Modelling risk of Blue Crane (*Anthropoides paradiseus*) collision with power lines in the Overberg region

By

Mapule Kotoane

Thesis presented in partial fulfilment of the requirements for the degree of Master of Arts at the University of Stellenbosch.

Supervisor: Mr. A van Niekerk

December 2004

AUTHOR'S DECLARATION

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

Signature: ……..………..

Date : November 12, 2004 ……………..

ABSTRACT

This study addresses the problem of Blue Crane (*Anthropoides paradiseus*) collisions with power lines in the Overberg region, home to approximately 50% of South Africa's national bird's global population. The low visibility of power lines against the landscape is considered to be the major cause of collisions. These claim at least 20 birds annually, which is a considerable loss to a vulnerable species.

For this study, expert knowledge of the Blue Cranes' biology, general behaviour and use of its habitat were compiled. These were then translated into rules that were integrated into a Geographic Information System (GIS) to establish a predictive model, which attempts to identify and quantify risk power lines that Blue Cranes are most likely to collide with. The criteria that were considered included landscape proximity of power lines to water bodies and congregation sites, land cover, power lines orientation in relation to predominant wind directions (North Westerly and South Easterly) and visibility of the power lines against the landscape.

The power lines were ranked as highest, high, medium, low and no risk. It is recommended that this classification be used to prioritize the proactive marking of power lines with bird flappers in order to reduce collisions. The results show that 27% of the power lines in the study area pose the highest risk and should therefore be marked immediately. The power lines classified as high (1%), medium (28%) and low risk (21%) should be marked over short, medium and long term, respectively.

The study demonstrated the potential of GIS in the conservation of Blue Crane. The GIS model developed in this study can be applied in areas of similar habitat such as the Swartland

or with some modifications in a slightly different habitat such as the Karoo. It is envisaged that the results of this study will be of great value to the ESKOM (South African Electricity Commission) and Endangered Wildlife Trust (EWT) Partnership and conservation authorities in the effort to save the Blue Crane.

OPSOMMING

Hierdie studie het die probleem van botsings deur Bloukraanvoëls met kraglyne in die Overberg-omgewing van die Wes-Kaap ondersoek. Die Overberg-omgewing huisves ongeveer 50% van Suid Afrikaanse nasionale voël se wêreldbevolking van Bloukraanvoëls, en aangesien kraglyne normaalweg nie maklik sigbaar is teen die landskapsagtergrond nie, verhoog dit, tesame met die biologiese eienskappe van Bloukraanvoëls, die waarskynlikheid dat die voëls met kraglyne sal bots. Hierdie botsings met kraglyne eis minstens 20 Bloukraanvoëls per jaar, wat 'n aansienlike en beduidende aantal vir 'n kritiese bedreigde spesie is.

Die studie het gepoog om spesialiskennis oor Bloukraanvoël-biologie, algemene gedrag en habitatgebruik, om te sit in 'n stel reëls, wat in 'n Geografiese Inligtingstelsel (GIS) geïntegreer is om 'n voorspellingsmodel te bou. Hierdie voorspellingsmodel is aangewend om kraglyne wat 'n hoë risiko vir Bloukraanvoëls inhou, te identifiseer en die waarskynlikheid vir botsings te kwantifiseer. Die model aanvaar dat die volgende omgewingsfaktore in die Overberg-omgewing verband hou met die waarskynlikheid van botsings, naamlik: die nabyheid van kraglyne aan waterliggame of gebiede waar voëls saamtrek, die voorkoms van natuurlike veld, die heersende windrigtings (Noordwes en Noordoos) en lae sigbaarheid van kraglyne teen die donker landskapsagtergrond.

Die geïdentifiseerde kraglyne is as eerste-, tweede, derde en vierderangse prioriteit geprioritiseer om as riglyn te dien vir die proaktiewe aanbring van flappers (wat dit ten doel het om voëlbotsings te verminder) deur ESKOM. Die studie het bevind dat 27% van die kraglyne in die Overberg-omgewing eersterang prioriteite is, en dat hierdie kraglyne onmiddellik gemerk sal moet word. Die tweederang prioriteit kraglyne (1%) sal oor die

mediumtermyn gemerk word, terwyl die derderangse prioriteit kraglyne (28%) oor die langtermyn gemerk sal word. Die vierde prioriteit kraglyne (21%) kon oor die langertermyn gemerk word.

Die studie het die omvang van die probleem, sowel as die rol van GIS in die bewaring van die Bloukraanvoëls beklemtoon. Die GIS-model wat in die studie ontwikkel en gebruik is, kan in soortgelyke gebiede soos die Swartland, of in ietwat verskillende omgewings soos die Karoo getoets word, met die doel om die habitatvoorkeure van Bloukraanvoëls beter te verstaan en navorsers te help om 'n beter begrip van die model te ontwikkel en sodoende die resultate te verbeter. Dit word voorsien dat hierdie studie en verslag baie belangrik sal wees vir die ESKOM-EWT Vennootskap en ander betrokke bewaringsorganisasies in 'n poging om Bloukraanvoël-bewaring aan te help.

ACKNOWLEDGEMENTS

My profound thanks goes to Jehovah God, the only true God to whom I owe the intellect to have come this far. To my family and friends, who constantly gave me support, courage and strength to persevere, your dedication is highly appreciated.

I also want to extend my deepest gratitude to my supervisors at different institutions. To Mr. Adriaan van Niekerk, my supervisor at the University of Stellenbosch, your assistance and sound advice was invaluable. To Dr Helen de Klerk (GIS Scientist) and Mr. Kevin Shaw (Ornithologist) at Western Cape Nature Conservation Board (WCNCB), Scientific Services at Stellenbosch. The continuous support and advice I got from you, every step of the way, is highly appreciated.

The successful completion of this thesis is also attributed to the generous funding from the ESKOM/EWT Partnership. To the Project Coordinator Mr. Kevin McCann and Mr. Chris van Rooyen, who in concert with WCNCB demonstrated dedication and devotion to the conservation of our natural heritage and long-term survival of the Blue Crane. I also want to thank Vicki Hudson, the Overberg Crane Group (OCG) Fieldworker, who was constantly helping with the field work and general information on the Blue Crane in the Overberg region.

I also want to thank Dr Edwin Hees and Miss Jeanne Ellis (Lecturers and language editors in the English Department of the University of Stellenbosch) for their technical assistance in shaping the language used in this thesis.

CONTENTS

FIGURES

TABLES

CHAPTER 1: BLUE CRANE CONSERVATION TRENDS IN THE OVERBERG

1.1 INTRODUCTION

Avifaunal communities have always been used to identify regions of high general biological diversity (Soorae & Seddon 2000). These communities have also been used to highlight the overall condition of the ecological region in which they live (Le Roux 2002). However, ornithological research indicates that in general terms, both in Africa and elsewhere, there has been a rapid decline in the number of large terrestrial bird species of which the Blue Crane (*Anthropoides paradiseus*) is no exception (Verdoorn 1996; Barnes 2000; McCann, Morrison, Byers, Miller & Friedman 2001).

Reports indicate that the South African national bird has experienced a general population decline of 20% between 1978 and 1998 to a nationwide population of approximately 24 000 birds (McCann 2002). An 80% decline is estimated to have occurred in the original grassland biome, where Blue Crane is considered to be the flagship species (Allan 1997; Le Roux 2002). It is against this background that the species is listed in the ESKOM Red Data Book as vulnerable (Barnes 2000).

1.2 THREATS

The population status of Blue Crane varies per ecological region (Allan 1997). In the grassland biome, which is viewed as its "ancestral stronghold" and where the majority of Blue Cranes were initially concentrated, the species has been under severe threat due to urbanisation, intentional and unintentional poisoning (usually prompted by the Blue Cranes' tendency to feed on agricultural fields and to cause crop damage), loss of habitat as a result of commercial forestation and the collisions of Blue Cranes with power lines. The population in the Karoo is however considered stable even though power line collisions are still a significant threat (Allan 1997), whereas the subpopulation in the cereal croplands of the Overberg and Swartland is growing (Scott & Scott 1998; Shaw & McCann 1998; Shaw 2003). It is estimated that approximately 50% of the global population occur on these agricultural lands (Barnes 2000).

Despite the fact that the population in the Overberg is growing, the future of Blue Cranes in a man-made habitat remains cause for concern. Only 2% of the national population occurs in nature reserves (McCann *et al.* 2001), while approximately 98% occurs on privately owned land. The majority of the population is concentrated in the Western Cape in an artificial habitat, and are therefore faced with human-induced threats such as agrochemical poisoning (both intentional and unintentional), direct exploitation and shooting (Shaw & McCann 1998; McCann *et al.* 2001). Additional threats (see Appendix A) include the removal of chicks from the wild to be kept as pets or for food, fence entanglements, chicks drowning in water troughs and the illegal and legal capture of Cranes for the zoo (Stuart & Stuart 1999; Barnes 2000).

This artificial habitat may also change due to agricultural economics, and this may well have a detrimental effect on the Blue Crane population. If, for example, there is a major switch from the cultivation of wheat to canola, an unsuitable habitat for the Blue Crane, the population will be affected because of the loss of habitat (Shaw & Hudson 2001). The survival of these birds therefore depends largely on the cooperation and participation of private landowners in conservation programmes (Shaw & McCann 1998).

1.3 EFFORTS TO PROTECT THE BLUE CRANE

Much has been accomplished in the drive to protect the Blue Crane in the Overberg region. A major achievement was the establishment in 1991 of the Overberg Crane Group (OCG), a partnership between the Western Cape Nature Conservation Board (WCNCB) and the local farming community, to promote the conservation of the Blue Crane in the Overberg region (Hudson & Leeuwner 2001). The OCG has been successful in educating farmers on the proper use of agro-chemicals, decreasing the number of chick deaths and reducing farmers' hostility towards the Cranes (Hudson 2001).

By 1993 the OCG had drawn up a conservation programme consisting of nine projects, one of which was to reduce mortalities caused by power lines (Hudson & Leeuwner 2001). As a result, a field worker was appointed to inspect collision sites and to work with the South African Electricity Commission (ESKOM) on the installation of marking devices on high risk power lines in an attempt to reduce collisions (Hudson 2001; McCann & Van Rooyen 2003). Since then many power lines have been marked to increase visibility. The growing population of Blue Crane in the region reflects the success of the OCG's intervention.

In 1996, ESKOM and the Endangered Wildlife Trust (EWT) formed a strategic partnership to assist in the conservation of Blue Crane. The partnership's aim was to ensure that electricity is supplied without significantly affecting the environment, and to minimise collisions and electrocutions (McCann & Van Rooyen 2003). Against the history of fragmented and inconsistent data, the partnership's major contribution was the consolidation of avian data, which facilitated acquisition of essential knowledge of the birds' interactions with power lines (McCann & Van Rooyen 2003).

coordinating Crane conservation efforts. The SACWG is made up of experts and several Crane groups in seven Crane regions. It is actively involved in Crane conservation projects throughout South Africa. Since its establishment, the SACWG has become one of the most effective and successful non-governmental organisation (NGO) for Crane conservation in South Africa (Rodwell & McCann 2001).

In view of concurrent risks facing the Blue Crane, it became clear to SACWG, EWT, OCG and the Conservation Breeding Specialist Group (CBSG) that the future of the species in a man-made habitat remains uncertain. Consequently, these conservation organisations convened a Blue Crane Population and Habitat Viability Assessment (PHVA) in 2001 to assess the declining population of Blue Cranes, over the past 20 years to estimate the potential for extinction within the man-made habitat. The workshop hastened the development of comprehensive conservation strategies aimed at securing the long-term survival of the Blue Crane in the Western Cape, which included the reduction of mortalities caused by power lines (McCann *et al.* 2001).

1.4 STATEMENT OF THE PROBLEM

Even though ESKOM and EWT have developed a programme to mark power lines in order to reduce collisions, the 157 collision records reported in the Overberg region since 1996 indicate that many unmarked hazardous power lines remain unknown, undocumented and therefore continue to be a major threat to Blue Cranes' population (McCann & Van Rooyen 2003). Taking into consideration that not all collisions are reported, it is estimated that annually, an average of about 20 Blue Cranes collide with power lines. Such high mortality rates can have a significant impact on a vulnerable species with a restricted global range (McCann 1999; Shaw 2002 *Pers com*). Apart from the biological significance of this type of mortality, the frequent collisions are also a source of irritation to ESKOM customers as they often lead to power outages (McCann 1999).

As a strategy to aid the conservation of Blue Cranes, a programme to mark hazardous power lines with bird flappers (see section 1.3) is proposed. A proactive approach should be adopted in which rule-based methods are integrated with predictive GIS models in order to identify hazardous power lines. Environmental factors such as landscape, proximity of power lines to water bodies and Blue Crane congregation sites, land cover and the orientation of power lines in relation to the dominant wind directions should be used to predict probable collision sites.

1.5 AIM AND OBJECTIVES OF THE STUDY

The aim of the study was to build a prototype model for the identification of hazardous power lines in the area identified for research. In order to achieve this aim, specific objectives include:

1. To provide a set of criteria for determining probable collision sites.
2. To develop a site-specific Geographical Information Systems (GIS) model that integrates expert knowledge of the Blue Crane in the Overberg region.
3. To compile a set of GIS tools that will guide conservation authorities in the identification of risk power lines.
4. To set up a program whereby ESKOM can proactively mark identified power lines with bird flappers.

1.6 STUDY AREA

The Overberg region is located in the Western Cape and was chosen as the study area (Figure 1.2). The Overberg is 60km east of Cape Town and can be reached via N2 road. The term

"Overberg" originates from the Dutch phrase 'overt geberghte' and means 'over the mountains' (Jordaan 2002). Topographically, the region consists of undulating hills and mountains. Altitude increases from sea level to approximately 1700m above sea level, the approximate height of the two majestic mountain ranges. The Langeberg range is to the north and extends from Worcester eastward towards the Gourits River in the Overberg. The Hottentots Holland Mountains is to the west of Overberg and stretches towards Gordon's Bay.

The area is also well known for pristine river systems that include the Bot River in the west and the Breede River in the east. Cape Agulhas, the most southerly point of Africa with the Atlantic Ocean on the one side and the Indian on the other, and Hermanus, well known for whale watching, attract thousands of tourists to the region. Because of its proximity to the sea the region experiences strong winds. The predominant wind directions are north-westerly and south-easterly in winter and summer, respectively.

The total surface of the study area is 1 378 301ha and incorporates the magisterial districts of Caledon, Bredasdorp, Hermanus, Swellendam, Riversdale and Heidelberg. Due to extensive farming in the Overberg, 54% of the natural veld has been transformed mainly by agriculture, urbanisation and invasive alien plants. The remaining 46% of untransformed land consists of 30 vegetation types covering 641 956ha (see Appendix B).

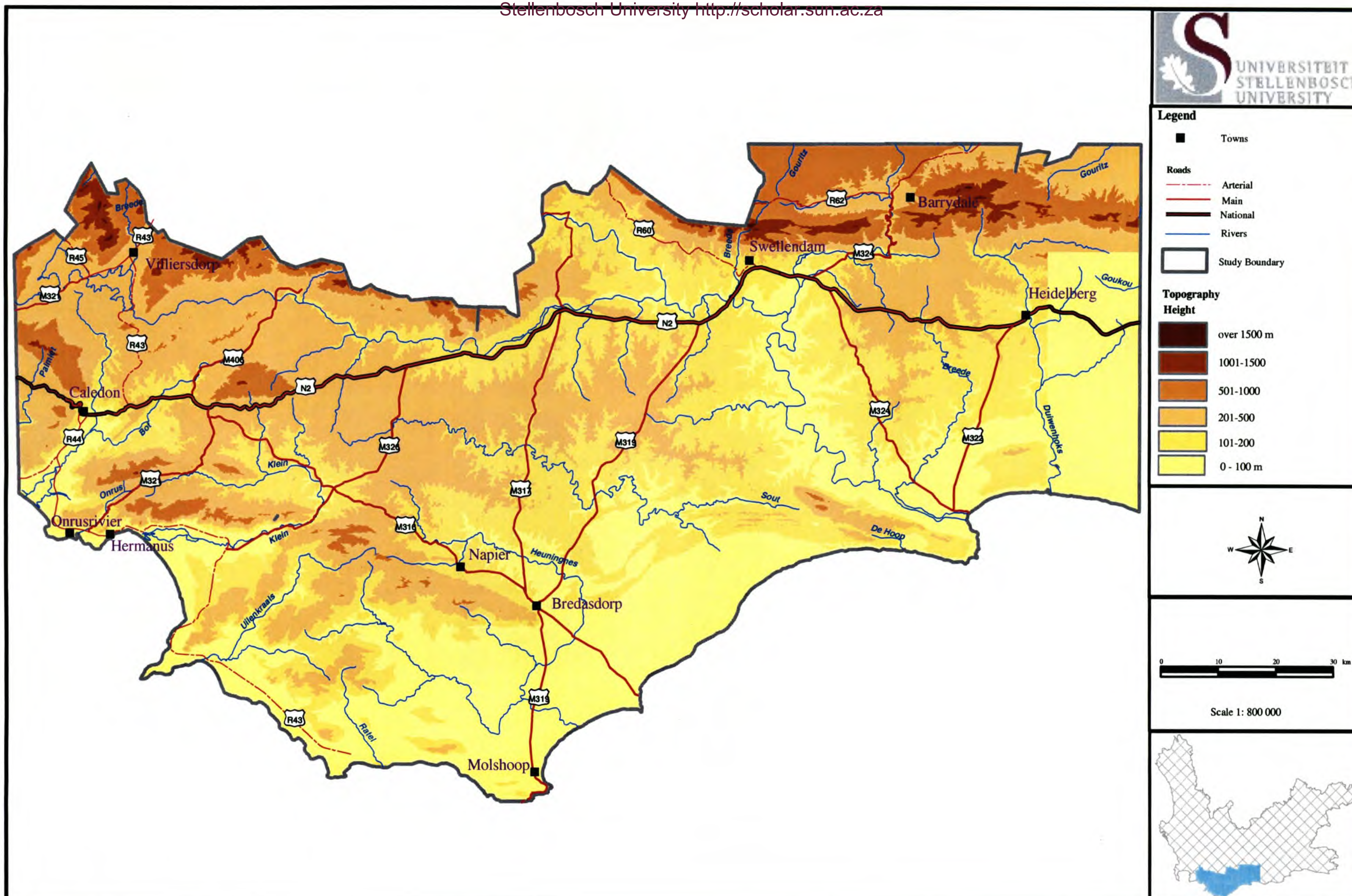

Figure 1.2: Study area

The Overberg region is home to approximately 50% of the global Blue Crane population and is therefore regarded as a critical conservation 'hot spot' (Barnes 2000) which, in contrast to Blue Crane subpopulations in other regions, experiences a steady growth in numbers. Well known as "the wheatbelt of South Africa", the Overberg's wheat, maize and barley fields provide the Blue Crane with plentiful and nutritious feed (Scott & Scott 1998; Hudson & Leeuwner 2001) and support more than 70 congregation sites that have been observed in the Overberg.

In addition, thousands of man-made dams and natural water bodies provide Blue Cranes with water and ideal roost sites. These environmental features and the extensive network of more than 3500km of power lines make the Overberg the collisions' hot spot and therefore the ideal region in which to conduct this research.

1.7 RESEARCH METHODOLOGY AND THESIS OUTLINE

A variety of methods were adopted to achieve the objectives of the study. A broad survey of the relevant ornithological literature was undertaken to obtain an overview of the Blue Crane distribution and ecology, current conservation status, habitat and its predisposition to colliding with power lines. A full account of the literature survey is provided in Chapter 2, which identifies the factors that affect collisions and describes how the installation of bird flappers addresses the problem.

The study adopted a rule-based approach to describe the bird's characteristics and general behavior and how these factors relate to the birds' tendency to collide with power lines. The rules were compiled via expert knowledge communicated through electronic and frequent telephonic communication, and regular discussions held between the researcher, Overberg Crane Group field worker, Ornithologist at WCNCB and Project Coordinator at National Crane Conservation Project. The National Crane Conservation Project was also involved in providing information about the pre-and post-mitigation collision incidents in the Overberg.

Heuristics were developed based on the expert knowledge of the behaviour, biology and habitat of Blue Cranes in the Overberg. Causal variables such as water bodies, congregation sites, natural vegetation, wind and topography were used to describe the landscape characteristics of sites where collisions are prevalent. A set of GIS procedures were built into the model and executed to highlight hazardous power lines. The model applied GIS subroutines on each landscape variable and computed the total length of hazardous power lines in the output layer. The design and application of rules are detailed in Chapter 3.

Analysis was carried out in ArcView GIS 3.2a with Spatial Analyst extension. The data manipulations and spatial analysis are fully documented in Chapter 3. The chapter also explores the theoretical and practical implications of integrating expert knowledge and GIS in models and illustrates the role of GIS in the conservation of Blue Crane in the Overberg. Furthermore, it discusses various GIS techniques such as overlays, proximity analyses and Avenue scripts that were applied to predict hazardous power lines.

Chapter 4 presents the findings of the research and the total length of hazardous power lines. The prioritisation of the mitigation procedure is also suggested. The chapter concludes by giving an account of model validation. Chapter 5 evaluates the results and suggests areas for future research.

CHAPTER 2: THE BLUE CRANE: ON A COLLISION COURSE?

2.1 THE CRANE FAMILY

The Blue Crane belongs to the ancient *Gruidae* family and *Gruiformes* order. The family consists of the world's most spectacular birds in terms of size, adornment and far-crying calls enhanced by "the long and folded trumpet-like neck" (Stuart & Stuart 1999:54). The Cranes range in height from 90cm to more than 150cm, with the Demoseille being the smallest and the Sarus Crane the tallest (Archibald & Lewis 1996; Meine & Archibald 1996; International Crane Foundation 2001). The 15 species are divided into two subfamilies, the Crowned Cranes (*Balearicinae*) and the Typical Cranes (*Gruinae*) (Ellis, Gee & Mirande 1996; Meine & Archibald 1996).

Crowned Cranes, that is the Black crowned Crane (*Balearica pavanina)* and the Grey crowned Cranes (*Balearica regulorum*), are distinguished from Typical Cranes by their ability to roost in trees (Meine & Archibald 1996). Typical Cranes are: Demoiselle (*Anthropoides virgo*), Blue Crane (*Anthropoides paradiseus*), Wattled Crane (*Bugeranus carunculatus*), Sandhill Crane (*Grus canadensis*), Siberian Crane (*Grus leucogeranus*), Whooping Crane (*Grus americana*), Sarus Crane (*Grus antigone*), White-naped Crane (*Grus vipio*), the Brolga (*Grus rubicundus*), Eurasian Crane (*Grus grus*), Hooded Crane (*Grus monuchus*), Black-necked Crane (*Grus nigricollis*) and the Red crowned Crane (*Grus japonensis*) (Ellis, Gee & Mirande 1996; Meine & Archibald 1996).

Crane species are found on five of the seven continents – Africa, Asia, North America, Europe and Australia (Archibald & Lewis 1996; International Crane Foundation 2001). In Africa, wetlands, grasslands, and recently agriculturally-transformed landscapes support six of the 15 Crane species, namely the Blue Crane; the Wattled Crane (the largest and rarest of

Africa's Cranes), the culturally significant Grey Crowned Crane; the Black Crowned Crane (Nigeria's national bird), the Demoiselle Crane (a winter visitor from Eurasia to Northeast Africa) and the Eurasian Crane (a winter visitor to Northern Africa) (International Crane Foundation 2001).

Cranes play an important spiritual role in many cultures. In Asia they are considered to be birds with a deep cultural and mythological significance (International Crane Foundation 2001). In Japan, due to their tendency to pair for life they are a symbol of happiness, good luck, long life and marital bliss (Meine & Archibald 1996). In African culture, only the king of a tribe could wear the long Blue Crane feathers in his headdress as the Blue Crane was regarded as a symbol of respect (International Crane Foundation 2001).

2.2 DISTRIBUTION AND ECOLOGY

2.2.1 Cranes in South Africa

Despite the high regard afforded to Cranes by cultures throughout their global distribution, 11 of the 15 Crane species are vulnerable and at risk of extinction, making Cranes one of the most threatened birds in the world (International Crane Foundation 2001). Three of these species are found in Southern Africa: the Blue Crane, the Wattled Crane and the Grey Crowned Crane (McCann 1999). According to South African Red Data Book, these three species are to some extent threatened, with Blue and Grey Crowned Cranes "Vulnerable", while the Wattled Crane is "Critically Endangered" (McCann 2002). Table 2.1 indicates the historical distribution and population of the three Crane species in South Africa.

Table 2.1: Population size of Blue, Grey Crowned and Wattled Cranes between 1999 and 2002.

Region	Blue Crane		Grey Crowned Crane		Wattled Crane	
	1999	**2002**	**1999**	**2002**	**1999**	**2002**
Northern Complex[1]	668	429	368	133	17	6
Free State	1810	4590	560	281	7	7
KwaZulu-Natal	1020	520	2282	1725	202	197
Northern Cape	2647	2856	0	0	0	0
Eastern Cape	3309	4224	1010	979	12	6
Western Cape	10 649	12 095	0	3	0	0
TOTAL	**20 103**	**24 714**	**4220**	**3121**	**238**	**216**

Source: McCann 2002

[1]*Includes Northern Province, North West, Gauteng and Mpumalanga*

All three Crane species have declined in the Northern Complex and KwaZulu-Natal. In general terms, the Blue Crane's population is increasing, while the Grey Crowned and Wattled Cranes' population is declining. As shown from the table above, the distribution and population differs per region, with the highest concentration of the Blue Crane in the Western Cape province. The following section discusses in detail the historical distribution of Blue Crane in the three core regions that hosts its subpopulation.

2.2.2 The Blue Crane

The Blue Crane (Figure 2.1), also known as the Paradise Crane or the Stanley Crane, is South Africa's national bird and is near endemic to South Africa (Barnes 2000). It is a large terrestrial bird that is approximately 107-150cm tall (Meine & Archibald 1996; International Crane Foundation 2001). In the field it is easily distinguished from other Crane species by the long neck and legs, the uniform grey-blue plumage and long streamer-like tertial feathers of the wing (often mistaken for a tail), a pinkish-yellow cone-like bill, black eyes, white crown and a head that looks swollen (Urban, Fry & Keith 1986; Newman 2000). The Blue Crane is essentially a bird of dry grassland (Meine & Archibald 1996; Barnes 2000) that due to its rapid decline in the grasslands has been identified as one of the flagship species to indicate the general ecological health of the grasslands (Le Roux 2002).

Figure 2.1: The magnificent Blue Crane (*Anthropoides paradiseus*) at a nest site.

The Blue Crane has the most restricted global range of all Crane species (Meine & Archibald 1996; Allan 1997; Stuart & Stuart 1999; Barnes 2000). It occurs exclusively in Southern Africa (Figure 2.2), with the majority of its population in South Africa (Urban, Fry & Keith 1986; Barnes 2000). Historically it was abundant in limited parts of its range in the short, dry grassland and upland areas of Southern Africa, with smaller populations in Namibia centred on the Etosha Pan and occasional vagrants in other parts of the country (Allan 1997). In Botswana, it is found towards the extreme south-east with no confirmed breeding records (Allan 1997). In Lesotho, it is found as a non-breeding summer migrant (Meine & Archibald

1996; Allan 1997). In Swaziland, it breeds at Malolotja Nature Reserve (Del Hoyo, Elliot & Sargatal 1996; Allan 1997; Barnes 2000).

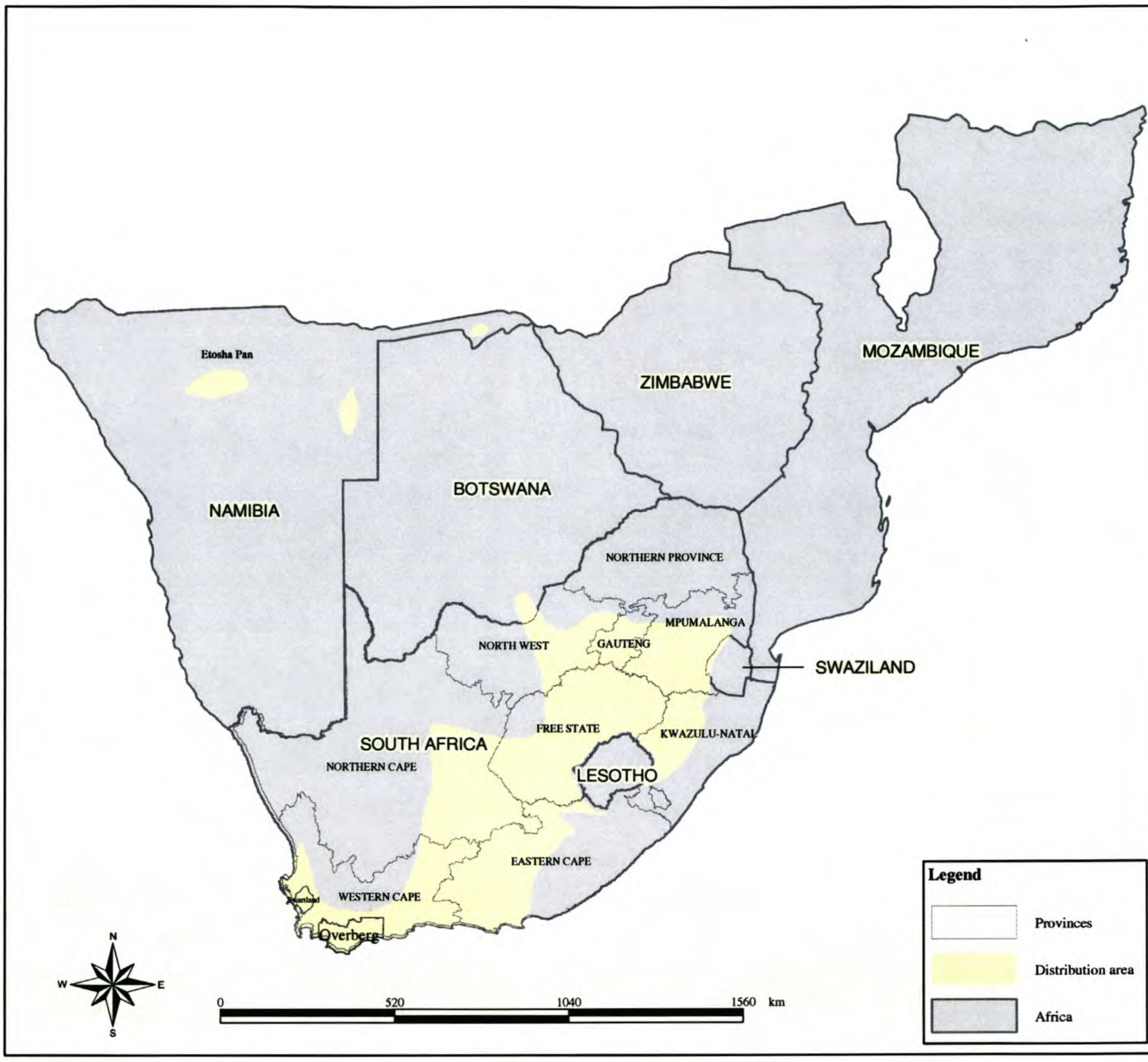

Figure 2.2: Distribution area of the Blue Crane in Southern Africa.

The global population of Blue Cranes is approximately 25 000 (McCann 2002). In South Africa approximately 24 000 Blue Cranes occur in three core sub-population concentrations (Barnes 2000). The first occurs naturally in the Central Karoo within the Northern Cape, southern Free State and reaching into the Eastern Cape. The second is centred at the junction of Mpumalanga, the north-eastern Free State and KwaZulu Natal and extending into the Eastern Cape.

Recently Blue Cranes have colonised the agricultural wheat belts of the Swartland and the Overberg of the southern region of the Western Cape and have adapted well to this environment (Allan 1997; Barnes 2000). This forms the third and largest core population of over 12 000 individuals, which is approximately half of the global population (Barnes 2000).

Historically the Blue Crane did not occur in the fynbos biome as they avoid tall and dense vegetation (Allan 1997). They moved into this area with the advent of the small grain/pasture agricultural system. These extensive tracts of grain fields and pastures in the Western Cape provide Blue Cranes with a suitable man-made habitat, as the wheat, maize and barley fields supply food during the summer breeding period (Urban, Fry & Keith. 1986; Meine & Archibald 1996; Shaw & McCann 1998; Hudson & Leeuwner 2001), while the pastures provide the species with an alternative habitat to move to during the non-breeding period in winter, when the wheat fields become unsuitable because of the height of the grain plants (Shaw & Hudson 2001).

The non-breeding period in the Overberg as mentioned above, coincides with winter and is shorter than the breeding period. During this time the Blue Cranes are gregarious and often observed in family groups and large flocks that occasionally exceed 800 birds. The congregations may even be larger at major roost and foraging sites (Allan 1997). With less dependence on water, the birds congregate at feeding grounds where food is more plentiful (Urban, Fry & Keith 1986). Some of the common activities at the congregation sites include feeding, preening, prancing and dancing.

Although these activities take place throughout the year, elaborate dances intensify prior to the breeding season as they serve as a prelude to the mating of unpaired birds in preparation for breeding (Meine & Archibald 1996). A male and a female bird engage in a courtship dance that ends when the excited birds stop and in duet give a unison call, which has a sexual function (Urban, Fry & Keith 1986; Ellis, Gee & Mirande 1996; Meine & Archibald 1996). For the already paired birds, the dances cement the bond (Stuart & Stuart 1999).

According to Shaw & Hudson (2001), the breeding season starts from the time when the first nests are built in September until the last chicks are fledged in May. During the breeding season, the distribution of birds is relatively dispersed because the flocks break up and form pairs (Shaw 2002 *Pers com*). Territories are built in open areas that provide an uninterrupted view of the surrounding region to enable the birds to detect predators from a distance (Barnes 2000). The mature birds are often seen in pairs, while the immature birds flock together (Urban, Fry & Keith 1986).

Nesting occurs in pastures, fallow fields and crop fields (Barnes 2000). A nest is just a scrape on the bare ground, sometimes with a few twigs or pebbles. A clutch of two dappled brownish eggs is laid on bare ground or rock and often circled with pebbles, sheep droppings or plant material (Barnes 2000). The bare ground camouflages the eggs and therefore effectively protects them from predators. Most of the Overberg Blue Crane pairs stay at the nest site for the second chick to hatch and then raise the two chicks (Shaw 2002 *Pers com*). The male and female take turns in incubating the eggs for a month until they are hatched. The Blue Crane has shown a level of dependence on water, as nests are often located close to water (McCann *et al.* 2001; Shaw & Hudson 2001).

As the Blue Crane engages in aforementioned activities on daily and/or seasonally, it interacts with man-made structures such as power lines. The following subsection discusses the factors affecting Blue Crane collisions with power lines.

2.3 FACTORS INFLUENCING POWER LINE COLLISIONS

Both the biological characteristics of the Blue Crane and the landscape features of the Overberg contribute to power line collisions.

2.3.1 Biological characteristics

The biology of a bird includes the physical and genetic features that distinguish it from other species. To some extent, the physiological features influence behaviour of birds in relation to their environment. They can also be used to determine the probability of birds colliding with aerial hazards such as power lines. The relationship between the physical build, flight characteristics and vision of the Blue Cranes and its tendency to collide with the power lines will be discussed in the following subsections.

2.3.1.1 Physical build

According to Peterson (1964), flying is one of the outstanding characteristics of birds that are common from the smallest humming birds to the largest albatross. The flight mechanism of birds is influenced by factors such as wing loading, tail and body shape (MacClean 1990). The Blue Crane, like other large birds is heavy due to the high wing loading (ratio of body weight to wing area). The heavy body limits manoeuvrability and makes it difficult to change course at the last minute when approaching aerial hazards such as power lines (McCann 1999).

2.3.1.2 Flight pattern

Blue Cranes have particular flight characteristics (McCann 1999). Since lightness is essential to flight, some small birds take off from the ground by jumping and flapping their wings or dropping from a perch in order to gain momentum. The heavier the bird, the greater the effort it will need for take off. Large birds such as Blue Cranes need a run into the dominant wind direction before gaining lift necessary for flight provided there is sufficient wind (MacClean 1990; Schmidt-Nielsen 1990).

The wind provides a propulsive force during take off and landing (Shergalin, Keskpaik & Kuznetsov 1995; Del Hoyo, Elliot & Sargatal. 1996; Meine & Archibald 1996). The Blue Crane lands in the direction of the dominant wind, approaching the ground with head semi-erect, wings extended and legs dangling (Schmidt-Nielsen 1990; Meine & Archibald 1996). During take off and landing, the bird is focused on either gaining altitude or slowing down, paying less attention to the objects on its flight course. It is against this background that power lines orientated roughly perpendicular to the dominant north-westerly and south-easterly wind directions of the Overberg, pose an obvious threat to the Blue Cranes because they are on the bird's flight course.

Additionally, Blue Cranes generally tend to fly low when traversing short distances in-between feeding and roosting sites, which increases the risk of a collision, taking into consideration that the height of the distribution power lines in the Overberg is between 5.1m and 9.2m (Shaw 2002 *Pers com*; Van Rooyen 2003 *Pers com*). Collisions are also caused by unforeseeable circumstances, for example when birds take off instantaneously to escape from a predator. Due to reduced concentration, the birds often collide with the power lines that lie ahead on the flight course (Hudson 2002 *Pers com*).

2.3.1.3 Vision

Birds are regarded as highly visual animals (Farner, King & Parkes 1973). Their visual acuity is an important prerequisite of flight because travelling at great speeds requires eyesight to be good to enable them to perceive movement and to avoid aerial hazards. The birds' eyes should therefore be able to register and react instantaneously to both distant and near objects. Peterson (1964) regards birds' to have the best vision of all living things. The superb eyesight is accounted for by the shape and position of the eyes, which vary from species to species.

According to Peterson (1964) the position of the eyes on either side of the head gives each eye a great deal of monocular vision to the side and a field of binocular vision straight ahead where the two monocular fields of vision overlap into a single image. A woodcock, for example, has a full vision of 360° because of the position of its eyes. The Blue Crane's eyes are positioned at the sides of the head.

Underhill (1998) maintains that this provides the bird with a two-dimensional vision. With this kind of vision, the bird judges the distance to the approaching object by the relative movement of the object against the background. Because power lines are not large enough to visibly move against any background, Blue Cranes find it difficult to determine the distance to the power line. Distance is also judged by the rate at which the object changes size as the bird approaches: the closer the object, the larger it becomes. Power lines do not conform to this principle because of their size and shape. As a result, the bird realises too late that it is too close to the power line and cannot avoid colliding with it (Underhill 1998). However, there are certain environmental factors that also influence Blue Crane collisions with the power lines.

2.3.2 Power lines and the Overberg landscape

Collisions also occur as a result of either natural or man-made features of the landscape. These may include the height of power lines and background land cover during different seasons of the year.

2.3.2.1 Height of power lines

The height of distribution power lines (11kV and 22kV) is between 5.1m (the lowest point on the power line) and 9.2m (the highest point on the power line). The height of these power lines poses a threat to Blue Cranes during short local flights when the birds are traversing short distances between roosting and feeding sites. The problem is exacerbated when visibility is poor, particularly during foggy periods in the early morning or late evening when the sun is low.

2.3.2.2 Land cover

During the growing and harvest season, the shade of vegetation blends in with the colour of power lines. The low colour contrast between vegetation and power lines makes it difficult for Blue Cranes to see the power line from a distance. Despite their ability to differentiate colours, Gauthreaux (1994) argues that birds have a poorer ability than humans do to resolve spatial frequency **at low contrast**. This study confirms that against the background of golden yellow fields (during harvesting) the power line reflects the colour of the field, and is therefore difficult to recognise from a distance. Similarly, it is difficult to see power lines from a distance against a dark green background (during the growing period) of fields, as they reflect the colour of the vegetation (Hudson 2002 *Pers com*). Figures 2.3 and 2.4 illustrate the effect of different shades of vegetation on the visibility of power lines.

Figure 2.3: Power line against a golden yellow background of the harvested fields. The arrow shows section of the power line that is not visible.

Figure 2.4: Power lines against a dark green background of a field during growing period. The arrow indicates section of the power line that is not visible.

2.3.2.3 Structure of power lines

Power lines are made from a highly reflective luminescent material whose visibility is reduced under light and dark conditions. The size and colour of the power lines contribute to collisions. A comparison of the visibility of power lines and telephone lines showed that due to their bigger size and deep black colour, telephones lines are more visible than power lines. The low visibility of the power lines therefore contributes to collisions.

2.4 HOW BIRD FLAPPERS HELP

Samples of power lines in the Overberg that were reported to be common collision sites were fitted with bird flappers and monitored. Table 2.3 lists the collision sites in the study area that have been monitored since 1997 (extracted from the central database). The table shows that since mitigation started in 1999, many high collision sites have experienced no collisions and that in general, collisions were dramatically reduced after bird flappers had been installed.

Table 2.2: Record of collisions at the 19 inspected localities in the Overberg. The table illustrates the effect of mitigation on the number of collisions.

Locality #	Total mortality pre-mitigation	Total mortality post-mitigation to date (Jan 2003)	Date monitoring commenced	Date flappers were fitted
73	34	0	January 97	May 00
321	6	1	October 98	August 99
337	1	0	February 99	August 99
550	1	0	March 01	March 02
561	3	0	April 01	March 02
562	1	0	April 01	March 02
564	1	0	April 01	March 02
565	1	0	April 01	March 02
566	1	0	April 01	March 02
574	1	0	May 01	March 02
575	2	0	May 01	March 02
579	4	0	May 01	March 02
585	2	0	June 01	March 02
599	3	0	June 01	March 02
631	2	0	November 01	March 02
651	3	0	November 01	March 02
699	1	0	August 01	December 02
713	1	0	September 02	November 02
714	3	0	September 02	November 02
Total: 19	**71**	**1**		

In view of the effect of bird flappers in reducing collisions, it is urgent that hazardous power lines are identified and marked with bird flappers. In order to mark these power lines, they have to be accurately identified because the cost of mitigation is high (see Table 4.2). The integration of GIS with the expert knowledge (as discussed in the following chapter) provided the accuracy and speed with which the identification process was required.

CHAPTER 3: CONSTRUCTION AND INTEGRATION OF RULES IN GIS

This chapter gives a short overview of the application of Geographical Information Systems (GIS) in conservation and examines the role of the rule-based approach in predictive modelling and how it can be integrated into GIS. The bulk of the chapter describes the construction of rules based on expert opinion. The rules define the behaviour and biology of the Blue Crane in the Overberg region that increase the probability of their collision with power lines. The application of proximity and overlay operations to define containment searches and the development of a script that determines power line orientation (angle) are discussed. The chapter furthermore explains the grid-based analysis of topography that was applied to identify power lines that are below the summit of nearby hills. The concluding section presents the model flowchart employed to identify high-risk power lines.

3.1 GIS IN CONSERVATION

GIS provides functions for capturing, storing, visualising, managing and manipulating spatially referenced data (Pullar 1997). Its ability to handle spatial data sets in a manner that ties objects to their specific location makes GIS more powerful than other information systems (Fischer, Henk & Unwin 1996). This functionality allows users to depict relationships between objects and their environment. Furthermore, it allows an integrated analysis of phenomena, modelling and prediction (Clarke 2001). Applications of GIS in environmental and conservation domains are probably the earliest contexts in which its functionality was realised.

GIS has been proved to be of importance in conservation biology and landscape ecology (Haines-Young, Green & Cousins 1993). It has become a common and useful tool in the generation of landscape indicators, which can provide quantitative measurements of the status or potential health of an area such as an ecological region, watershed or county (Fischer, Henk & Unwin 1996). For instance, a GIS-driven Gap Analysis Program (GAP) assists planners and conservation authorities to identify conservation hotspots (Patrick & Kohley 1998).

GAP is the practice of mapping habitats of sensitive species and overlaying the protected and undisturbed areas of habitat to determine conservation status. The National GAP at Moscow built a Biological Decision Support System in ESRI's ArcView that allows the user to analyse individual parcels for known or predicted biotic occurrences of plant communities and terrestrial vertebrates, and to identify the state, federal and GAP conservation status of the species within that parcel. As a decision support tool, it provides planners and conservation biologists with the means to identify and compare species-rich areas before requesting or issuing development permits (Crist 1998).

With the increase in available landscape data from satellite imagery, ground surveys and public agencies, GIS is becoming irreplaceable for performing spatial analyses in conservation biology (Clarke 2001). The satellite images are useful for modelling the spread of fires, wildlife habitat, potential wildlife movement corridors, land ownership and status, and a variety of other data. These kinds of analyses are primarily important to identify areas, on both public and private lands, where there is the greatest conservation potential and need for conservation intervention (Allen 1999). Through the proper use of spatial models, stakeholders can prioritise conservation and devise appropriate conservation strategies.

3.2 SPATIAL MODELLING

Spatial modelling has been the mainstay of geographical research from well before the quantitative revolution of the 1950s and 1960s (DeMers 1997). The integration of models in GIS simplifies the complex processes of the real world, aids our understanding of the dynamics of how these processes interact with the environment and provides easy and flexible ways in which spatial problems can be solved. One of the fundamental roles of models in GIS is to provide a predictive tool for the management of the environment.

3.2.1 Predictive models

Predictive models are complex cartographic models that contain a prescriptive component and rely on a description of existing conditions to formulate predictions. Such predictions can be problematic because the variables sought must have a clear and verifiable causal relationship, whereas spatial association among different mapped variables does not necessarily indicate a cause-and-effect relationship. It may simply mean that the variables occupy more or less the same space (DeMers 1997).

Predictive modelling is particularly important in this research because there are environmental features (such as water bodies, congregation sites, land cover, orientation of power lines in relation to wind direction and topography) that are directly related to Blue Crane collisions with power lines, and are therefore perceived as strong predictors of sites where collisions are most likely to occur. It is against this background that the predictive model developed and applied in this research has been integrated with rule-based approach in order to provide the expert knowledge required to explain the existing conditions and cause-and-effect relationships in the study area.

Fischer, Henk & Unwin (1996) describe the predictive power of GIS and expert knowledge in a so-called favourability function. Predictive modelling is described as applicable where there are known and unknown occurrences of the phenomenon being investigated within the study area. In this context, the crucial task is to identify the areas where the unknown phenomenon is likely to occur by taking into account the known occurrences and the expert knowledge. The favourability function inherent in predictive modelling was applied in this research by studying the known collision sites in the study area in order to gain a general understanding of the conditions under which these collisions occur. The conditions thus identified were used to formulate rules that were applied to locate unknown collision sites in the study area.

3.2.2 Rule-based approach

The application of expert knowledge in modelling is often achieved through a rule-based approach, also known as expert systems. These models rely on the development of rules, or heuristics, to solve real world problems that require expert interpretation (Johnston 1998). Expert knowledge provides empirical evidence gathered through observation, field work and extensive knowledge of the problem at hand in order to draw conclusions and support decision making (Fedra, Winkelbauer & Pantulu 1991; Abebe, Solomatine & Venneker 2000). Unlike other methods, the rule-based approach has been known to narrow down and clearly define problems because it does not offer universal solutions, but is rather based on an explicit understanding of a given problem area (Fedra, Winkelbauer & Pantulu 1991).

Examples of applications where GIS were coupled with rule-based models to identify and solve ecological problems include the evaluation of the bear habitat in north-eastern Minnesota (Johnson, Host, Jordan & Rogers 1991); the prediction of the hazard of southern pine-beetle outbreaks based on environmental factors and levels of environmental disturbance in Angelina National Forest in Texas (Coulson, Lovelady, Flamm, Spradling & Saunders 1991); the investigation of landscape/disturbance relationship in the Everglades ecosystem in Florida (Silveira, Richardson & Kitchens 1992) and modelling of habitat suitability for the red deer within the Grampian region of north-east Scotland (Aspinall 1993). Similarly, the rules applied in this research were coupled with GIS to identify hazardous power lines in the Overberg region.

3.3 RULES

The application of rules, as indicated above, is of paramount importance in predictive modelling. The rules applied in this study were based on relevant literature, extensive monitoring and field observation of the Blue Crane's behaviour and habitat. The environmental characteristics of sites where most collisions occur were also examined and integrated into the rules. This study does not, however, apply expert knowledge through the generic rule-based model that operates on "if" conditions and "then" statements, but rather through the formulation of heuristics from which data layers (including water bodies, Blue Crane congregation sites, natural veld, wind direction and topography) were derived and integrated into a predictive GIS model.

Although these rules may find wider application in other Blue Crane habitats, they have been developed in response to a specific research problem: identifying hazardous power lines for Blue Cranes in the Overberg region. The rules were organised logically, by first excluding no risk power lines thereby narrowing the scope of the problem, while simultaneously identifying higher level of risk; systematically in terms of GIS operations applied; and hierarchically in terms of ranking the risk factor. The rules were as follows:

Rule 1: Blue Cranes avoid natural vegetation

As discussed in section 2.2, the original renosterveld of the Overberg was never a favourable habitat for Blue Cranes because it is too tall and dense for this grassland species (Hilton-Barber 1997; Shaw & McCann 1998). Since there is a lower probability that Blue Cranes will congregate and/or roost in areas covered by natural veld, sections of power line that intersect remnants of natural veld pose little or negligible collision risk. This is confirmed by the fact that there are no records of collisions on the power lines that intersect the natural veld. Furthermore, there are no Blue Crane congregation sites on the natural veld. These findings support the assertion that Blue Cranes of the Overberg region avoid natural vegetation (Meine & Archibald 1996; Shaw & McCann 1998).

Rule 2: Blue Cranes congregate at feeding sites

Blue Cranes spend most of the daylight time in areas where food is abundant (International Crane Foundation 2001). With the adoption of wheat/pasture agricultural system and sheep farming in the area, the Blue Crane population has grown, as these agricultural activities provide the species with nutritious feed and an open habitat that suits them. In the study area, this constitutes the wheat, maize and barley fields, or areas where sheep are fed (Hudson 2002 *Pers com*). To delineate collision sites that may occur closer to these congregation sites, a 1500m radius was created. This distance also referred to as a buffer, accounts for the total extent of the site because these sites are area rather than point features (see section 3.5.2). It also allows for the natural movement of these large birds in these sites. Since these sites are frequently visited, there is a probability that collisions may occur on the power lines that occur within 1500m of congregation sites. The records indicate that 34% of collisions in the Overberg have occurred within this buffer.

Rule 3: Blue Cranes roost in shallow water bodies

Blue Cranes roost in shallow water bodies such as farm dams, estuary banks, marshes and vleis in order to avoid predators, which include caracal and jackal (Allan 1995; Shaw 2003). Field observation indicates that most of the collisions occur within a 500m distance of a water body. In the study area, more than half of recorded collisions have occurred on power lines that are within the 500m range of water bodies. These power lines are therefore considered hazardous.

Rule 4: Blue Cranes take off and land into the dominant wind direction

As mentioned in section 2.3, the wind direction plays an important role in the birds' flight by providing the necessary lift and forward thrust during take off and for slowing down during landing (Schmidt-Nielsen 1990; Shergalin, Keskpaik & Kuznetsov 1995; Del Hoyo, Elliot & Sargatal 1996; Meine & Archibald 1996). The birds take off and land by orientating themselves into the dominant wind direction. With the north-westerly wind in winter and the south-easterly wind in summer, sections of power lines that are orientated more or less perpendicular (0°-105° and 180°-285°) to these dominant wind directions are potential collision sites.

Rule 5: Power lines below the summit of hills are difficult to see

The height of power lines in relation to the surrounding topographical features plays an important role in determining the probability of a collision. Due to the Overberg's undulating hills and mountains, the visibility of power lines back dropped by these hills is greatly reduced (see section 2.3). With the power line's height below the summit of hills or mountains, it becomes difficult for the birds to see the power line against such a dark background. All the power lines that are below the summit of nearby mountains and hills pose a potential collision risk.

In order to facilitate the integration of the expert knowledge into GIS, the above mentioned rules were translated into the research questions below (see Table 3.1), from which data layers and GIS commands were derived.

Table 3.1: Questions from which data layers and GIS operations were derived.

Questions	**Power line subsets**	**Data layers**	**GIS commands**
1	Do power lines intersect the natural veld?	Power lines and natural veld	Erase
2	Is power line within 1500m of a congregation site or 500m of a water body?	Remaining power lines, congregation sites and water bodies	Buffer
3	Is power line's azimuth between 0-105° or 180-285°?	Remaining power lines	Script
4	Is power line height lower than nearby (1500m) hills?	Remaining power lines and DEM	Various grid commands

Table 3.1 is translated in this manner: question 1 establishes research question, power lines and the natural veld as data layers to be used for the analysis, while the term "intersect" relates a spatial overlay operation, such as erase. In question 2, power lines, congregation sites and water bodies are identified as data layers, while the term "within" relates to a buffer operation. The similar procedure was followed for power lines' orientation in relation to wind directions and power lines below summit of hills. The execution of these GIS commands on the power lines and other data layers results in the identification of various levels of priority for marking power lines in the study area.

3.4 CRITERIA FOR PRIORITISING POWER LINES MARKING

The power lines were classified according to five priority levels, as shown in Table 3.2, in order to assist ESKOM in the proactive marking of the hazardous power lines. The priority levels range from power lines that should be marked immediately to power lines that do not require marking. Prioritisation for marking the power lines is based on the convergence of risk factors (as discussed in section 3.3) on sections of the power line **and not** on the number of collisions occurring on the power lines. This implies that the higher the number of risk factors converging on certain sections of the power line, the higher the probability of a collision, and the higher the priority, while the lower the number of risk factors converging at certain localities projects the lower level of risk.

The importance of assessing risk level by the number of collisions cannot be overlooked as it may be used to gauge the speed with which the species approaches extinction. But for the purposes of this study, the collision risk is based on the presence or absence of a collision factor such as natural veld, water body, congregation site; the influence of physical features such as wind direction and height of power lines against the surrounding topography; and the intersection of these factors on the power lines. Furthermore, assigning risk level on the basis of physical features is dependable because the influence of these features may change over a long period of time, while the number of collisions may vary seasonally and/or annually as a result of certain circumstantial event(s).

In addition, prioritising hazardous power lines on the basis of physical features is cost-effective because identified hazardous power lines will always pose a threat as long as these natural features exist. On the other hand, circumstantial collision factors may change within a short time and render a previous high risk power line, a no risk status because of the temporal nature of the factor itself. It is against this background that the number of physical features converging on certain sections of the power line is a reliable measure for prioritizing marking process.

The criteria for prioritizing power lines marking, as tabulated in Table 3.2, is illustrated with logical operators such as AND, OR, and NOT. It also applies comparison expressions such as greater than (>), less than (<) and (=). Subsets operators such as intersection (∩) are also used to simplify the criteria.

Table 3.2: Priority levels for proactive marking of power lines

Level	Priority	Criteria (based on questions)*
1	Mark immediately	((P ∩ Wb) OR (P ∩ Cs) AND (P ∩ Wd) AND (P < hills) AND (NOT (P ∩ Nv)))
2	Mark in the shorter term	((P ∩ Wb) OR (P ∩ Cs) AND (P ∩ Wd) AND (P >= hills) AND (NOT (P ∩ Nv)))
3	Mark in the medium term	((P ∩ Wb) OR (P ∩ Cs) AND (NOT (P ∩ Nv)) AND (NOT (P ∩ Wd)))
4	Mark in the long term	(NOT (P ∩ Nv) AND (NOT (P ∩ Wb) OR (P ∩ Cs)))
5	No marking necessary	(P ∩ Nv)

*Where:
P represents power lines
Wd represents wind direction
Wb represents water bodies
Cs represents congregation sites
Nv represents natural vegetation

Level 1: Power lines in this category intersect water bodies or congregation sites, are orientated between 0-105° or 180-285°, occur below the crest of local hills, and do not intersect natural vegetation. This implies that all the factors that have been set out as causative agents of collisions (see section 3.3) converge on these power lines. Therefore, power lines that meet all of these criteria pose the highest risk of collisions to Blue Cranes.

Level 2: Power lines in this category intersect water bodies or congregation sites and occur between 0-105° or 180-285°. These power lines are also below the crest of local hills, and do not intersect natural vegetation.

Level 3: These power lines intersect water bodies or congregation sites, and do not intersect natural vegetation and dominant wind direction (between 0-105° or 180-285°).

Level 4: In this category, power lines do not intersect natural vegetation and do not intersect water bodies or congregation sites.

Level 5: These are no risk power lines as they intersect natural vegetation, an unfavourable habitat for Blue Cranes.

The fully detailed account of the four levels of priority for the marking of the power lines is discussed in Chapter 4.

3.5 DATA COLLECTION

To obtain the required information, both primary and secondary data collection techniques were used. Data was solicited from various sources as indicated below.

3.5.1 Primary data collection

Primary data were collected during field trips. These included field trips that were organised to capture common collision sites with a Global Positioning System (GPS) and a digital camera, and to identify the environmental features found within close proximity of such collisions.

3.5.2 Secondary data sources

The majority of spatial data used in the GIS analysis were collected from various sources in different formats. All vector data was supplied in ArcView shapefile format. These included:

(i) Power lines as supplied by ESKOM. This included 11kV and 22kV distribution power lines. The data was captured by ESKOM at 1: 50 000 scale.

(ii) Water bodies including marshes, vleis, perennial pans, non-perennial pans, dry pans, lakes, dams and large reservoirs, were obtained at 1: 50 000 scale from the Department of Land Affairs.

(iii) Congregation sites were captured at 1:50 000 scale as point features by WCNCB. The points represent localities where Blue Cranes congregate in large numbers, either permanently or temporarily. Up to 317 Blue Cranes were observed while feeding or roosting (Van Rooyen 2003 *Pers com*).

(iv) The boundaries of the magisterial districts of the Western Cape were supplied by WCNCB. These were originally captured by the Department of Land Affairs at 1:50 000 scale.

(v) The Botanical Society of South Africa provided a layer containing patches of natural vegetation that was captured from LANDSAT imagery at 1: 250 000 scale.

(vi) A Digital Elevation Model (DEM) with a 60m resolution was provided by WCNCB in ESRI grid format. The DEM was clipped and resampled from the 20m resolution Western Cape DEM (WCDEM) developed by the Centre for Geographical Analysis (CGA) at the University of Stellenbosch.

(vii) Collision sites were supplied by EWT in Microsoft Excel format. These sites were captured with a GPS and represent the locations where Blue Cranes collided with power lines. The table was imported into ArcView GIS 3.2a and converted to a shapefile using Avenue "ImportTable" script.

Where necessary, the data layers were clipped or subsetted to the extent of the study area. Clipping and subsetting confine the selected feature within the defined boundary of other features (Chou 1997). These techniques are important when only a portion of a map area is required for analysis. In order to carry out an integrated analysis, all the layers were projected to the Lambert Conformal Conic using the following parameters:

- Central Meridian = 21
- Reference Latitude = 0
- Standard parallel 1 = -34
- Standard parallel 2 = -32
- False Easting & Northing = 0
- Datum = WGS 84

3.6 SPATIAL ANALYSIS

Various spatial analysis tools are in use to support decision making in both public and private sectors. These include geospatial analysis, statistical analysis, ecological risk assessment and cost/benefit analysis (Burrough & McDonell 1998). The following spatial analyses were used to identify hazardous power lines in the study area: overlay analysis; proximity analysis; orientation analysis and visibility analysis. The analyses procedure is presented graphically in Figure 3.1.

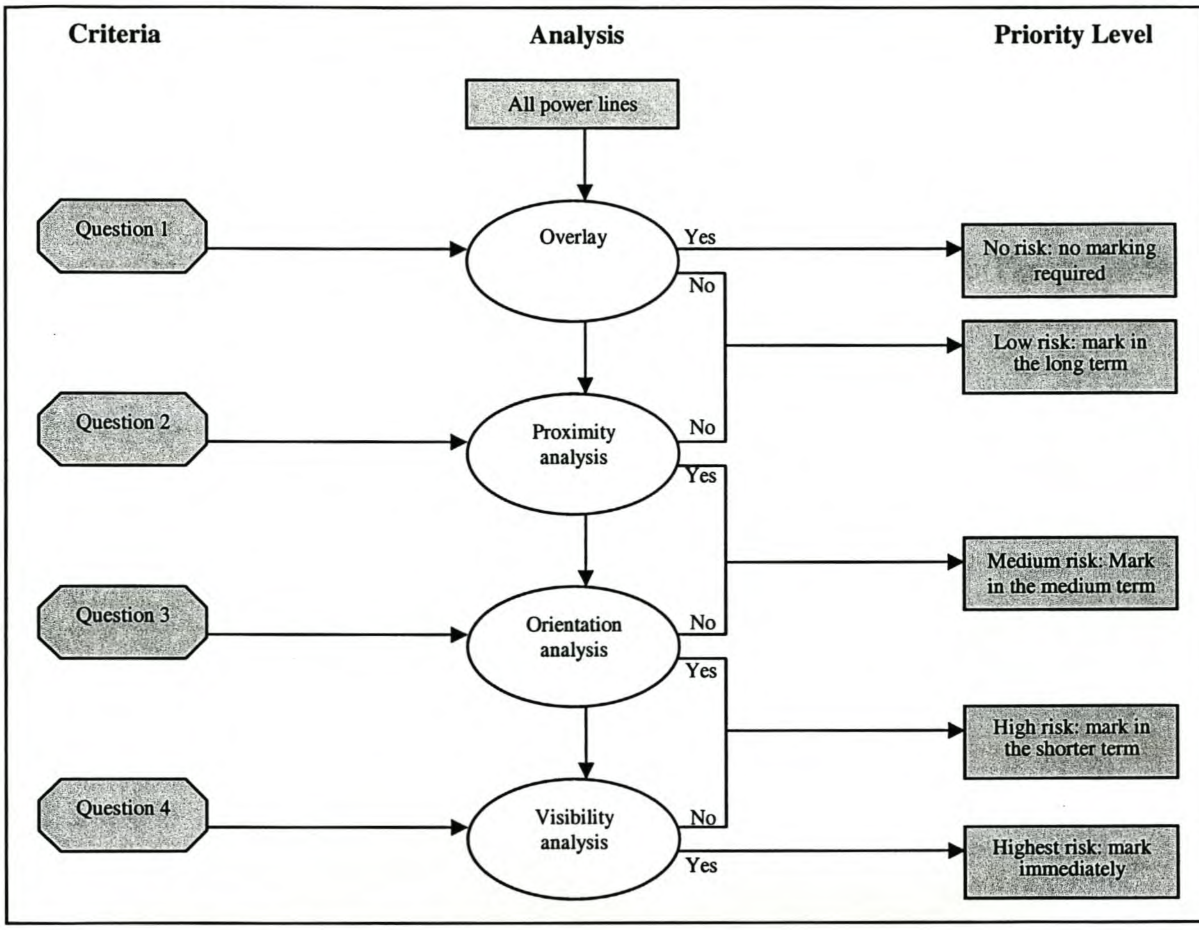

Figure 3.1: Procedure followed to identify hazardous power lines.

Each stage of analyses is fully discussed in subsections 3.6.1, 3.6.2, 3.6.3 and 3.6.4, respectively.

3.6.1 Overlay analysis

As illustrated in Figure 3.1, all the power lines in the study area were overlaid with the natural veld (question 1). The specific overlay technique used was "erase", an ArcView extension written in Avenue programming language. As a type of map overlay operation, "erase" integrates different map layers through a common spatial reference and works like an eraser to exclude or delete selected features of the input layer (power lines) using features of a polygon data layer (natural veld) (Chou 1997; Chrisman 1997; Clarke 2001).

This operation was applied to all the power lines in the study area in order to identify power lines that (i) occur on the natural veld and (ii) do not occur on the natural veld. The power lines that occur on the natural veld were considered as no risk and therefore excluded from further analysis. Subsequently, the analysis narrowed down the scope of the problem and reduced the total length of power lines from 3515km to 2709km. The power lines that do not occur on the natural veld were considered as potential collision sites and therefore classified as low risk. These power lines were brought forward for further analysis to identify those that are within specified distance of water bodies or congregation sites, while simultaneously determining the higher level of risk.

The overlay analysis identified both the no risk and the low risk power lines. Figure 3.2 shows low risk power lines that do not intersect the natural veld.

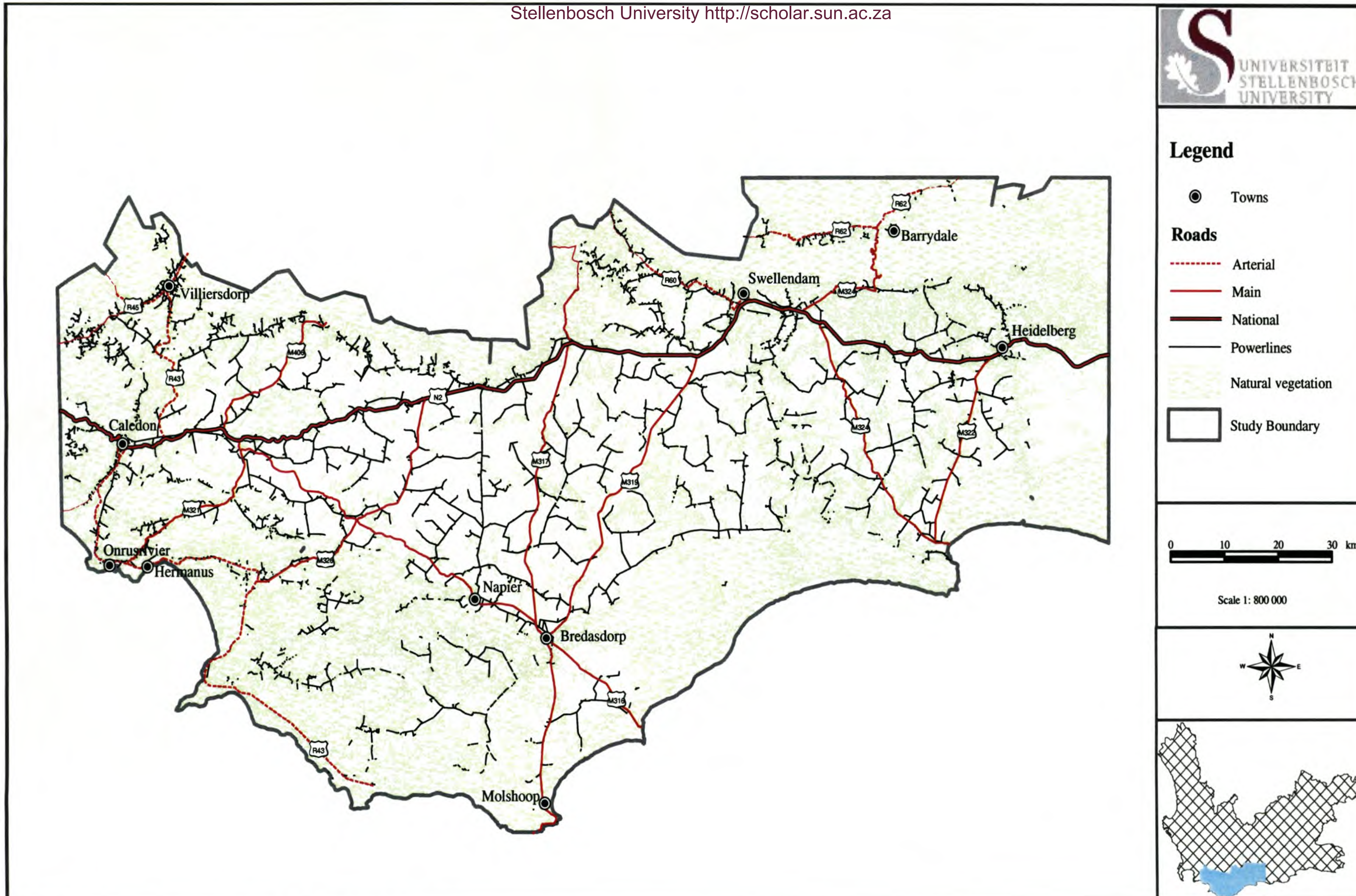

Figure 3.2: Power lines that do not intersect natural veld.

3.6.2 Proximity analysis

Proximity analysis generates new polygons based on the distance from selected map features and is one of the fundamental tools for spatial analysis (Chou 1997). In this type of analysis, distance, often expressed as Euclidean distance, is the primary element (Chou 1997; Jones 1997). Proximity analysis tools allow data organised on separate layers to be manipulated as if they were on one layer, which helps to identify relationships among different features (Longley & Batty 1996; Chou 1997). Examples of proximity analysis tools include buffer, thiessen polygons and nearest neighbour (Jones 1997; Hutchinson & Daniel 2000).

A buffer of 1500m and 500m was created around congregation sites and water bodies (question 2) respectively. The buffer generates an offset of specified distance around selected features and describes localities where collisions are most likely to occur. The resultant polygons were used on the power lines off the natural veld (Figure 3.2) while being within the specified distance of water bodies or congregation sites. With this functionality it was immediately possible to visually assess power lines within 1500m of congregation sites and 500m of water bodies as well as power lines outside these buffers.

The power lines within the buffers pose a higher collision risk and were therefore accorded a higher priority (see Figure 3.1) and used in the next step of analysis, while power lines outside the buffers were assigned a lower priority and subsequently excluded from further analysis. Figures 3.3 and 3.4 below represent power lines that do not intersect the natural veld but are within 1500m of congregation sites or 500m of water bodies. A theme-on-theme selection was used to calculate the number of collisions within 500m of water bodies and within 1500m of congregation sites.

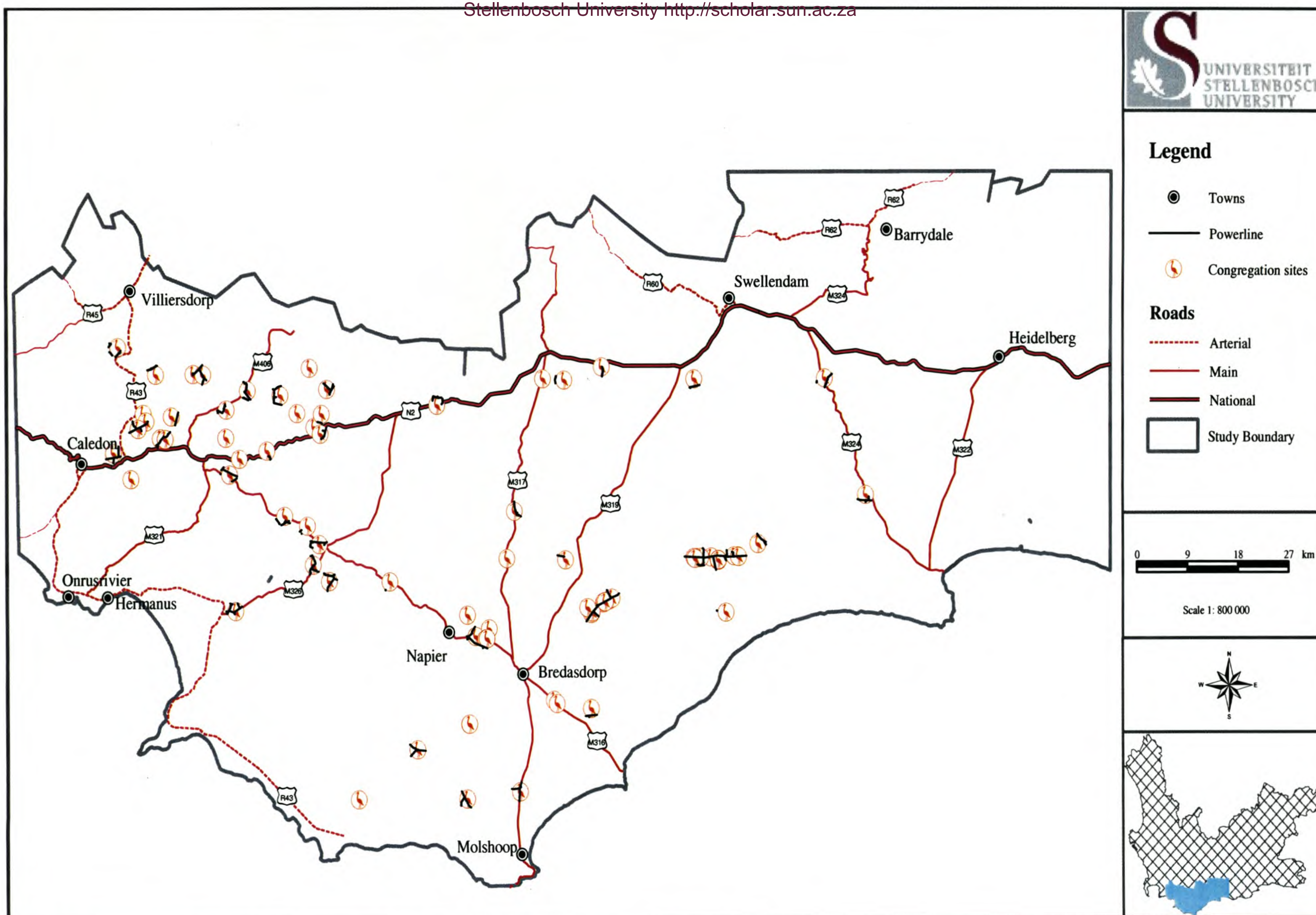

Figure 3.3: Power lines that do not intersect natural veld but within 1500m of congregation sites

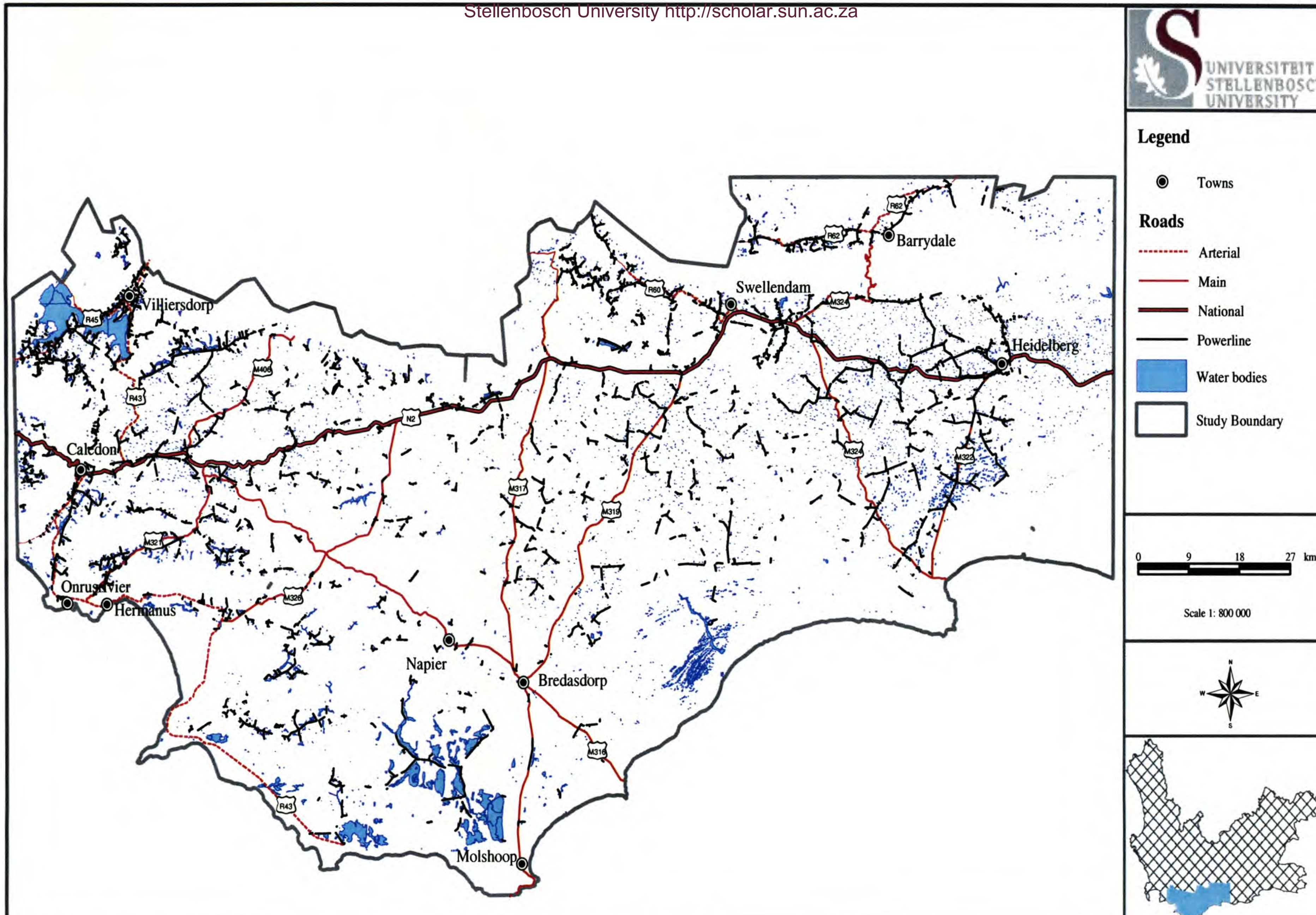

Figure 3.4: Power lines that do not intersect natural veld but within 500m of water bodies

3.6.3 Orientation analysis

As discussed earlier, orientation of power lines is important in determining direction of each span of power lines, consequently determining whether there is a risk of Blue Cranes colliding with power lines or not because of their flight pattern (sees section 2.3.1.2 and 3.3 and question 4 – Figure 3.1). As illustrated in Figure 3.1, orientation analysis was performed on power lines that do not intersect natural veld and are within 1500m of congregation sites or 500m of water bodies.

The Avenue programming language was used to develop a script that calculates the direction (angle) of each span of power line. The script saves the results of the operation in the power lines attribute table. A spatial query was then applied to extract power lines that are roughly perpendicular to the dominant SE (135°) and NW (315°) winds. The identified hazardous power lines' orientation was between 0 to 105° and 180 to 285°. These are medium risk power lines as Blue Cranes may collide with these during take off and/or landing (see Figure 3.5 below).

The power lines that were oriented between 0 to 105° and 180 to 285° were brought forward for visibility analysis to determine which of these are less visible against the height of hills and/or mountains.

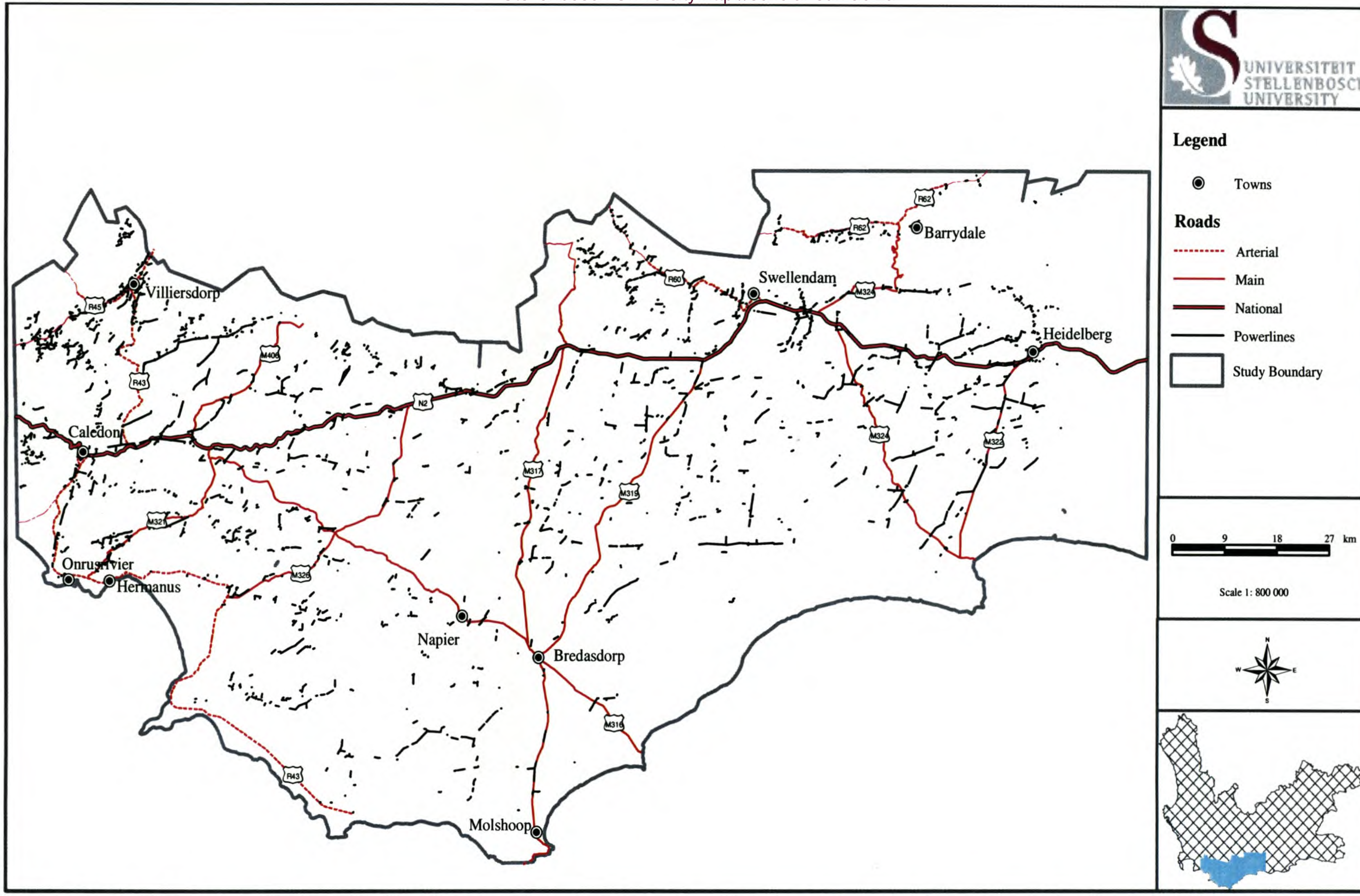

Figure 3.5: Power lines oriented between 0-105° and 180-225° but which do not intersect natural veld, are within close proximity of water bodies or congregation sites.

3.6.4 Visibility analysis

Surface analysis has a variety of applications in GIS, which includes visibility analysis (Chou 1997). Visibility analysis is often associated with viewshed or line-of-sight operations (Morais & Baros 1995; DeMers 1997; Burrough & McDonell 1998; Johnston 1998). In this study, the objective of determining visibility is slightly different. The task involves identifying power lines that due to their height against the surrounding hill or mountain are difficult to perceive. In order to identify these power lines it became necessary to compare the height of the power lines with the elevation of the surrounding landscape. The lowest elevation in the study area is at sea level and the highest peak is at 1600m above sea level. The extent to which hills and mountains influence the visibility of power lines is therefore great.

ArcView Spatial Analyst, a raster extension for ArcView was used to perform the visibility analysis. It applies ArcInfo's Map Algebra data structure to store and model raster data. To allow for an integrated analysis of surface and power line data, the power line data layer was converted to raster. The base height of the power line was offset to a constant value of 5m (the lowest point on the mid-span of the 11kV and 22kV power lines. The resultant data layer was an integer grid with values of 5m (Grid1 in Fig 3.6) along the power lines and No Data values representing cells that are not occupied by the power lines. The No Data values were then reclassified to zero in order to integrate these values in the model. The resultant data layer was a grid consisting of values 0 and 5 (grid2 in Figure 3.6).

To obtain the actual elevation (as height above sea level) of the power lines and the surrounding hills, Grid2 was added to a DEM. This overlay operation assigned absolute terrain elevation to zero values on Grid2, while offsetting terrain elevation by 5 metres where power lines occur. The result of the overlay was called Grid3, a grid data layer that consists of the elevation of the power line and surrounding landscape.

To determine whether the particular section of the power line is higher or lower than the surrounding landscape, a three-step process was followed. First, a spatial filter (maximum) was applied on the DEM to extract the highest hills within 1500m of the power line. The following parameters were specified for the filter:

Statistic: maximum

Neighbourhood: rectangle

Width & height: 1500 * 1500

Units: distance

The maximum filter searches for the cell in the neighbourhood (kernel) with the highest value (elevation). For instance, if the highest value within a kernel is 850m, it is assigned to the cell in the centre of the kernel. The moving kernel examines successive cells and assigns values to each cell in the centre until the whole study area is examined (Burrough & McDonell 1998). The filtered grid was named Grid4, a grid data layer that represents the elevation of local (1500m) crests.

The second step was to overlay (multiply) Grid4 with the power lines' mask (binary) grid in order to extract only the elevation values of local crests along the power lines (Grid5). In the same manner, the height of the power line (above sea level) was extracted by overlaying (multiplying) the power lines' mask grid with Grid3 to create grid Grid6, representing the height of the power lines.

In the final step to determine whether the power lines are below (not visible) or above (visible) the local crests, a relational operator was used to compare Grid6 with Grid5. This was achieved by subtracting Grid5 from Grid6. The resulting grid (Grid7) contains both negative and positive values. The negative values represent the sections of power lines that are below the hills (Grid8).

The results showed that most of the power lines are below the hills and are a result hazardous to Blue Cranes. In Chapter 4 the results of the analyses (see Figure 3.6 for a diagrammatic summary) are discussed and interpreted

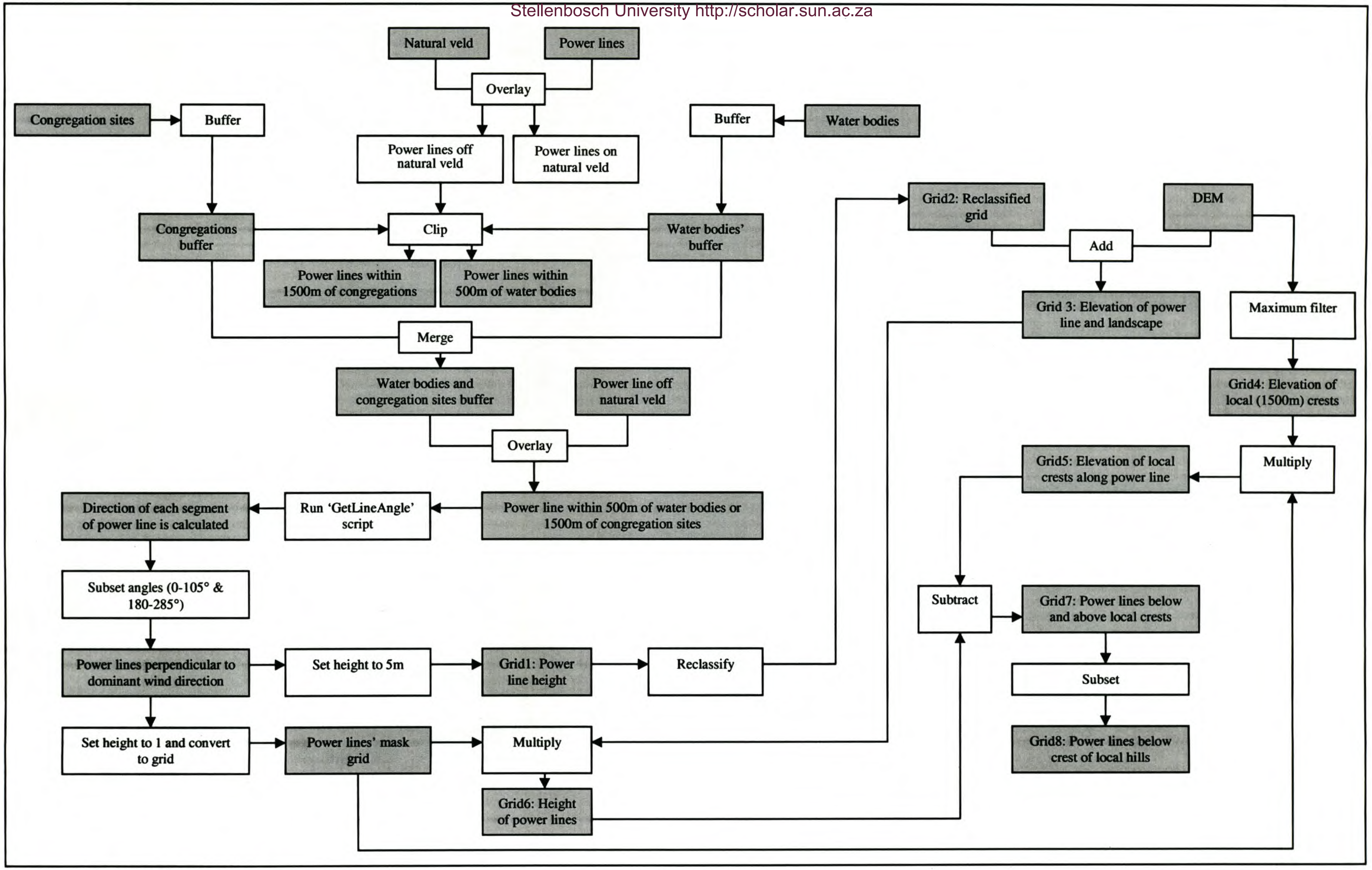

Figure 3.6: Model flowchart

CHAPTER 4: GEOGRAPHICAL LOCATION OF HIGH RISK POWER LINES

This chapter discusses the main findings of the research in terms of the total length of power lines that require mitigation. The predictive GIS model applied in this study was tested for accuracy by comparing the predicted spatial location of hazardous power lines with the observed and known 157 collision localities. The data was collected from reports and surveys since 1996 to 2002. The chapter also focuses on the classification of identified power lines into five categories ranging from highest risk to no risk power lines. These categories serve as a guideline whereby ESKOM\EWT Strategic Partnership can prioritize proactive marking of the hazardous power lines based on the level of risk.

4.1 RULE-BASED QUANTIFICATION AND PRIORITISATION OF POWER LINE MARKING

The marking of the power lines with bird flappers is an expensive and laborious process (see section 2.4). It is therefore important to prioritise the marking process in terms of power lines that require immediate attention to those that pose less collision threat. Prioritisation was based on risk factors (see section 3.3) in accordance with expert knowledge and predictive modelling. The criteria for determining the risk is based on the probability of a collision in relation to the number of risk factors converging on particular sections of the power lines **rather than** on the number of collisions occurring on the power lines (explained in section 3.4). The following subsections interpret the results of the analyses and simultaneously elaborate on the various levels of priority.

4.1.1 Highest risk power lines

The total length of power lines identified as first order priority is 955km, which is 27% of the total length of power lines in the study area. These power lines (see Figure 4.1) require immediate installation of bird flappers because all the risk factors converge on them. Firstly, they do not intersect the natural veld, which implies the possibility of a collision. Secondly, they are backdropped by hills and/or mountains. This reduces the visibility of the power lines and consequently, Blue Cranes cannot see them from a distance. Thirdly, these power lines are oriented roughly perpendicular to the birds' flight course, taking into consideration that Blue Cranes take off and land into the dominant north-westerly and south-easterly winds of the Overberg. Orientation of the power lines is an important collision factor as Blue Cranes orientate themselves into the dominant wind directions in order to gain speed and altitude necessary for flight. This kind of flight pattern predisposes the birds to collisions even before other factors, such as dark background, proximity to water bodies and congregation sites, may possibly pose a threat.

Lastly, these power lines are within 500m of water bodies or 1500m of Blue Crane congregation sites. These sites are frequently visited, indicating a high level of activity, and a greater risk of collision. Furthermore, due to the early morning sun's reflection on the power lines, it becomes difficult for these birds to see the power lines as they take off from the roost sites and/or feeding sites. Similarly, at sunset when they land to settle for the night the intensity of the sun reflects on the power lines and blinds the birds' eyes from avoiding the power lines.

The above category of power lines is classified as highest risk because they conform to all the rules (see section 3.3) applied to identify high-risk power lines. This implies that if the bird does not collide with a power line due to its proximity to a water body or a congregation site, it might collide with the same section of the power line due to its orientation in relation to wind directions, or a dark background of hills or mountains. The total number of collisions on these power lines was 31, constituting 20% of collisions in the Overberg.

4.1.2 High risk power lines

The total length of power lines classified as high risk is 33km, accounting for 1% of the power lines in the study area. These power lines (Figure 4.1) are similar to the highest risk power lines in the sense that they do not intersect natural veld, occur within 500m of water bodies or 1500m of congregation sites, are oriented more or less perpendicular to the predominant north-westerly and south-easterly wind directions. The only difference is that they are not back-dropped by hills or mountains. Due to this spatial configuration, such power lines pose a high risk to Blue Cranes regardless of whether their visibility is reduced further by surrounding topography or not.

The high probability of a collision is due to the interplay of the above-mentioned collision factors. These power lines should therefore be marked in the shorter term, subsequent to highest risk power lines. The total number of collisions along these power lines was 16 out of 157, constituting 10% of all the collisions in the study area.

4.1.3 Medium risk power lines

The total length of power lines identified, as third order priority is 986km, which is 28% of the total length of power lines in the study area. These power lines are considered to be medium risk because they do not intersect natural veld, but are within 1500m of congregation sites or 500m of water bodies. The close proximity to water bodies and congregation sites, induce collisions in the morning when Blue Cranes take off from roost sites; during the day when the birds traverse short distances between feeding, drinking or congregating sites, and/or late evening when they land to settle for the night (also refer to 4.1.1).

One hundred and four birds were killed on these power lines, accounting for 66% of the total number of collisions. The high percentage of collisions may be attributed to the high density of water bodies (7986) in the study area. It may also be an indication of the frequent use and the high level of activity of Blue Cranes near water bodies, as these water bodies are utilised for roosting, drinking and as a source of water for chicks (Meine & Archibald 1996; Shaw & Hudson 2001).

Even though the number of collisions on medium risk power lines is higher when compared to highest and high risk power lines, they are regarded as low risk because they satisfy **only two** criteria for identifying risk power lines, while the highest and the high risk power lines satisfy four and three criteria, respectively. This implies that the probability of a collision on medium risk power lines is lower when compared to highest and high risk power lines. These power lines should therefore be marked in the medium term.

4.1.4 Low risk power lines

The total length of power lines identified as low risk is 735km, accounting for 21% of all the power lines in the study area. These power lines are potential collision localities because they do not occur on the natural veld. Even though these power lines do not occur within 1500m of congregation sites or 500m of water bodies, are not oriented perpendicular to the dominant wind directions, and above the crests of local hills, they are still considered hazardous because they occur in areas that maybe frequented by Blue Cranes.

Six birds were killed on the low risk power lines, which accounts to 4% of the collisions in the study area. Since these power lines satisfy one criterion for hazardous power lines, they were classified as low risk (Figure 4.1). These power lines should be marked in the long term.

4.1.5 No risk power lines

The total length of these power lines is 806km, which represents 23% of the power lines in the study area. This category of power lines pose a negligible collision risk to Blue Cranes because they intersect natural veld, a habitat that is unsuitable for, and therefore less likely to be visited by Blue Cranes. To confirm that these power lines pose a negligible risk to Blue Cranes, there were no Blue Crane congregation sites on the natural veld and also no records of collisions, indicating that Blue Cranes avoid natural vegetation. Even though there are water bodies surrounded by natural veld, they are not utilised by Blue Cranes. The no risk power lines require no marking.

Table 4.1 summarises 5 levels of risk, the total length of power lines and the number of collisions that occurred on different categories of hazardous power lines.

Table 4.1: Total length of power lines and number of collisions per risk level.

Risk	**Length of power line (km)**	**% of the total power lines**	**Number of collisions**	**% of collisions**
Highest	955	27	31	20
High	33	1	16	10
Medium	986	28	104	66
Low	735	21	6	4
No risk	806	23	0	0
Total	**3515**	**100**	**157**	**100**

The four priority levels for marking the power lines are shown in Figure 4.1

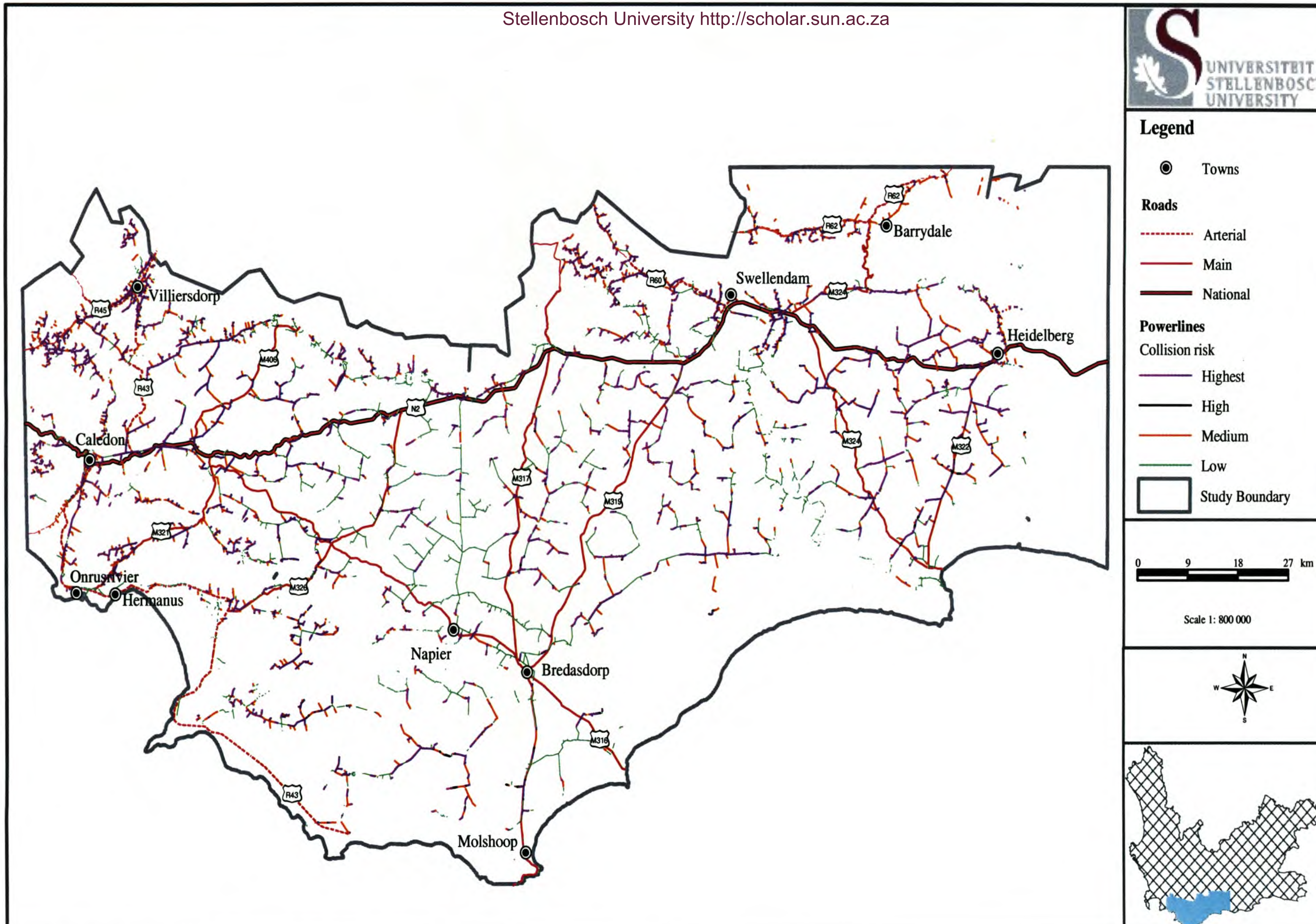

Figure 4.1: Priority levels for marking hazardous power lines

4.2 COST IMPLICATION

The cost of installing bird flappers includes labour, material and transport to the site where flappers are to be fitted (see Table 4.2). Due to the substantial cost of marking the power lines with bird flappers, it is imperative that hazardous power lines are accurately identified. The total length of power lines to be marked is 2709km (see table 4.1).

Table 4.2: Cost of marking power lines with bird flappers

Mitigation measure	Labour	Transport	Material	Total cost
One span[1]	R258.80	R199.00	R258.00	R715.80
Twelve spans[2]	R57.53	R16.58	R258.00	R332.11

Source: Kruger (1999)

[1] *The cost if only one span is marked per day*

[2] *The cost for the maximum number of spans that can be marked per day*

The number of spans marked per day also affects the cost of marking the power lines. The maximum length of power lines that can be marked per day is 1200m. The total cost for marking all the hazardous power lines (2709km) in the study area will therefore be R19 391 022. The same procedure can be followed to determine the total cost of marking the power lines per risk category.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

This final chapter evaluates the predictive model in terms of its usefulness as a tool for conservation authorities. The concluding section considers the implications of the findings for conservation of Blue Crane in the Overberg. The contribution of GIS to the identification of the high-risk power lines is also discussed.

5.1 MODEL EVALUATION

The model was run in ArcView GIS (3.2a) with the Spatial Analyst extension and forms the basis of the study as it integrates human expertise, field observations and GIS. The model transcends the basic GIS functions to the complex raster-based spatial analysis to support decision making. The application of these techniques simplifies the real world problem of identifying hazardous power lines that pose a collision risk to Blue Crane.

The model should be seen as a prototype from which similar models can be built. For instance, incorporating permanent feed troughs to represent feeding sites can further increase the robustness of the model, (as Blue Cranes tend to congregate and feed at these sites). Additionally, the exact location of nest sites could also be used to refine the identification process since Blue Cranes tend to territorialize nest site. In addition, the database could be more extensive and descriptive to include attributes such as the size and seasonality of dams in the study area. Such attributes would help to determine the frequency with which the Blue Cranes visit particular dams, thereby indirectly gauging the level of risk at these dams.

Nonetheless, care should be exercised to deter from over-specifying the rules as this may result in over-fitting the model. Typical of an over-fitting models that perform well on training data, but poorly during verification, is indicative of over specification that subsequently leads to lack of flexibility to generalise during application (Muller, Lagrange & Weibel 1995; Abebe Solomatine & Venneker 2000). A balance should therefore be maintained between being too specific and/or too general.

5.2 RECOMMENDATIONS FOR FUTURE RESEARCH

There are a number of areas that require further work in order to minimise Blue Crane collisions with power lines. Against the background of the findings of this study, it is suggested that surveys be conducted to identify and map conservation hotspots such as major feeding and congregation sites, favourite roosting dams and frequently utilised nest sites. This kind of information will facilitate ESKOM in planning where new power lines should be routed in order to avoid routes that occur within close proximity of such sites. Such proactive planning is important, as re-routing of power lines at a later stage is cost-defective and hardly feasible.

Monitoring the problem at the identified collision localities will improve the accuracy of data collection and subsequently minimise over-representation or under-representation of mortalities. In addition it will assist in the assessment of the effectiveness of bird flappers in reducing collisions. Accurate quantitative and qualitative data collection is therefore of paramount importance as it will enhance the reliability and validity of collision incidences at the monitored sites.

Lastly, there is a general concern about the lack of research undertaken to assess or estimate Blue Crane's vision along a colour spectrum to ascertain the nature and quality of Blue Crane's vision, as this is central to the problem of collisions with power lines. Of equal importance is the need to establish Blue Crane's perception of stationary or moving objects such as power lines and bird flappers, respectively. The model applied in this study can be verified further by applying it in other Blue Crane habitats such as the Swartland or in a slightly different habitat such as the Karoo. The findings would enable a deeper understanding of the model and in the process assess and upgrade data requirements for subsequent models.

5.3 VALUE OF THE RESEARCH

This study has demonstrated the role of GIS in solving conservation problems by analysing the spatial location of power lines in relation to environmental features, such as water bodies, congregation sites, natural vegetation, wind direction and topography. It has also pioneered the integration of GIS with expert knowledge to predict, quantify and classify hazardous power lines in the Overberg region. The identification and quantification of these power lines will serve to inform ESKOM of the magnitude of the collision problem, which in its own right is a step forward towards conserving the Blue Crane. The Blue Crane is vulnerable and its conservation is a matter of urgency. Mitigation of these power lines will reduce collisions and provide the means whereby the Blue Crane sub-population in the Overberg will be protected.

The findings will be valued for several reasons. Firstly, it will be of great value to ESKOM, as the categorisation of power lines into high, medium and low risk will speed up the marking process. Furthermore, the reduced collisions and incidences of power outages will ameliorate ESKOM's public image and subsequently increase customer satisfaction. In addition, conservation concerns that exist between conservation organisations and ESKOM will abate because all the hazardous power lines will be marked. Furthermore, it is an important GIS tool for conservation authorities because it will greatly save time and effort currently spent in the field searching for high-risk power lines.

Finally, as a prototype for the prediction of high-risk power lines in the Overberg, it is perceived that the model will be of great value in the conservation of Blue Cranes and a useful analytical tool for the ESKOM/EWT Partnership. With the emphasis on the proactive approach, the model transpires the transition from a reactive approach where power lines are marked only after collisions have occurred; to a proactive approach, where all the identified hazardous power lines will be marked with bird flappers before collisions occur in order to minimise collisions.

REFERENCES

Abebe AJ, Solomatine DP, Venneker RGW 2000. Applications of adaptive fuzzy rule-based models for reconstruction of missing precipitation events. *Hydrological Sciences Journal* 45, 3: 425-436.

Allan DG 1995. Observations on roosting Blue Cranes. *Ostrich* 66: 148-150.

Allan DG 1997. Blue Crane Anthropoides paradisea. In Harrison JA, Allan DG, Underhill LG, Herremans M, Tree AJ, Parker AV & Brown CJ (eds) *The atlas of southern African birds: Non-passerines.* Johannesburg: BirdLife South Africa.

Allen W 1999. *GIS in conservation planning.* Chapel Hill: The Conservation Fund.

Archibald GW & Lewis JC 1996. Crane biology. In Ellis DH, Gee GF, & Mirande CM (eds.) *Cranes: their biology, husbandry, and conservation.* Baraboo: National Biological Service and International Crane Foundation.

Aspinall RJ 1993. Use of GIS for interpreting land use policy and modelling effects of land use change. In Cousins SH, Haines-Young R & Green D (eds) *Landscape ecology and GIS.* London: Taylor & Francis.

Barnes KN (ed) 2000. *The Eskom Red Data Book of birds of South Africa, Lesotho and Swaziland.* Johannesburg: BirdLife South Africa.

Burrough PA & McDonell RA (eds) 1998. *Principles of Geographical Information Systems.* New York: Oxford University Press.

Chou Y 1997. *Exploring spatial analysis in GIS.* Entrada: OnWord Press

Chrisman N 1997. *Exploring Geographical Information Systems.* Toronto: John Wiley & Sons.

Clarke KC 2001. *Getting started with Geographical Information Systems*. 3rd ed. New Jersey: Prentice Hall.

Coulson RN, Lovelady CN, Flamm RO, Spradling SL & Saunders MC 1991. Intelligent Geographic Information Systems for natural resource management. In Turner MG & Gardner RH (eds) *Quantitative methods in landscape ecology,* pp153-172. New York: Springer-Verlag.

Crist P 1998. Decision Support Systems: New tools for data users [online]. Idaho: National GAP Analysis Program. Available from http://www.gap.iudaho.edu/Bulletins/7/DSSNTDU.htm [Accessed 20 June 2002].

Del Hoyo J, Elliot A & Sargatal J (eds) 1996. *Handbook of the birds of the world,* pp60-89 Barcelona: Lynx Edicions.

DeMers MN 1997. *Fundamentals of Geographic Information Systems*. New York: John Wiley & Sons.

Ellis DH, Gee GF & Mirande CM 1996. *Cranes: Their biology, husbandry and conservation*. Washington, DC: Department of the Interior, National Biological Service.

Farner DS, King JR & Parkes KC 1973. *Avian biology: Volume 3*. London: Academic Press.

Fedra K, Winkelbauer L & Pantulu VR 1991. Expert systems for environmental screening: An application in the Lower Mekong Basin. (Office report No. RR-91-19). Laxenburg, Austria: Institute for Applied Systems Analysis.

Fischer M, Henk J & Unwin DS (eds) 1996. *Spatial analytical perspectives on GIS – GISDATA IV*. London: Taylor & Francis Ltd.

Gauthreaux SA 1994. The History of Wind-Related Avian Research in the U.S.A. In Proceedings of National Avian-wind power planning meeting. Washington: The Avian Working Group of the National Wind Coordinating Committee.

Haines-Young R, Green DR & Cousins S (eds) 1993. *Landscape ecology and Geographical Information Systems*. London: Taylor & Francis.

Hilton-Barber B 1997. Birds on a wire. *Out There* September: 6.

Hudson V 2001. Blue cranes cannot survive without farmers. *ProAgri* May-June: 33.

Hudson V & Leeuwner W (2001). Blue Crane fact sheet Duplicated copy. Caledon: Overberg Crane Group.

Hutchinson S & Daniel L 2000. *Inside ArcView GIS*. 3rd ed. Denmark: OnWord Press.

International Crane Foundation 2001. *Crane species*. Baraboo, USA: International Crane Foundation.

Jordaan A (ed) 2002. Explore eco-attractions in the Cape Overberg. *Explore Cape Nature reserves and other eco-attractions*. Cape Town: Cape Nature Conservation.

Johnson LB, Host GE, Jordan JK & Rogers LL 1991. Use of GIS for landscape design in natural resource management: habitat assessment and management for the female black bear. In GI/LIS'91 Proceedings: 507-517. Atlanta.

Johnston CA 1998. *GIS in ecology*. Edinburgh: Blackwell Science.

Jones C 1997. *Geographical Information Systems and computer cartography*. Essex: Addison Wesley Longman.

Kruger R 1999.Towards solving raptor electrocutions on ESKOM Distribution structures in South Africa. MSc (thesis). Bloemfontein: University of the Free State.

Le Roux J (ed) 2002. *The biodiversity of South Africa 2002: Indicators, trends and human impacts*. Cape Town: Struik Publishers.

Longley P & Batty M (eds) 1996. *Spatial analysis: modeling in a Geographical Information Systems environment*. New York: Pearson Professional.

MacClean GL 1990. *Ornithology for Africa*. Pietermaritzburg: University of Natal Press.

McCann K 1999. The Wattled Crane Proactive Marking Project. Parkview: Endangered Wildlife Trust. (Unpublished report).

McCann K 2002. National Crane census: 2002. *Grus Grapevine* October: 5.

McCann K, Morrison K, Byers A, Miller P & Friedmann Y (eds) 2001. Blue Crane (*Anthropoides paradiseus*): A Population and Habitat Viability Assessment Workshop. Final workshop report. Apple Valley: Conservation Breeding Specialist Group (SSC\IUCN).

McCann K & Van Rooyen C 2003. The Overberg powerline marking project. *Journal of the Endangered Wildlife Trust* Autumn 44:36.

Meine CD & Archibald GW (eds) 1996. *The cranes: status survey and conservation action plan*. Cambridge: IUCN.

Morais S & Baros SL (eds) 1996. *Raster imagery in GIS*. Entrada: OnWord Press.

Muller JC, Lagrange JP & Weibel R (eds) 1995. *Geographical Information Systems and generalisation: methodology and practice*. London: Taylor & Francis.

Newman K 2000. *Newman's birds by colour: Southern Africa's common birds arranged by colour*. Cape Town: Struik Publishers (Pty).

Patrick C & Kohley T 1998. A GAP Biological Decision Support System for county planning. Moscow: National Gap Analysis Program.

Peterson RT 1964. *Life nature library: The birds. Netherlands*: Time-life International.

Pullar D 1997. Rule-based modelling in GIS. Paper (presented) at the second conference of GeoComputation, University of Otago, New Zealand.

Rodwell L & McCann K 2001. The formation and role of South African Crane Working Group and the potential for use as a model in other countries in Africa. *Ostrich* 15: 255.

Schmidt-Nielsen K 1990. *Animal physiology: adaptation and environment*. 4th ed. Cambridge: Press Syndicate of Cambridge.

Scott HA & Scott RM 1998. *A conservation program for the Blue Crane in the Overberg, South Western Cape*, South Africa. Voëlklip: Cape Nature Conservation.

Shaw K & Hudson V 2001. Blue Crane Habitat in the Overberg/ Swartland. In: Proceedings of the 13th Southern African Crane Working Group Workshop & the Southern African Strategy Meeting. (Unpublished report).

Shaw K & McCann K 1998. The Blue Cranes of the Overberg region. *Farmer's Weekly* 21 August: 48-49.

Shaw K 2003. Anthopoides paradiseus. In Young DJ, Harrison RA & Anderson MD: *Big birds on farms: MAZDA CAR Report 1993-2001*. Cape Town: Avian Demography Unit.

Shergalin JE, Keskpaik J, Kuznetsov GA 1995. The common crane with its migration conditions and as a hazard to aircraft in Estonia. In Prange H (ed) *Proceedings of the palaearctic crane workshop in Tallinn, Estonia, Crane research and protection in Europe.* Halle-Wittenberg: Martin Luther University.

Silveira JE, Richardson JR & Kitchens WM 1992. A GIS model of fire, succession and landscape pattern in the Everglades. In *Proceedings, ASPRS/ACSM//RT '92 Convention on Monitoring and Mapping Global Change* 5: 89-97. Bethesda: American Society for Photogrammetry and Remote Sensing.

Soorae PS & Seddon PJ (eds) 2000. Special bird issue. *Re-Introduction News* 19: 3. Abu Dhabi: IUCN/SSC Re-Introduction Specialist Group.

Stuart C & Stuart T 1999. *Birds of Africa: From seabirds to seed-eaters*. Rivonia: Southern Book Publishers.

Underhill L 1998. Why birds collide with power lines, and how flappers help. *The newsletter of the Avian Demography Unit* December 7: 3.

Urban EK, Fry CH & Keith S 1986. *The birds of Africa*. London: Academic Press Inc.

Verdoorn GH 1996. The conservation of birds of prey in South Africa. *Journal of Raptor Biology* 11: 1.

PERSONAL COMMUNICATIONS

Hudson V 2003. Field worker, Overberg Crane Working Group. Caledon. Discussion on 7 November, about the high risk localities for the Blue Crane in Caledon.

Shaw K 2002. Ornithologist, Cape Nature Conservation (CNC). Stellenbosch. Discussion on 5 May about the high risk periods for the Blue Cranes.

Van Rooyen C (chrisewt@global.co.za) 13/03/ 2003. Re: Collision hot spots in the Overberg. E-mail to M. Kotoane (mapule@cncjnk.wcape.gov.za)

APPENDICES

APPENDIX A: Existing and potential threats to Cranes

Threats to cranes

Critical threat (C) (has been, or has the potential to be, a major factor in the decline of the population size and/or restriction of the species' range)

Significant threat (S) (has been, or has the potential to be, an important though not leading factor in the decline of the population size and/or restriction of the species' range)

Lesser threat (L) (has been or has the potential to be a detrimental factor in some localities or for some populations, but not with a significant or critical impact on the species as a whole)

Type of Threat	B.p.	B.r.	A.v.	A.p.	B.c.	G.l.	G.c.	G.an.	G.r.	G.v.	G.m.	G.g.	G.am.	G.n.	G.j.
Habitat Loss and Degradation															
Conversion of wetlands	S	C	L	L	C	C	S	C	S	C	S	S	L	S	C
Over-exploitation of wetland resources	S	S	L	L	C	C	L	C	S	S	S	S	S	L	S
Agricultural conversion of grasslands	C	L	C	S	-	-	L	-	-	C	-	L	L	L	S
Changes in agricultural land use	-	C	S	C	S	-	C	S	S	S	S	S	-	S	S
Other agricultural impacts (see text)	S	S	-	S	-	S	-	-	L	L	-	-	-	L	L
Dams and water diversions	C	L	-	L	C	C	C	S	-	C	S	S	S	S	C
Urban expansion and land development	-	-	-	L	-	L	L	S	L	S	S	-	S	L	S
Deforestation	S	S	-	-	-	-	-	-	-	-	L	L	-	L	L
Afforestation	-	-	-	C	L	-	L	-	-	-	L	-	-	-	-
Other changes in vegetation (see text)	-	-	-	-	L	S	-	-	S	-	-	-	C	-	C
Coastal marsh and shoreline erosion	-	-	-	-	-	-	-	-	-	-	-	-	C	-	S
Pollution and environmental contamination	-	-	-	-	L	S	-	L	-	S	S	-	C	S	C
Oil development	L	-	-	-	-	S	-	-	-	-	L	L	C	-	C
Collision with utility lines	-	-	L	L	L	-	L	-	L	-	L	L	S	-	L
Direct exploitation															
Overhunting	-	-	S	-	-	C	L	-	-	-	-	S	-	-	-

Poaching	S	C	-	L	-	-	-	-	-	-	-	-	L	S	-
Live trapping for commercial trade	S	S	L	S	L	-	-	S	-	-	-	-	-	-	-
Live trapping for domestication	L	L	-	L	-	-	-	-	L	-	-	L	-	-	-
Poisoning	-	L	L	C	S	L	L	-	L	L	L	-	-	-	L
Other anthropogenic threats															
Human interference or disturbance	C	S	S	-	L	L	L	S	L	L	L	L	S	L	L
Warfare and polictical instability	C	S	-	-	L	L	-	S	S	S	L	L	L	S	S
Lack of effective legislation and administration	L	L	-	-	-	-	-	-	-	S	-	-	-	-	L
Lack of knowledge and public support	S	S	L	S	S	S	L1	L	S	L	L	-	-	L	L
Biological factors															
Predation	-	-	-	-	-	-	L	-	L	-	L	-	L	L	-
Exotic species	-	-	-	-	-	-	-	L	L	-	-	-	-	-	-
Genetic and demographic problems of small populations	-	-	-	-	-	C	L	-	-	-	-	-	S	-	L
Disease	-	-	-	-	-	-	L	-	-	S	S	-	L	-	L
Other environmental factors (storms, drought, etc.)	S	L	-	-	L	S	L	-	-	-	-	-	S	-	-

Notes:
1. Cuban Sandhill Crane
2. Mississippi Sandhill Crane
3. Florida Sandhill Crane
4. Central population (Siberian Crane)
5. Southern population (Brolga)
6. Florida population (Whooping Crane)

B.p. = *Belearica pavonina*
B.r. = *Belearica regulorum*
A.v. = *Anthropoides virgo*
A.p. = *Anthropoides paradisea*
B.c. = *Bugeranus carunculatus*
G.l. = *Grus leucogeranus*
G.c. = *Grus canadensis*
G.a. = *Grus antigone*

G.r. = *Grus rubicundus*
G.v. = *Grus vipio*
G.m. = *Grus monachus*
G.g. = *Grus grus*
G.a. = *Grus americana*
G.n. = *Grus nigricollis*
G.j. = *Grus japonensis*

Source: Meine & Archibald (1996)

APPENDIX B: 30 Remnants of natural vegetation (per hectare) in the study area

Vegetation type	Area (ha)	Percentage (%) of total
1. Agulhas fynbos	37792	5.8
2. Albertinia sand plain fynbos	205	0.03
3. Ashton inland renosterveld	52547	8.1
4. Bredasdorp mountain fynbos complex	26233	4.09
5. Caledon swartberg mountain fynbos complex	7818	1.21
6. Canca limestone fynbos	13187	2.05
7. Cannaland inland renosterveld	2168	0.33
8. De Hoop limestone fynbos	59656	9.29
9. Elgin fynbos/ renosterveld mosaic	383	0.07
10. Elim fynbos/ renosterveld mosaic	23675	3.68
11. Franschhoek mountain fynbos complex	9712	1.51
12. Genadendal grassy fynbos	28226	4.40
13 Hagelkraal limestone fynbos	26171	4.07
14 Hawequas mountain fynbos complex	10994	1.71
15 Klein river mountain fynbos complex	28813	4.48
16. Kogelberg mountain fynbos complex	18482	2.87
17. Little Karoo broken veld	22590	3.51
18. Montagu inland renosterveld	25233	3.93
19. Overberg coast renosterveld	46494	7.24
20. Potberg mountain fynbos complex	11325	1.76
21. Riversdale coast renosterveld	52362	8.15
22. Riviesonderend mountain fynbos complex	32444	5.05
23. Robertson broken veld	1722	0.2
24. South dune pioneer	1590	0.2
25. South west dune pioneer	1254	0.19
26. Southern Langeberg mountain fynbos complex	74785	11.64
27. Springfield sand plain fynbos	34846	5.42

28. Stilbaai fynbos/ thicket mosaic	3957	0.61
29. Suurbrak grassy fynbos	24 656	3.84
30. Swellendam afromontane forest	1372	0.21
TOTAL	**641 956**	**100**

APPENDIX C: Avenue script

```
'Get the angles for each line feature in a line theme
 'A. Turner & M. Kotoane
 '10/12/2002

 'get the view
 theView = av.GetActiveDoc

 'get the first active theme and put its table in edit mode
 theTheme = theView.GetActiveThemes.Get(0)
 theFTab = theTheme.GetFTab
 theFTab.SetEditable(true)

 'for each record in the attribute table look for the field 'shape' and the field 'angle'
 for each rec in theFTab.GetSelection
   theShapeField = theFTab.FindField("Shape")
   theShape = theFTab.returnvalue(theShapeField,rec)
   theAngleField = theFTab.FindField("Angle")

   firstpt = theShape.Along (0)
   lastpt  = theShape.Along (100)



   'get the x & y coordinates for the start node of a segment
    sx = firstpt.GetX
    sy = firstpt.Gety

   'get the x & y coordinates for the end node of a segment
    ex = lastpt.GetX
    ey = lastpt.GetY


  'calculate the difference for the x coordinates' start & end node
  'calculate the difference for the y coordinates' start & end node
    dx = ex-sx
    dy = ey-sy

  'if the value of x is equal or greater than zero and y is equal or greater than zero, direction is
in the first quadrant (0-90)
    if ((dx >= 0 ) and (dy >= 0 )) then
     Q = 0
    end
  'if the value of x is equal or greater than zero and y equal or less than zero, the direction is in
the second quadrant (90-180)
    if ((dx >= 0 ) and (dy <= 0 )) then
     Q = 180
    end
```

```
'if the value of x is equal or less than zero and y is equal or less than zero, the direction is in
the third quadrant (180-270)
   if ((dx <= 0 ) and (dy <= 0 )) then
    Q = -180
   end
  'if the value of x is equal or less than zero and y is equal or greater than zero, the direction is
in the fourth quadrant (270-360)
   if ((dx <= 0 ) and (dy >= 0 )) then
   Q = 360
   end


  'Angle

  'get the absolute value of y
   h = dy.abs
  'get the absolute value of x
   w = dx.abs
  'divide x by y
   ta = w/h
  'get the tangent
   ar = ta.aTan
  'get the angle in degrees
   theAngle = ar.AsDegrees
  'get the absolute angle
   a = (Q - theAngle).abs
  'assign a value to each record in the angle field in the attribute table
   theFTab.SetValue (theAngleField, rec, a)
 end
 'theTheme.ClearSelection
```