the remaining natural habitat in the south-eastern part of the study area. Figure 5.4 illustrates two areas where connectivity of renosterveld vegetation could be improved.

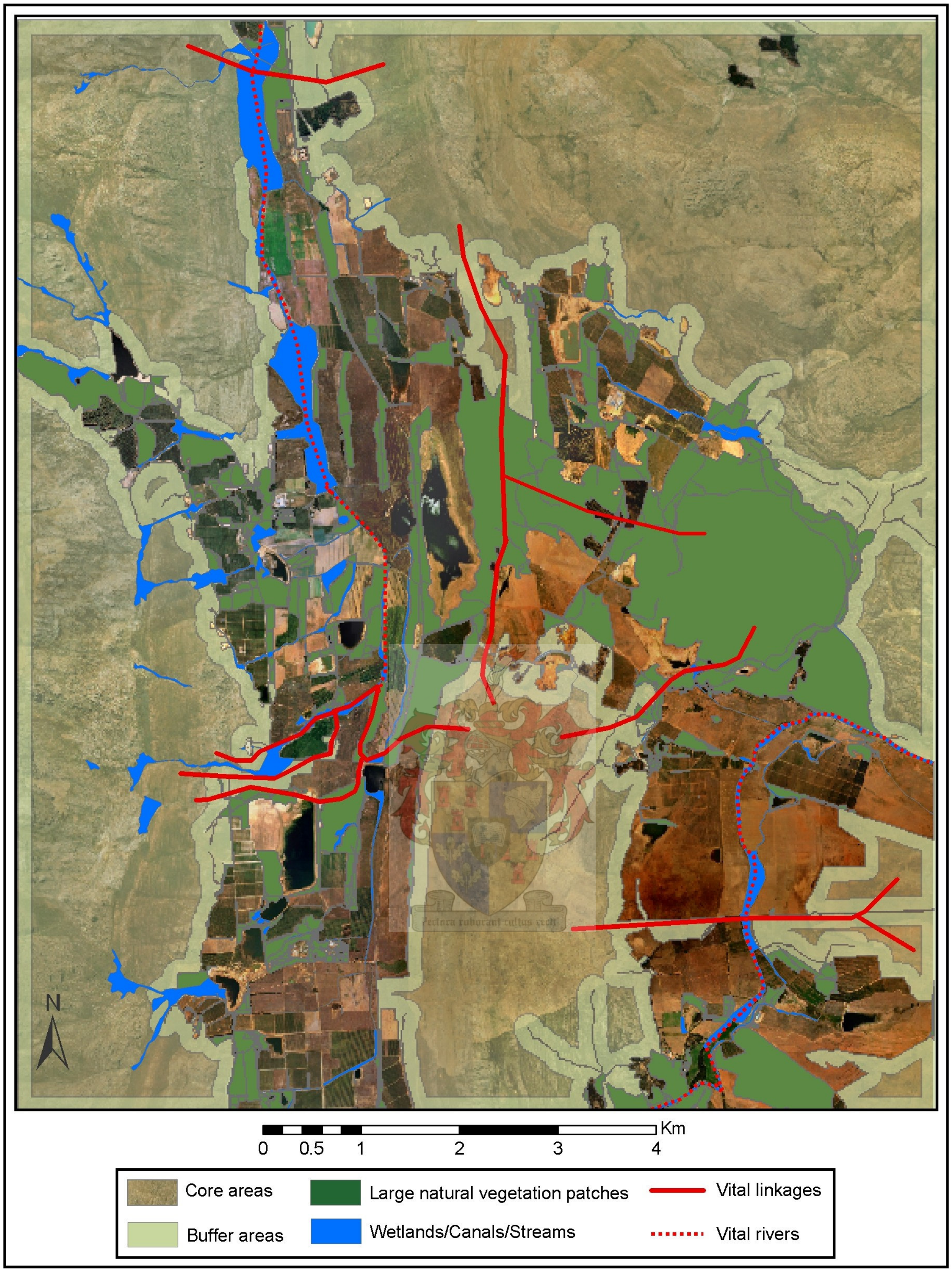


Figure 5.3 Important areas for conservation

As Bennett, Kimber & Ryan (2000:21) state: "A single line of trees, for example has little chance of being an effective corridor … A useful goal is to aim for a linear strip from 20-50m in width…". Figure 5.4 provides a good example of this. In map 1, a potential linkage between the two core areas is highlighted. This linkage makes use of fragmented renosterveld

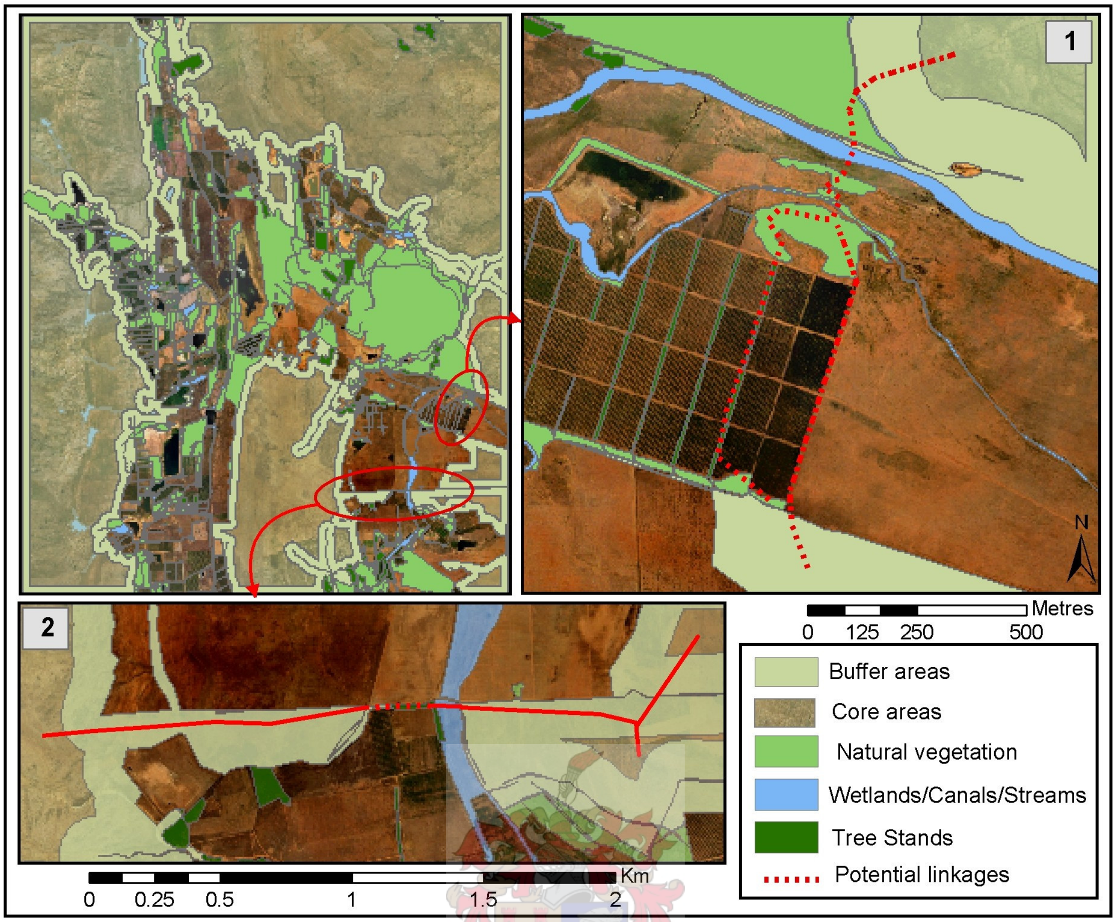


Figure 5.4 Two ecologically important areas for establishing connectivity

patches surrounded by annual agriculture occurring just above the centre of the map. On the right a linear strip of vegetation could be established, while on the left the rows of trees between the orchards could form a possible corridor. Map 2 highlights an area where two core areas are close to each other and a high degree of connectivity could be achieved. A strip of trees and wetland connects the two core areas. By improving the habitat quality of the trees and increasing the width of the linkage by revegetation connectivity could be restored.

To conserve linkages, core areas, wetlands and riparian zones anthropogenic impacts should be kept to a minimum. This will aid in the maintenance of habitat quality. A set of farm operation rules could be formulated and enforced in order to prevent further disturbance. Examples include not using these areas as dumping sites, limiting the use of vehicles in sensitive areas and barring heavy vehicles and machinery. The effects of roads can extend to at least 1km in the landscape (Carr, Fahrig & Pope 2002). The effect of the tar road as a barrier to animals could be reduced by the construction of a wildlife crossing structure (Carr, Fahrig & Pope 2002) as suggested in Section 4.5. An underpass (space created under the roads such as a tunnel or culvert) or vegetated overpass (small-scale land bridge) could be constructed if feasible.

The creation of a monoculture landscape can be avoided by establishing linear strips of vegetation around and through large fields. Examples of a few areas where this could be applied are highlighted in Figure 5.5.

Figure 5.5 Possible areas for revegetation

If wide enough, these strips could play a role in improving habitat connectivity. Existing fences could be used as a starting point by creating linear vegetation strips around them. The revegetation of clearances and excavations can also play a role in increasing the diversity and connectivity of the landscape. Guidelines for revegetation are laid out in Section 5.2.7. Areas which can be revegetated are highlighted in dark orange in Figure 5.5. Revegetation is an important tool contributing to all aspects of restoring rural environments (Bennett, Kimber & Ryan 2000).

Landscape connectivity could be improved to a large degree by re-establishing vegetation around canals, wetlands and streams. The importance of riparian vegetation is highlighted in Section 4.4.3. At present there is a lack of such areas in the landscape. Possible areas where revegetation of riparian zones and canals could take place have been highlighted by adding a buffer of 20m on either side and are shown in Figure 5.5. The restoration of riparian zones could be very significant in increasing the connectivity and ecological functioning of the landscape as illustrated by their spatial structure in Figure 5.5. This is especially true in the case of the Houdenbeks River and Kruis River. A minimum riparian buffer width of at least 10m is required to provide water quality, stability and habitat, while widths of 100m or more are usually needed to ensure values related to wildlife habitat and use as migration corridors (Fischer & Fischenich 2000).

CHAPTER 6: TOWARDS CREATING A SUSTAINABLE LANDSCAPE

In order for science to be immediately relevant it needs to be of use in the real world. The practical recommendations for management of the study area are the culmination of this report and illustrate the use of landscape ecology and GIS as tools for managing the agricultural landscape.

6.1 Summary of results

6.1.1 Land cover analysis

Leitao & Ahern (2002) see pattern and process relationships as crucial to understanding the functioning of landscapes. Landscape metrics were used to quantify land cover pattern and relate it to process. Agriculture covers 47% and natural vegetation 31% of the developed portion of the study area. In developed landscapes, linear habitats and small fragments with high edge ratios often form the bulk of remaining natural habitats (Bennett 2003). This is true in the study area. Most of natural vegetation left is anthropogenically influenced and highly fragmented. This is indicated by a low mean patch size, high number of patches and high patch density. This is also indicated by the average patch shape metrics, where more complex shapes were expected and the large amount of total edge. The natural land cover components (tree stands, wetlands/streams/canals, natural vegetation) could form the basis for an ecological network.

6.1.2 Topographical analysis

Calculation of primary topographic attributes from the DEM laid the basis for the topographical analysis. The majority of man-made land cover elements are found in the lower-lying areas. The standard deviation of the slope theme allowed outcrops and ridges to be identified. Profile and plan curvature provided areas of water accumulation and deflection. Landform elements were created using the topographic attributes of slope and profile and plan curvature. These aided in assessing the movement of water and other materials over the landscape. Watersheds were created and the land cover and landform elements discussed in context of the six main catchments. The drainage lines correlate well with the landform elements where accumulation is expected. The wetlands, streams, canals and dams in the study area also correlate well as areas of accumulation. A broad perspective of the process-controlling effect of topography was obtained.

6.1.3 Ecological linkages

The role of linkages in the landscape was discussed and guidelines for their management and creation laid out. Areas where important existing and potential linkages occur were identified and the structure of each discussed. Improvements that could aid in increasing connectivity in the study area include:

- Constructing structures to facilitate movement of animals across tar roads;
- Adding riparian vegetation buffers to streams, canals and wetlands;
- Revegetating clearances and excavations;
- Conserving medium and large patches;
- Increasing the value of rows of tree stands as linkages by revegetation.

6.1.4 Ecology-based management guidelines

General guidelines for ecology-based management of the agricultural landscape were compiled from literature:

- Conserve large areas of habitat;
- Expand the area of protected natural habitats;
- Maximize quality of existing habitats;
- Minimize impacts from surrounding land uses;
- Maintain and restore connectivity;
- Conserve vital habitats in the agricultural landscape;
- Revegetate unused/unproductive areas;
- Avoid creating a monoculture landscape.

6.2 Evaluation of research

The aim of the research was to assess the functioning of the agricultural landscape and provide scientifically-based guidelines for the management of the agricultural landscape. The land cover pattern provides a snapshot of the present state of the landscape. Landscape metrics allow the spatial pattern to be quantified, especially that of the natural vegetation. The natural components of the landscape are vital for healthy landscape functioning and the fragmentation of natural vegetation is highlighted by the landscape metrics. The effects of fragmentation are complex and to determine the exact effects of natural vegetation fragmentation in the study area more in-depth study is required (Debinski & Holt 2000).

The topographical analysis aids in providing an overall view of the flow of materials, especially water, over the landscape. A broad overview is obtained, but a more in-depth analysis could have been done. This requires a firm grasp of the complex subject of topographic landscape processes. As Wilson & Gallant (2000:65) state: "…we have not yet built a consistent and interpretable picture of the link between various terrain attributes and the environmental parameters of interest … to improve our ability to use terrain attributes to describe processes, we need to develop a better understanding of the links between terrain and spatio-temporally varying surface and atmospheric processes…". The landform elements that were created could be further investigated to get a better picture of topographic landscape process.

The practical recommendations provided in Section 5.3 represent the application of principles obtained from literature and are applied spatially using GIS. These recommendations were the ultimate aim of the research and can aid in improving agricultural landscape function. The recommendations represent the ideal and it is not feasible to expect a rigid application of them by the farming community, but each measure that is applied is another step towards a sustainable and healthy landscape.

6.3 Recommendations for further research

There is much room for further research on the analysis of landscape function, as well as optimal management of the agricultural landscape. This report has provided an overview of some elements of the landscape, namely land cover pattern and topographical analysis. Many of the recommendations below illustrate the value of inter-disciplinary research. This study has shown how GIS can be used as a tool for landscape function analysis and management. The landscape scale was investigated and further research at larger and smaller scales could aid in a better understanding of landscape function being obtained.

With regards to the land cover analysis, the stage is set for a comparison of land cover change in the future, which would provide valuable information about the process-pattern dynamics of a changing landscape. An investigation into the flora and fauna present in the disturbed and pristine areas would be of great value and aid in assessing the biodiversity of the area. This would aid in identifying those areas which are valuable and should be conserved, and those natural fragments which are in need of rehabilitation. The populations of key indicator flora and fauna species could then be investigated in order to assess the state of various parts of the landscape.

There is much room for further research with regards to the topographical analysis. The research which was done in this study lays the foundation for a more in-depth investigation of the relationship between topography and landscape function and how this affects agricultural practice. A finer resolution DEM would aid in a better identification of those areas which are critical to landscape function, especially in the agricultural areas. As has been stated (Section 6.2), knowledge of exactly how landform affects ecological function is often broad and not applicable to all scales. The calculation of secondary topographic attributes such as the CTI (Section 3.2) could provide indexes related to specific processes occurring in the landscape and the relationship between soil, landform and geology could be investigated. Modelling of landscape processes could be applied to aid in visualisation and assessment of how these processes, such as soil erosion, occur and to sketch various management scenarios.

Monitoring linkage use could aid in investigating the actual functionality of linkages. This would entail monitoring the occurrence and status of flora and fauna within the linkage. The goal would be to determine exactly how the linkage is being used and which species are using the linkage. Individual animals could be monitored (Bennett 2003), as could the status of populations and communities in habitat connected by linkages. All of this could aid in providing feedback for suitable design, dimensions and management practices with regard to linkages.

With regards to the guidelines and recommendations for ecology-based management of the study area, the roadside vegetation could be studied, especially the vegetation along the tar road running from north to south through the landscape. The field margins, rows of trees and other linear habitats could be investigated in more detail to determine the quality and structure of these often functionally significant areas of the agricultural landscape. Those areas that support rare plant species and communities could be identified and focused upon in management of the landscape.

The landscape is a complex, highly integrated system which is the result of both human and natural processes (Bastian 2001) and should be managed as such. There are many components which can be investigated and each provides a unique perspective of the environment. In an agricultural landscape natural components play a vital role in landscape function and their habitat quality should be maximized. Growing demands are being placed on science for instant solutions to conservation issues (Couper 1993). The solutions are not quick, cheap or easy. Restoring and managing a landscape pushes the limits of our understanding about ecological patterns and processes (Knight & Landres 2002). The challenge lies in taking concepts developed by the research community and making them accessible and useful to landscape managers (Dale & Haeuber 2001).

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APPENDIX

Table A.1 Landform classification used by MacMillan

Landform category	Landform element			Slope (%)	Slope curvature (deg/100m)	
	No.	Name	Comments		Profile	Plan
Upper slope	1	Level crest	Level area in upper slope	0-2	+10 to -10	-
	2	Divergent shoulder	Convex upper, water shedding element	>2	> +10	-
	3	Upper depression	Depression in upper slope position	0-2	< -10	< -10
Mid-slope	4	Backslope	Rectilinear transition mid-slope segment	>2	+10 to -10	+10 to -10
	5	Divergent backslope	Sloping 'ridge'	>2	+10 to -10	> +10
	6	Convergent backslope	Sloping 'trough'	>2	+10 to -10	< -10
	7	Terrace	Level mid-slope >2m above base level	0-2	+10 to -10	na
	8	Saddle	Special case of a divergent footslope	na	< -10	> 10
	9	Midslope depression	Depression in midslope position	0-2	< -10	< -10
Lower slope	10	Footslope	Concave, water receiving element	>2	< -10	na
	11	Toeslope	Rectilinear in lower slope > 20% of slope	>2	+10 to -10	+10 to -10
	12	Fan	Special case of a divergent toeslope	>2	+10 to -10	> +10
	13	Lower slope mound	Crown in linear slope < 2, above base level	>2	> +10	> +10
	14	Level lower slope	Level in lower slope, > 20% of low slope	0-2	+10 to -10	+10 to -10
	15	Depression	Concave element in lowest landform position	0-2	< -10	<0

Source: MacMillan et al. 2000