The Role of the Geomaticist in Natural Resource Management

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Abstract

The essence of this thesis may be described by Rüther's argument that the survey profession is confronted with the necessity of having to redefine its role in society, or face the consequences of having the profession become marginalised (n.d: 1). The thesis reviews the functions of a traditional land surveyor, and shows how these functions are diminishing. This is done to illustrate the need for change in the profile of a traditional land surveyor, and the necessity of him redefining his role in society, in order to prosper in the future. The concept of geomatics, as an integrated approach to the acquisition and management of spatial data is introduced, and is used to illustrate the types of skills which a traditional land surveyor already has, and would need to acquire, in order to make the transition to a modern land surveyor, or what is termed a geomaticist. A case study is then carried out in order to test the validity of the conceptual framework.

Preface

The whole of this dissertation, unless specifically indicated to the contrary in the text, is my own work, and has not been submitted in part, or in whole to any other University.

The research was carried out at the University of Natal, Durban, and was supervised by Doctor Clarissa Fourie and Mr Angus Forbes. The research was conducted in order that a new role for a traditional land surveyor might be investigated. For a number of years, there has been a great deal of talk within the land surveying community, of the necessity of land surveyors becoming more involved in the field of geographic information systems. However, very little has been done to investigate the feasibility of this. This dissertation has investigated the need for land surveyors to diversify from their traditional role within society, and has examined how they might accomplish this.

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Glossary of Terms

ASCII - American Standard Code for Information Interchange

EROS - Earth Resources Observation Systems

GPS - Global Positioning System

NCGIA - National Centre for Geographic Information and Analysis

NOAA - National Oceanic Atmospheric Administration

UNEP/FAO - United Nations Environmental Programme

Chapter 1 - Introduction

1.1) Background

West argues that traditionally, the land surveyor has been seen as providing five basic roles to the community. These are: "guarantor of title to rights in land; custodian of an owner's and mortgager's (*sic*) rights in interests in land; arbitrator and mediator in disputes concerning the corner points and boundaries of those rights, consultant in respect of any development project contemplated, and finally, controller of surveys" (1981: 104.2/1). The International Standards Organisation defines geomatics in the following manner: " Geomatics is a field of study which, using a systematic approach, integrates all the means used to acquire and manage spatial data required as part of scientific, administrative, legal and technical operations involved in the process of production and management of spatial information. These activities include, but are not limited to, cartography, control surveying, digital mapping, geodesy, geographic information systems, hydrography, land information management, land surveying, mining surveying, photogrammetry and remote sensing." (University of New South Wales Annual Report: 1994: 1).

The quotations above have been included to provide an indication of the degree of change which has taken place in the surveying industry over the last two decades. The change in name from land surveying to geomatics is in itself, a minor issue. Rather, it is the implications associated with this change, and reflected in the differing definitions given above, that carry significant weight. Having worked for a brief period in what could be described as the traditional land surveying industry, I was somewhat surprised at the number of land surveyors who were of the opinion that the land surveying industry was stagnating. A general feeling that the profession was losing the prestige with which it was once held, was evident, as was the much-voiced opinion, that something new was required in order to once more make the land surveyor's skills sought after. Time and again, that 'something new' was referred to as GIS or geographic information systems. However, despite all the talk of land surveyors being the ideal people to get involved in the GIS industry, very few land surveying firms had actually put in place measures to do so. Rather, it was people from other professions - geographers and town planners, for example, who were embracing GIS technology, and using it as a tool to aid them in their respective jobs. Furthermore, many of these people were using GIS, despite having received no formal academic training in this area. The question which arose, and to which I sought an answer, was: how can a land surveyor get involved in GIS?

1.2) Prior Work and Research Objectives

After some investigation into the possibilities of land surveyors becoming involved in GIS, it was discovered that a GIS in itself is merely a tool which might be used as an aid for achieving a particular task - hence town planners were using it for town planning applications, and geographers were using it for geographical applications. Taken on its own, this piece of information might have proved discouraging for those in the land surveying profession, given that they were looking for a new dimension to add to their professional profile, not merely a more advanced type of calculator to assist them in their existing tasks. However, what emerged, was that there did appear to be a need for someone with the ability to integrate the acquisition, storage, analysis, distribution, management and application of spatial information used in a GIS - something very different to someone who merely uses the GIS as a tool. Thus, while the GIS is used as a tool in a variety of industries, there is the underlying aspect involving the management of spatial information which prevails, regardless of the industry using the GIS. The question of whether or not a land surveyor could fit into this niche of spatial data management thus became the primary research objective. A secondary objective which required further investigation was how a land surveyor might fulfill this role.

1.3) Research Methodology and Report Structure

Essentially, this thesis is divided into two sections. The first establishes the conceptual framework for the thesis by examining the need for change in the surveying industry and the manner in which a traditional land surveyor should go about adapting his skills in order to increase the scope of his professional profile. Drawing on relevant literature, personal experience and a number of interviews with professional land surveyors, an argument is developed which illustrates the way in which the land surveying profession is changing and the need for land surveyors to adjust their services accordingly. It also details the type of work which a land surveyor of the future, or what I term a geomaticist could become involved in.

The second section of the thesis tests this conceptual framework by means of a real-life example. The methods used, skills needed and problems and successes encountered are reported on, in relation to the concepts established in the first section. Finally, the necessity of the geomaticist to the research carried out in the case study area is discussed.

Chapter 2 - Geomatics

2.1) Introduction

"The surveyor...must, in order to claim the right to exercise profession, be capable of exercising it competently by continuous training. Throughout his professional career the surveyor must keep abreast of new developments whether of legislation or new methods" (Allred: n.d: 1). Rüther argues that on a worldwide level, the survey profession is faced with the necessity of having to redefine its role in society. He maintains that unless a new professional profile is developed, the profession is threatened with being marginalised and down-graded to one of service provision (n.d: 1).

West's analysis (1981) of the five functions of the traditional land surveyor is used to construct a profile of the traditional surveyor in order to show that his functions are diminishing, but that the skills which he has, provide a good grounding from which to move into more specialised fields, an argument that will be further developed in Chapter 3. From the review of West's analysis, it is argued that one area where the traditional surveyor is as active now as he was in the past, is controller of surveys. However, an argument which highlights the rapidly expanding growth of new technologies, and shows that this has resulted in measurement being removed from the list of skills of a professional surveyor (Greene: 1994: 93) is developed in order to demonstrate the need for a traditional surveyor to expand his profile so as to keep pace with the changing needs of society.

At this point, the concept of geomatics as an integrated approach to the acquisition and management of spatial data is introduced. A number of themes emerging from the definitions of geomatics are investigated further and linked to a Geomatics Business Model, developed by Gagnon *et al* (1993). This review of geomatics serves two purposes. Firstly, it links back to the previous section on the need for change, and secondly, it points forward to the following chapter, which goes on to define a geomaticist, and then a further specialisation thereof, namely, an environmental geomaticist.

2.2) The Traditional Surveyor

In this section, it is my intention to build up a professional profile of what I term a traditional surveyor. As a basis for this profile, West's (1981) analysis of the functions of the traditional land surveyor is used. This review of the traditional land surveyor is carried out for two reasons. Firstly, to lay the foundation for an argument which will be developed further in this section. That is, that the functions of the traditional surveyor are diminishing. Secondly, it is done to support an argument which will emerge in Chapter Three, that is, that the traditional surveyor has an ideal platform from which to move into more specialised fields. While the principles of West's argument apply on a global or international scale, and while it is my intention to review them as such initially, these principles will then be applied to the South African situation in order to illustrate their inadequacies. What will emerge from this section, is that of the five basic roles of the land surveyor, as outlined by West, and as applied to the South African situation, only one remains the exclusive domain of the traditional land surveyor. In the following section, it will be argued that even this is likely to change in the not too distant future, resulting in the land surveyor needing to take on new roles (see Chapter Three) if he is to survive this change.

Traditionally, the land surveyor has been seen as providing five basic roles to the people of his country, namely those of *guarantor* of title to rights in land; *custodian* of an owner's and mortgagor's rights in interests in land; *arbitrator and mediator* in disputes concerning the corner points and boundaries of those rights; *consultant* in respect of any development project contemplated and lastly, *controller of surveys* in respect of all types of surveys (West: 1981: 104.2/1). In addition to this, West argues that there are a number of services which the land surveyor renders to the people in his community. These include: interpretation of the title deeds of the rights in land, providing descriptions of the purposes for which the land may be used, surveys and plans for the development or subdivision of the land, setting out and controlling all works on it, land valuation and conducting a variety of surveys of investigatory and probate nature (1981: 104.2/1).

While I support West's description of the five basic roles of the surveyor, I argue that, in the years since he wrote his article, changing circumstances have resulted in the roles described above becoming diminished. To justify this statement, it is my intention to review the five basic roles of the surveyor, as described by West, in order to show how they have diminished in the present day South African situation.

West describes the land surveyor as being both a *guarantor* of title to rights in land, and a *custodian* of an owner's and mortgagor's rights in interests in land. The importance of security of title to rights in land is highlighted by Williamson, who argues that a secure title in the rural context promotes increased investment in agriculture, allows for more effective husbandry of the land, and makes development more sustainable. In an urban context, it gives security of title and supports an active land market by permitting land to be bought, sold, mortgaged and leased efficiently, effectively, quickly and at low cost (1993: 1). Williamson argues further that cadastral systems consist of a land registration system and a cadastral survey and\or mapping system. He maintains that cadastres have the flexibility to record a continuum of land tenure arrangements from private and individual land rights, as well as having the ability to accommodate traditional or customary land rights. He argues that examples of such flexibility are to be found in many developed and developing countries (1993:

3). However, I will argue that this is not the case in South Africa.

Simpson and Sweeney (1973: 113-114) quote W. van Breda Smith, the Director-General of Surveys in 1970, thus:

> "The South African public enjoys the benefits of a system of land registration which stands second to none in the world. It is acknowledged...as providing almost absolute security of title despite the fact that the State accepts no responsibility for the security of title."

van Breda Smith attributes this state of affairs to:

> "(a) the (specific) definition of the limits of the parcel of land by means of imaginary straight lines between beaconed corner points except in isolated instances of well defined curvilinear boundaries;
>
> (b) the definition on a diagram, which forms part of the title deed of the limits of the parcel of land, by means of numerical data derived from a survey which must be based on the national trigonometrical system;
>
> (c) the statutory provision that no transfer of land may be registered unless it is based on a diagram approved by the surveyor-general, which means that the cadastre is automatically kept up to date;
>
> (d) the control of the quality and correctness of cadastral surveys exercised by the surveyor-general;..." (Simpson and Sweeney: 1973: 114).

While I agree with both Williamson's point that a good cadastral system and secure title will result in an active land market, and van Breda Smith's reasons for the success of the South African cadastre and land registration system, I argue that neither are wholly applicable in present day South Africa.

Claassens, arguing in 1991, states that the distribution of land in South Africa is startling, with figures indicating that over eighty percent of the population was prohibited up to 1991 from owning or leasing land in over eighty percent of the country. Claassens attributes this to centuries of conquest, dispossession and forced removal of black people by white governments (1991: 43). Cross argues that up to the early 1990's black tenure systems in South Africa fell onto a tripolar map, varying between communitarian systems of indigenous origin, modern systems of individual option, and state-imposed tenures aimed at forcing black production towards intensified land use. She maintains that apart from state tenures, most of the actual operation of these systems was informal, with discrepancies between on-the-ground practice, and what is written into law (1991: 63).

Although both Claassens and Cross published their articles in 1991, and there have subsequently been measures put in place, through a restitution and redistribution programme, to change the skewed bias of land ownership in South Africa, the key points of their arguments still apply. That is, that within South Africa, there remains a wide variety of tenure systems, and forms of ownership which run contrary to the statutory definitions of such. I argue further that active land markets can be found to be operating informally within these systems. However, it is not the intention of this thesis to explore these areas any further, suffice to mention that reference to Budlender and Latsky (1991), Cross (1991), Claassens (1991), Marcus (1991), Haines and Cross (1988), Fourie (1994), Hindson and McCarthy (1994) and Jenkins *et al* (1986) will support my argument that there is a great diversity of tenure patterns in South Africa, within which active, informal land markets are to be found.

Thus, while I agree with Williamson's view that a good cadastral system and secure title will result in an active land market, I argue that for the purposes of obtaining an active land market, it is not required that the cadastral system and security of ownership of land comply with the statutory requirements of the country within which the tenure system operates. Further, while I agree with van Breda Smith's assessment of the success of the South African cadastre, I argue, that at the time at which he made these statements, it was not necessary for him to take into account the variety of existing tenure systems which were not recognised or catered for in the apartheid era. Thus, when he argues the efficiency of the South African land registration system, he is referring to a highly efficient system which catered solely for a very small percentage of the population. van Breda Smith gives several reasons for the success of the South African cadastre and land registration system, all of which emphasise the necessity of the land surveyor to the whole process. Thus, within this system, the land surveyor was indeed seen as being the *guarantor* of title to rights in land, and *custodian* of an owner's or mortgager's rights in interests in land. However, based on my argument above, that is , that there is a great variety of tenure patterns operating outside of the statutory confines of land registration, I am suggesting that in many of the systems, the land surveyor is not viewed as the *guarantor* of security of tenure or *custodian* of an owner's rights in land.

From numerous interviews with land surveyors, it has been established, from their experience, that the closer a particular tenure system is to an urban centre, the greater the faith of the local populace in the land surveyor's ability to provide them with formal title to land. However, in many rural communities, the role of *guarantor* of rights in land, and *custodian* of a person's rights in land falls not on the land surveyor, but on a high ranking or powerful member of the community. I have thus shown that, when applied in a modern day South African context, West's description of the land surveyor as *guarantor* of title to rights in land, and *custodian* of an owner's rights in interests in land is not universal.

West maintains that the land surveyor acts as a *consultant* in respect of any development project contemplated. However, based on my own experience, as well as a series of interviews carried out with numerous, more experienced land surveyors, I argue that in the years since West wrote his article, this situation has changed. The general feeling amongst interviewees, was that twenty years ago, a major role of the land surveyor was to act as a development consultant. The land surveyor in those days was required to carry out the necessary applications, and furnish appropriate designs for the manner in which a piece of land was to be developed. However, with the introduction of town planning as a separate discipline in the early 1980's, many surveyors feel that a part of their profession has been taken away from them. However, all the surveyors questioned felt that they were well qualified to manage or control the development of a piece of land. Many also stated that the surveying profession in general, have not marketed these development skills aggressively enough, but that those surveyors who had promoted themselves as land developers, were the ones currently running successful businesses. What I deduced from the interviews, was that there are a small number of very successful surveyors who view themselves as development consultants, but that the majority feel that this role has been usurped by other professions. Thus, I argue that the role of the land surveyor as *consultant* in respect of any development project contemplated, as outlined by West, has diminished considerably in the past eighteen to twenty years, and is not a universal role as it was at that time.

West also argues that another role of the land surveyor is as *arbitrator* or *mediator* in settling boundary disputes. There was consensus among the land surveyors interviewed, that this function was still the sole domain of the land surveyor, for the reason that he is the only person with the technical ability necessary for relocating beacons to settle boundary disputes. However, there was general agreement that this was not a very common task of the land surveyor. I argue that this role of the land surveyor, as described by West, is thus also a diminishing or at best, a minor function of the land surveyor of today.

The final traditional role of a land surveyor, as described by West, is that of *controller of surveys*, and it is in this largely technical domain that the professional surveyor still dominates. However, in the following section, I will argue that as a result of technological advances, and the consequent ease with which the measurement process can be carried out, this role is likely to diminish as well.

This section has established what role the land surveyor has traditionally played within a society. This review of the traditional surveyor will be used in the following chapter as a foundation for my argument that the land surveyor is ideally placed to specialise in another domain. It has also been used to show that in the past, the South African land surveyor has conformed to the international profile established by West. However, I have argued that changing circumstances in South Africa have resulted in the role of the professional land surveyor today becoming considerably diminished in both content and extent, from that of the professional land surveyor twenty years ago, as outlined by West. I have argued that the only area in which the surveyor is as competitive today as he has been in the past, is that of *controller of surveys*. Thus of the services listed above, the preparation, production and maintenance of maps and plans has become the major function of the traditional land surveyor.

2.3) The Need for Change

In the previous section, I argued that of the five functions of the traditional land surveyor, as outlined by West, four of these have diminished to such an extent that they can no longer be regarded as major factors in the professional profile of a typical land surveyor. I argued that the only area where the land surveyor is as active now as he was in the past, was as *controller of surveys*. In this section, I will argue that as a result of major advances in measurement technology, this role too, is under threat. Using both local and international material, I will show that the automation of much of the measurement process has resulted in it becoming a push-button operation in which very little skill is required. I will argue that because of this, the focus of the professional land surveyor must shift from measurement of spatial information to the management thereof.

As a result of the rapidly increasing growth of new technologies, and the subsequent decrease in time needed to complete the surveys, the needs of the public will in future be able to be served by fewer land surveyors. In fact, with the introduction of new technologies, the actual measurement or fieldwork aspect of most surveys can be carried out by people who do not necessarily have specialised knowledge in this regard. My argument, that technology is going to change the profile of the professional surveyor is supported by both Merry, who argues that the discipline of surveying, both locally and globally, is undergoing profound changes, with the technical skills required in the past being overtaken by technological advances (1994: 86), and van Gysen, who maintains that in the past, surveying always required a considerable degree of technical skill, but that in the face of new surveying technologies, that position is changing (1994: 16). This is further supported by Jones and Ellis who argue that a common trend in all surveying is the increased automation and computerisation, with the result that new technology is tending to supersede human observers (1994: 202.2/5). My argument that the growth of new technologies resulting in the surveying needs of society being met by fewer surveyors in a reduced amount of time is also substantiated by Young who states: "The impact of technology automation ... on surveying and cartography has meant traditional tasks have been reduced or can be completed more efficiently in less time." (1994:

207.3/1).

The major result of these developments, is that "technology has removed measurement from the list of skills (of the professional surveyor) and has made it a push button operation." (Greene: 1994: 93). That is, the professional land surveyor will no longer be the sole master of the technical skills of his discipline. However, this same technology has provided the surveyor with a far more diverse market and demand for the results of his measurements, provided that he is prepared to change his pattern of thought from "how to measure", to what can be done with the results of my measurement (Greene: 1994: 93). Fourie maintains that great demands will be made on people who are trained as surveyors in the future South Africa, because of their specialised technical background, as well as their easy familiarity with spatial relationships (1994: 92). I argue that because of the advances in technology, and the impact of this on the surveying profession, as has been discussed above, it is more their familiarity with and understanding of spatial relationships, as opposed to their specialised technical knowledge, which will make surveyors invaluable in the future.

Chen and McLaughlin argue that the environment of surveying and mapping is changing from the traditional surveying and mapping field, characterised by analog instruments and core expertise in positioning, map design and accuracy analysis, through a Spatial Information Engineering environment, characterised by digital image technology, user needs analysis and information management, towards a Spatial Decision Support environment, based on decision support systems, built on a spatial information infrastructure, with core expertise of system analysis and decision support (1992: 257). In my opinion, this implies a corresponding shift in the profile of a professional land surveyor, from measurement towards management. Gracie, in Jones and Ellis (1994: 202.2/3) illustrates this by means of the figure reproduced below.

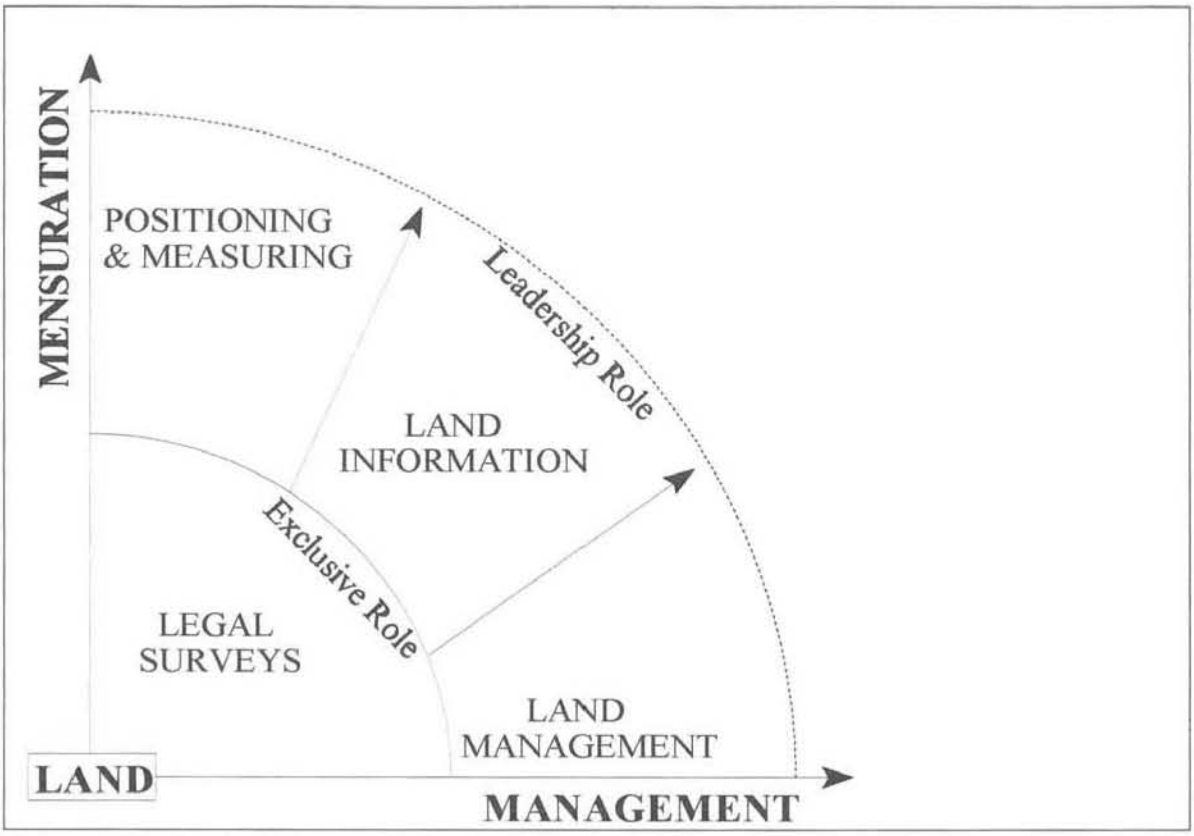

Figure 1 Modernised Survey Profession (Gracie 1985)

The necessity of this shift from measurement to management is supported by Rüther who argues that because of technological advances, other professions are more and more able to carry out their own spatial measurements (n.d: 2). A major consequence of this, is that the previously well defined boundaries which existed between the surveying and other professions are disappearing.

I argue that this impacts on the role of the traditional land surveyor as *controller of surveys*. Figure 1 illustrates that while there is still an exclusive role for the traditional land surveyor to play (in the form of legal or cadastral surveys), this role is limited, and encompasses only a very small section of the market. Further, my argument, that as a result of new technologies, the traditional surveying needs of society will be met by fewer land surveyors in a reduced amount of time, indicates that the ratio of work per surveyor generated for traditional land surveyors from legal surveys is likely to decrease. Thus for the traditional land surveyor to generate more work, it will be necessary for him to become more involved in the provision of spatial data to aid decision-making in other disciplines. However, I have already argued that as a result of technological advances, other professions are more and more able to carry out their own spatial measurements. It thus becomes evident, that if one is referring to surveys as being the measurement of land, be it topographical or cadastral, the role of the traditional land surveyor as *controller of* such *surveys* is likely to decrease, either due to other professions carrying out their own measurements in topographical surveys, or due to fewer surveyors being required to carry out cadastral work.

Rüther maintains that the surveyor of the future must not restrict his activities to those of surveying and mapping of land, but, because of his ability to collect and manage spatial data, should become a spatial data and general measurement expert, with the capability to specialise in measuring objects ranging from the topography of the earth's surface and parcels of land, to the recording of dynamic processes such as the movement sequence of an athlete. He stresses that even more important than building on and expanding the existing measurement skills of the profession, the future surveyor must grow beyond the level of data acquisition and become a spatial data manager and analyst (n.d: 2).

I have argued that advances in technology, resulting in more efficient measurement with a reduction in the level of skills required, has meant that the role of the traditional surveyor, as *controller of surveys*, has already, and will continue to decrease in the future. In the previous section, I built up a profile for a traditional land surveyor, using West's material as a basis. I have subsequently shown that all of the functions of a traditional land surveyor, as described by West, have diminished, and are likely to diminish further as technology progresses. I have thus laid a foundation which indicates that there is a need for the professional land surveyor to adjust or broaden his profile if he is to keep pace with a changing society. I have referred to numerous sources to support my argument that, for the professional surveyor to survive, it is essential that he adjust his profile and move away from the measurement of spatial data and towards the management of such data. In the following section, I will examine various definitions of geomatics, and develop my own definition for the surveyor of the future - the geomaticist. I will argue that a geomaticist is a surveyor with that broader profile.

2.4) Geomatics

I have shown that the functions of the traditional land surveyor are diminishing and I have argued that there is a need for him to broaden or adapt his professional profile if he is to survive and grow in the future. In the following section, I will define a geomaticist. However, in order to build this definition, I will review three definitions of geomatics in order to establish the major and sub-themes which are common throughout. Following this, I will analyse a Geomatics Business Model developed by Gagnon *et al* (1993), which will allow me to establish how a traditional land surveyor might become a geomaticist.

Van Gysen (1997: 1) defines geomatics in the following manner: "Geomatics is a modern scientific term to describe an integrated approach to the acquisition, analysis, storage, distribution, management and application of spatially referenced data. It embraces the traditional areas of surveying and mapping, such as geodesy, cadastral surveying, photogrammetry and hydrography, as well as the comparatively new fields of remote sensing and spatial information systems." This definition is expanded on by the International Standards Organisation, which gives the following definition: "Geomatics is a field of activity which, using a systematic approach, integrates all the means used to acquire and manage spatial data required as part of scientific, administrative, legal and technical operations involved in the process of production and management of spatial information. These activities include, but are not limited to, cartography, control surveying, digital mapping, geodesy, geographic information systems, hydrography, land information management, land surveying, mining surveying, photogrammetry, and remote sensing." (University of New South Wales Annual Report: 1994: 1).

A third definition for Geomatics is one given by Fourie, who defines it as: "a modern discipline associated with the acquisition, analysis and management of geographically-referenced, land related data, for use in a wide range of essential activities in the community. This may be associated with land, property, natural resources and the environment. Using a systematic approach, Geomatics integrates all the means used to acquire and manage spatial data required as part of scientific, administrative, legal and technical operations involved in the process of the production and management of spatial information." (1997: 1).

The major theme which runs throughout all three definitions, is that geomatics is an integrated approach to the acquisition and management of spatial data. The Oxford Paperback Dictionary defines the verb *integrate* as being "to combine or form (a part or parts) into a whole" (1979: 340). This is a particularly apt description of geomatics if one considers it in the light of the other theme which runs through all three of the definitions, that is, the linking of traditional methods of surveying with the new technology and new methods for acquiring spatial data. The sub-themes which then evolve from these major themes are the acquisition, storage, analysis, distribution, management and application of such data to produce information in support of some managerial requirement.

It is evident, that in all three definitions, the verb *integrate* is referring to the integration of traditional and modern measurement techniques. While I agree with this standpoint, I will argue (see Chapter Three below) that one could take the concept of integration to the next level, and apply it in a situation where experts from various disciplines work together and integrate their own specialist knowledge, in order to arrive at a solution to a particular problem. I will argue that a geomaticist is a person able to interact with other professionals in a teamworking situation.

In this section, I will examine in greater detail the sub-themes which have evolved from the definitions, as well as expand on the concept of integration as it has been used in the definitions given above.

Young argues that geomatics portrays a contemporary and evolving unified philosophy of the various disciplines found within the surveying and mapping industry. He maintains that the word implies modern technical knowledge, administrative, legal, management and human relations abilities, while the unifying theme of geomatics encourages a transition from data collection to proactive involvement in the data environment (1994: 207.3/4). He argues further that the emphasis in geomatics education, must shift from "dependence on state-of-the-art instrumentation and equipment specific training to the appropriate application and analysis of the use of these ever changing technologies." (American Congress on Surveying and Mapping in Young: 1994: 207.3/4). In view of the fact that education is intended to prepare scholars for the business world, I argue that the same manner of thought, that is, the shift from measuring to management and application is required in the business or non-academic world.

Spatial information systems, which link spatial data to other related information, are an integral component of the data environment mentioned by Young (1994) above. Also, they provide the tool which enables one to manage and analyse measured data. They therefore play a key role in the shift from measurement towards management, which I am advocating. This view of their importance, is supported by reference to such systems in the definitions given for geomatics above. Therefore, in order to facilitate the understanding of geomatics, and in particular, the sub-themes listed above, a brief explanation of an information system is required.

Dale and McLaughlin define an information system as "a combination of human and technical resources, together with a set of organising procedures, that produces information in support of some managerial requirement."(1988: 8). They maintain that the operation of a land information system includes the acquisition and assembly of data; their processing, storage, and maintenance; and their retrieval, analysis, and dissemination (*ibid.*). I have argued the importance of the surveyor broadening his professional profile, and the need for change. From Dale and McLaughlin's argument, it is evident that even within the context of information systems, the mere acquisition of data is not sufficient. Rather, this is seen as the first step, with the processes of storage, maintenance, retrieval, analysis and dissemination emanating therefrom. This view is supported by Larsson, who argues that while there is a need for the systematic collection of data, of even greater importance, is the updating, processing and distribution of spatially referenced land related data, in order to support legal, administrative and economic decision-making, for development planning and for evaluating the consequences of different actions (1991: 3-4). Thus, again it can be seen how it is the use of data, and not merely the collection of that data, which gives it value.

Barry distinguishes between the collection and analysis and management of data by arguing that there are three main components to information systems, namely: technical, application and management (1994: 12). He argues that technical issues include a wide range of topics, including data acquisition, integration and analysis, data base design and maintenance, and the graphic design and visualisation of geographic information system (GIS) outputs. Barry maintains that applications of GIS technology are becoming more and more relevant to an increasing number of disciplines, and a number of commercial organisations outside of the technical fields are beginning to recognise the potential benefits of integrating spatially referenced information with marketing information, financial data and other non-spatial attributes (1994: 12). He goes on to define the different sets of skills required by those involved in the technical, application and management aspects of GIS, namely: the operators, analysts and managers.

He argues further, that operators require functional skills, which can be acquired on the job, through exposure to software and hardware training offered as part of vendor implementation contracts and through short courses (1994: 13). I argue that this operation function relates to the sub-themes of 'acquisition', 'storage' and a small portion of 'application', as discussed above.

Barry maintains that analysts require a technical understanding of the principles on which the system is built, and a grasp of the problem solving capabilities of GIS (1994:13). I maintain that this function relates to the sub-theme of 'analysis', as well as a large proportion of the 'application' sub-theme, derived from the definition of geomatics above.

Finally, Barry argues that GIS managers require both technical skills and an understanding of the GIS's capabilities, as well as having a thorough understanding of the organisational context of GIS and the skills in business economics to design, implement and maintain systems, as well as cope with the implications of obtaining a satisfactory return on investment in a climate of rapidly advancing technological and fluctuating financial markets (1994: 13). I argue that this function relates to the sub-themes of 'management' and 'distribution' derived from the definitions of geomatics given above.

I have shown that even within the relatively new field of information systems, there are distinct levels, ranging from mere data collection to the management and effective use of such data. These levels are represented by the different sub-themes, which evolved from the definitions of geomatics given earlier.

All of these sub-themes, of acquisition, storage, analysis, distribution, management and application of data have been expanded on by Gagnon *et al*, in Kennedy and Woolnough (1994: 205.2/7), where a functional model of geomatics, describing the different functions which define the process of production of spatial information is developed. They define a function as being a broad categorization or grouping of tasks which have a logical link between them, while a task is defined as an activity performed to obtain a product. For example, assessing the needs of a client related to spatial data and information, and calibrating the instruments used for the collection of that spatial data would be two tasks forming part of a collection function.

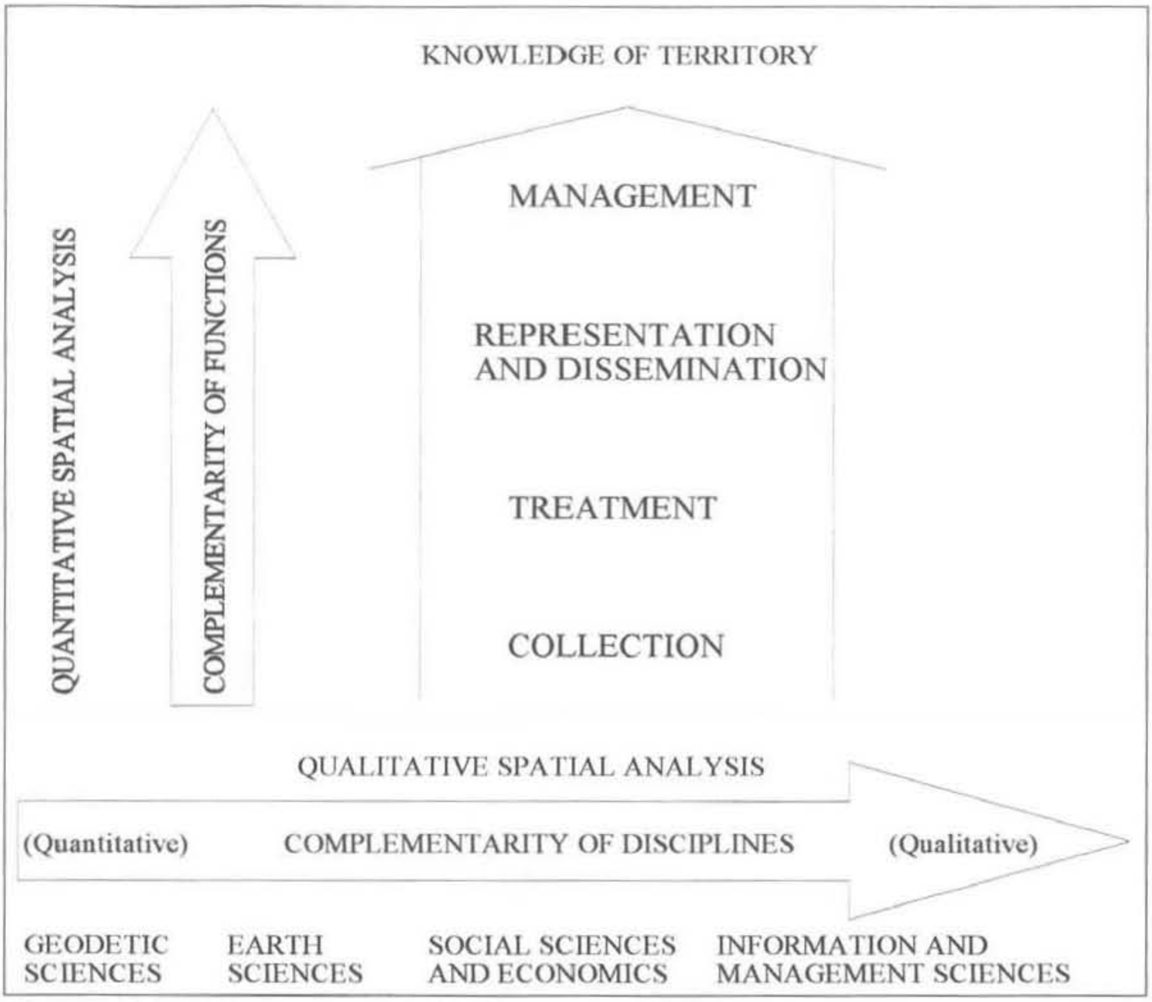

Figure 2 Geomatics Business Model (Gagnon *et al*: 1993)

Figure 2 illustrates the functional Geomatics Business Model, as developed by the Geomatics Industry Adjustment Committee in 1991, and used by Gagnon *et al* (1993). The figure illustrates how knowledge of a particular territory is gained through the combination of a series of different functions, namely: collection, treatment, representation and dissemination and management. These functions, in turn, are generated through the integration of expertise from various disciplines. From Figure 2, it is evident that the greater the integration or complementarity of disciplines becomes, the more qualitative the nature of the information gleaned therefrom becomes. The 'knowledge of territory' (Gagnon *et al*:1993) grows as this qualitative information, represented by the complementarity of disciplines, is linked to the quantitative information, represented by the complementarity of the functions mentioned above. It is thus evident that the functions themselves provide the link between the expertise from various disciplines and the tasks required to assimilate or correlate these expertise, in order to arrive at the goal of 'knowledge of territory' (Gagnon *et al*:1993). I have introduced Figure 2 here in order to link it to the sub-themes which emerged from the definitions of geomatics which I have reviewed. Below, I will show how the functions illustrated in Figure 2 relate to these sub-themes. This is done to enable me to define a geomaticist in the following section and also so that I might show how a traditional land surveyor might become a geomaticist.

Kennedy and Woolnough (1994: 205.2/7-205.2/8) argue that the aim of Geomatics is to produce and manage spatially related information "through an optimum complementarity among a set of functions and disciplinary areas." They maintain that the model illustrated above may be defined by the following four functions: the collection function, the treatment function, the representation/dissemination function and the management function.

The collection function covers all the measuring methodologies and techniques used to collect new data or convert existing data on physical objects or phenomena, and/or administrative or thematic situations, which are usually geographically positioned (Kennedy and Woolnough: 1994: 205.2/7-205.2/8). This corresponds to the sub-themes of 'acquisition' and 'storage', discussed above.

The treatment function relates to the sub-theme which I termed 'analysis', and includes all the operations related to the processing of raw data in order to make it more compatible with a data model or structure. It includes the manipulation of spatial analysis functions related to the production of scenarios of actions in a decision-making process, using processed data (Kennedy and

Woolnough: 1994: 205.2/7-205.2/8).

The representation/dissemination function covers all the operations related to the presentation and dissemination of analysed spatial data and information in a format which is understandable for users, and which meets their requirements (Kennedy and Woolnough: 1994: 205.2/7-205.2/8). It relates to the distribution and application of spatial data to produce information in support of some managerial requirement, discussed in the sub-themes above.

Finally, the management function relates to the sub-theme I termed 'management', and includes all the operations related to the exploitation of the various components of an information system, namely, human resources, procedures, equipment and spatially related data. It is important to note that this function involves administrative management, but not technical management, as the latter is implicitly included in the other three functions (Kennedy and Woolnough: 1994: 205.2/7-205.2/8).

In order to assess the way in which the above functions were prioritised by those involved in the geomatics field, a survey was conducted by the Geomatics Industry Adjustment Committee in 1994. Approximately 1100 individuals involved internationally in the geomatics field were used as the sample set. It is interesting to note that the results of this survey indicated that the management function held top priority for those interviewed, at the time of the survey, and, it was indicated, would still be of greatest importance five years from the survey. Those who formed part of the survey also indicated that the representation/dissemination function was a low priority at the time of the survey, but felt that five years hence, it would become the second highest priority function; while the treatment function was considered a low priority both at the time of survey and for the future. Also of importance, is the fact that those questioned indicated that the collection function would shift from a high to a low priority over five years (Kennedy and Woolnough: 1994: 205.2/8).

The conclusions drawn from the survey (Kennedy and Woolnough: 1994: 205.2/8) discussed above substantiate my argument that the mensuration component of data collection is becoming a minor aspect. I am arguing that for the professional surveyor of the future to be successful, he must shift the emphasis of his job from measurement towards management. Based on those results of the survey indicating that the importance of the collection function is likely to decrease considerably with time, I would argue further that it is not necessarily the management of the collection of spatial data that is important, as this merely expands on the role of the traditional surveyor as *controller of surveys*. Instead, it will be the management of how such data is used, along with the surveyor's ability to interact with other professionals in a teamworking situation, through the provision of meaningful information, which will make him a vital cog in the machinery of a project team. This will be discussed further (see Chapter Three).

In this section, I have defined geomatics as being an integrated approach to the acquisition and management of spatial data. I have also argued that it can be thought of as being the discipline one obtains by linking traditional methods of surveying with new technology and new methods for acquiring spatial data. I have also emphasised that it is not merely the acquisition of such data that is important, but that the storage, analysis, distribution and application of such data to produce information in support of some managerial requirement is also vital. This view is supported by Young (1994: 207.3/4) who argues that the geomatics unifying theme encourages a transition from data collection to proactive involvement in a data environment and a general "move from technical specialist roles to participants in the solution of societal problems" (American Congress on Surveying and Mapping in Young: 1994: 207.3/4).

2.5) Conclusion

This chapter reviewed West's model (1981) of the functions of the traditional land surveyor. By applying West's analysis to a modern day South African situation, it was shown to be inadequate, in that all of the roles of a land surveyor, as described by West, have diminished markedly. This review was carried out to demonstrate the need for modern land surveyors to broaden their profile if they were to meet the changing needs of society.

Having established the necessity for change, it was then required that a broad conceptual framework, within which a modern land surveyor should operate, be developed. This was achieved by reviewing several definitions of geomatics in order to extract the two major themes present, namely, that geomatics is an integrated approach to the acquisition and management of spatial data, and, that it involves the linking of traditional methods of surveying with the new technology and new methods for acquiring spatial data. It was also argued that a number of sub-themes, namely: the acquisition, storage, analysis, distribution, management and application of spatial data emerged from the definitions of geomatics.

Mention was made of the fact that the integration theme could be viewed from two standpoints. Firstly, it could be seen as referring to a situation where experts from various disciplines work together, integrating their own specialist knowledge in order to reach a solution to a specific problem. This teamworking aspect was not pursued any further, as it will be more appropriate to deal with it in detail in the following chapter, once definitions for a geomaticist and an environmental geomaticist have been established.

Secondly, the integration theme could be seen as referring to the integration of traditional and modern measurement techniques to enable proactive involvement in the data environment, which in turn, means a shift from "dependence on state-of-the-art instrumentation and equipment specific training to the appropriate application and analysis of the use of these...technologies" (American Congress on Surveying and Mapping in Young: 1994: 207.3/4). Due to the fact that spatial information systems link spatial data to other related information, and therefore play a vital role in the data environment, and because they provide the tool which enables one to manage and analyse measured data, a brief review of these systems was given. It was shown that within a spatial information system, there are distinct levels, ranging from the collection of data to the analysis thereof. These levels were then able to be linked to the sub-themes which evolved from the definitions given for geomatics.

The sub-themes of acquisition, storage, analysis, distribution, management and application of data were then analysed in terms of the way in which they define the process of production of spatial information and the use of that information for analysis and subsequently management. Reference was made to the Geomatics Business Model developed by Gagnon *et al* (1993), to facilitate the development of a conceptual framework within which a geomaticist (to be defined in the following chapter) could operate, and to strengthen the argument that the land surveyor must move from measurement towards management if he is to become a geomaticist.

The following chapter will draw on the framework established in this section to outline the roles of a geomaticist, which will in turn lead to the further development of that part of the integration theme still to be dealt with, that is, the teamworking aspect.

Chapter 3 - The Environmental Geomaticist

3.1) Introduction

The previous chapter reviewed several definitions of geomatics and examined a model which reflected the various sub-themes or concepts which could be derived from the definitions. I concluded, by using these concepts to strengthen my argument, that there is a need for the traditional surveyor to change his professional profile, in order to place more emphasis on the management of spatial data and its use. I also raised the idea that teamworking and the ability of the professional surveyor to interact with specialists from other fields would become central in the future.

This chapter utilises the conceptual framework established in Chapter Two to formally define a geomaticist, his skills set and his potential role in society. It shows that proficiency in the use of spatial information systems, particularly in the area of adding value to data, will be an essential aspect of the geomaticist's job.

Following this, a specialist category of geomaticist, namely an environmental geomaticist is examined. This is achieved by firstly investigating the need for such a person, using the relevant sections of Agenda 21 to support the argument. Having established that there is such a need, the functions of the environmental geomaticist are then defined, using a UNEP/FAO land use classification model as a basis for the definition.

It is then argued that there are two skills sets necessary for the sustainable management of the various UNEP/FAO-based categories. The first relates to the collection and correlation of the data necessary for successful management to take place. This links back to the sub-themes of acquisition, storage and distribution which were discussed above (see Chapter Two). The second set of skills required by an environmental geomaticist, is the ability to integrate his expertise with the expertise of specialists within whichever category he is working. Thus, the need for this second set of skills provides the link to the concept of teamworking or integration - the other major theme derived from the definitions of geomatics (see Chapter Two).

The chapter concludes by examining in greater detail, the concept of teamworking, and its relevance to an environmental geomaticist.

3.2) The Geomaticist

In the previous chapter, geomatics was defined as being an integrated approach to the acquisition and management of spatial data (University of New South Wales Annual Report: 1994: 1; van Gysen: 1997: 1). As a corollary to this definition, I now define a geomaticist as being one who is skilled in the discipline of geomatics. That is, a geomaticist is one who is involved in the acquisition and management of spatial data.

In this section, I will define in more detail, the concept of a geomaticist - what knowledge he has, what skills he should have, and what role he could play within society. It will be shown that the traditional surveyor is well positioned to make the transition to becoming a geomaticist. Some of the steps which I feel will be necessary to make this transition will also be illustrated.

In order to define the manner in which a traditional surveyor might move towards becoming a geomaticist, it is necessary to examine the role a geomaticist would play within society, and what skills he would need to fulfill that role. As has been discussed above (see Chapter Two), Rüther argues that a great mistake would be made in restricting the future surveyor's activities to those of the surveying and mapping of land. He maintains that the ability of the surveyor to collect and manage spatial data equips him uniquely for a range of activities well beyond conventional mapping (n.d: 2). He views the role of the future surveyor as being one of a general measurement expert with the capability to specialise in measuring objects ranging from parcels of land, to objects of art, or archaeological artefacts (n.d: 2).

In order to fulfill this role, there are a number of skills which the geomaticist will require. I have shown through examining the definitions given for geomatics (see Chapter Two), that the major aspects of a geomaticist's job are the acquisition, analysis, storage, distribution and application of spatial data. As discussed above (see Chapter Two), spatial information systems, which form an integral component of the data environment, provide the tool which enables one to manage and analyse measured data. Further, it was argued that the geomaticist's ability to make full use of spatial information systems will form a vital part of his skill's set (University of New South Wales Annual Report: 1994:1; van Gysen: 1997: 1; Fourie: 1997:1).

My argument as to the increasing importance of using new technologies and computers in the form of spatial information systems, is supported by Jones and Ellis (1994), Ormeling (1994), Rouch and DeLoach (1994) as well as numerous other papers, all of which serve to illustrate the importance of computers in what is being termed "the information age" (Rouch and DeLoach: 1994: 208.1/2). I argue that it is the increasing importance of electronic data which has defined the set of skills which a geomaticist will need.

For example, if one examines the aspect of acquisition of spatial data, it is evident that the traditional surveyor has always been involved in this, by way of making measurements of the Earth's surface. However, with regards to this forming part of a geomaticist's professional profile, it is necessary for him to utilize new sources, such as digital satellite imagery, to acquire spatial data. The concepts or aspects of a geomaticist's job relating to the storage and distribution of spatial data also take on new meanings when used in the context of a geomaticist's set of skills. Jones and Ellis (1994: 202.2/5) argue that the ability to create and manipulate data files within a computer network, and how to make use of applications software packages will be of great importance for future surveyors, or what I have termed geomaticists.

Jones and Ellis go on to list a variety of applications which require spatial information for their management. These include facilities management, real estate information management and resources management (1994: 202.2/5). They refer to Trinder (1990) to suggest that if surveyors are not willing to become significantly involved in spatial information systems, especially the area of adding value to data, then other professions will take over. To become involved, argues Trinder, "requires knowledge of technical aspects of dealing with spatial data, such as vector/raster data structures, including topology; spatial and attribute data and database management systems, polygon overlay, merging of data of different accuracies and resolutions, methods of data display such as perspective views, remotely sensed data, generalisation of graphic data and visualisation of data" (1990). The same theme is propounded by Divett and Mawn in Jones and Ellis (1994: 202.2/5) who argue that "the success of the (survey) profession in the 21st century will be a function of the ... ability to react to technological changes ... to meet the information science implications and opportunities."

Based on the above, I argue that within the discipline of surveying, there has already been a shift from the traditional tasks towards the set of skills required by a geomaticist discussed in the preceding paragraphs.

This view is supported by Chen and McLaughlin who in 1992, described the environment of surveying and mapping as moving from the traditional field, through a Spatial Information Engineering environment towards a Spatial Decision Support environment. Viitanen (1994: 204.4/7-8) argues that one of the strengths of the traditional surveyor is his ability to assemble, assess and utilize information. He argues that this provides the traditional surveyor with opportunities to lead and coordinate project work, use and develop GIS and other information systems and communicate and cooperate with many other professions. Thus, I argue that the traditional surveyor is capable of moving from his current position through the stages described by Chen and McLaughlin above. In this manner, the traditional surveyor makes the transition to becoming a geomaticist.

Having thus unpacked the concept of a geomaticist and illustrated the importance of using new technologies to the full extent, I will now refine this concept further by defining a specialist category of geomaticist, namely an environmental geomaticist, in the following section. I will use this specialist category as a starting point for giving a more detailed examination of the concept of integration mentioned above.

3.3) The Environmental Geomaticist

In the previous section, I defined a geomaticist. I illustrated the skills and knowledge which such a person would require, and showed what type of role he could play in society. In this section, a specialised category of geomaticist, namely an environmental geomaticist, will be defined. However, I will first illustrate the need for such a person by briefly examining Agenda 21, and showing how the need for environmentally sound development has already been established at an international level. I will then show that a geomaticist has the necessary skills to make a meaningful contribution to more sustainable development policies, following which I will arrive at a definition for an environmental geomaticist.

Talvitie argues that environmentally sound development is considered an elemental goal of our society (1993: 149). At the time of Talvitie's writing, this need for environmentally sound development had already become an international agenda item, when, in 1992, the United Nations met in Rio to produce a document, outlining international consensus on actions necessary to move the world towards the goal of truly sustainable development (www.fao.org: 1997). This policy became known as Agenda 21. The document outlining this policy covers a large number of different aspects, and it is not my intention to review it in any great detail. Rather, I will review relevant sections of it, in order to support my argument of the need for an environmental geomaticist.

Chapter 35 of Agenda 21 deals with the role which the sciences can play in ensuring the sustainable development of natural resources. It recognises the fact that in order to promote sustainable development, more extensive knowledge of the Earth's carrying capacity is needed (www.funet.fi: 1992). It is argued further that the sciences should play an increasing role in providing for an improvement in the efficiency of resource utilization and in finding new development practices, resources and alternatives. This could be achieved by applying scientific knowledge to support the goals of sustainable development, through scientific assessments of current conditions and future prospects for the Earth system. Such assessments should then be used in the decision-making process (*ibid.*).

I argue that by applying modern survey techniques, within the framework of the science of geomatics, it is possible to gather such information as would be useful in the decision-making process. Further, the application of such data in both analysing and modelling current and future trends would be of great benefit to those involved in the formulation of more sustainable development policies. In this manner, the discipline of geomatics could be effectively used in bringing about the major goal of Agenda 21, namely, the more sustainable development of natural resources.

From the scientific viewpoint, there are three major aspects in the formulation of development strategies. These are: collection, analysis and modelling of relevant data. I have shown that at present, the traditional land surveyor is involved in only the first phase, namely, the collection of data. As argued, the collection of spatial data is becoming ever easier, due to the major technological advances which have occurred in recent times. Thus, the fact that such data is now able to be collected by people without specific knowledge in that field, means that the traditional surveyor could find the market for his services shrinking. I have argued that if the professional land surveyor is to survive and grow amidst the changes in technology, it is essential that he broaden his profile and acquire the skills necessary to undertake or contribute to the other two aspects mentioned above. That is, he should acquire the necessary knowledge, which will allow him to become involved in the analysis and modelling aspects of development strategies. In this way, the traditional surveyor would simultaneously be falling into line with the objectives of Agenda 21, and be moving away from the profile of land-measurer and towards one of geomaticist.

This view is supported by Goodwin, who argues that the professional surveyor should not be merely a "black box" technologist, but rather, he should be involved in land and its management (19992: 2). I understand this to mean that the professional surveyor should become more involved in utilising the information he collects in order to better manage the land, rather than merely collecting or producing data and then passing it over to others so that they might use it in a decision-making process. This will be investigated further below, where a specialist category of geomaticist, that is, an environmental geomaticist, is defined.

In order to illustrate the areas in which an environmental geomaticist could operate, a land use classification table developed by UNEP/FAO was used. UNEP/FAO argue that land cover and land use data are needed for assessments of the state of the Earth's environment, and that better information is needed to model policy scenarios and forecast impacts on the environment of policies and decisions. They maintain that by harmonising definitions of land cover and land use, so that they are described in a systematic manner, the value of statistics relating to land cover and land use will be greatly increased. A project was thus undertaken, in which broad categories for land use and land cover were established (UNEP/FAO: 1993: 3). It is my intention to use an adapted version of these categories to illustrate areas in which an environmental geomaticist might operate. The table below is the one developed by UNEP/FAO.

Table 1 - An international classification of land use: first approximation (UNEP/FAO: 1993)

Level I - Degree of modification of ecosystem	Level II - Functional land use	Level III - Biophysical land use
USES BASED ON NATURAL ECOSYSTEMS		
	NOT USED	
	CONSERVATION	
	TOTAL CONSERVATION	
	PARTIAL CONSERVATION	
	COLLECTION	
		COLLECTION OF PLANT PRODUCTS
		COLLECTION AND ANIMAL PRODUCTS *(sic)*
		COLLECTION OF PLANT AND ANIMAL PRODUCTS
USES BASED ON MANAGED ECOSYSTEMS		
	PRODUCTION AND MULTIPURPOSE FORESTRY	
		MANAGEMENT OF NATURAL FORESTS
		MANAGEMENT OF PLANTED FORESTS
	AGRICULTURAL PRODUCTION	
	LIVESTOCK PRODUCTION	
		NOMADIC GRAZING
		EXTENSIVE GRAZING
		INTENSIVE LIVESTOCK PRODUCTION
		CONFINED LIVESTOCK PRODUCTION
	CROP PRODUCTION	
		SHIFTING CULTIVATION
		SEDENTARY CULTIVATION, PERMANENT CROPPING
		SEDENTARY CULTIVATION, TEMPORARY CROPPING
		WETLAND CULTIVATION
		COVERED CROP PRODUCTION

Level I - Degree of modification of ecosystem	Level II - Functional land use	Level III - Biophysical land use
	PODUCTION *(sic)* OF FISH AND RELATED PRODUCTS	
		FISHING
		AQUACULTURE
SETTLEMENT AND RELATED ISSUES		
	RECREATION	
	MINERAL EXTRACTION	
		MINING
		QUARRYING
	SETTLEMENT	
		RESIDENTIAL SETTLEMENT
		COMMERCIAL ACTIVITIES
		INDUSTRIAL ACTIVITIES
		SETTLEMENT INFRASTRUCTURE
	USES RESTRICTED BY SECURITY	
Land use phase:		IRRIGATED LAND USE

The table above is very extensive, in that it was their intention to provide a category of classification for all forms of land use. While this level of detail is not practical for my purposes, it has provided me with a framework within which I can define the functions of an environmental geomaticist. For the purpose of defining these functions, I have refined and adapted the model developed by UNEP/FAO in the following ways:

Firstly, the names of the Level I categories have been slightly adapted, to shift the emphasis away from land use and towards a more general category, within which an environmental geomaticist could operate. Thus, Uses Based on Natural Ecosystems, was changed to Natural Ecosystems, and

Uses Based on Managed Ecosystems became Managed Ecosystems. Settlement and Related Issues remained unchanged.

The sub-category, Collection, refers to land where the ecosystem is not substantially altered through management, but on which collection of products from that ecosystem takes place (UNEP/FAO: 1993: V-15). It has been excluded from the functions of an environmental geomaticist, as UNEP/FAO argue that the management requirements of this sub-category are minimal to zero (UNEP/FAO: 1993: V-16). I thus discarded it on the basis that if the environmental geomaticist is to be involved in the management of natural resources, there must be scope for management in the category in which he would be required to operate. In other words, because there is no need for management in this particular category, I decided not to explore it any further, in terms of it becoming an area in which an environmental geomaticist could operate.

Also, I have not included the Level III or Biophysical land use aspects of the UNEP/FAO table in the functions of an environmental geomaticist. The reason for this exclusion, is that I am attempting to illustrate general categories, where the expertise of an environmental geomaticist might be required, and the Level III classification of UNEP/FAO is too detailed and specific for my purposes.

The category, 'Land use phase: irrigated land use', was introduced by UNEP/FAO, as they argue that the activity of providing water for crops is a land use which cuts across many classes. Rather than create an additional level by subdividing classes at Level III, it was included as a separate land use phase (UNEP/FAO: 1993: V-22). However, for the purposes of my argument, it is of little consequence, and was thus not included in the functions of an environmental geomaticist.

Having adapted the UNEP/FAO table in the manner detailed above, I now argue that the three major categories within which an environmental geomaticist could operate, are Natural Ecosystems, Managed Ecosystems and Settlement and Related Issues. These categories, as well as the sub-categories which fall under them, are depicted in Figure 3 and defined below:

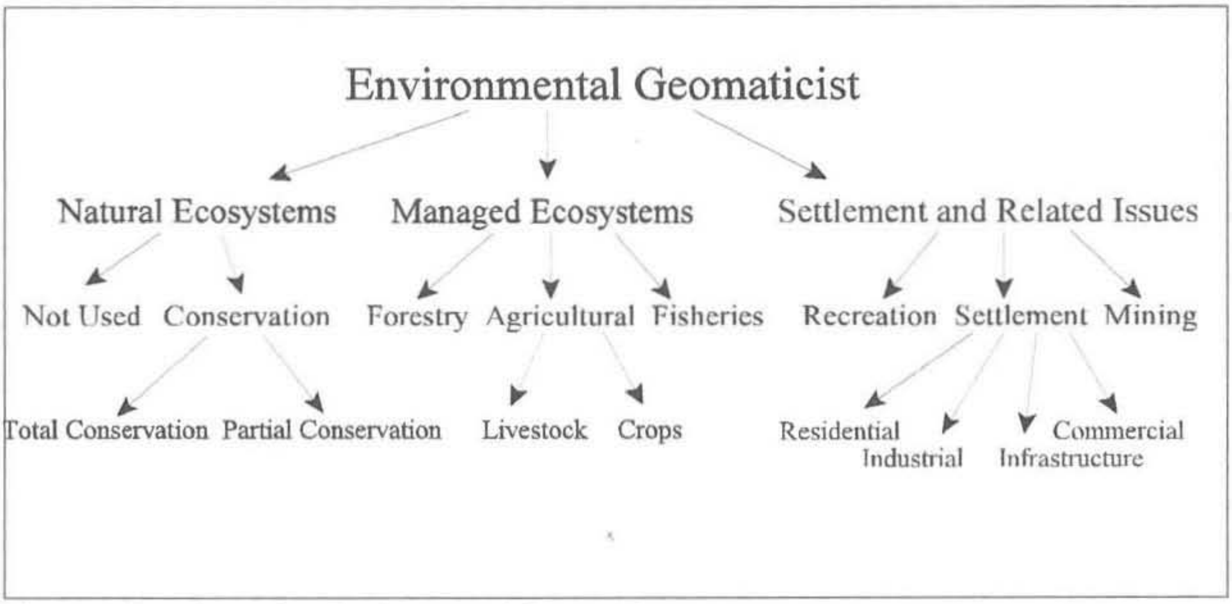

Figure 3 Functions of an Environmental Geomaticist

Natural Ecosystems are based on natural and semi-natural ecosystems which have not been fundamentally changed by human activities, and from which there is no substantial production. The vegetation in this category has not been cleared. The category includes semi-natural ecosystems, which have been modified to a certain degree by past or present management practices. There may be conservation as well as recreation of the ecosystem, provided that, in the case of recreation, conservation is of equal importance, and the ecosystem is not fundamentally changed. Conservation forestry of natural forests, as well as water bodies which are used for conservation are also included (UNEP/FAO: 1993: V-14).

The category, Managed Ecosystems, deals with land uses whose major purpose is production. The natural vegetation may be cleared, either permanently or temporarily. Where the natural ecosystem remains, there is substantial impact upon it from human activities for production purposes (UNEP/FAO: 1993: V-14).

Settlement and Related Issues covers systems of land use which are not fundamentally dependent on biological production, or in which "substantial parts of the land have been covered by buildings or other human structures." (UNEP/FAO: 1993: V-14). Land which is used for mining and quarrying is also included in this category (UNEP/FAO: 1993: V-14). Although it could be argued that the category, Settlement and Related Issues, deals primarily with human activities, and should thus not fall under the functions of an environmental geomaticist, I justify its inclusion by arguing that there are environmental issues related to the sub-categories of Recreation, Mining and Settlement. Thus, an environmental geomaticist, when operating within the framework of Settlement and Related Issues, would involve himself in the environmental aspects thereof.

As is reflected in Figure 3, each of the categories described above is further subdivided, with divisions at this new level based on the purpose for which land is used.

The category, Not Used, refers to land which is not actively managed for conservation, nor used for production. The land may be permanently unproductive, for example barren land; formerly productive, for example abandoned land; or potentially productive (UNEP/FAO: 1993: V-15).

Conservation refers to land on which the primary purpose of management is conservation and the protection of the natural ecosystem and environment. Conservation may be further subdivided into: Total Conservation, where conservation is the only, or highly dominant land use, and Partial conservation, where conservation is the primary objective, but there is controlled use for other purposes, such as recreation which does not impact on the natural ecosystem in a large way. For example, hiking and wildlife viewing. Research and scientific study would be classified under Total Conservation (UNEP/FAO: 1993: V-15).

Under the category, Managed Ecosystems, the sub-category, Forestry, refers to the management of ecosystems consisting predominantly of trees, for purposes such as the production of wood and associated products. Agricultural, refers to land which is used for the production of both primary and secondary agricultural products. It may be further subdivided into Livestock and Crops (UNEP/FAO: 1993: V-16). Fisheries refers to land or water which is used primarily for the production of fisheries products. Under the major category of Settlement and Related Issues, the sub-category of Recreation includes land which is used for both sporting and competitive activities. Mining, is as the name implies, and refers to land where the extraction of minerals, either from underground or surface workings occurs. Settlement refers to activities which occur in or on built-up areas, buildings, and other human structures, such as roads. The subdivisions of Settlement, are: Residential settlement, which includes homes, flats etc., Commercial activities, which involves all activities connected with shops, warehouses, and other commercial or trade activities, Industrial activities, which are activities carried out in factories and on land used for the production of industrial goods and Infrastructure, which refers to activities pertaining to transport and settlement services (UNEP/FAO: 1993: V-17).

In order to manage the three major categories and their various sub-categories (see Figure 3) in a sustainable manner, suitable spatial information is required. I have argued that such information is becoming more and more easily attainable, and that it is the management of this information, and its use in the decision-making process, which is in future going to be of primary importance. I have argued further that the opportunity exists for the traditional land surveyor to step into this role, and carve a niche for himself in this new market. As has been mentioned, with his training in accuracy in a fitness for purpose approach, the traditional surveyor has an ideal platform from which to launch himself into this new dimension, and thus become a geomaticist. As a geomaticist, he will also have at his disposal a wide range of tools for the collection and analysis of spatial data. What is now needed if the geomaticist is to move into the category of environmental geomaticist, is for him to gain expertise in one or more of the fields discussed above, so that he might use the information which he gathers in order to contribute to the making of informed managerial decisions.

Thus, I define an environmental geomaticist as being someone who has at his disposal, both the knowledge and the tools necessary to gather the relevant spatial information which will then be used in order to make more effective decisions in the management of a particular category, as illustrated in Figure 3. For example, an environmental geomaticist specialising in forestry management, would have the ability to gather information on the condition of those forests, through techniques such as remotely sensed digital imagery. Combining such data with information, for example, base maps of topography, rainfall, soil and geological data, he would be able to assist in the making of informed decisions regarding the management of such forests.

In order to achieve this, there are two sets of skills which are identifiable. Firstly, the ability to collect and correlate the data. This includes obtaining the different information sets, and then integrating them so that they may be used in conjunction with one another. For example, the data might be available at differing scales and a knowledge of how certain information will be distorted in converting to a common scale will be necessary. The second set of necessary skills, which I will discuss in detail below, will be the ability of the environmental geomaticist to teamwork with experts in the field of specialisation under which the project falls. Thus in the forestry management example, the environmental geomaticist would be required to interact with experts in this field, in order to add value to the data which he has captured for their management purposes.

I have thus defined an environmental geomaticist as being a specialised category of geomaticist. I have shown that there are two sets of skills which an environmental geomaticist will require in order to operate efficiently as such. Firstly, the technical skills, and the ability to manipulate and correlate different data sets, and secondly, the ability of the environmental geomaticist to teamwork with experts from other disciplines. The technical skills and aspects of the environmental geomaticist's profile, namely: the acquisition, storage, analysis, distribution, management and application of spatial data as already indicated at length, are included in the profile of the geomaticist. What will now be addressed is the concept of teamworking, and the importance of this to the environmental geomaticist.

3.4) Teamworking

In the previous section, I indicated the importance of the environmental geomaticist being able to relate to experts in other fields. Margerison and McCann argue that teamwork is the key to modern management. They maintain that management world-wide is realizing the importance of an efficient team, and the fact that decisions can no longer be made solely by one person. They argue further that in high-tech businesses, a wide range of multi-disciplinary skills is often required, and because managers cannot be skilled in all the different areas, it is essential for them to rely on teamwork (1990: 9).

I argue that this integration of skills from a variety of disciplines, or teamworking, within the high-tech environment of spatial information, is vital for the success of any project in which an environmental geomaticist is involved. To support this argument, I will examine the aspect of teamworking in greater detail, in order to illustrate its application in the manner in which an environmental geomaticist should operate. This will be achieved by presenting an initial concept of how the environmental geomaticist should function. The flaws in this particular model will then be highlighted and the model revised and expanded to show that teamwork is a necessary condition for the success of any particular project.

The initial conceptual framework for how the environmental geomaticist would proceed with the carrying out of the functions illustrated above (see Figure 3), argues him specialising in one of the categories depicted there. This therefore implies a situation where all environmental geomaticists would have two identifiable sets of skills. The first, as has been discussed above, would be the ability to collect and correlate data. The second set of skills of an environmental geomaticist would then be dependent on the area in which he chose to specialise. For example, if he were to specialise in the management of planted forests, he would be required to accumulate a reasonable standard of knowledge in this regard, in order to make informed managerial decisions. This initial conceptual framework is depicted in Figure 4 below.

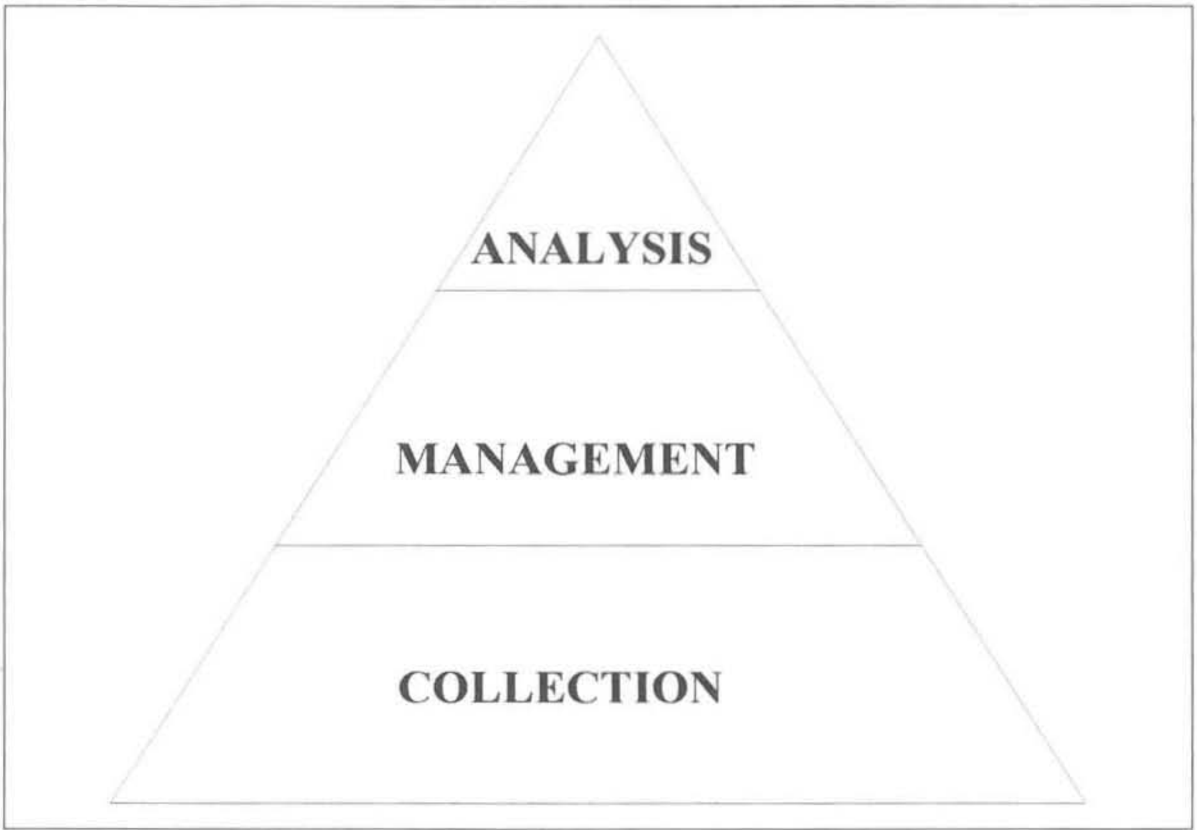

Figure 4 Initial Conceptual Framework

In Figure 4, Collection refers to the accumulation of the spatial data required in order to assist in the making of informed managerial decisions. It is shown as appearing at the base of the pyramid, as it is the initial step in the whole process. Once the raw data has been collected the Management of the data, follows. In my initial conceptual framework, this Management was to include the classification, manipulation and storage of the data in a manner which would enable it to be easily analysed. As is reflected in Figure 4, the Management of the data is a refinement of the Collection of the data. The final building block of the pyramid, is the Analysis component. This would involve using the manipulated data obtained from the management or refining of the raw data, in order to make pertinent, informed decisions regarding the management of whichever category the environmental geomaticist would specialise in. An example of this would be that given in the previous section, of the environmental geomaticist being involved in the construction of a model of topography/rainfall/soils data to aid forestry management.

The predominant flaw in this initial conceptual framework, is that it does not allow for teamworking. Parker (1990: 9) argues that the primary benefits of teamworking include greater productivity, more effective use of resources and better problem solving ability. The exclusion of teamworking from this initial conceptual framework resulted in there being three major drawbacks.

Firstly, it does not leave room for teamworking, in that any explicit reflection of the client's needs or specifications is not possible. Rather, these are implicitly included in the 'Collection' function illustrated in Figure 4. The depiction of the client's needs is vital, as it forms the basis of the whole process, in that it determines the data sources and accuracies that will be required for an effective analysis to be carried out. This view of the client's importance is supported by Margerison and McCann (1990: 161), who argue that one of the characteristics of high-performing teams, is that they make every effort to identify the needs of those whom they serve. Hastings, Bixby and Chaudhry-Lawton in Parker, also stress the "importance of the invisible team" (1990: 51) - customers, clients, users and sponsors. They argue that these people make demands on the team, provide access to needed resources and are a source of valuable feedback on team performance. I therefore argue that it is important that any revised conceptual framework should make provision for interaction with the client, and that one way of accomplishing this, is through a teamworking strategy.

The second drawback to the initial model, in terms of teamworking, is that it requires the environmental geomaticist to carry out an analysis on his own. The implication of this, is that he must become an expert in whichever field he chooses to specialise in, so that he is then able to use his spatial analysis expertise in conjunction with his knowledge of his field of chosen specialisation. This could prove to be problematic as the learning curve associated with gathering sufficient expertise, to allow one to make managerial decisions, in a new discipline, is a steep one. It is naive to believe that the input of an environmental geomaticist, who has, for example, five years experience within a particular category, could be more pertinent than that of a scientist with twenty years experience in the same category. Ideally, one would hope to use the experienced scientist's knowledge in conjunction with the environmental geomaticist's knowledge of data manipulation and spatial analysis. The whole concept of teamworking, however, negates the need for the environmental geomaticist to become an expert in a new field, as the fundamental principle behind teamworking is that it draws on individual expertise and combines them in order to achieve set objectives (Margerison and McCann: 1990: 14).

Based on the above, and Parker's argument that a "new, more intricate form of teamwork is emerging that is cross-functional and multi-disciplinary"(1990: xiv), I argue that it is unreasonable and impractical to expect an environmental geomaticist to acquire specialised knowledge in a particular field, in order to make managerial decisions. Rather, his ability to interact with experts from other fields, in order to make informed managerial decisions will be of great importance. In this manner, the skills of the various experts constituting the team, of which the environmental geomaticist is one, will be used in a complementary fashion in order to achieve optimal results.

The third drawback to the initial conceptual framework, which excludes teamworking, follows on from the idea discussed above. That is, that without teamworking, the environmental geomaticist would be required to specialise in one particular area. This would necessitate him becoming an expert in a particular field, and could prove to be very limiting and inflexible. By this, I mean that an environmental geomaticist's chief skills lie in his ability to correlate spatial data. I argue that this provides him with a broad base from which he could set himself up as a consultant to a large variety of differing fields, whose common denominator, is that they all require spatial information in order to improve the management of their operation. Because teamworking involves bringing experts together, I argue that this route will provide both the combination of expertise which will enable the most effective decision-making to take place, and further, it will provide the environmental geomaticist with greater flexibility in his job description. In other words, his spatial expertise will be required in a number of differing scenarios, and he will thus not be restricted to one particular discipline. The figure below illustrates a refined conceptual framework of the role of an environmental geomaticist.

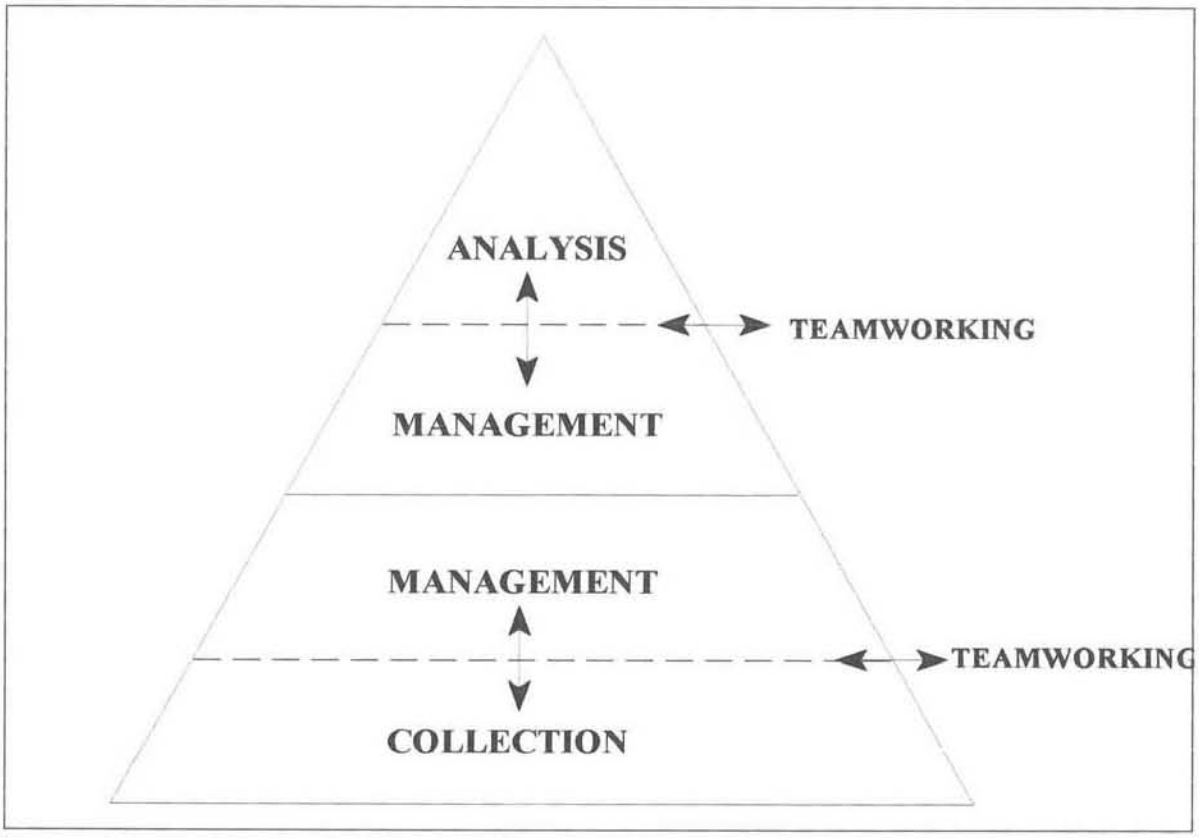

Figure 5 Refined Conceptual Framework

Essentially, Figure 5 differs from Figure 4, in that the Management function has been split into two parts, and linked firstly with the Collection function, and secondly with the Analysis function. The interaction with external experts in a teamworking situation is reflected, in order to illustrate the exchange of information which takes place in the quest for attaining the optimum solution.

In the lower half of the pyramid, the Management function is separated from the Collection function by means of a broken line. This is to show the correlation between the two, in that the Management function here relates to the management of the collection of the spatial data. There is a link here to the *controller of surveys* role of the traditional land surveyor, as described by West (1981: 104.2/1) (see Chapter Two). However, I argue that in the context of environmental geomatics, this role has changed to include the use of new technologies for the data collection. The management of the data collection now involves ascertaining the client's requirements in terms of what the information is ultimately going to be used for, which, in turn, determines the accuracies and other specifications which will be required in the collection of the data. Here, we see the environmental geomaticist teamworking with the client in order to ascertain what will be required from the spatial analysis. The environmental geomaticist thus plays a bridging role in that he must be able to assess the end product which the client requires, and in so doing, determine what data will be necessary in order to produce this final product.

The Management function in the top half of the pyramid relates to the management of the Analysis function. As is illustrated, this involves interacting with those possessing expertise in the particular field in which a decision needs to be reached. The management of the analysis now involves driving the analytical process in such a manner as to provide experts from other disciplines with whatever scenarios or data they might require to aid the decision-making process. Again, it is the environmental geomaticist's proficiency in the understanding of spatial information and the consequences of its manipulation which enable him to play the role of linking someone else's knowledge to the spatial data.

Figure 5 therefore illustrates how it is possible for the environmental geomaticist to fulfill a role in both the collection and analysis of spatial information. In fact, based on the necessity of having someone who understands spatial data in order to act in a bridging role between that data and the knowledge of experts within a particular field, I would suggest that it is highly desirable for an environmental geomaticist to form part of such a team.

3.5) Conclusion

This chapter defined, in detail, the concept of a geomaticist, and examined what role he might play within society. It also reviewed the knowledge and skills which a geomaticist might require and illustrated what steps a traditional surveyor would have to take in order to make the transition to a geomaticist.

Following this, I examined the need for the more sustainable development of natural resources by drawing on certain aspects of Agenda 21, emphasizing the role which science could play in this process. This was done to illustrate the need for someone with the skills of a geomaticist to specialise in the application of these skills to environmental issues. I proposed that a specialist category of geomaticist, namely, an environmental geomaticist, could fulfil this role.

I then used a land use classification produced by UNEP/FAO as the basis for developing a framework within which an environmental geomaticist could function. Using a simplistic example of forestry management, I showed that there were two sets of identifiable skills which an environmental geomaticist would require. Firstly, the technical skills, and secondly, the ability of the environmental geomaticist to teamwork with experts from other disciplines, in order to use the spatial information in the best possible manner.

I then reviewed this concept of teamworking in greater detail, in order to illustrate its necessity. This review was carried out by examining a conceptual framework which could be used by an environmental geomaticist in a project situation. An initial conceptual framework, which did not take teamworking into account, was compared with a revised conceptual framework, which included teamworking, in order to demonstrate the importance thereof.

Having set up a conceptual framework for an environmental geomaticist, it is my intention, to test the theories which I have reviewed and built up, on a practical case study. The following chapter will provide the background for such a case study, and will also detail the need for it, as well as give an overview of its objectives.

Chapter 4 - Case Study Background

4.1) Introduction

The conceptual framework within which an environmental geomaticist could operate has already been established (see Chapters Two and Three). This was achieved by examining the role which a surveyor has traditionally played in society, and then illustrating why there was a need for the traditional surveyor to change. Having identified this need for change, I then developed a professional profile for a modern surveyor, or what I termed a geomaticist. A further specialization of this concept was then developed, and the conceptual framework for an environmental geomaticist was established. Having thus built up the theoretical background in which an environmental geomaticist could function, I argue that it is necessary to test this theory against a practical situation, in order to test its validity.

In order to test the theory put forward in Chapters Two and Three, I became involved in an environmental team, fulfilling the role of an environmental geomaticist. In this chapter, I will examine the need for the case study which I undertook, following which, I will provide a brief outline of the case study area, and the research which has been carried out there to date. This is done to illustrate the need which the environmental project team operating in that region has for someone with the skills of an environmental geomaticist. In this manner, Chapter 4 will serve as a link between the theoretical aspects of the thesis, discussed in Chapters Two and Three, and the more technical aspects which will follow in Chapter Five.

4.2) The Need for a Case Study

I have already reviewed Chen and McLaughlin's argument (see Chapter Two) that there are three phases of change which could be identified within the environment of surveying and mapping (1992: 257). The first phase involved the use of analog instruments and expertise in positioning, map design and accuracy analysis, and I argued that the traditional land surveyor fell into this category. The second phase was described as a Spatial Information Engineering environment, and was characterized by the use of digital image technology, user needs analysis and information management. The third phase, known as the Spatial Decision Support environment, was based on decision support systems, built on a spatial information infrastructure, with core expertise in the areas of system analysis and decision support (Chen and McLaughlin: 1992: 257).

I argue that a geomaticist, as I have defined above (see Chapters Two and Three) would fall into the categories defined by the second and third phases of Chen and McLaughlin's model. That is, the work of a geomaticist would be characterized by the use of digital image technology, analyzing user needs and providing a spatial information infrastructure, within which management decisions could be made.

Following a review of geomatics, and the subsequent definition of a geomaticist as one who is involved in the acquisition and management of spatial data, I defined, a further specialization, namely, an environmental geomaticist. By means of Figure 3, I illustrated what function an environmental geomaticist would have within society, and highlighted the necessity of him teamworking with experts from other disciplines (see Chapter Three).

Having therefore linked the various sub-themes which emerged from the definitions of geomatics, to the functions defined in the Geomatics Business Model (Gagnon *et al*: 1993), and incorporated these into the conceptual framework used to define an environmental geomaticist, I argue that a case study is necessary in order to investigate, whether or not, in the course of a spatial analysis project, different tasks can be categorized as falling under the functions of Collection, Treatment, Representation/Dissemination and Management, and whether or not the services of an environmental geomaticist are needed within the project team.

It is my intention to achieve this investigation by undertaking a case study which involves research and scientific study within an area situated in eastern Botswana, and bordering both South Africa and Zimbabwe. Thus the tasks of an environmental geomaticist operating within the category Natural Ecosystems: Conservation: Total Conservation, as defined by Figure 3, will be investigated. In the following section, I will detail the history of the research carried out to date in the case study area, as well as give details as to why the environmental project team requires the services of someone with the skills of an environmental geomaticist. Note that the purpose of this chapter is solely to provide background to the case study area. The issues of teamworking, as well as the other sub-themes of acquisition, storage, analysis, distribution, application and management of spatial data, will be addressed at a later stage (see Chapter Six), once the technical aspects of the case study have been fulfilled.

4.3) Background to the Case Study

The area in which the case study was undertaken, is known as the Tuli Block, and is situated in the region where the South African, Zimbabwean and Botswanan borders meet. The area is a unique wilderness of savannah, riverine forests, marshland, open plains and sandstone cliffs (www.african travel.com: 1999). A locality plan (see Figure 6) shows the Northern Tuli Game Reserve, which forms the core area of the case study, in relation to the rest of Southern Africa. The core area at a larger scale is also shown (see Figure 7).

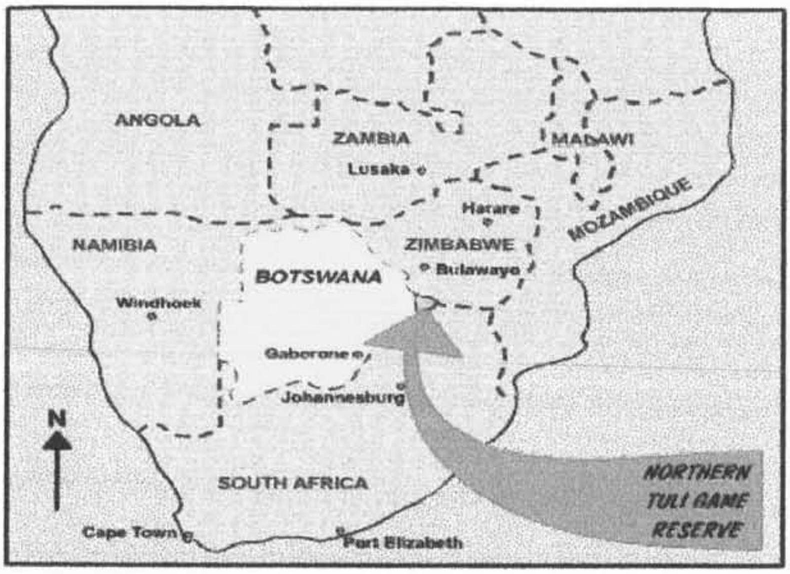

Figure 6 Location Map of Northern Tuli Game Reserve (www.ref.org.za/tuli/index.html: 1999)

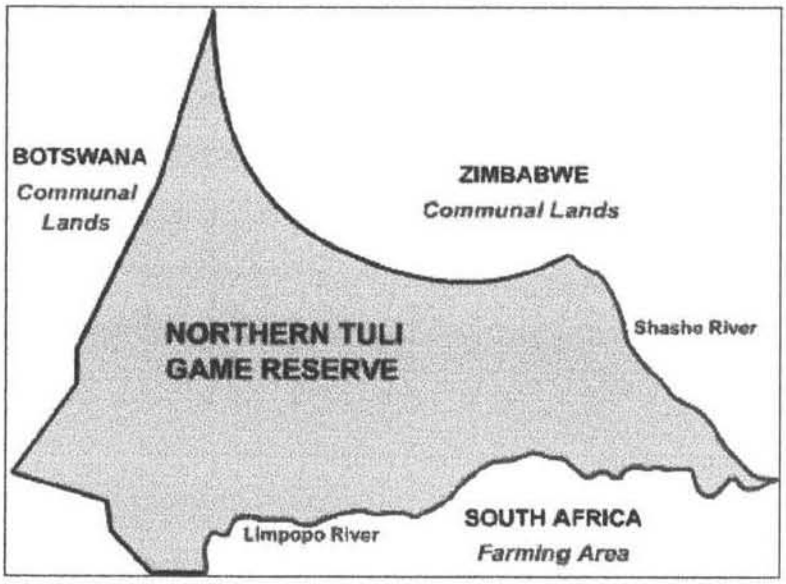

Figure 7 Map of Core Area (www.ref.org.za/tuli/index.html: 1999)

The following two pages give a brief account of the history of the area over the last thirty years. They also provide some insight into the type of research that has been carried out. This section is included at this point to demonstrate that because of the large spatial and long temporal scales involved, and as a result of the inadequacy of the research techniques used, very little progress has been made to date. From this, it will emerge that the ability of an environmental geomaticist to collect, manipulate and analyse data, as well as teamwork with the scientists who have been involved in the research to date, could be of significant benefit in achieving better results in this research.

In the early 1970's, plans to erect foot-and-mouth disease control fences along the international borders which frame the Tuli Block, resulted in concerns being raised as to what effects these fences would have on the elephant population in the region. These elephants were known to move across both the Botswana/Zimbabwe border and the Botswana/South Africa border. This concern in turn resulted in the start of a research programme, which sought to understand the interaction of elephants with their environments (Page: 1997: 32).

Page argues, that although a great deal of effort has been expended on researching this interaction, the knowledge gained has merely been a refinement or confirmation of issues already known. One of the reasons Page gives for this, is the lack of research into firstly, understanding the dynamics of vegetation, and secondly, into understanding the interaction between elephants and vegetation (1997: 32).

He maintains that even prior to the erection of the foot-and-mouth disease control fences, the impact of elephant feeding activity on the vegetation was apparent, with large areas of mopane woodland, with six to eight metre tall trees, being transformed to pollarded shrubland under three metres tall (1997: 32).

Several studies carried out in the early 1970's indicated that elephants utilized plants selectively, by taking some species in greater proportions than their occurrence, and rejecting others entirely. This, coupled with observations of their apparently wasteful mode of feeding by uprooting and felling trees, and observations of habitats which had been transformed from woodlands to open grasslands, suggested strongly that elephants were capable of significantly modifying both the structure and composition of vegetation. However, the intensity of the impact on the woodlands was not clear, because the effects of variables such as climate could not be separated from the effects of the elephant (Page: 1997: 31). The figure below is included to give an indication of the effects of elephant feeding and low rainfall on the vegetation in the area.

Figure 8 Vegetation in the Tuli Area (www.ref.org.za/tuli/reserve: 1999)

In 1976, the Endangered Wildlife Trust and the Tuli Landholders Association initiated a study to establish the number of elephants in the population, the extent of their movement and the degree of impact which they had on the vegetation (Page: 1997: 31).

The spatial distribution of feeding activity, the species utilized and the quantities involved were estimated at seventy sampling sites spread through the area. The population dynamics of the trees which formed the bulk of the elephants' diet were investigated by measuring growth rates, seedling production, survival and the intensity of elephant feeding at ten permanently located sites of $50m^2$, in which the location of every individual of all woody species was mapped. The size of each individual, its growth rate and the quantity of material removed by elephants was measured at yearly intervals. These data, together with climatic records were used to determine the effects of climate and elephant feeding on the growth and survival of woody vegetation. It has been established that at least three tree species have been eliminated from the system, and several have been reduced to very low densities over the duration of the project. Elephants appear to be the sole cause in one case, while in the others, a series of low rainfall seasons appear to be responsible for the declines (Page: 1997: 32-33).

Page argues that the interaction between elephants and their habitat is an ecological process which occurs at large spatial and long temporal scales. He maintains that the failure of the research project to make any substantial progress in the past has to a very large extent been a consequence of the researchers' efforts being concentrated at the wrong scale. He argues further that "large scale phenomena (processes which take a long time or operate over wide areas)"(1997: 34) cannot be adequately investigated without the use of experiments specifically designed for investigation at such scales. He maintains that ecology has almost no experience in detailed studies at spatial scales of between a hundred and several thousand square kilometres, or temporal scales of between one or two decades (1997: 33-34).

In this light, the need for two new projects was established by Page. The first was to carry out a more detailed analysis of factors influencing vegetation distribution, while the second was to study in greater depth, the relationship between the movements of the elephant population, and the degeneration of vegetation in the Tuli area (pers. comms.: Page: 1999). According to Page, the concept of using satellite imagery for the vegetation analysis was an attractive one, as it was the only data source which could provide the necessary vegetation data at the scale required. Also, by using imagery from the late 1970's or early 1980's, and comparing it with more recent satellite images, it would be possible to detect changes which had occurred in the vegetation over a temporal period of approximately two decades. The environmental project team, convinced of the benefits of using remotely sensed data in their analysis, were therefore seeking the services of a spatial analyst, who would be able to acquire and interpret the satellite imagery, and integrate it with other data in order to provide them with information relevant to their research (pers. comms.: Page: 1999).

In this section, I have outlined the research which had taken place in the Tuli Block from the 1970's until 1997. I also examined the reasons given by Page (1997: 34), as to the failure of the research team to make any substantial progress over this period. I concluded by stating that the decision had been made to instigate a project which would make use of satellite imagery and the skills of a spatial analyst in order to provide data which could be used for further research.

4.4) Conclusion

This chapter examined the need for the involvement of someone with the necessary skills to carry out a spatial analysis in the Tuli area. This need was examined from two different perspectives.

Firstly, an overview of the concepts established in Chapters Two and Three was given, in order to illustrate the necessity of a case study for the purposes of this thesis. That is, it was established that a case study was required in order to test the hypotheses posed in preceding chapters. Secondly, a review of the research already undertaken by the environmental project team in the Tuli area was presented, in order to show their need for someone with the skills of an environmental geomaticist.

The technical needs of the environmental project team will be explained in the following chapter, and details of the type of analysis required, and the manner in which the analysis was undertaken will be given.

Chapter Six will review in detail, the role which I played, as an environmental geomaticist, in the project team, and will address the issues of whether or not the theory formulated in Chapters Two and Three, with particular reference to teamworking, was borne out by the case study.

Chapter 5 - Case Study: Tuli Block

5.1) Introduction

The previous chapter reviewed the need for a case study in order to explore further the possibilities of having an environmental geomaticist within an environmental project team. I reviewed the involvement of Page in the Tuli Block over the past twenty years and outlined the need which he has expressed for a spatial analysis of certain aspects of the area to be carried out. This chapter will detail the technical approach used, and will not attempt to provide any explicit link to the skills needed by an environmental geomaticist, as discussed in Chapter Two and Three. In the following chapter (see Chapter Six) I will link the roles outlined for a geomaticist to the actual case study.

I will achieve this technical review by dividing this chapter into two sections. The first will deal with the preliminary stages of the analysis, while the second will review the methods I used in conducting the analysis. The preliminary phase of the analysis may be split into three distinct themes. I will firstly review the technical objectives of the case study. That is, I will discuss the end product which is required by the environmental project team. Following this, I will examine the data sets which will be required in order to achieve this end product, and explain the sources from whence this data came. Finally, I will explain the choice of software for the product.

5.2) Preliminary Aspects

5.2.1) Technical Objectives

An initial meeting was held amongst Page of The School of Environmental and Life Sciences, University of Natal, Durban (UND), Forbes of The School of Civil Engineering, Surveying and Construction, UND, and myself, on the 5 March 1999, in order to establish what Page required from the spatial analysis. Forbes attended in his capacity as my co-supervisor, and spatial analysis expert.

It was established that Page required a three-fold analysis. The first phase would be to ascertain, qualitatively, the relationship between different vegetation types, and the rainfall and topography of the area in question. The second aspect of the analysis would be a change detection analysis in order to ascertain the degree to which the vegetation pattern had changed over a period of fifteen to twenty years, and also to assess the degree to which any possible change in vegetation was dependent on a change in rainfall over the same period of time. The third and final phase, which will not be dealt with in this thesis, due to time and resource constraints, would be to determine whether any change in the vegetation pattern had resulted in a change in the movement of elephant in the Tuli Block area.

Having therefore established what was required as a final product, it was necessary to move onto the phase of obtaining the data sets which would enable that final product to be brought about. The following section reviews briefly the process of cartographic modelling, and how it is used in determining what data sets are necessary for a particular analysis to be carried out.

5.2.2) Data Sets

This section will deal primarily with the procedure used to determine which data sets were necessary for the analysis outlined above. The acquisition, manipulation and integration of the data sets will be dealt with under Section 5.3.1, where the method used for the entire process is discussed.

Eastman argues that the procedure used to determine which data sets are required for a project, is known as cartographic modelling. He defines a cartographic model as a graphic representation of the data and analytical procedures used in a study. Its purpose is to aid the analyst in organizing and structuring the procedures that will be performed within a study, and to identify the data needed (1997: Int-31).

Eastman maintains that in developing a cartographic model, it is most useful to begin with the final product and work backwards, step by step, toward the existing data. In this manner, the tendency to let the available data shape the final product is negated (1997: Int-31). Thus, the procedure begins by defining the final product and determining what data are necessary to produce that product. It therefore becomes necessary to define each of the data inputs, and how they might be derived. The following example illustrates the process and types of questions which must be asked:

> "Suppose we wish to produce a final product that shows those areas with slopes greater than 20 degrees. There are several questions we ask ourselves: What data are necessary to produce such an image? To produce an image of slopes greater than 20 degrees, we will first need an image of all slopes. Is an image of all slopes present in our database? If not, we take one step further back and ask more questions: What data are necessary to produce a map of all slopes? An elevation image may be used to create a slope map. Does an elevation

image exist in our database? If not, what data are necessary to derive it? The process continues until we arrive at existing data." (Eastman: 1997: Int-31).

As discussed in the procedure outlined above, in order to determine what data sets were required for the Tuli Block case study, it was necessary to begin with the final product. As was mentioned in the previous section, there were two primary objectives which would be dealt with in the case study. Firstly, it was required that the relationship between vegetation, rainfall and topography be qualitatively determined, and secondly, a change detection analysis of the area was to be carried out.

It was decided, that in order to accomplish the first objective, it would be necessary to produce three individual maps of the vegetation, rainfall and topography, and then overlay them so that any patterns could be visually determined. This is depicted in the figure below, with data sources illustrated using italics.

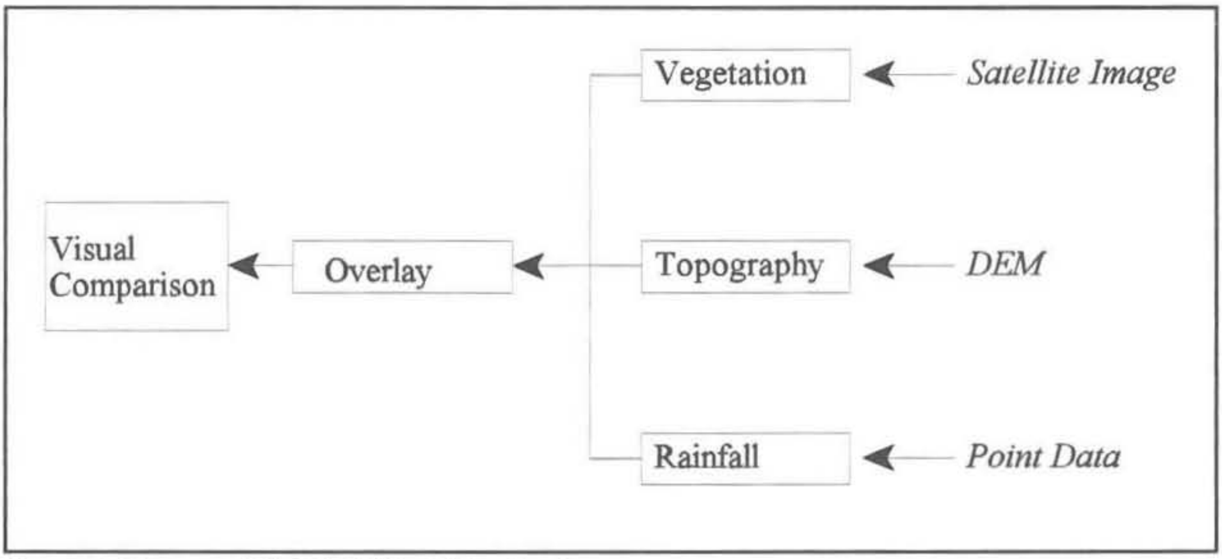

Figure 9 Cartographic Model for Objective I

Thus, the three data sets which were required, were: vegetation data, rainfall data and topographic data. The vegetation data was available from satellite imagery of the area, while the rainfall data was sourced from rainfall records of the area, dating back to the 1930's, and to which Page had access. The topographical data was freely available in the form of a digital elevation model (DEM) produced by the United States Government.

The second aspect of the case study involved a change detection analysis of the vegetation, as well as an investigation into whether or not any possible change was related to a change in rainfall over a corresponding period. This required two sets of vegetation and rainfall data of the same area, but from different time periods. Due to the fact that this section is intended to deal only with the data sets required, it is my intention to give a more detailed review of the change detection analysis in Section 5.3.3, suffice to say that the only additional data needed was vegetation and rainfall data obtained at a different temporal scale to that acquired for the vegetation/rainfall/topography analysis. The figures below illustrate the cartographic models for this second objective.

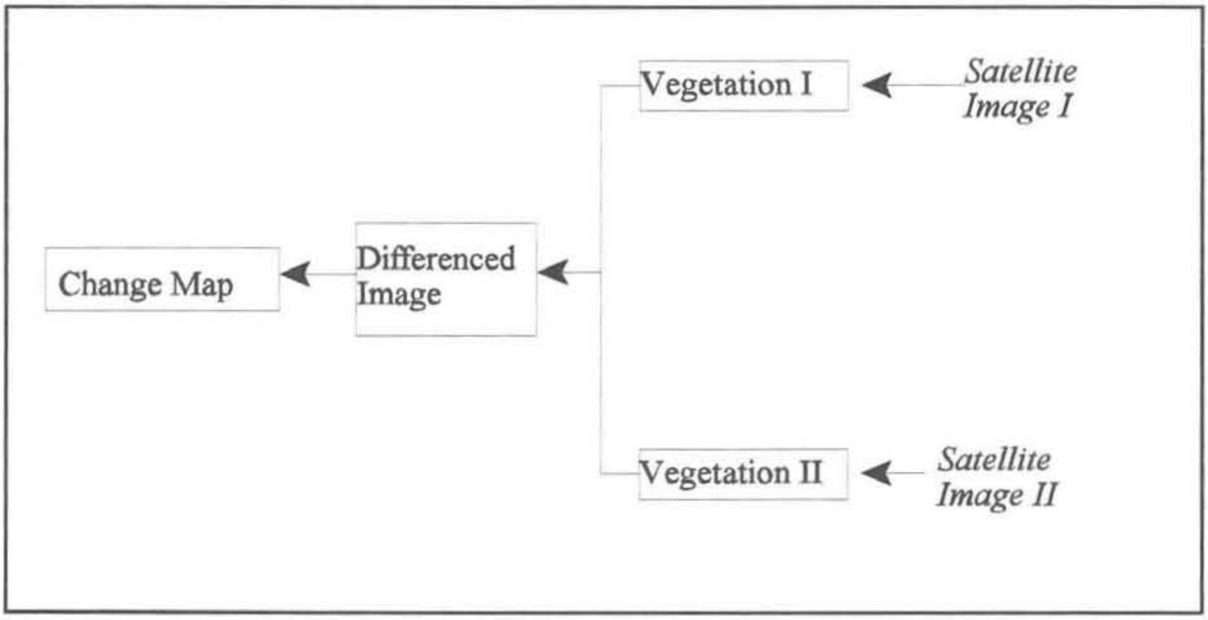

Figure 10 Cartographic Model of Change Detection Analysis

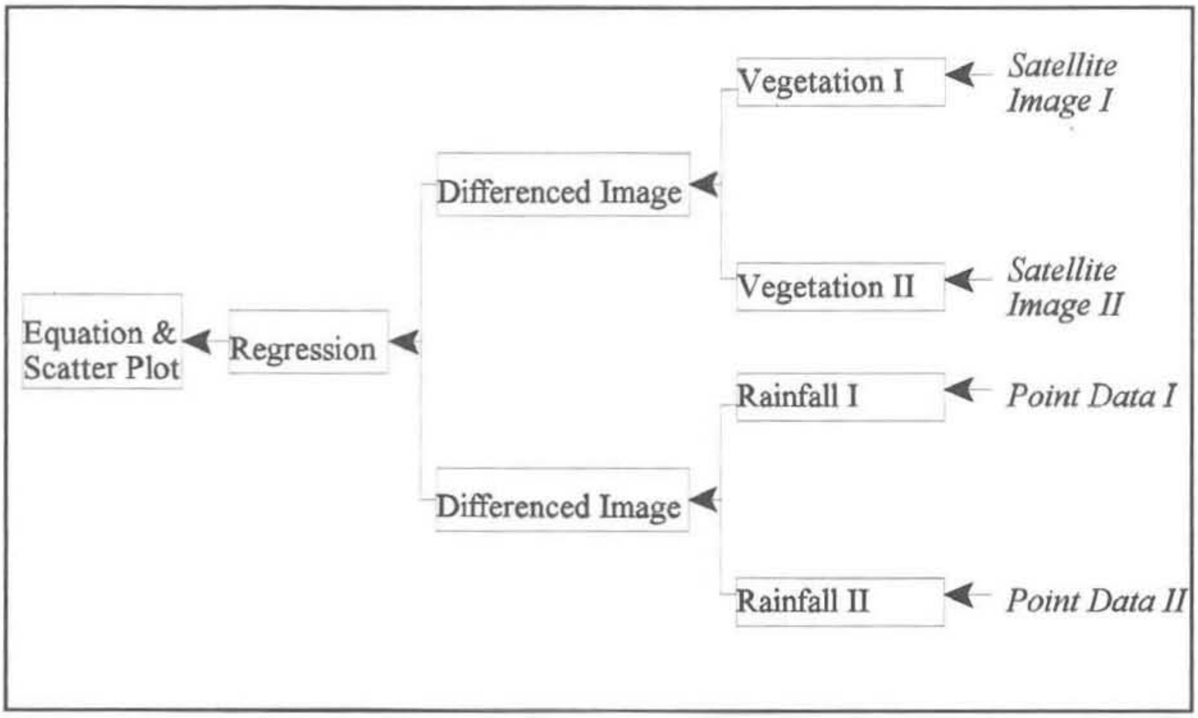

Figure 11 Cartographic Model of Regression Analysis of Differenced Images

I have thus examined the technical aspects of the case study, and have established the data sets which were necessary in order to carry out the spatial analysis. The final preliminary aspect which needs to be dealt with relates to choice of software. This will be examined in the following section.

5.2.3) Software

I have established what technical objectives were required to be met by the case study, and have ascertained the data sets which were necessary in order to meet these objectives. What remains of the preliminary aspect of the case study, is the decision as to what GIS software package would be most appropriate for carrying out the analysis. The NCGIA argue that at this point, there is a fundamental choice which must be made, namely, the choice between a raster or vector based GIS package. It is my intention to review briefly, the difference between raster and vector based packages. Following this, I will examine a few of the capabilities of Idrisi for Windows, a geographic information and image processing software system developed by the Graduate School of Geography at Clark University (Eastman: 1997a: 1-1), in order to demonstrate its suitability for the purposes of the Tuli Block case study.

5.2.3.1) Raster versus Vector

Star and Estes (1990: 33) argue that one of the simplest data structures is a raster or cellular organization of spatial data. In a raster structure, a value for the parameter of interest, be it elevation, land use class, plant biomass etc., is developed for every cell in an array over space (Star and Estes: 1990: 33). Points in raster structures are represented by a single grid cell, lines by a number of neighbouring cells strung out in a given direction and areas by an agglomeration of neighbouring cells. While this type of data structure is easy to handle in the computer, it also means that the two dimensional surface upon which the geographical data are represented is not continuous, but quantized. This can have an important effect on the estimation of lengths and areas when grid cell sizes are large with respect to the features being represented (Burrough: 1986: 20). Thus, because raster representation assumes that the geographical space can be treated as though it were a flat Cartesian surface, each pixel or grid cell is then, by implication, associated with a square parcel of land. This means that the resolution or scale of the raster data is then the relation between the cell size in the database, and the size of the cell on the ground (Burrough: 1986: 20). As a result of this, the ability to specify a location in space, in raster based systems, is limited by the size of the raster elements, since it is impossible to know anything about different locations within a raster cell. In other words, there is a limit to geographic specificity (Star and Estes: 1990: 48).

The vector representation of an object is an attempt to represent the object as exactly as possible.

Unlike the raster coordinate space, which was quantized, the vector coordinate space is assumed to be continuous, thus allowing all positions (points), lengths (lines), and dimensions (areas) to be precisely defined. Besides the assumption of mathematically exact coordinates, vector methods of data storage use implicit relations that allow complex data to be stored in a minimum of space (Burrough: 1986: 25).

The NCGIA maintains that the arguments surrounding choice of raster or vector based systems have been around since the earliest systems were created (www.ncgia.ucsb.edu). Star and Estes (1990: 58) argue that traditionally, basic issues in the raster versus vector debate, included data volume (or storage efficiency), retrieval efficiency, robustness to perturbation, data manipulation (or processing efficiency), data accuracy and data display. However, the NCGIA maintain that in terms of modern day GIS, there are four basic issues central to the debate, namely: coordinate precision, speed of analytical processing, mass storage requirements and characteristics of phenomena (www.ncgia.ucsb.edu). I will review each of these issues below.

The NCGIA maintain that if one examines the coordinate precision with regards to a raster based system, it is evident that the locational precision is limited by the size of the cells, while the locational precision in a vector based system can be encoded with any conceivable degree of precision. In terms of the precision necessary for data, the NCGIA maintain that vector precision is necessary for certain classes of data, such as data captured from precise surveys, whereas for natural phenomena data, which does not necessarily have true, clearly defined edges that can be accurately represented by mathematical lines, raster precision is most suitable (www.ncgia.ucsb.edu).

In terms of computational speed, the NCGIA argue that raster data can be processed very quickly to answer analytical questions, involving overlays, proximity, and Boolean queries, in such a manner that very little arithmetic computation is required. The NCGIA maintain that the same questions would require considerable computation in vector systems where the topology is complex, and thus, the geometrical problems requiring solutions are complex. These requirements slow down the response times of vector-based systems (www.ncgia.ucsb.edu).

The simplest raster data storage method requires one memory location per cell. This method is not at all efficient, and severely limits the maximum number of rows and columns that can be used, although various file compression techniques are available to reduce this problem (www.ncgia.ucsb.edu). In vector data storage, the memory requirements depend on the complexity of objects and the precision of coordinates. The volume also depends on which relationships between objects are stored in the database. Generally, vector systems should use less mass storage than a raster based system of high enough resolution to emulate the vectors (www.ncgia.ucsb.edu).

The final issue, as described by the NCGIA, in the raster versus vector debate, is that of the characteristics of phenomena. Raster sampling may be defined as a regularly spaced sampling of phenomena, which reflects a lack of knowledge of spatial variation. It is appropriate for remote sensing, as the satellite is not intelligent enough to vary its sampling in response to variation on the earth's surface, and satellite imagery, both raw and classified, is typically collected in raster format (www.ncgia.ucsb.edu). Vector sampling and representation, on the other hand, permits more variability in some areas than in others. This approach is appropriate for social, economic and demographic variation, which is far more intense in some areas than in others (www.ncgia.ucsb.edu). Below, by way of a summary, a table comparing the various advantages and disadvantages of raster and vector methods is given. Although the table is fairly outdated, much of what is contained therein is still relevant today.

Table 2 Comparison of vector and raster methods (Burrough: 1986: 36)

Vector methods

Advantages
- Good representation of phenomenological data structure
- Compact data structure
- Topology can be completely described with network linkages
- Accurate graphics retrieval, updating and generalization of graphics and attributes are possible

Disadvantages
- Complex data structures
- Combination of several vector polygon maps or polygon and raster maps through overlay creates difficulties
- Simulation is difficult because each unit has a different topological form
- Display and plotting can be expensive, particularly for high quality, colour and cross-hatching
- The technology is expensive, particularly for the more sophisticated software and hardware
- Spatial analysis and filtering within polygons are impossible

Raster Methods

Advantages
- Simple data structures
- The overlay and combination of mapped data with remotely sensed data is easy
- Various kinds of spatial analysis are easy
- Simulation is easy because each spatial unit has the same size and shape
- The technology is cheap and is being energetically developed

Disadvantages
- Volumes of graphic data
- The use of large cells to reduce data volumes means that phenomenologically recognizable structures can be lost and there can be a serious loss of information
- Crude raster maps are considerably less beautiful than maps drawn with fine lines
- Network linkages are difficult to establish
- Projection transformation are time consuming unless special algorithms or hardware are used

The four issues detailed in the preceding paragraphs, and summarised in the table above, namely:

precision, speed, storage requirements and suitability for the phenomena being studied, were examined with respect to the Tuli Block case study, in order to determine whether a vector or raster system should be used.

As a result of the fact that the case study will deal with natural phenomena on a very large scale, it was decided that the type of precision offered by vector systems would not be required, as the boundaries of different vegetation types and rainfall areas are not of a very precise nature themselves. The speed at which the processing of raster information could take place, in comparison to that of vector information, was viewed as a definite advantage of raster systems. Whilst NCGIA argue that raster data storage is not efficient (see above), for the purposes of this case study, storage space was not viewed as being a problematic issue. The final issue, and one which was of major importance in deciding what type of system to use, was that of matching a system to the phenomena being studied. The fact that satellite imagery was to be a major source of information, coupled with the fact that the satellite image comes in raster format, resulted in the decision being made to use a raster system. Below, I will provide a brief description of Idrisi for Windows in order to justify its selection as the GIS package to be used.

5.2.3.2) Idrisi for Windows

As has been mentioned, Idrisi is a geographic and image processing software system designed to provide professional-level geographic research tools. Since its introduction in 1987, Idrisi has grown to become the largest raster based microcomputer GIS and image processing system on the market (Eastman: 1997a: 1-1).

Its raster analytical functionality is widely used and covers the full spectrum of GIS and remote sensing needs, from database query to spatial modelling, to image enhancement and classification. My primary reason for selecting Idrisi as the software package to be used in the Tuli Block project, was the fact that, included in its special facilities are capabilities for environmental monitoring and natural resource management. This includes change and time series analysis, as well as functions for creating vegetation indices and dealing with image restoration and classification of remotely sensed imagery (Eastman: 1997a: 1-2).

I have examined the preliminary aspects of the technical side of the Tuli Block case study. Having established what objectives were required to be met, I discussed the method of cartographic modelling as a means for deciding which data sets would be required. This was followed by an outline of the debate over the use of raster or vector based systems, following which I gave a brief introduction to the raster based system, Idrisi, and my reasons for selecting this particular GIS for the Tuli Block case study. The second section of Chapter 5 will detail the methodology which I followed in actually carrying out the project. Aspects such as the integration of the different data sets, the classification of data and the various types of analysis carried out, will be discussed.

5.3) Analysis

5.3.1) Acquisition, Manipulation and Integration of Data

As discussed above, the major data set for this project, was the satellite imagery, which was used to provide information on the different vegetation types found within the case study area. Initially it was hoped that images spanning a period of between fifteen to twenty years would be available, as Page felt that this would provide a time frame within which any vegetation changes would be most noticeable (pers. comms: 1999). Page also required that the images used, be images taken during the months of April, or early May, that is, just after the rainy season. Also, in order for the vegetation to be adequately classified and analysed, it was a prerequisite that the images be free of any cloud cover.

The Satellite Applications Centre's interactive web page was visited, in order to browse through their archives, to find suitable imagery for the case study. It was decided that as a result of the LANDSAT Thematic Mapper's superior "spectral, spatial and radiometric characteristics" (Richards: 1986: 13), images from this satellite would be used. By specifying the location of the area being studied, thumbnail images of that area could be viewed on line.

Unfortunately, due to the cloud cover constraint mentioned above, it was not possible to obtain images that were taken fifteen years apart. The two most suitable images available were taken in 1991 and 1998, a time span of only seven years. This problem was discussed with Page, and it was decided that the constraint that the images be cloud free, was of greater importance than the constraint that they be fifteen to twenty years apart. The decision was thus taken to order the data from The Satellite Applications Centre.

Financial constraints dictated that only three of the seven bands of imagery would be available, and thus bands 3, 4 and 5 were ordered, on Forbes's recommendation, as he argued that these would provide sufficient information for the purposes of this case study (pers. comms.: 1999). It was necessary, upon ordering the data, to specify various parameters concerning the format in which the data was to be presented, and Forbes's experience as a spatial analyst, was invaluable in dealing with these matters. A copy of the Output Data Specifications is included in Appendix A.

The satellite data was copied from the CD's on which it had been stored to a directory on the computer's hard drive, which would serve as the working directory for Idrisi. While map layers in Idrisi are referred to by a simple name, they are actually stored as a pair of data files. One contains the data, while the second contains information about those data. Thus, while a raster image will be stored in a data file with an ".img" extension, it will also have an accompanying documentation file with a ".dvc" extension (Eastman: 1997a: 4-7). At this point it was necessary to change the file format of the images supplied by The Satellite Applications Centre from ".dat" to ".img" so that they could be imported into Idrisi, following which a documentation file was created for each image. In creating the documentation files, it was necessary to input information such as the number of rows and columns in the images, the data and file types of the images, the reference system and units used, as well as the maximum and minimum X and Y coordinates of the images. All of the information above, was provided by The Satellite Applications Centre, in a header file, supplied with the images. It was, however, necessary to transform the coordinates of the images from latitude and longitude to Universal Transverse Mercator (UTM) coordinates. This was done using XForm Version 4.1, a transformation software package.

Once the satellite data had been input into Idrisi, it was then required that these images be georeferenced. According to Eastman, georeferencing is "the manner in which locations in raster images...are related to earth surface locations" (1997a: 8-1). This involves identification of a sufficient set of control points on both the image and the ground, or on a map, and then developing a transformation which would enable one to estimate the ground coordinates of any pixel, from the image pixel coordinates. This transformation is usually a first or second order polynomial equation.

If a second order polynomial equation is used, it takes the form:

$$P_x = a_0 + b_0E + c_0N + d_0EN + e_0E^2 + f_0N^2 \quad (1)$$

$$P_y = a_1 + b_1E + c_1N + d_1EN + e_1E^2 + f_1N^2 \quad (2)$$

where P_x, P_y are the corrected pixel coordinates (McCloy: 1995: 198-199). This requires a minimum of six control points to solve the twelve unknowns, and is the most common form used in image rectification (McCloy: 1995: 199).

In Idrisi, the RESAMPLE module uses the logic described above to perform geometric restoration of images (Eastman: 1997a: 5-18). Fifteen well distributed control points whose coordinates were scaled from a 1:50 000 map of the area were used in order to georeference the images. For both the 1991 and 1998 images, the three points with the highest root mean square error were omitted from the process, thus resulting in twelve control points being used for each transformation. A summary of the transformations for both 1991 and 1998 appears in Appendix B. Overall root mean square errors of 32,26 metres and 36,99 metres were obtained for the 1991 and 1998 images respectively. Given the application that these images were to be used for, and that the pixel size for the images is 25 metres, and also that the control points were scaled from a 1:50 000 map, these errors were deemed acceptable.

The rainfall data which was to be used in the analysis, was obtained from Page, who had access to records dating back to the 1930's. This data consisted of a number of readings taken at rainfall stations over a seventy year period, together with the geographical positions of these stations. It should be noted that this data set was largely incomplete, and inconsistent in that there are numerous years where rainfall measurements at various stations were not taken. It was, however, the only source of rainfall data available to the team, and having discussed the matter with Page, and made him aware of some of the consequences of interpolating surfaces from such data (see below), the decision was made to use the rainfall data.

The next stage in the manipulation and integration of the three data sets was to input the rainfall data into Idrisi. As discussed, the rainfall data consisted of average rainfalls over various years, and the geographical position of the rainfall stations, given in latitude and longitude. The first phase in entering this data into Idrisi involved the conversion of the geographical coordinates into the UTM system. As with the satellite data, this conversion was undertaken using XForm Version 4.1.

In order that the satellite images, and digital elevation model might be compared and related to the rainfall data, it was necessary to generate a surface from the point data which was available to the team. Since the change detection analysis would require two sets of satellite and rainfall, it was decided, after consultation with Page, that two different rainfall surfaces be generated - one which would reflect the rainfall situation before 1991 (when the first satellite image was taken), and one which would reflect the situation between 1991 and 1998 (the date of the second satellite image). On Page's recommendation, the data to be used in generating the first surface, was to span the period 1979/80 to 1990/91, and that to be used for the second image, was to span the period 1991/92 to 1997/98. He argued that these periods would provide an accurate portrayal of the rainfall experienced leading up to the dates of the satellite imagery. The stations to be used in the interpolation procedure were all those for which there was data available during the above-mentioned periods. This meant that for the first rainfall surface, Pont Drift, Tuscannen, Nekel, Macuville and Ntani were to be used, and for the second surface, Platjan, Pont Drift, Macuville and Ntani were to be used. Unfortunately, the station at Macuville fell outside the limits of the satellite imagery, and was thus not able to be used in the generation of the rainfall surface. This was worrying, in that it not only reduced the number of points which could be used in the interpolation process, but it also affected the distribution of the points used. The consequence of using poorly distributed points in an interpolation procedure, namely a less accurate interpolation of the surface were discussed with Page, and it was decided that for the purposes of the analysis, the exclusion of the station at Macuville was not of major consequence. A map illustrating the positions of all the rainfall stations, and those stations which were actually used may be found in Appendix F.

In Idrisi, the module INTERPOL interpolates a surface according to a distance-weighted average, given a vector input file of points, and a values file that lists the magnitudes of those points (Eastman: 1997a: 5-29).

The final data set which was required for the project, was the topographic information. This information, known as the HYDRO1k data set, was obtained, at no cost, from the United States Geological Survey's (USGS) EROS Data Center, via the internet website http://edcdaac.usgs.gov/gtopo30/hydro.

HYDRO1k is a geographic database which provides global coverage of topographically derived data sets, such as aspect, slope, flow directions and accumulations, stream lines and drainage basin boundaries. The basis of all these layers is the hydrologically correct DEM, which is itself based on the GTOPO30 data set, a 30 arc-second DEM of 1 kilometre resolution, developed by EROS Data Center in 1996 (http://edcdaac.usgs.gov).

The entire data set for the continent of Africa was downloaded, and the DEM image file, along with the header file, the world file and the statistics file were copied to the Idrisi working directory. The image file is provided as signed integer data in a simple binary raster format. The DEM layer is supplied as 16-bit data, with no header or trailer bytes embedded in the image, and with data being stored in row major order. The header file is an ASCII text file containing size and coordinate information for the DEM layer, while the world file is of the same format, and contains additional coordinate information. The header and world files were used in conjunction with one another to input the DEM into Idrisi, and to georeference it correctly (see below). Further details of the information contained in each file may be found in Appendix C. The other file which was supplied, that is, the statistics file, is also an ASCII text file, and lists the band number, minimum, maximum and mean values, and the standard deviation of the values contained in the image file (http://edcdaac.usgs.gov).

In order to properly perform area calculations on the DEM, the supplied data was projected in the Lambert Azimuthal Equal Area projection. Although Idrisi does support this projection, the reference file which it uses (LAZEA.ref) to define certain parameters regarding the projection, uses North American Datum, 1927 (NAD27) as a datum, and a longitude and latitude of origin of -100° and 45° respectively. Therefore, in order to input the Africa DEM in the correct format, it was necessary to edit the Idrisi reference file, to conform to the parameters with which the data set was generated. This involved changing the latitude and longitude of origin to those given in the HYDRO1k documentation, as well as changing the datum to World Geodetic System, 1984 (WGS84). Associated with this change, was a corresponding change to the Molodensky constants. These three values, expressed in metres, give the differences (in the X, Y and Z axes respectively) between the centre of the earth of the datum in use, and that of the WGS84 datum. Therefore the change in datum to the WGS84 system, meant that the Molodensky constants were changed to 0, 0, 0 (Eastman: 1997a: 8-10). The final change to the reference file involved editing the semi-major and semi-minor axes. For the HYDRO1k data set, a spheroid of radius 6 370 997 metres was used (http://edcdaac.usgs.gov), and both the semi-major and semi-minor axes were therefore set to this value. The new reference file (LAZEANEW.ref) was saved for future use. The table below shows the differences between the original and adapted reference files.

Table 3 Comparison of LAZEA.ref and LAZEANEW.ref

	LAZEA.ref	LAZEANEW.ref
Reference System	USGS Lambert Azimuthal Equal Area	USGS Lambert Azimuthal Equal Area
Projection	Lambert Oblique Azimuthal Equal Area	Lambert Oblique Azimuthal Equal Area
Datum	NAD27	WGS84
Delta WGS84	-8 160 176	0 0 0
Ellipsoid	Clarke 1866	na
Semi-Major Axis	6378206.40	6370997
Semi-Minor Axis	6356583.80	6370997
Origin Longitude	-100	20
Origin Latitude	45	5
Origin X	0	0
Origin Y	0	0
Scale Factor	na	na
Units	m	m
Parameters	0	0

The Africa DEM was then imported using BILIDRIS, and the adapted reference file LAZEANEW.ref. The necessary information on the number of bands in the image and the data type was obtained from the world and header files. BILIDRIS also required the maximum and minimum

X and Y coordinates of the image to be imported. The world file provided the coordinates of the centre of the top left pixel. However, because the Idrisi reference system works with the edges of the pixels, as opposed to their centres, it was necessary to calculate the coordinates of the top left hand edge of the aforementioned pixel. Given that the resolution, or pixel size of the HYDRO1k data is one kilometre, this was easily accomplished by subtracting 500 metres from the X coordinate supplied in the world file, to obtain the minimum X value in the Idrisi system, and adding 500 metres to the Y coordinate from the world file, to obtain the maximum Y value in the Idrisi system. The remaining maximum X and minimum Y coordinates required for Idrisi documentation purposes, were calculated by adding the product of the cell size (1000 metres) and the number of columns (8736), supplied in the header file, to the minimum X coordinate calculated above, and by subtracting the product of the cell size (1000 metres) and the number of rows (9194) from the maximum Y coordinate. This process is illustrated in the figure below, where A illustrates the X and Y coordinates as per the world file, and B, C, D and E illustrate the manner in which coordinates are referred to in Idrisi.

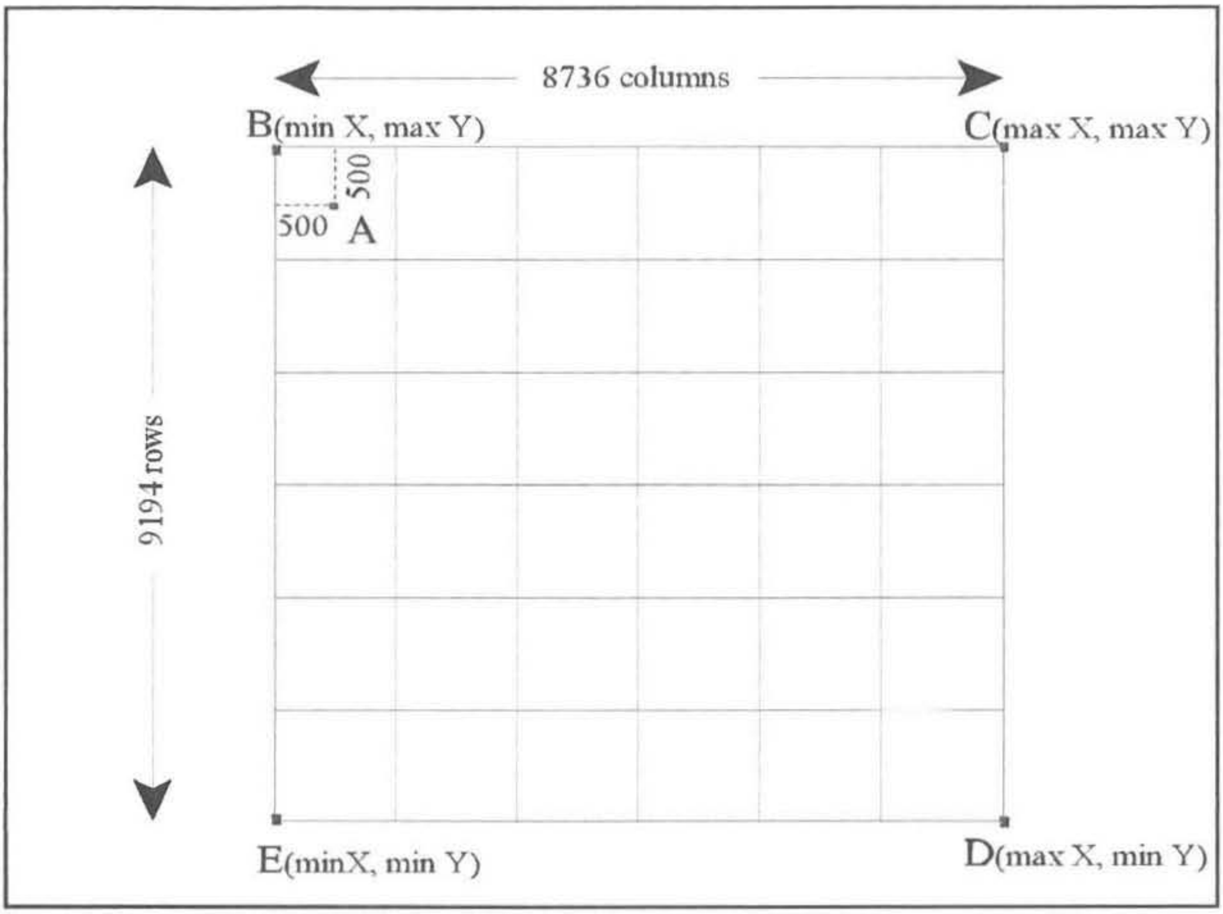

Figure 12 Illustration of Method Used to Calculate Coordinates for Idrisi

All that now remained, was to integrate the topographical data with the vegetation and rainfall data sets. That is, it was necessary to transform the topographical data onto the same system (UTM) as the other two data sets. This was achieved using the PROJECT module in Idrisi, together with the LAZEANEW.ref reference file. However, one minor modification to this reference file was necessary, in order to avoid division by zero errors in the transformation process. As a result of the fact that the transformation used subtracts the value of the semi-minor axis from that of the semi-major axis, and inserts this result into the denominator of one of the transformation equations, the semi-major axis value was changed from 6 370 997 metres to 6 370 998 metres. In this way, division by zero was avoided, and the datum, although not strictly spheroidal any longer, was as near to being a spheroid as possible. The final step in PROJECT was to enter the boundary coordinates of the output image. This was done to ensure that the DEM image covered the same area as the vegetation and rainfall images.

It is important to note that the manipulation and integration of the different data sets, particularly the DEM, was very time consuming. The process of inputting raw data into the GIS and ensuring that the various data sets were all correctly georeferenced, took a considerable amount of thought and effort, especially in the situations where changes of projection were required. This is discussed further in the conclusion.

5.3.2) Objective I - The Relationship Between Vegetation, Topography and Rainfall

5.3.2.1) Literature Review

Introduction

In order to investigate the relationship of different vegetation types and topography and rainfall, it is first necessary that those different vegetation types be defined. The focus of this literature review, is therefore on the different procedures which might be employed in the classification of data sets in general, and remotely sensed, natural resource data sets in particular.

Spectral Signatures

Most remote sensing devices are used to gauge interactions between earth surface materials and electromagnetic energy. When electromagnetic energy strikes a material, it is either reflected, absorbed or transmitted. For remote sensing purposes, the major concern is with the reflected portion, since it is usually this which is returned to the sensor system. Exactly how much is reflected will vary, and depends both upon the nature of the material and where in the electromagnetic spectrum the measurement is being taken. Therefore, if the nature of this reflected component is studied over a range of wavelengths, the result can be characterised as a spectral response pattern, or signature. It can be thought of as a description (often in the form of a graph) of the degree to which energy is reflected in different regions of the spectrum (Eastman: 1997a: 3-1/4). Of importance, is the fact that this reflectance varies according to the nature of the material. Thus different spectral response patterns or signatures can be associated with different types of materials. Eastman argues that finding these distinctive spectral signatures is "the key to most procedures for computer-assisted interpretation of remotely sensed imagery" (1997a: 3-5). Classification of remotely sensed imagery makes use of these distinctive spectral signatures in order to group materials with similar signatures into the same class. The success with which this can be done depends on two things. Firstly, the presence of distinctive signatures for the land cover classes of interest, and secondly, the ability to reliably distinguish these signatures from other spectral response patterns that might be present (Eastman: 1997a: 3-15).

Supervised and Unsupervised Classification

Eastman argues that there are two general approaches to image classification: supervised and unsupervised (1997a: 3-15). Essentially, these differ in how the classification is performed.

In unsupervised classification, clustering algorithms are used to partition image data into a number of spectral classes. Unsupervised classification requires no advance information about the classes of interest, but rather examines the data and breaks it into the most prevalent natural spectral grouping or clusters. These spectral classes are then associated with information classes by the analyst, through a combination of familiarity with the region and ground truth visits (Eastman: 1997a: 3-16). The major disadvantage of unsupervised classification procedures, is that they are largely concerned with uncovering the major land cover classes, and thus tend to ignore those classes that have low frequencies of occurrence (Eastman: 1997a: 11-1).

The underlying requirement of supervised classification procedures, is that the analyst has available a sufficient number of known pixels for each class of interest, so that representative signatures can be developed for those classes. These prototype pixels are often referred to as training data, and collections of them are known as training fields, or training sites. The training sites are used by the software system to develop a statistical characterisation of the reflectances for each information class. Once these representative signatures have been developed, a procedure (known as a classifier) is used to evaluate the likelihood that each pixel in the image belongs to one of these classes. There are a number of classifiers which might be used to accomplish this. Essentially, these can be divided into two categories, namely: hard classifiers and soft classifiers (Eastman: 1997a: 11-1/2; Richards: 1986: 225).

Hard Classifiers

The major characteristic of all hard classifiers, is that they reach an unequivocal decision about the class to which each pixel belongs (Eastman: 1997a: 11-7). That is, they make the assumption that an image scene can be decomposed into a small number of spectrally separated classes, each of which can be allocated to a well-defined type of land cover. All hard classifiers are based on the logic that describes the expected position of a class (based on training site data) in what is known as band space, and then measuring the position of each pixel to be classified in the same band space relative to these class positions (Canter: 1997: 404; Eastman: 1997a: 11-7). Two of the most common classifiers are the minimum-distance-to-means classifier, and the maximum likelihood classifier. These are discussed below.

Based on training site data, the minimum-distance-to-means classifier characterises each class by its mean position on each band of the image. Figure 13, below, illustrates an example of a situation where only two bands were used. Here each axis indicates reflectance on one of the bands. Therefore, using the mean reflectance on these bands as x,y coordinates, the position of the mean can be placed in this band space. Similarly, the position of any unclassified pixel can also be placed in this space by using its reflectance on the two bands as its coordinates. The minimum-distance-to-means classifier then examines the distance from the unknown pixel to each class, and assigns it the identity of the nearest class. In Figure 13, the unclassified pixel would be assigned the "sand" class since this is closest (Eastman: 1997a: 11-8).

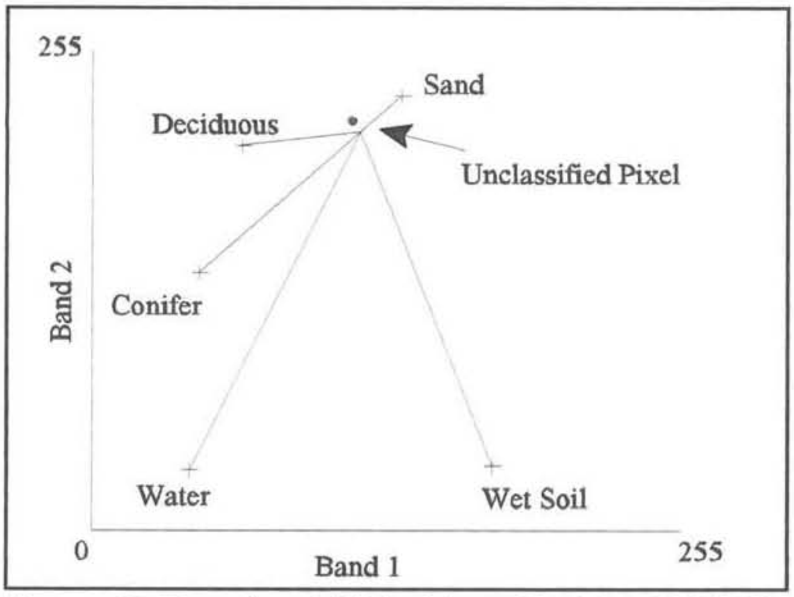

Figure 13 Example of Methodology Used by MINDIST Classifier (Eastman: 1997: 11-8)

The advantage of this approach, is that it is particularly suitable for situations in which the quality of the training site data is poor, while the major disadvantage of this approach is that it does not take into account any variability within the different classes. By characterising each class according to its mean band reflectances only, the minimum-distance-to-means classifier has no knowledge of the fact that some classes are inherently more variable than others. This can lead to misclassification. This is shown by Figure 14 which illustrates a highly variable deciduous class, and a very consistent sand class. Both circles represent a distance of two standard deviations from the mean. Thus, the unclassified pixel falls within the variability of the deciduous class, but would incorrectly be classified as sand, as it is closer to this category. This problem may be overcome by introducing a standardised distance which is defined as:

standardised distance = (original distance - mean)/standard deviation

If the standardised distance was used in the example illustrated in Figure 14, the pixel would be correctly classified as deciduous, as the standardised distance from the deciduous mean would be less than two, while that from the sand mean would be greater than two (Eastman: 1997a: 11-8/9).

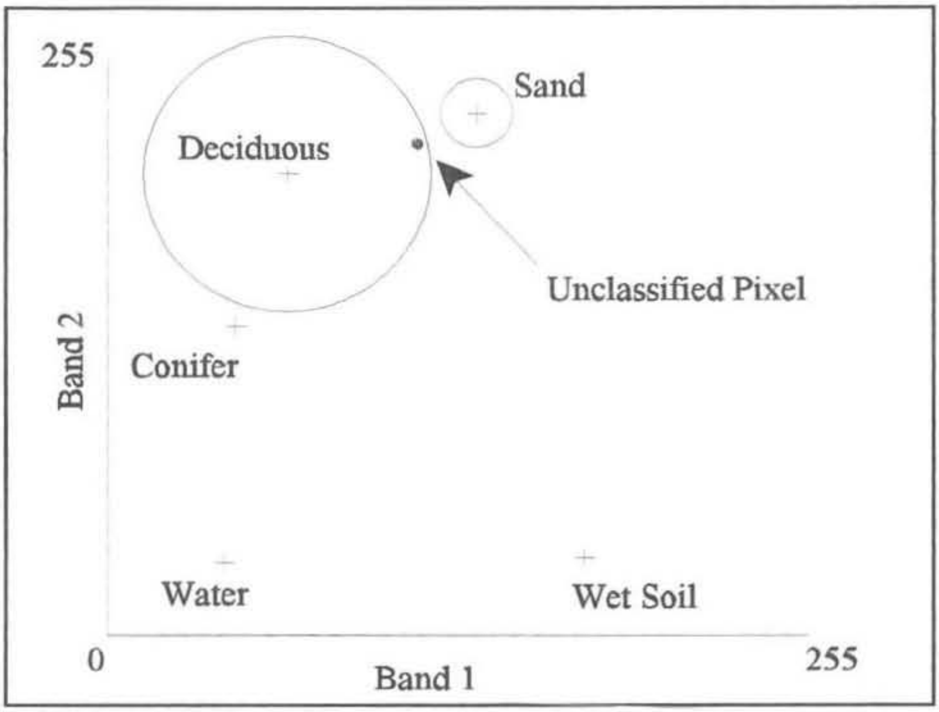

Figure 14 Example of Potential Problem with MINDIST
(Eastman: 1997: 11-9)

The maximum likelihood classification procedure uses the mean and variance/covariance data of the training site signatures to estimate the posterior probability that a pixel belongs to each class. It is very similar to the standardised distance option of the minimum-distance-to-means classifier discussed above, with the only major difference being that it accounts for intercorrelation between bands, as well as taking into account the inherent variance within bands. It therefore produces what can be visualised as an elliptical zone of characterisation of each signature. This is shown in Figure 15 below. Note that the probability of belonging to a particular class is highest at the mean position of the class, and falls off in an elliptical pattern away from the mean (Eastmann:1997a: 11-10/11).

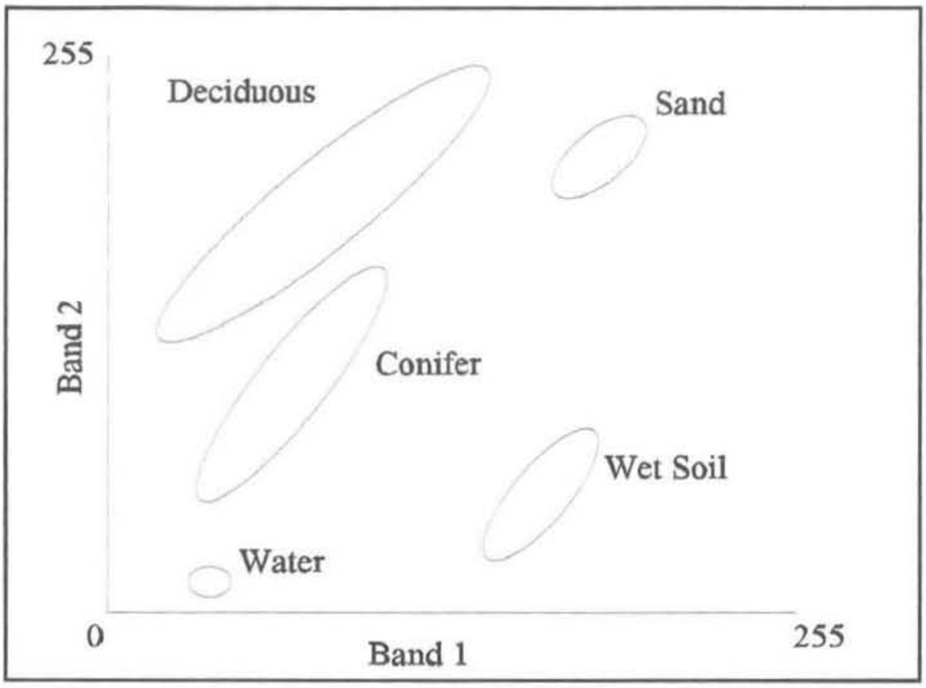

Figure 15 Example of Methodology Used by MAXLIKE Classifier (Eastman: 1997: 11-11)

The problem inherent in all hard classification techniques, is that they depict distributions of continuous attributes in the form of exhaustive, non-overlapping areal units separated by boundary lines. In adopting this approach, one makes two basic assumptions: firstly, that the classification of landscape units is crisp, and spatial objects within these classes can be clearly determined; and secondly, that objects are internally homogeneous and can be differentiated by crisp boundaries. However, these assumptions are not valid when the spatial extents of objects change gradually and continuously, so that no crisp boundaries can be identified (Cheng and Molenaar: 1999: 797; Zhang and Kirby: 1999: 1379). For example, vegetation classes tend to inter-grade gradually, making it very difficult to assign part of a transition zone to one vegetation class (Foody *et al.* in Canters: 1997: 404). Canters argues that this problem of class definition is encountered in visual as well as in digital image interpretation, and illustrates the inability of Boolean classification methods to properly deal with the mapping of continua (1997: 404). An alternative approach to classification, namely through the use of soft classifiers, is reviewed below, as a possible solution to the problems posed by using hard classification procedures.

Soft Classifiers

Unlike hard classifiers, soft classifiers defer making a definitive judgement about the class membership of any pixel in favour of a group of statements about the degree of membership of that pixel in each of the possible classes. Unlike hard classification techniques, where the output is a single classified land cover map, the output from soft classifiers, is a set of images (one per class) that expresses for each pixel, the degree of membership in the class in question. The determination of this degree of membership is what characterises the different types of soft classifiers (Eastman: 1997a: 11-11). Two soft classifiers, one based on Bayesian probability theory, and one based on Dempster-Shafer theory are reviewed below.

Classifiers based on Bayesian probability theory output a separate image to express the posterior probability of belonging to each considered class, according to Bayes' Theorem, which reads:

$$p(h \setminus e) = \frac{p(e \setminus h).\,p(h)}{\sum_i p(e \setminus h_i).\,p(h_i)} \tag{3}$$

where:

p(h\e)= the probability of the hypothesis being true given the evidence (posterior probability)

p(e\h)= the probability of finding that evidence given the hypothesis being true

p(h)= the probability of the hypothesis being true regardless of the evidence (prior probability)

Thus, the variance/covariance matrix derived from training site data is that which allows one to assess the multivariate conditional probability p(e\h). This quantity is then modified by the prior probability of the hypothesis being true and then normalised by the sum of such considerations over all classes. This latter step is important in that it makes the assumption that the classes considered are the only classes that are possible as interpretations for the pixel under consideration. Thus even weak support for a specific interpretation may appear to be strong if it is the strongest of the possible choices given (Eastman: 1997a: 11-13).

Sub-pixel classification is the main motivation for using classifiers based on Bayesian probability theory. Such classifiers are capable of determining the extent to which mixed pixels exist in an image, as well as their relative proportions. Thus, the probabilities derived from the classification process may be directly interpreted as statements of proportional representation. Therefore, if a pixel has posterior probabilities of belonging to, for example, deciduous and conifer classes of 0,68 and 0,32 respectively, this would be interpreted as evidence that the pixel contains 68% deciduous species and 32% conifers. It is important to note that this requires several assumptions to be true. Firstly, it requires that the classes for which training site data have been provided are exhaustive. In other words, it requires that there are no other possible interpretations for that pixel. Secondly, it assumes that the conditional probability distributions p(e\ h) do not overlap in the case of pure pixels. In reality, these two conditions may be difficult to meet (Eastman: 1997a: 11-13).

The major difference between classifiers based on Bayesian probability theory and those based on Dempster-Shafer theory, is that the latter approach explicitly recognises the possibility of ignorance. Dempster-Shafer theory does not assume that it has full information, but accepts that the state of one's knowledge may be incomplete. Absence of evidence about a hypothesis is treated as exactly that - lack of evidence. As a result, there can be a difference between one's belief in an hypothesis and one's attendant disbelief in that same hypothesis (Eastman: 1997a: 11-14).

In Dempster-Shafer theory, a distinction is made between belief, or the degree to which evidence provides concrete support for an hypothesis, and plausibility, or the degree to which the evidence does not refute that hypothesis. The difference between belief and plausibility is known as a belief interval, and acts as a measure of uncertainty about a specific hypothesis. In addition to the concepts of belief and plausibility, the logic of Dempster-Shafer theory is able to express the degree to which the state of one's knowledge does not distinguish between the hypotheses. This is known as ignorance, and expresses the inability to tell to which class a particular pixel belongs (Eastman: 1997a: 11-14/15).

Conclusion

A number of different classification procedures have been examined. Two hard classifiers were reviewed, and the problems of using these in attempting to depict distributions of continuous attributes in the form of " exhaustive, non-overlapping areal units" (Zhang and Kirby: 1999: 1379) were discussed. It was suggested that the use of a soft classifier might be more appropriate for use in mapping continua, and two such classifiers were reviewed.

The assumptions of no ignorance, associated with using a classifier based on Bayesian probability, were shown to be problematic in attempting to depict real world situations. With respect to classifiers based on Dempster-Shafer theory and the argument that they are better able to handle uncertainty that involves ignorance, Eastman argues that they are best suited for checking the quality of one's training site data (1997a: 11-15).

It is therefore evident that there is no perfect method for classification, and one's choice of classifier depends largely on the situation with which one is dealing.

5.3.2.2) Case Study: Analysis and Results

Classification of Vegetation Data

As discussed in the literature review (see above), the initial step in any classification procedure involves the development of spectral signatures for different training sites. The availability of GPS coordinates linked to descriptions of the vegetation at each coordinate, meant that a supervised classification procedure was feasible, and that training sites could be established using the GPS data (a copy of which may be found in Appendix D). The first step required that the GPS coordinates be converted from decimal degrees to UTM coordinates. This was achieved using XForm Version 4.1. A number of training sites for each of thirteen major vegetation classes, and each of three different water classes were then digitised. Each site had dimensions of approximately five pixels by five pixels, centred around the GPS coordinate. This translates to an area on the ground of approximately 15 625m^2, for each training site. Whilst digitising these sites, it was suspected that the GPS information being used was not of the highest quality, as there appeared to be considerable variation within numerous sites which should have been pure. The poor quality of the training sites was confirmed, after MAKESIG had been used to generate spectral signatures for each training site. When histograms reflecting the values of pixels used to generate spectral signatures for each class were examined, a number of them were shown to be multi-nodal, indicating that the data used in defining the training sites was not always suitable. Unfortunately, this was the only means available for classification of the image, and it was therefore adopted.

Initially, the MAXLIKE classification procedure was used, in order to account for intercorrelation between bands of imagery, as well as take into account the inherent variance within bands (argued above). However, as a result of the poor training site data, numerous misclassifications were detected by Page, and this approach was abandoned. Attempts were also made to classify the image using soft classification procedures. It is important, when using these procedures, that there exists sufficient training site data to accurately define each of the classes to which a pixel may be assigned. As discussed above, this was not the case with the training site data available, and therefore these classification attempts were largely unsuccessful.

As a result of Eastman's argument that MINDIST is the best classification procedure available for situations where training site data is poor, it was decided to use this process for the classification of the vegetation data. An extract of the classified vegetation image is shown in the figure below. The entire image is illustrated in Appendix E.

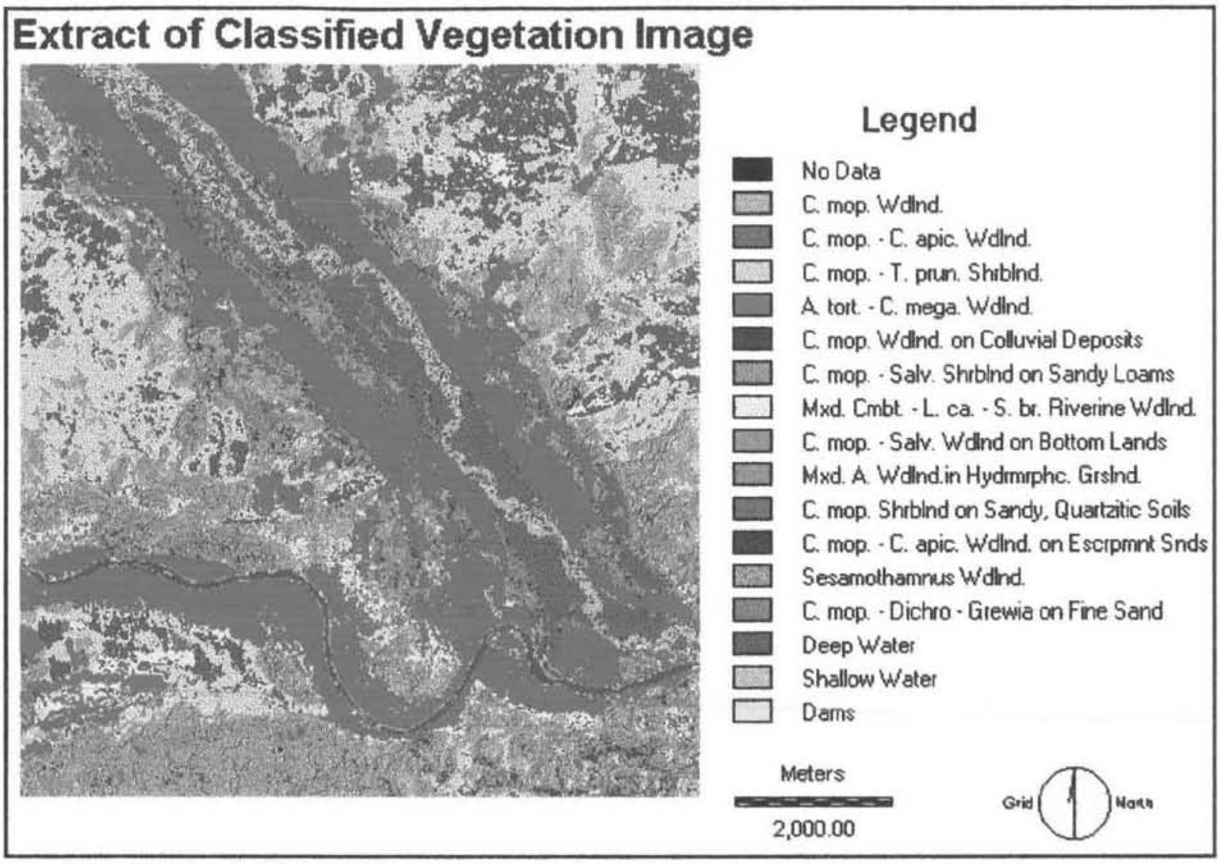

Figure 16 Extract of Classified Vegetation Image

The Digital Elevation Model and Rainfall Data

The digital elevation model was reclassified into fourteen different categories, each containing a 25m range of elevation data. This was achieved using the Idrisi module RECLASS. RECLASS was then used to reclassify the 1991 rainfall image, generated using INTERPOL (see above). The new rainfall image was split into 5mm categories. Both the reclassified DEM and rainfall images are shown below. The major rivers are included for orientation purposes. As discussed in Section 5.3.1, there were numerous years where rainfall readings at various stations were not taken. This meant that the rainfall image, shown below, was generated using a small number of rather poorly distributed points. As has been mentioned, the effects of this were brought to Page's attention, but as no alternative sources of rainfall data were available, the team was resigned to using this existing data. This is discussed further in Chapter Six.

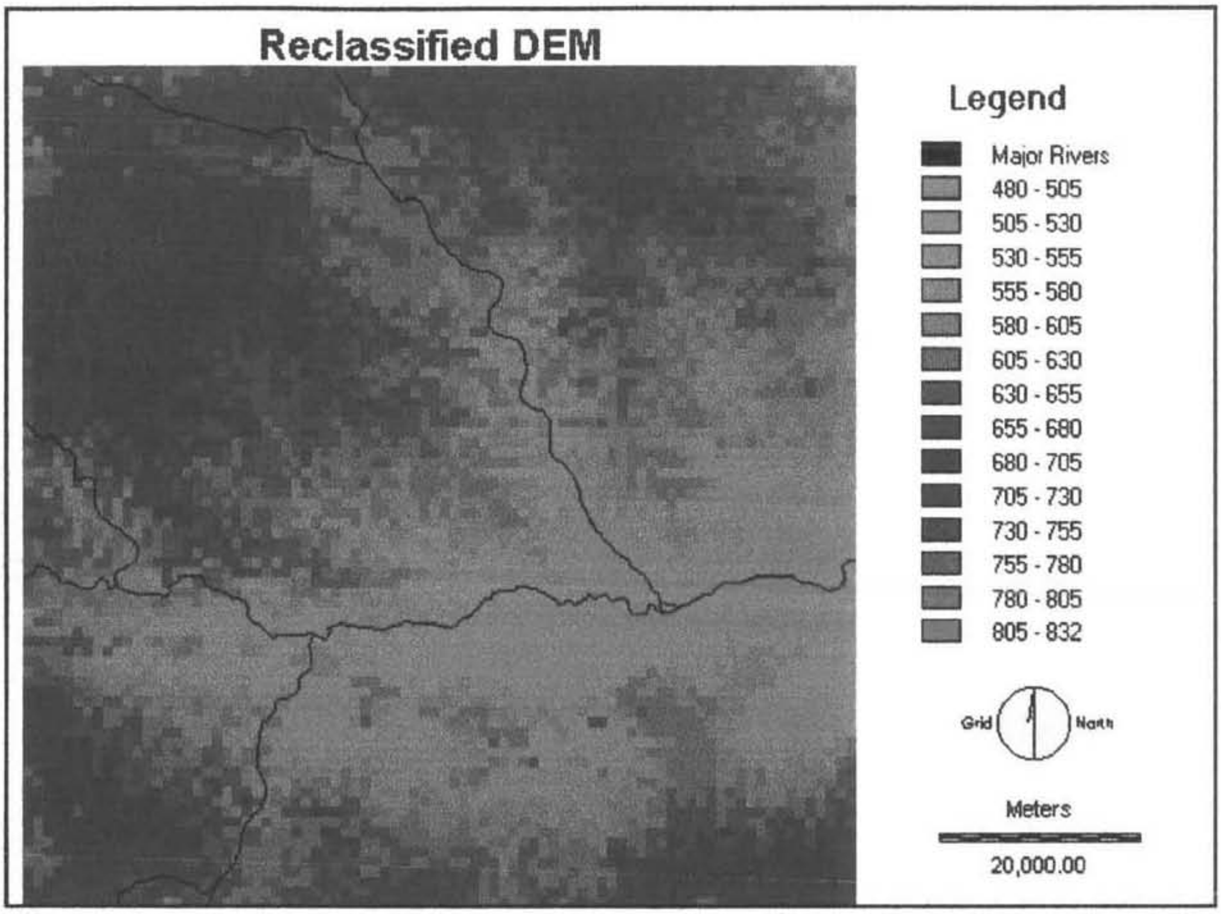

Figure 17 Reclassified Digital Elevation Model with Major Rivers

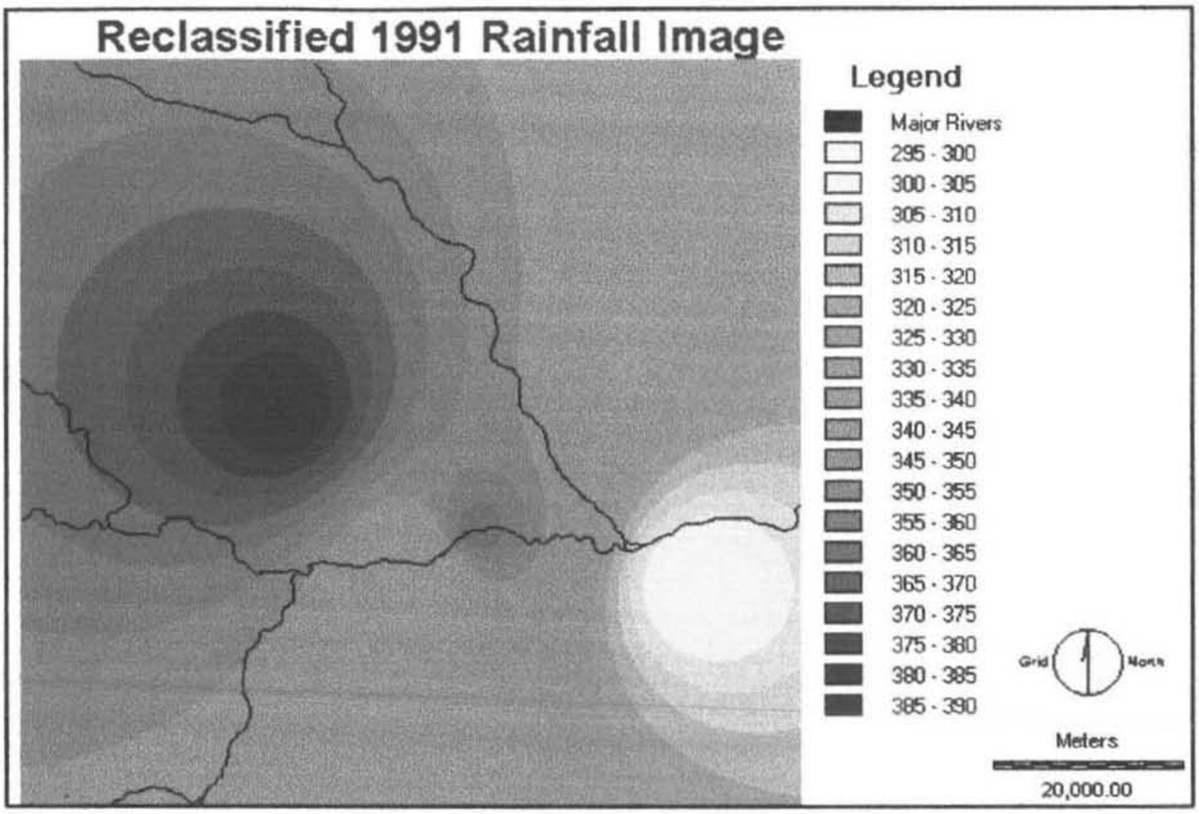

Figure 18 Reclassified 1991 Rainfall Image with Major Rivers

Conclusion

Having produced the three images illustrated above, it was now possible for the environmental project team to gain a better qualitative understanding of the relationship between different vegetation types, and rainfall and topography.

A number of problems, namely with regard to the quality of the training sites used for the vegetation classification, and also pertaining to the small number of rainfall stations used in the interpolation of the rainfall surface, were mentioned. These will be further discussed in the conclusion.

5.3.3) Objective II - Change Detection Analysis

5.3.3.1) Literature Review

Introduction

Green *et al.* argue that changes made on the surface of the earth today are more extensive and occur more rapidly than ever before (1994: 331). Increased interest in climate change, changing land-use patterns and natural and man-made disturbances, as well as the ramifications of these changes has resulted in planners and resource managers seeking a reliable mechanism with which to detect, monitor and analyse these changes quickly and efficiently, in order to assess their consequences (Green *et al.*: 1994: 331; Michener and Houhoulis: 1997: 1363-4). Until recently, many strategies for monitoring change in general, and subtle environmental change over broad geographic areas in particular, relied on either subjective observations or on small sample plots (Price *et al.*: 1992: 455). Michalek *et al.* argue that due to cost and time constraints, the exclusive use of traditional surveying tools may not be practical for monitoring large, remote, or rapidly changing areas (1993: 381). This is supported by Sader, who argues that the visual interpretation methods (associated with data generated from traditional surveying methods) are time consuming and labour intensive for large land area mapping (1995: 1145). What is needed if change is to be effectively monitored, is a regularly updated, information-rich data source, which permits analysis on a regional scale.

According to Star and Estes, remotely sensed data acquired from satellite images have a number of advantages, including: a synoptic view, repeat-coverage capabilities, and the ability to cover a wide range of spatial and temporal scales. Also, because satellites are capable of acquiring imagery in one or more wavelength bands of the electromagnetic spectrum, each band of image data acquired has a different information content, making the data very information rich (1990: 195-6). According to Chavez and MacKinnon, multi temporal satellite image data have become more and more important in analysing change which occurs on a large scale, with information about change being used to create models of past and possible future conditions (1994: 571). This view is supported by Macleod and Congalton, who argue that an increasingly popular application of remotely sensed data is for change detection (1998: 207).

Singh, in Macleod and Congalton, defines change detection as "the process of identifying differences in the state of an object or phenomenon, by observing it at different times" (1998: 207). Macleod and Congalton argue that as a result of increasing versatility in manipulating digital data, as well as increases in computing power, techniques to perform change detection with satellite imagery have become numerous (1998: 207). This view is supported by Green *et al.* who argue that the introduction of digital imagery, including satellite imagery, has extended the techniques available for change detection (1994: 332). It is my intention to review the process one applies when conducting a change detection analysis, as well as a number of the techniques used to perform such an analysis. This is done to support my choice of change detection method for use in the case study.

Image Rectification and Normalisation

The initial step in the comparison of multi temporal remotely sensed images is image rectification and normalisation, which involves calibrating the images geometrically and radiometrically. Image rectification is a relatively simple procedure, where ground control points are used to rectify the image onto a specific map projection, and the images of different time periods are aligned so that the same pixel at one date overlaps the same pixel for the other date (Michener and Houhoulis: 1997: 1365; Macleod and Congalton: 1998: 209; Chavez and MacKinnon: 1994:572). Image normalisation is a slightly more complicated process, and is carried out on multi-date images in order to minimize changes in brightness values (BVs) due to detector calibration, sun angle, Earth/sun distance, atmospheric attenuation, and phase angle between dates. Once scene normalisation has taken place, changes in BVs between multi-date images are assumed to reflect changes in surface conditions. This normalisation is essential for change detection, where BVs over time are used to identify changes in land-cover, or other surface characteristics. Without this radiometric calibration, it can be more difficult to quantify and interpret changes on multi temporal images (Michener and Houhoulis: 1997: 1365; Macleod and Congalton: 1998: 209; Chavez and MacKinnon: 1994:572).

Ideally, the influence of such factors as were mentioned above, that is: detector calibration, sun angle, atmospheric attenuation etc., would be eliminated through a sophisticated atmospheric transmission model, but in practice, the necessary data on field reflectances and atmospheric conditions are rarely available for historical imagery. As a result, empirical methods of scene normalisation must be performed instead (Heo and FitzHugh: 2000: 173). Heo and FitzHugh list a number of such methods, and quote a number of sources in stating that normalisation by linear regression, using *y*-intercept and slope parameters, is widely regarded as the best method. This method involves matching the BVs of normalisation targets present in both the normalised and reference image to derive an expression such as:

$$(BV_{Reference})_i = a + b * (BV_{Normalised})_i \qquad \textbf{(4)}$$

where a and b are the linear regression parameters and i is the band number of the image. Eckhardt *et al.* in Heo and FitzHugh list five criteria for the selection of radiometric control targets for the estimation of regression parameters. These are:

- targets should be approximately the same elevation so that the thickness of the atmosphere over each target is approximately the same.
- targets should contain a minimal amount of vegetation, because the spectral reflectance of vegetation is likely to change over time.
- targets should be in relatively flat areas so that changes in sun angle between images will produce the same proportional increases or decreases in insolation to all normalisation targets.
- when viewed on an image display screen, patterns seen on the normalisation targets should not change over time.
- the set of targets must have a wide range of BVs for the regression model to be reliable.

If targets are selected which satisfy these criteria, they are assumed to be constant reflectors, and as such, any change in BVs are solely as a result of non-surface effects (2000: 173).

There are various analytical approaches differing in mathematical complexity, processing and analysis intensity, classification technique and interpretability which have been used to detect vegetation change (Michener and Houhoulis: 1997: 1363). Michener and Houhoulis argue that in the past, many studies have relied on the less computationally intensive post classification change detection techniques, using images from one or two dates, but that recently, principal components analysis (PCA), various vegetation indices, and logic rules have been implemented utilising multi temporal satellite data (1997: 1363). Macleod and Congalton identify three major change detection algorithms, namely: post classification, image differencing and PCA (1998: 207-216).Below is a brief review of each of these algorithms as well as one other, used by Lyon *et al.* (1998: 143-150), namely: image differencing using a normalised difference vegetation index (NDVI).

Post Classification

Post classification change detection analysis is a technique where multi-date digital data sets are independently classified and then compared on a pixel-by-pixel, or polygon-by-polygon, basis for each class, in order to create a change image map (Muchoney and Haack: 1994: 1247).

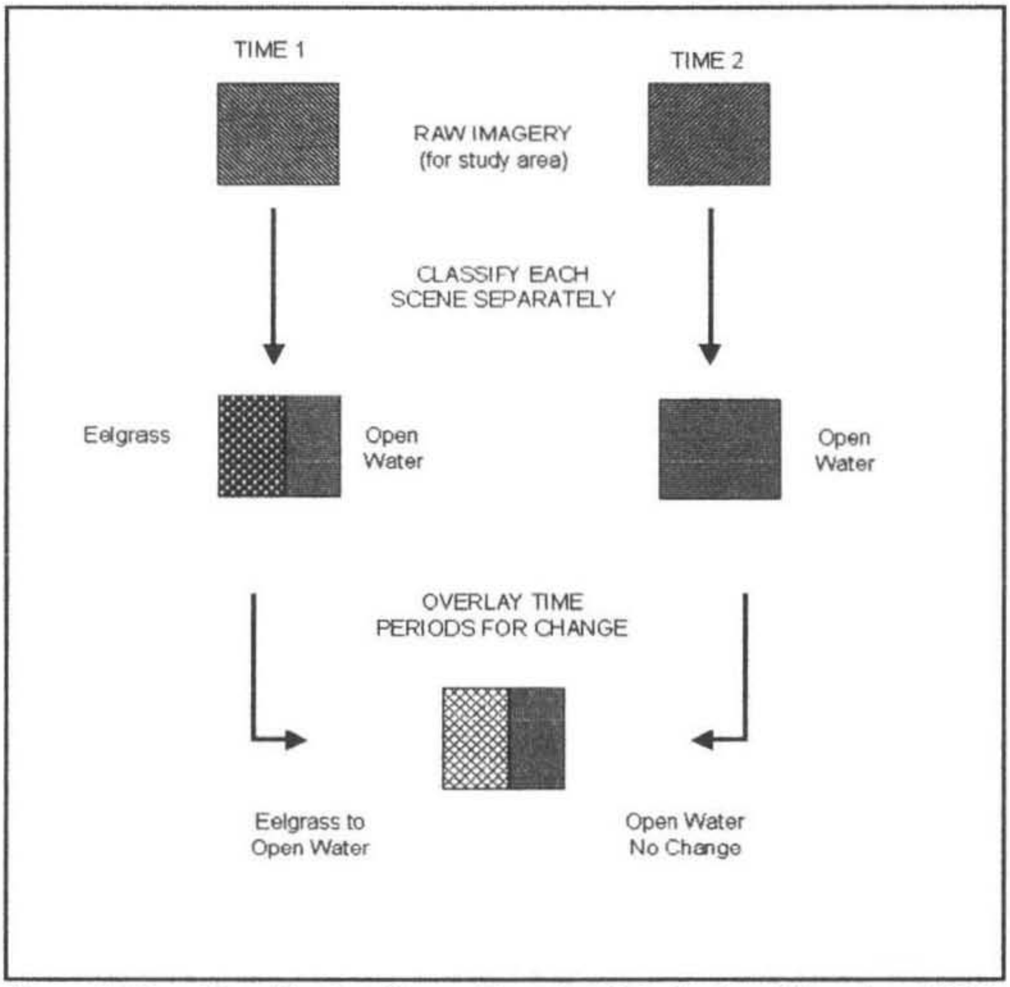

Figure 19 Post Classification Change Detection (Macleod and Congalton: 1998: 210)

Of the four techniques, post classification change detection is the most straightforward change detection process. However, it also has the most potential for being least accurate. This is because the accuracy of this technique may be adversely affected as a result of the combining of errors from both of the classifications. Other change detection techniques, such as image differencing and PCA (see below) minimize some of the classification errors by only classifying the areas that have changed for the second date. Also, for the post classification technique, there must be enough ancillary data to classify both dates. This is not the case with image differencing or PCA, where the amount of ancillary data for the second date may be greatly minimized due to classifying only a portion of the scene (Macleod and Congalton: 1998: 214). A further disadvantage of the post classification change detection technique, is that it does not allow for normalising differences between multitemporal data caused by sensor and atmospheric influences, and care must be taken so that non-feature changes are not classified as change (Muchoney and Haack 1994: 1250).

Image Differencing

Image differencing is a change detection technique whereby changes in BVs between two or more data sets are determined by cell-by-cell subtraction of co-registered image data sets. This differencing produces an image data set where positive and negative values represent areas of change, and values close to zero indicate areas which have remained relatively unchanged. Threshold values are often defined and used to indicate whether or not significant change has occurred (Macleod and Congalton: 1998: 209-210). A common strategy is to use a threshold value of one standard deviation (Macleod and Congalton: 1998: 209; Michener and Houhoulis: 1997: 1368; Eastman: 1997: 14-1). The figure below illustrates the procedure used in an image differencing technique.

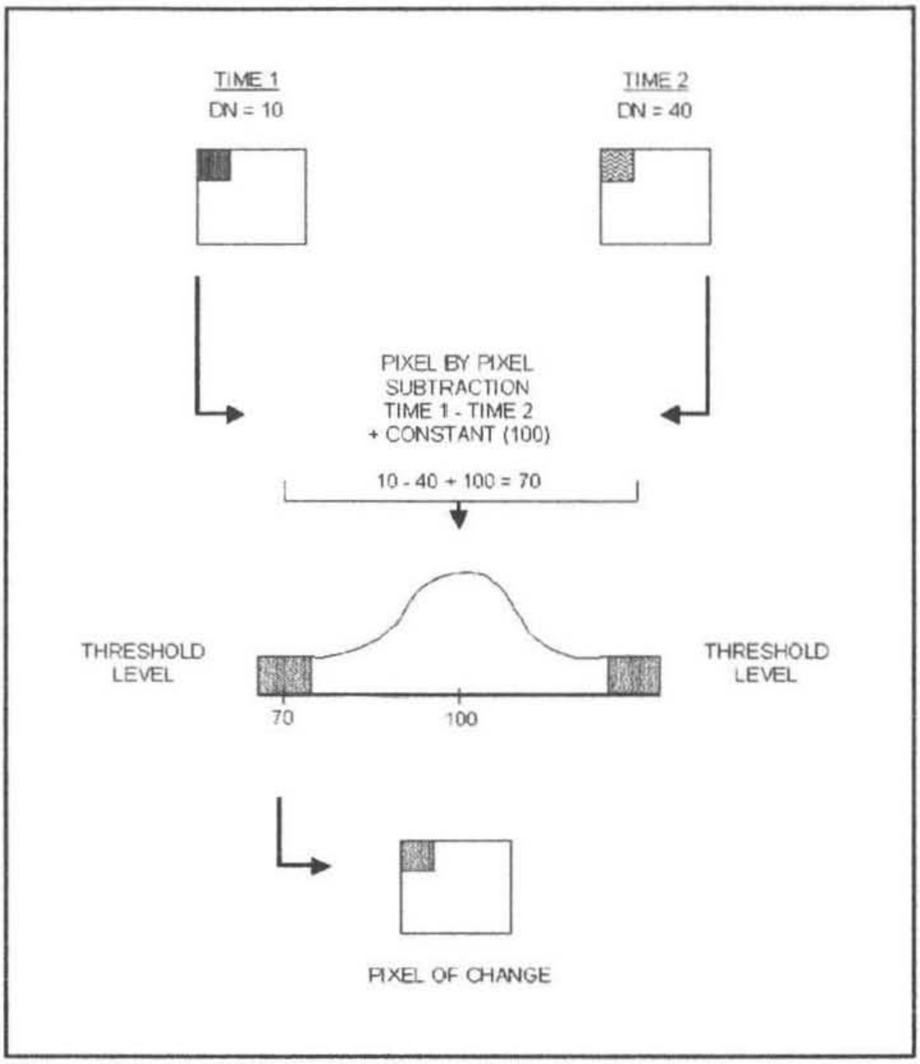

Figure 20 Image Differencing Change Detection (Macleod and Congalton: 1998: 210)

However, in most instances, more information than merely whether or not the area has changed is required. Therefore there needs to be some sort of classification process where the changed pixels are assigned the appropriate 'changed from' and 'changed to' identifiers (Macleod and Congalton: 1998: 209-214; Muchoney and Haack: 1994:1246). Macleod and Congalton describe such a procedure, originally created by Pilon *et al.* and subsequently adopted as the NOAA Coastal Change Analysis protocol. They use the example of an image differencing change detection technique applied to imagery from 1990 and 1992. In their example, the 1990 image was classified and used to label pixels that the image differencing technique had determined had not changed between 1990 and

1992. A combination of the 1990 classification and the resulting classification of the changed pixels were used to label the changed pixels in the final change classification, as illustrated in the figure below (Macleod and Congalton: 1998: 210).

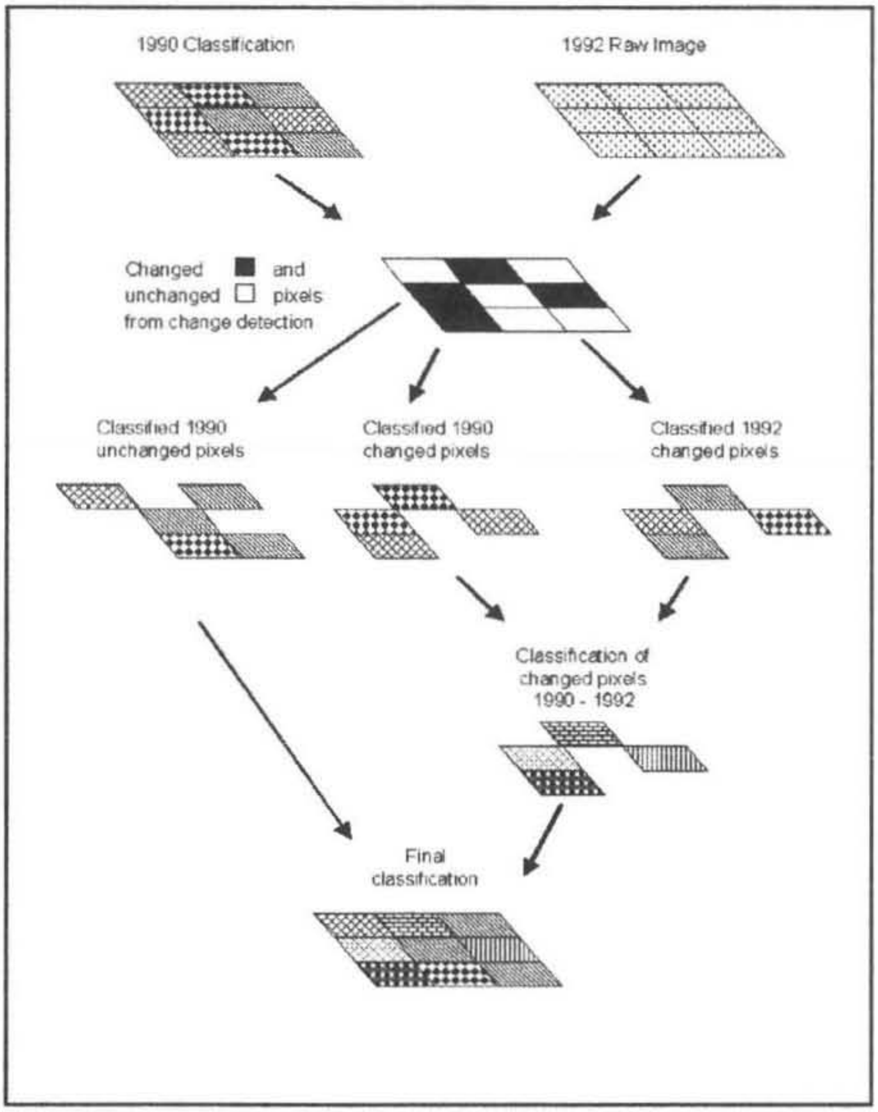

Figure 21 Classification Process of the Image Differencing Change Detection Technique (Macleod and Congalton: 1998: 210)

That is, the final change classification for the image differencing technique consisted of the pixels labelled from the 1990 classification where the pixels were considered unchanged as determined by the image differencing procedure. These unchanged pixels were then removed from the 1992 image and a classification was performed on only the changed pixels in the 1992 image. The classified change pixels in the 1992 image were combined with the same classified pixels of the 1990 classification to generate the 'changed from' and 'changed to' identifiers. The classified changed pixels were then combined with the unchanged pixels of the 1990 classification to create the final change classification (Macleod and Congalton: 1998: 210).

In general, image differencing is a very simple, yet effective method for determining whether or not an area has changed. However, difficulties may arise if more detailed information on the nature of that change is required, and it becomes necessary to perform a classification such as the one outlined above (Macleod and Congalton: 1998: 214).

Principal Components Analysis

PCA is a multivariate statistical technique where data axes are rotated into principal axes, or components, that maximize data variance. As a result of the high correlation in spectral information that is present in multi-date images, PCA is used to transform the data into new images containing bands that are entirely uncorrelated. The basic premise for PCA in change detection is that one or more of the new PCA bands contains information that can be directly related to change (Muchoney and Haack: 1994:1244-45; Michener and Houhoulis: 1997: 1367). The figure below illustrates the principal components change detection technique.

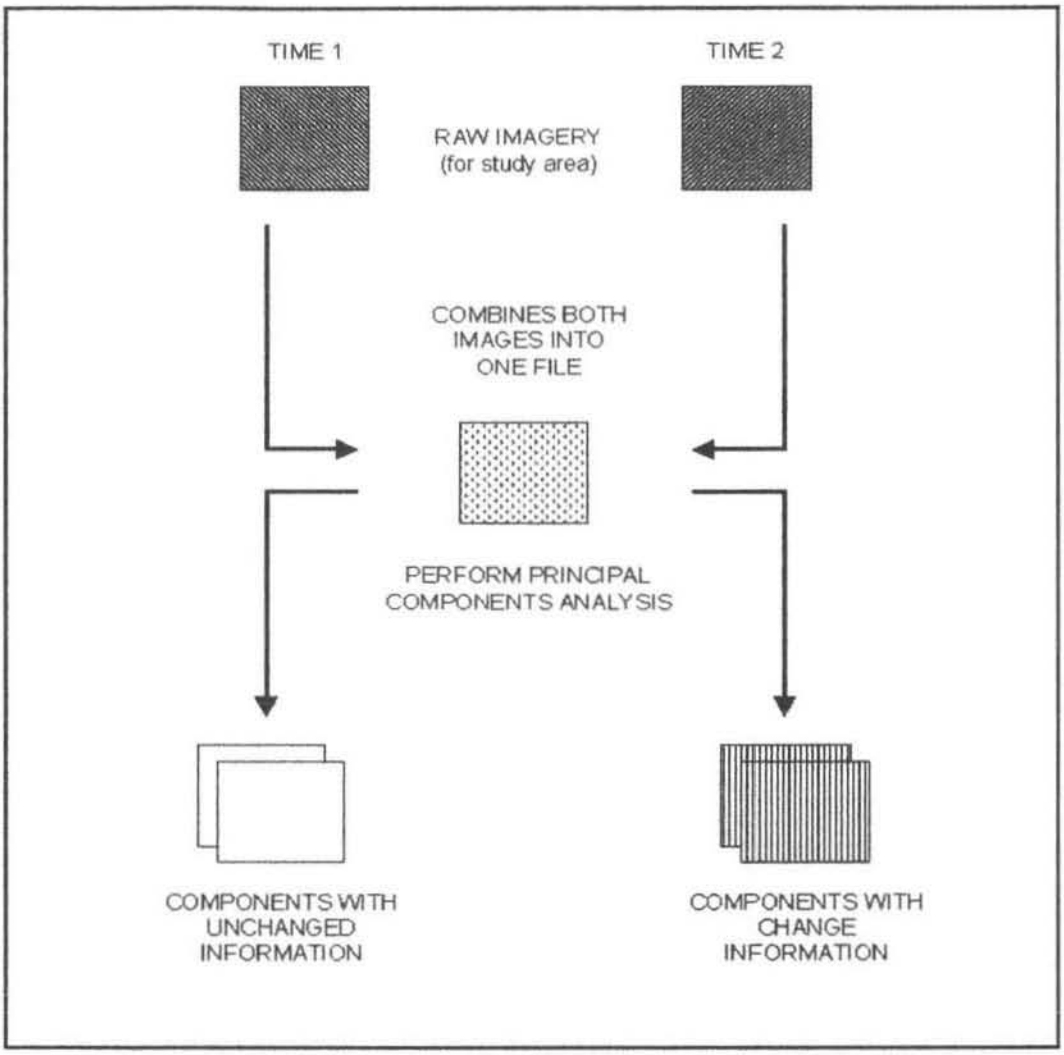

Figure 22 Principal Components Change Detection Technique (Macleod and Congalton: 1998: 211)

PCA for change detection can prove to be quite a complicated process, as an understanding of the spectral characteristics of the classes of interest and corresponding principal components is necessary. Also, as is the case with image differencing, the threshold level is very important and may be the determining factor as to the accuracy of the final change classification (Macleod and Congalton: 1998: 214).

Normalised Difference Vegetation Index (NDVI) Image Differencing

The development of vegetation indices from BVs is based on the differential absorption, transmittance, and reflectance of energy by the vegetation in the red and near-infrared portions of the electromagnetic spectrum. Numerous vegetation indices have been formulated to make use of this difference, with basic techniques ranging from subtraction of the near-infrared and red bands and division of the near-infrared band by the red band, to combinations of both, that seek to normalise the response. The NDVI is defined by the following equation:

NDVI = (Near-Infrared Band - Red Band)/(Near-Infrared Band + Red Band) **(5)**

(Lyon *et al.*:1998: 143-144).

NDVI image differencing is a technique whereby changes in NDVI values between two image plates are derived by cell-by-cell subtraction of co-registered data sets. The basic premise is the same as for image differencing (see above). That is, that subtraction results in an image data set where values less than or greater than zero indicate areas of change (Michener and Houhoulis: 1997: 1368).

The three major advantages to using NDVI images in an image differencing change detection technique are as follows: firstly, strong differences in BVs of the spectral response curves of different features may be emphasised in band ratio images, thus aiding classification. Secondly, band ratios can help to suppress differential solar illumination affects due to topography and aspect, and help normalise differences in BVs when using multi-date images. Thirdly, the ratioing of two spectral bands reduces much of the effects of any extraneous, multiplicative factors in sensor data that act equally in all wave bands of analysis (Lyon *et al.*: 1998: 143).

Conclusion

From the above, it is evident that the application of remotely sensed data for change detection is becoming increasingly popular. This review has focussed on the procedure which is followed in order to carry out a change detection analysis. The importance of image rectification and normalisation was discussed, following which four methods of change detection were analysed.

Macleod and Congalton list three aspects of change detection which are of importance when monitoring natural resources: firstly, detecting that change has occurred; secondly, identifying the nature of the change; and thirdly, measuring the areal extent of the change (1998: 207). Each of the change detection techniques reviewed above have advantages and disadvantages in terms of these three aspects. In their paper, which reviewed various change detection algorithms, Macleod and Congalton rate image differencing as having a significantly higher accuracy than the PCA and post classification techniques. This is indicated by a K_{hat} statistic, which shows the degree of improvement over a random method (0 representing chance alone; 1 indicating complete agreement), of 0.41 for image differencing, as opposed to K_{hat} values of 0.30 and 0.11 for post classification and PCA change detection techniques respectively (1998: 213-14). This greater accuracy, as well as the ease of application of an image differencing change detection technique, leads to the conclusion that image differencing is the best all round method of change detection. The fact that if one were to use NDVI images for this procedure, one would eliminate, to a certain extent, the need to normalise the images (argued above), makes NDVI image differencing a very attractive proposition for change detection analysis.

5.2.3.2) Case Study: Analysis and Results

Image Rectification and Normalisation

The images for 1998 and 1991 were geometrically rectified in the manner detailed above. A summary of the transformations is given in Appendix B. As a result of the argument that if one uses the NDVI image differencing change detection technique, it is not necessary to normalise multi-date images (see literature review above), no radiometric corrections were carried out on the images.

Image Differencing, Reclassification and Regression Analysis

Of the four change detection techniques discussed in the literature review, the first one, namely: post classification change detection was immediately ruled out due to the poor quality of the training site data used in the classification of the satellite imagery, as discussed above. For the same reasons, the prerequisite of having an understanding of the spectral characteristics of the classes of interest, in order to undertake a principal components analysis also meant that this was not a feasible option. Thus, the choice of methods to be used for the change detection process was reduced to that of image differencing, and image differencing using NDVI images. For reasons pertaining to image normalisation requirements, as discussed above, the option of using NDVI image differencing was selected.

The NDVI images were used in a simple image differencing technique, with the 1991 NDVI image being subtracted from the 1998 NDVI image. This process resulted in the production of a NDVI vegetation difference image, which needed to be reclassified into areas of negative change (areas which had greater vegetation cover in 1991 than in 1998), areas of positive change (areas which had less vegetation cover in 1991 than in 1998) and areas where there was no change in vegetation cover between 1991 and 1998. In order to set a threshold value, which would distinguish change from natural variability, it was necessary to produce a set of statistics pertaining to the difference image created. This was achieved using the HISTO module in Idrisi, which produces a frequency histogram of cell values in an image, as well as basic statistics about the file. The histogram and set of statistics output by Idrisi are shown below.

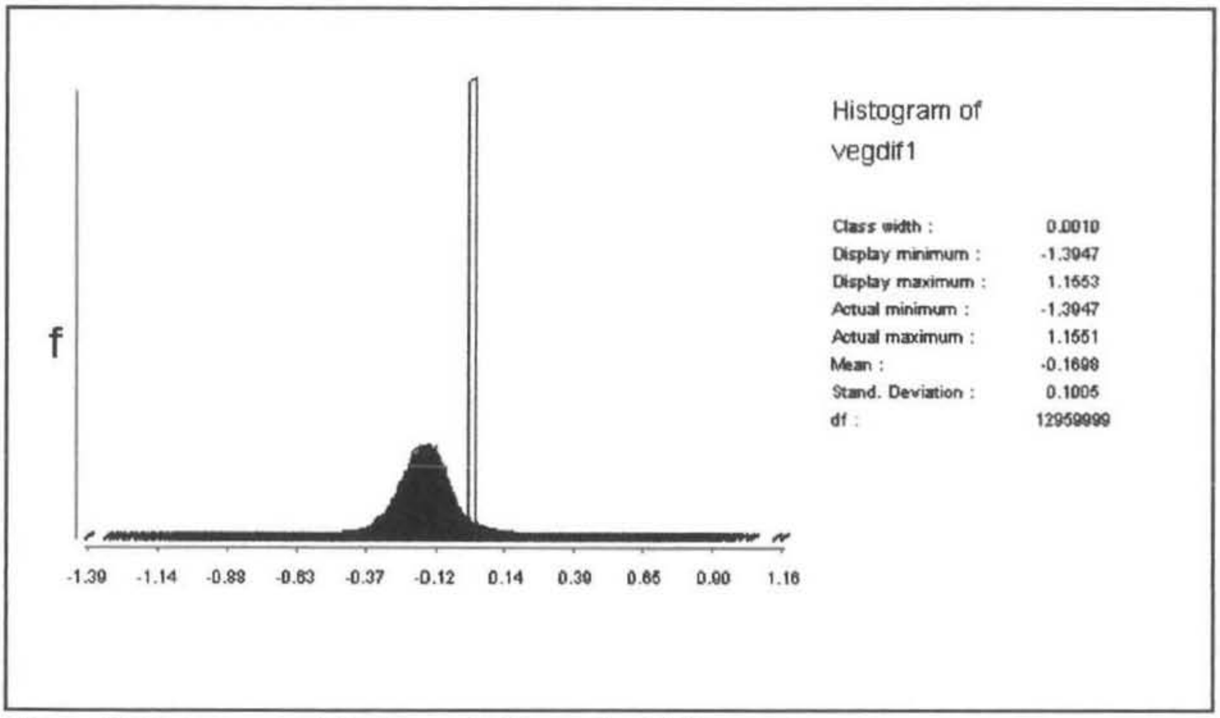

Figure 23 Histogram and Statistics for Vegetation Difference Image

As argued in the literature review (see above), a threshold value of one standard deviation is a common choice, and was thus used in defining the categories for reclassification, discussed above. The reclassified vegetation difference image is shown below.

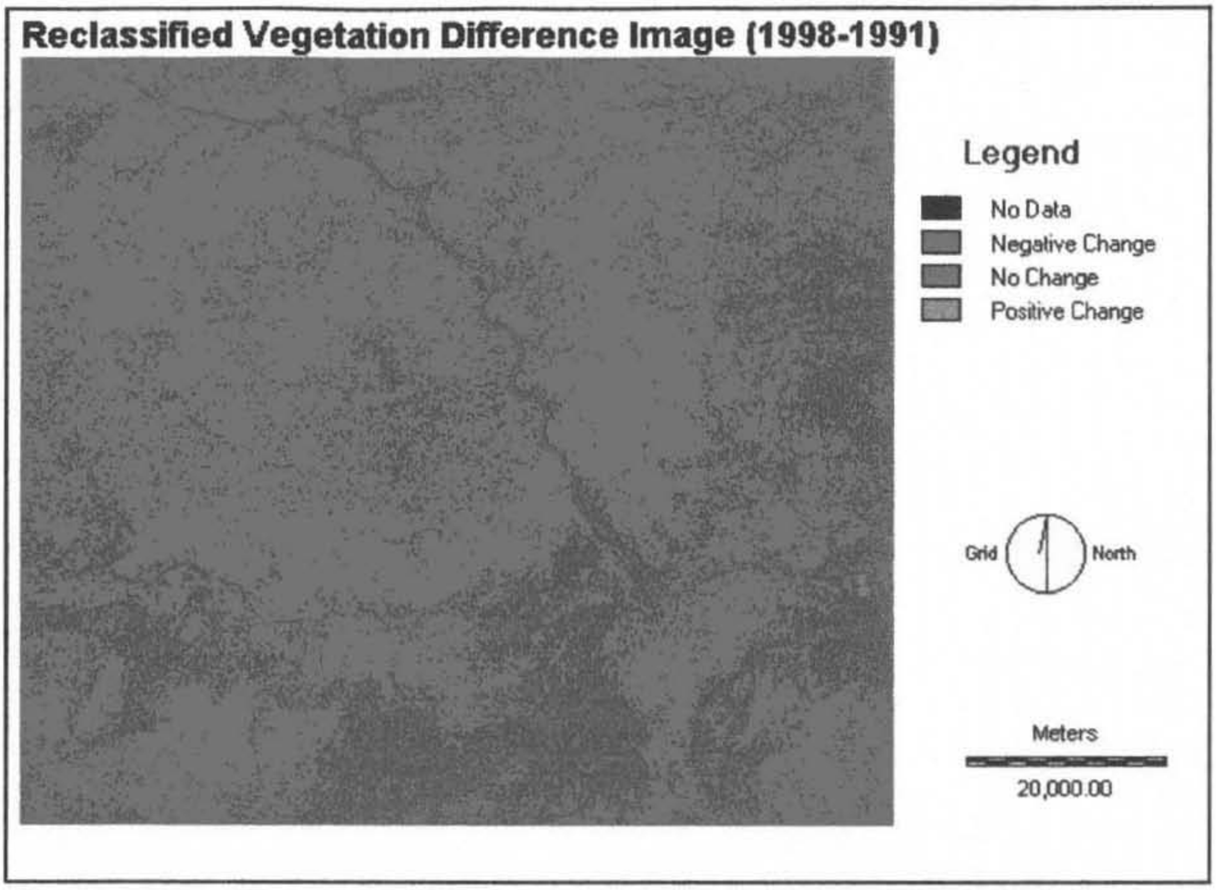

Figure 24 Reclassified Vegetation Difference Image

The final stage in the process, was to determine whether or not there was any correlation between the change in the vegetation pattern and a change in the rainfall over the 1991 to 1998 period. In order to achieve this, it was necessary to produce a rainfall difference image and, using regression analysis, establish the relationship between change in rainfall and change in vegetation.

Two rainfall images were created (see Section 5.3.1) and differenced in the same manner as the NDVI images. That is, the 1991 image was subtracted from the 1998 image, to generate a rainfall difference image. Again, the module HISTO was used to obtain the necessary statistics for reclassifying the rainfall difference image. The Idrisi output of this histogram of the difference image, as well as the actual reclassified image (with the major rivers superimposed for orientation purposes) are shown below.

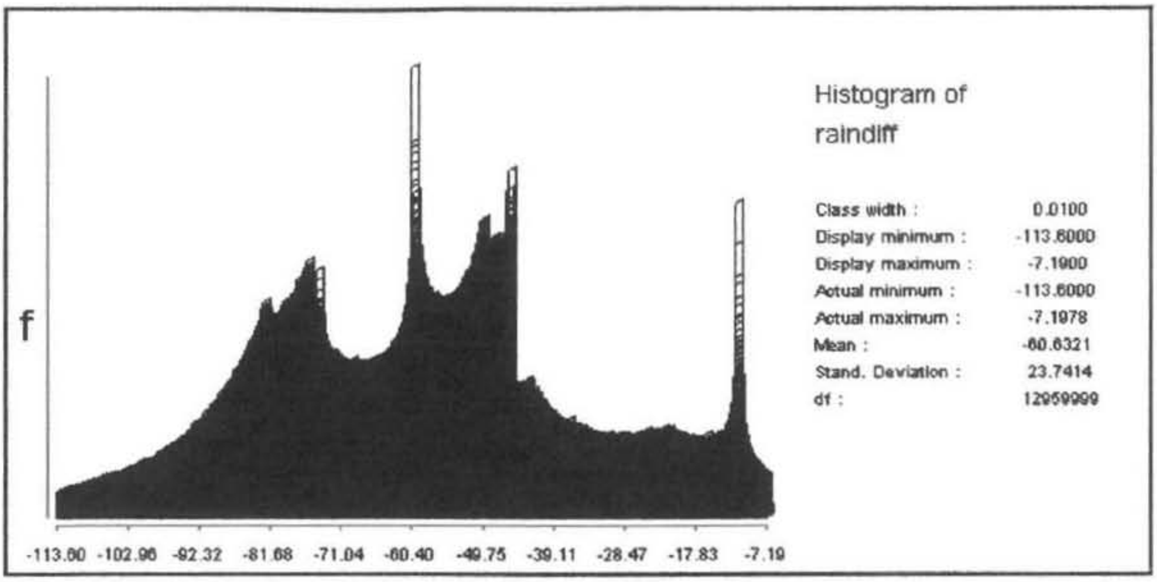

Figure 25 Histogram and Statistics for Rainfall Difference Image

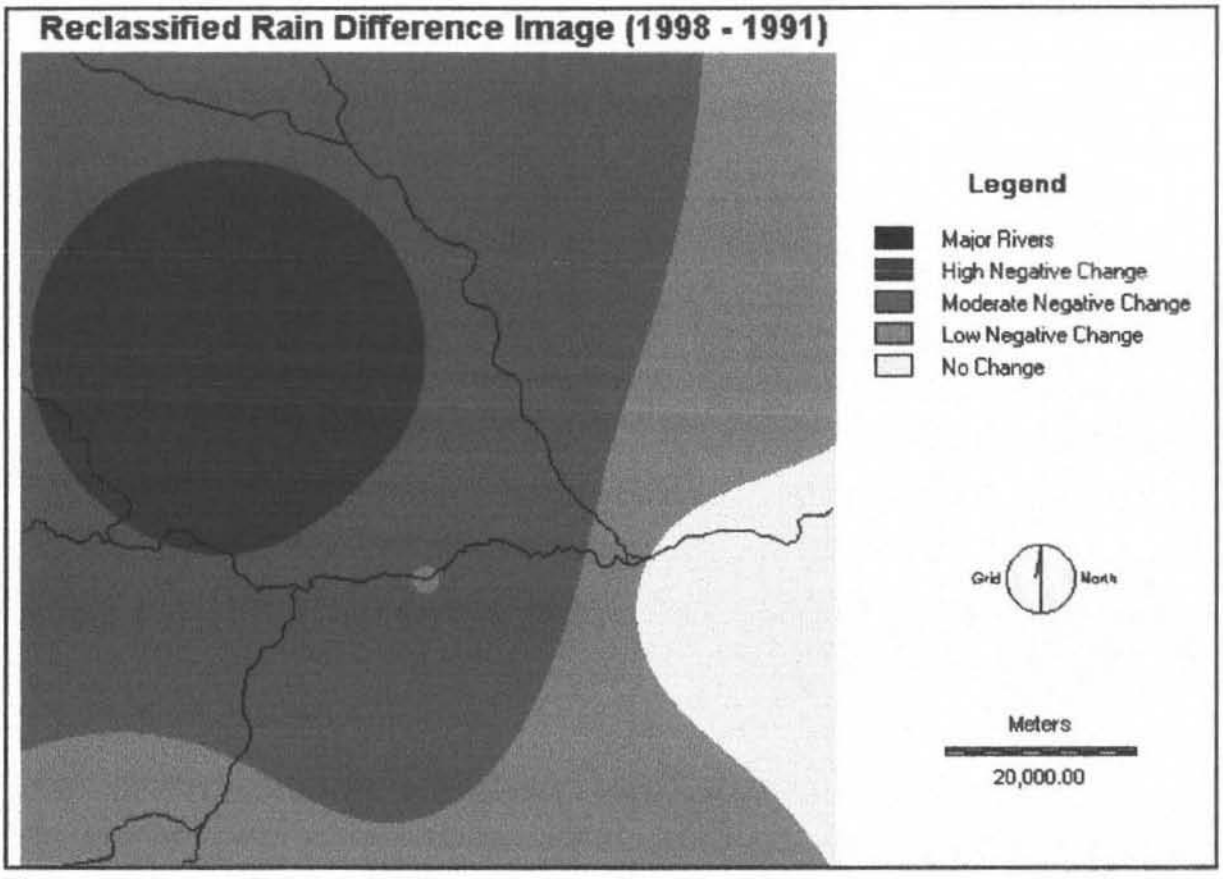

Figure 26 Reclassified Rain Difference Image with Major Rivers

Finally, a regression analysis, with the rainfall difference image as the independent variable, and the vegetation difference image as the dependent variable, was carried out. The relationship established is shown below in the form of a scatter plot, and best-fit equation.

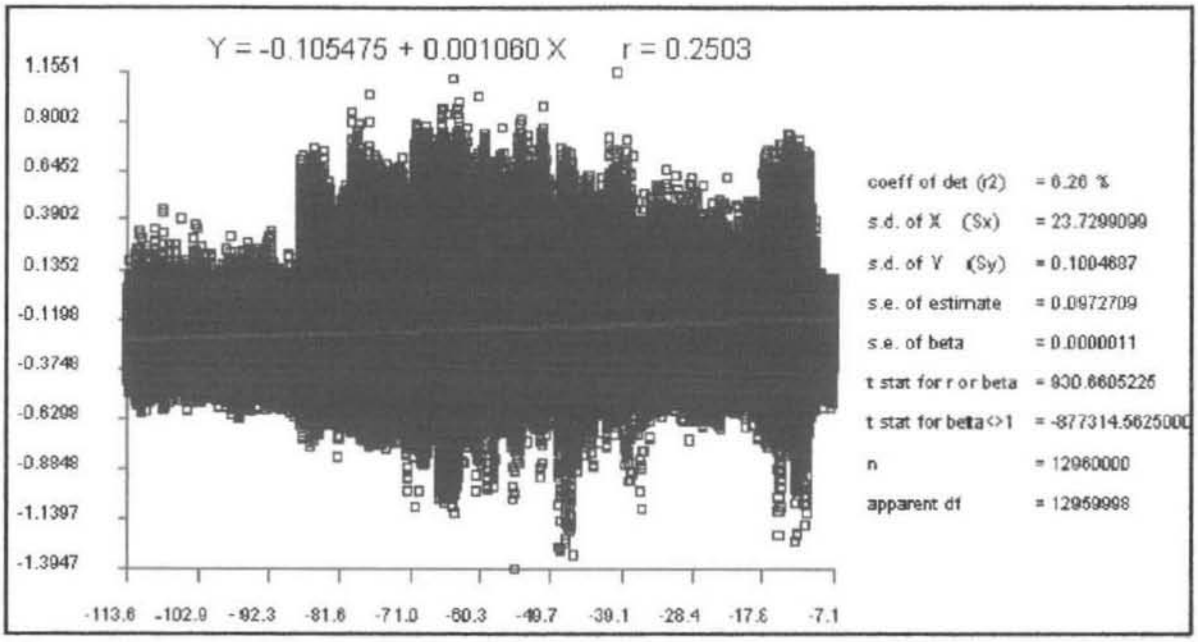

Figure 27 Results of Regression Analysis

Conclusion

Figure 24 above, indicates that a substantial negative change in the vegetation pattern of the Tuli area took place between 1991 and 1998, with very little positive change occurring. The positive change that did occur, took place largely in the vicinity of the river beds.

An investigation into the correlation between change in vegetation and change in rainfall, by means of a regression analysis, revealed that there is, in fact, very little correlation between the two, suggesting that some factor, other than the decrease in rainfall is responsible for the decrease in vegetation.

5.4) Conclusion

This chapter has examined the technical approach used in the case study. The objectives of the project were reviewed, and it was shown how the data sets which were required were determined. A brief review of raster and vector based systems was carried out, in order to support the choice of the raster based Idrisi for Windows software.

The final section of this chapter dealt with the actual analysis which was carried out in the Tuli area. Details were given of the manner in which the various data sets were acquired, and then manipulated so that they might be integrated with each other. This was followed by a literature review of the methods to be used in the case study, following which, the actual findings of the case study were reviewed and discussed. The relevance of the case study to the conceptual framework established in Chapters Two and Three above, will be discussed in the following chapter.

Chapter 6 - Conclusion

6.1) Introduction

This thesis has examined the professional profile of a traditional land surveyor, and has highlighted the need for him to adapt this profile if he is to prosper in the future. Chapters Two and Three established a conceptual framework within which a specialist category of a modern land surveyor, or what was termed an environmental geomaticist could operate. The need for a case study to test these theories was discussed in Chapter Four, and a review of the actual case study was carried out in Chapter Five. This chapter reviews the validity of the concepts propounded in Chapters Two and Three, by examining them in terms of the case study. It is divided into three sections, which examine firstly, the necessity of the environmental geomaticist to the research team, secondly the skills which were required in carrying out his tasks, and finally the teamworking aspect of the role which he played.

6.2) The Necessity of the Environmental Geomaticist to the Project Team

Michener *et al.* argue that, more and more, environmental scientists are being called upon to work at both broader spatial and temporal scales (xvii: 1994). These new research directions have created a need for rapid and easier data analysis. This in turn, means that data management will evolve far beyond its traditional role of being viewed simply as a "scientific custodial service" (Stafford *et al.*: 1994: 4-6). They foresee data management within scientific organisations expanding and evolving to emphasize the timely and effective transformation of data into information and provision of that information to scientists, managers and policy makers. As a result of this, they predict the emergence of "scientific information management" as an entirely new discipline (Stafford *et al.*:1994: 4-5).

In Chapter Two, geomatics was defined as an integrated approach to the acquisition and management of spatial data. It was argued that geomatics encouraged a transition from mere data collection, to proactive involvement in the data environment (see page 18). It is important to realise that this statement is not intended to give the impression that a geomaticist should restrict his role in the acquisition of data. On the contrary, data collection remains a vital role of the geomaticist, and his ability to utilize traditional, as well as new sources of data, such as satellite imagery, is of great importance in any project contemplated. The proactive involvement in the data environment, mentioned above, means taking this acquisition of data a number of steps further. That is, it involves the storage, distribution and integration of different data sets, and can include (as discussed in Chapter Three, page 31) the creation and manipulation of data files, and the use of various software packages. The importance of this aspect was very evident in the case study, where, from the point of ordering the satellite imagery, to the input of that imagery, as well as other data sets into the GIS, the skills of the environmental geomaticist proved absolutely vital.

The knowledge of the environmental geomaticist with regards to what particular bands of satellite imagery would best serve the objectives of the project team, as well as the format in which such imagery was to be presented was a vital first step in the data acquisition process. Furthermore, an understanding of different coordinate systems and geodetic projections, skills acquired as part of the training of a traditional land surveyor, was of great importance in the integration of the various data sets. Other technical aspects, such as georeferencing to correct for errors in satellite orbit parameters, and conversion of coordinates from one system to another, are both processes included in the training of a traditional land surveyor, and thus, an awareness of their importance was inherent in the mind-set of the environmental geomaticist. This meant that such aspects were taken into account in the data used by the research team, and illustrates the importance of the environmental geomaticist to the team.

Rudd argues that "remote sensing is envisaged as a data source for inventorying, monitoring and gaining new insights into the complexity of the natural environment" (1974: 83). This is supported in part by Gosz, who maintains that whilst images provide a great deal of spatial and geometric information about many real-world objects, the image processing aspect presents a dilemma (1994: 36). Essentially, it was the role of image processor, which constituted the bulk of the environmental geomaticist's input into the research project. While it is readily admitted that this was a learning process and that the role was fulfilled with very little experience in such an area, I argue that my education in land surveying, part of which included courses in remote sensing and digital mapping, gave me a distinct advantage in dealing with the image processing aspect of the case study, making this contribution to the research invaluable.

From the case study, it was very evident that there was an important role for someone with the skills of an environmental geomaticist to play. The necessity of examining environmental processes at large temporal and spatial scales meant that the use of satellite imagery and its integration with other data sets was essential for effective analysis to take place. This in turn, meant that there was a very definite need for someone with the ability to manage both the acquisition and use of this and other data. Thus, the environmental geomaticist proved to be a very necessary part of the project team.

6.3) Skills Required by an Environmental Geomaticist

In Chapter Two, geomatics was defined as an integrated approach to the acquisition and management of spatial data. Following this, an environmental geomaticist was defined as a specialist category of geomaticist, who has at his disposal, both the knowledge and the tools necessary to gather the relevant spatial information, which would aid the management of one of the categories illustrated in Figure 3 (page 39). It is the integration of this acquisition of relevant spatial information and its management, which essentially both defines and determines the skills of an environmental geomaticist.

As was mentioned in the previous section, whilst geomatics encourages a transition from data collection to data management, it is vital that the importance of data collection is not underestimated. A major problem of the case study, was that, due to time and financial constraints, the environmental geomaticist was restricted to using data which had not been collected with the needs of this particular case study specifically in mind. Ideally, the rainfall data should have come from stations which were more evenly distributed throughout the extent of the study area, in order to enable a better interpolation process for the generation of the rainfall surfaces. Furthermore, the training site data used for the classification of the satellite imagery was below standard, again, for the reason that it was not collected with the intention of being used for classifying satellite data. Ideally, had the resources available allowed for it, the environmental geomaticist would have been actively involved in the management of the data collection, as postulated in the Refined Conceptual Framework (see Figure 5). This would have provided focus to the type of information which needed to be collected in order to best meet the needs of the user. As it stands, the inadequacies of the data used and the consequences thereof, have been pointed out to the project team, who accept that what has been produced is of the highest possible quality, given the circumstances.

In Chapter Three (page 32) mention was made of the traditional land surveyor's ability to assemble, assess and utilize information, and how this skill would be of importance in making the transition to becoming a geomaticist. This proved to be a valid point when viewed in terms of the case study, where a great deal of time was spent in acquiring the relevant data, assessing its worth and accuracy (and the possible effects of its inaccuracy), and manipulating it into a readily usable format. It was found that the ability to do this seemed to be a natural extension of the analytical skills which I developed whilst working as a traditional land surveyor, albeit that the majority of the work done here was in a digital environment. A prime example of this would be the selection of control points for georeferencing the satellite images. A sound knowledge of the importance of this process, gained from my experience working as a traditional land surveyor, meant that I was able to surmount the difficulties inherent in such a procedure. These included selecting points that were easily identifiable both on the satellite image and on the map, and which would provide a good geometrical solution to the georeferencing procedure. A further example would be the fact that the potential inaccuracies of using the narrowly spread rainfall stations (as discussed in Chapter Five above) and the implications thereof were readily seen, and reported on.

In Chapter Two the argument was developed, that a geomaticist should become more involved in the use and application of the spatial data which he collected. It was further argued (page 13) that surveying and mapping was changing from a traditional environment, where analogue instruments were used and a land surveyor's expertise were largely in positioning, map design and accuracy analysis, through a Spatial Information Engineering environment, characterised by digital image technology, user needs analysis and information management, towards a Spatial Decision Support environment, based on decision support systems, with core expertise in system analysis and decision support (Chen and McLaughlin: 1992 : 257). Figure 1 (pg.16) was used to illustrate this shift from measurement towards management.

The argument put forward by Chen and McLaughlin was very much borne out by the case study, where I found myself operating out of both a Spatial Information Engineering environment and a Spatial Decision Support environment. The use of digital image technology, and managing the information or data sets used within that technology constituted a large part of my function, as did determining exactly what Page required from the analysis (user needs analysis). I was also involved in systems analysis and providing decision support information to the project team, by way of producing maps of rainfall, topography and vegetation, so that the relationship amongst these three factors could be qualitatively assessed, and through the construction of vegetation and rainfall difference images, to aid the modeling of the dependence of vegetation change on rainfall change.

In terms of Figure 1, the environmental geomaticist in this project, could be seen to be operating between the regions of Land Information and Land Management, as indicated by the hatched area, in the revision of Figure 1 below:

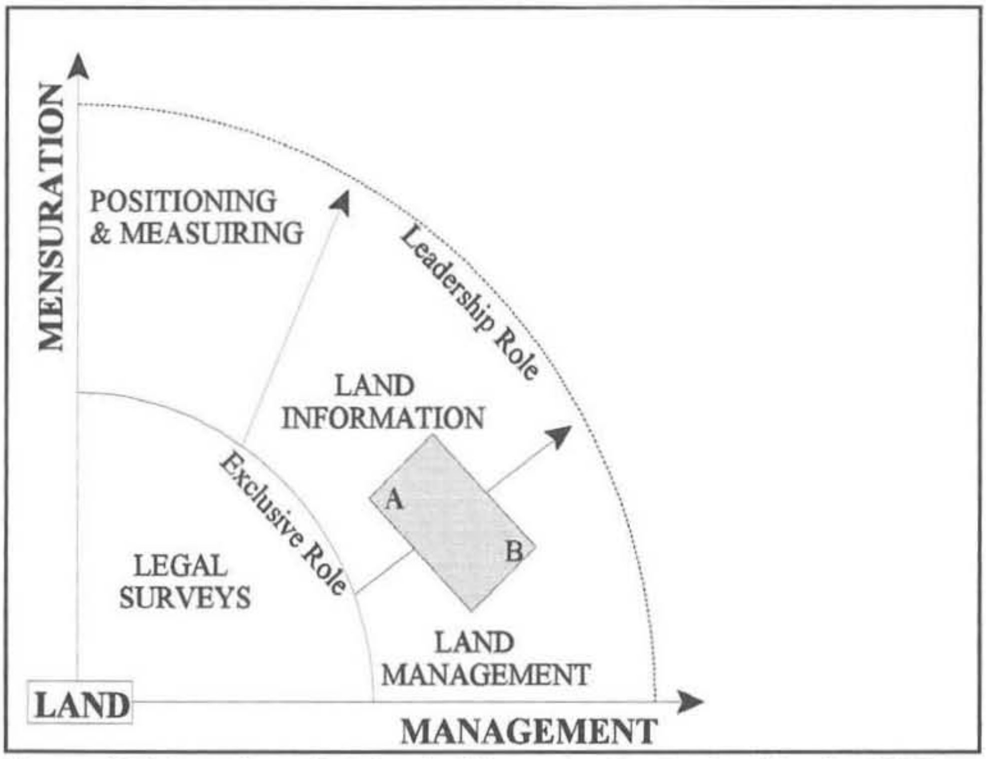

Figure 28 Adaptation of Modernised Surveying Profession (Gracie: 1985)

Note, that the position of the environmental geomaticist within the hatched area, was fluid, and varied according to the task or set of tasks with which he was involved at any given time. For example, position A, could indicate his position whilst acquiring information relevant to the study area, such as the DEM. In this case, the mensuration component of his function is fairly high, whilst the management of the actual land, although present, is not exceedingly high. This is in contrast to position B, which might, for example represent the environmental geomaticists' position in discussions with the research team over the results of the change detection analysis. In this situation, his management role increases, with a corresponding decrease in his mensuration role. With regards to the skills required by an environmental geomaticist, the case study bears out the argument that it is necessary for him to progress from merely collecting or acquiring data to a more active role in the management and use of that data. However, it is essential that the environmental geomaticist not lose sight of the extreme importance of being involved in the acquisition of that spatial data.

6.4) Teamworking

It was argued in Chapter Two, that the theme of integration which emerged from the definitions of geomatics, could be interpreted in two ways. Firstly, as the integration of the acquisition and management of spatial data, as has already been discussed, and secondly, it could be interpreted as referring to the necessity of the geomaticist being able to integrate his skills with the expertise of professionals from other disciplines.

The Geomatics Business Model, represented in Figure 2, (page 22), illustrates how knowledge of territory is gained through the integration of the collection, treatment, representation and dissemination, and management functions, and also, how these functions are generated through the integration of expertise from various disciplines. Although the Geomatics Business Model is used in Chapters Two and Three as a link to the sub-themes generated from the definitions of geomatics, it may also be used to highlight the importance of integrating disciplines, or teamworking, in order to achieve the goal of knowledge of territory. This is very relevant to the case study which draws on expertise from the geodetic and information and management sciences, and the earth sciences (see Figure 2).

The importance of teamworking to the success of meeting the technical objectives of the case study cannot be emphasized enough. Brown argues that ecologists should not and cannot tackle large-scale problems in isolation. He maintains that there is both a need and an opportunity for interdisciplinary research, and acknowledges the advantages of having multiple disciplines contributing "invaluable data and insights" (1994: 23). This is supported by Jelinski *et al.* who argue the importance of the role which GIS and related technologies such as remote sensing, GPS and image processing will play in future research (1994: 43). From the initial meeting amongst Forbes, Page and myself, in order to perform a user needs analysis, through the acquisition, manipulation and input of the various data sets, right up to the analysis of the models developed, it was only through the constant exchange of information, ideas and requirements, that the end product was able to be achieved.

The argument put forward in Chapter Three, that within the high-tech environment of spatial information, the success of any project is dependent on the integration of skills from a variety of disciplines, was totally validated by the case study. Furthermore, the case study highlighted the relevance of the Refined Conceptual Framework (see Figure 5), by illustrating both the importance of constant communication amongst the experts involved, and the manner in which the environmental geomaticist was able to drive the analytical process, by acting in a bridging role between the knowledge of Page, and the application of that knowledge to the data contained within the spatial information system, in order to achieve the set objectives.

6.5) Conclusion

This thesis has reviewed the need for a change in the profile of the traditional land surveyor. Prompted by the frequently heard call for land surveyors to get involved in GIS, a considerable amount of investigation into the matter took place, and, it was discovered that involvement in GIS, on its own, is not the solution to increasing the demand for a traditional land surveyor's services. Rather, it has been shown, that a shift in the profile of a traditional land surveyor, from measurement towards management, is what will ultimately provide the boost which the profession has been searching for.

Corresponding to this shift in professional profile, is the transformation from traditional land surveyor to geomaticist, and, as has been discussed, a further specialisation, namely, an environmental geomaticist. The areas within which an environmental geomaticist could utilize his spatial analysis skills have been discussed, and furthermore, it has been shown, by way of a real-life case study, that there is a very definite need in the marketplace, for someone with the skills of an environmental geomaticist.

Appendix A - Output Data Specifications

Work Order Number: LOOP1		Scene A
OUTPUT DATA SPECIFICATION		Product A1
Product Type: Tape Product		
Systematic Geocoded Subscene		
Bands:	3 4 5	
Tape Agency:	EOSA	
Tape Organisation:	No Supplementary file	
Interleaving:	BSQ	
Tape Density:	EXA2	

Product Scene Centre Time:	7-APR-1991 07 : 23 : 00.827830
Product Scene Centre Latitude:	S 22 : 07 : 01
Product Scene Centre Longitude:	E 029 : 10 : 00
Scene Identification:	2593072300
Sun Elevation at Product Centre:	41.88 degrees
Sun Azimuth at Product Centre:	58.61 degrees
Product Dimensions (X/Y span):	90km x 90km
Map Projection:	UTM
UTM Zone:	35
Map System:	STANDARD
Tape Identifier(s)	Device Identifier(s):
1) G0005441	VENUS$MUB1

Appendix B - Summary of Georeferencing Transformations

Resample : Summary of Transformation - 1991 Images

Computed polynomial surface : Quadratic (based on 12 control points)

Coefficient	X	Y
b0	3962472.5390625000	-1051354.0000000000
b1	-0.0151444030925632	0.7318331655114889
b2	-0.9513551220297813	1.2099258750677109
b3	0.0000001040493764	-0.0000000682943404
b4	0.0000001150938231	-0.0000000837858987
b5	0.0000000574116751	-0.0000000100265130

Note : Figures are carried internally to 20 significant figures.
Formula shown is the back transformation (new to old).

Control points used in the transformation :

Old X	Old Y	New X	New Y	Residual
709176.00	7539126.00	708100.00	7541050.00	41.29
743519.00	7542247.00	742300.00	7544150.00	omitted
686859.00	7554705.00	685850.00	7556700.00	11.17
721519.00	7540155.00	720500.00	7542050.00	37.47
707083.00	7555472.00	706100.00	7557350.00	47.03
714161.00	7586191.00	713150.00	7588150.00	6.09
722535.00	7547190.00	721475.00	7549100.00	25.73
730984.00	7561885.00	729900.00	7563850.00	35.05
688876.00	7543953.00	687850.00	7545925.00	33.96
682522.00	7558674.00	681525.00	7560725.00	35.56
703826.00	7562124.00	702875.00	7564050.00	17.82
755552.00	7536446.00	754350.00	7538200.00	omitted
743174.00	7542407.00	742000.00	7544250.00	44.98
703439.00	7556123.00	702450.00	7558000.00	omitted
740486.00	7536246.00	739350.00	7538125.00	18.72

Overall RMS = 32.25

Note : RMS Error is expressed in output map units.
With low RMS errors, be careful that an adequate sample exists
(eg. 2-3 times the mathematical min).

Resample : Summary of Transformation - 1998 Images

Computed polynomial surface : Quadratic (based on 12 control points)

Coefficient	X	Y
b0	7317064.7421875000	-5684926.7500000000
b1	-0.4896830220241100	1.3812772147357464
b2	-1.7938849842175841	2.3730327337980270
b3	0.0000001416023572	-0.0000000319697620
b4	0.0000001707916705	-0.0000001767455309
b5	0.0000001104851796	-0.0000000824488700

Note : Figures are carried internally to 20 significant figures.
Formula shown is the back transformation (new to old).

Control points used in the transformation :

Old X	Old Y	New X	New Y	Residual
708558.00	7539827.00	708100.00	7541050.00	15.44
742911.00	7543039.00	742300.00	7544150.00	51.82
686255.00	7555457.00	685850.00	7556700.00	56.75
721129.00	7540620.00	720500.00	7542050.00	omitted
706519.00	7556238.00	706100.00	7557350.00	omitted
713569.00	7586933.00	713150.00	7588150.00	4.02
719145.00	7550779.00	718775.00	7551950.00	44.34
730388.00	7562655.00	729900.00	7563850.00	9.33
687034.00	7545510.00	686550.00	7546725.00	34.40
681934.00	7559419.00	681525.00	7560725.00	omitted
702422.00	7564124.00	702075.00	7565250.00	21.74
752448.00	7538404.00	751800.00	7539525.00	19.73
736254.00	7543965.00	735750.00	7545175.00	60.71
704386.00	7556883.00	704000.00	7558000.00	48.97
739911.00	7536990.00	739350.00	7538125.00	8.24

Overall RMS = 36.98

Note : RMS Error is expressed in output map units.
With low RMS errors, be careful that an adequate sample exists
(eg. 2-3 times the mathematical min).

Appendix C - Information in World and Header Files

Table C-1 - Header File (http://edcdaac.usgs.gov)

BYTE ORDER:	Byte order in which image pixel values are stored M = Motorola byte order (most significant byte first)
LAYOUT:	organization of the bands in the file BIL: band interleaved by line (note: the raster layers are all single band images)
NROWS:	number of rows in the image
NCOLS:	number of columns in the image
NBANDS:	number of spectral bands in the image (1)
NBITS:	number of bits per pixel (16 or 32)
BANDROWBYTES:	number of bytes per band per row (twice the number of columns for a 16-bit image; four-times for the 32-bit image)
TOTALROWBYTES:	total number of bytes of data per row (twice the number of columns for a single band 16-bit image; four-times for the 32-bit image)
BANDGAPBYTES:	the number of bytes between bands in a BSQ format image (0)

Table C-2 World File (http://edcdaac.usgs.gov)

XDIM:	X-dimension of a pixel (1000)
Rotation term:	Always zero
Rotation term:	Always zero
Negative YDIM:	Negative Y-dimension of a pixel (-1000)
XMIN:	X-location of centre of upper-left pixel (projected metres)
YMAX:	Y-location of upper-left pixel (projected metres)

Appendix D - GPS and Vegetation Data

Table D-1 - Northern Tuli Game Reserve

#	Map Latitude	Map Longitude	GPS Latitude	GPS Longitude	Cd #	Vegetation Type
1	22° 10.058'	29° 10.353'			4.1	S. angustifolia Shrubland
2	22° 9.526'	29° 10.217'	22° 9.472'	29° 10.433'	1.2	A. tort. – C. mega. Wdlnd.
3	22° 8.058'	29° 10.679'	22° 8.005'	29° 10.780'	7.1	C. mop. – T. prun. Shrblnd.
4	22° 8.058'	29° 10.408'	22° 8.037'	29° 10.487'	1.2	A. tort. – C. mega. Wdlnd
5	22° 6.897'	29° 10.204'			8.1	C. mop. – C. apic. Shrblnd.
6	22° 11.625'	29° 3.204'	22° 11.71'	29° 3.095'	7.1	C. mop. – T. prun. Shrblnd
7	22° 10.815'	29° 2.978'	22° 10.792'	29° 2.928'	7.2	T. prun – C. mop. Shrblnd
8	22° 9.734'	29° 4.102'			7.1	C. mop. – T.prun. Shrblnd.
9	22° 6.027'	29° 3.044'			8.1	C. mop. – C. apic. Wdlnd.
10	22° 5.693'	29° 2.423'	22° 5.695'	29° 2.36'	8.1	C. mop. – C. apic. Wdlnd.
11	22° 3.937'	29° 0.905'			8.1	C. mop. – C. apic. Wdlnd.
12	22° 5.394'	29° 5.423'			8.1	C. mop. – C. apic. Wdlnd.
13	22° 2.924'	29° 4.467'			8.1	C. mop. – C. apic. Wdlnd.
14	22° 5.299'	29° 7.905'	22° 5.303'	29° 7.843'	8.1	C. mop. – C. apic. Wdlnd.
15	22° 6.625'	29° 10.175'			8.1	C. mop. – C. apic. Wdlnd.
16	22° 8.136'	29° 17.832'	22° 8.438'	29° 18.112'	1.1	A. albida Gallery Forest
17	22° 9.815'	29° 19.876'	22° 9.900'	29° 19.647'	1.1	A. albida Gallery Forest
18	22° 9.340'	29° 17.219'			7.1	C. mop. – T. prun. Shrblnd.
19	22° 10.598'	29° 7.146'			7.1	C. mop. – T. prun. Shrblnd.
20	22° 9.285'	29° 6.146'			7.1	C. mop. – T. prun. Shrblnd.

21	22° 10.557'	29° 6.000'			7.1	C. mop. – T. prun. Shrblnd.
22	22° 11.340'	29° 16.657'			1.2	A. tort. – C. meg. Wdlnd.
23	22° 11.516'	29° 19.628'	22° 11.490'	29° 19.660'	1.1	A. albida Gallery Forest
24	22° 8.435'	29° 8.351'			1.2	A. tort. – C. meg. Wdlnd.
25	22° 13.503'	28° 58.511'	22° 13.515'	28° 58.402'	1.2	A. tort. – C. meg. Wdlnd.
26	22° 11.679'	28° 59.175'	22° 11.632'	28° 59.077'	9.2	C. mop. Wdlnd.
27	22° 6.652'	29° 8.088'	22° 6.700'	29° 7.973'	7.1	C. mop. – T. prun. Shrblnd.
28	22° 10.978'	29° 4.993'	22° 10.992'	29° 4.983'	7.1	C. mop. – T. prun. Shrblnd.
29	22° 9.258'	29° 12.935'	22° 9.302'	29° 12.933'	7.1	C. mop. – T. prun. Shrblnd.
30	22° 10.652'	29° 16.146'			7.1	C. mop. – T. prun. Shrblnd.
31	22° 7.870'	29° 13.978'	22° 7.938'	29° 13.973'	8.1	C. mop. – C. apic. Shrblnd.
32	22° 5.272'	29° 11.263'			7.1	C. mop. – T. prun. Shrblnd.
33	22°10.285'	29° 14.044'	22° 10.455'	29° 13.667'	6.3	Mxd. Acacia –B. foet Shrblnd.
34	22°12.652'	29° 9.044'			1.2	A. tort. – C. meg. Wdlnd.
35	22° 6.489'	29° 10.175'			8.1	C. mop. – C. apic. Wdlnd.
36	22° 6.761'	29° 7.628'			8.1	C. mop. – C. apic. Wdlnd.
37	22°11.408'	29° 10.803'			1.2	A. tort. – C. meg. Wdlnd.
38	22°10.652'	29° 12.847'	22° 10.635'	29° 12.795'	1.2	A. tort. – C. meg. Wdlnd.
39	22° 8.598'	29° 2.789'	22° 8.508'	29° 2.925'	8.1	C. mop. – C. apic. Wdlnd.
40	22° 5.938'	29° 4.905'			8.1	C. mop. – C. apic. Wdlnd.
41	22° 8.503'	29° 8.789'			1.2	A. tort. – C. meg. Wdlnd.
43	22° 6.000'	29° 8.847'			8.1	C. mop. – C. apic. Wdlnd.
44	22° 5.707'	29° 5.730'			9.2	C. mopane Woodland
45	22° 4.136'	28° 59.584'			8.1	C. mop. – C. apic. Wdlnd.

46	22° 4.136'	28° 59.584'	22° 4.028'	28° 59.672'	8.1	C. mop. – C. apic. Wdlnd.
47	22° 4.761'	29° 59.657'			2	Mxd. Cmbt.- L.ca.–S.br.R.W.
48	22° 3.245'	29° 1.803'			2	Mxd. Cmbt.- L.ca.–S.br R.W.
49	22° 4.272'	28° 59.321'	22° 4.000'	28° 59.273'	2	Mxd. Cmbt.- L.ca.–S.br.R.W.
50	22° 11.231'	29° 10.968'			1.2	A. tort. – C. meg. Wdlnd.
51	22° 4.380'	28° 57.920			2	Mxd. Cmbt.- L.ca.–S.br.R.W.
52	22° 12.313'	29° 7.365'			12	Sandveld Valley Woodland
53	22° 12.584'	29° 7.044'	22° 12.388'	29° 6.635'	11	Sandstone Outcrop
54	22° 12.611'	29° 5.263'			11	Sandstone Outcrop
55	22° 8.720'	29° 7.701'			1.5	Mxd. Acac. – Salvadora Wld.
56	22° 12.707'	29° 8.920'			11	Sandstone Outcrop
57	22° 5.476'	28° 59.643'			2	Mxd. Cmbt.- L. ca–S.br.R.W.
58	22° 6.204'	29° 0.862'	22° 6.215'	29° 0.875'	2	Mxd. Cmbt.- L.ca –S.br.R.W.
59	22° 5.584'	28° 58.380'			2	Mxd. Cmbt.- L.ca –S.br.R.W.
60	22° 12.408'	28° 57.263'	22° 12.368'	28° 57.355'	1.2	A. tort. – C. meg. Wdlnd.
61	22° 8.217'	28° 58.876'	22° 8.263'	28° 59.060'	8.2	C. apic. – C. mop. Wdlnd.
62	22° 4.068'	29° 14.832'			1.1	A. albida Gallery Forest
63	22° 6.163'	29° 9.307'			3.3	A. stuhlmanii Shrblnd.
64						
65	22° 5.285'	28°58.131'	22° 5.330'	28° 58.100'	8.1	C. mop. – C. apic. Wdlnd.
66	22° 10.095'	29° 13.248'			6.3	Mxd. Acacia –B. foet Shrblnd.
67	22° 9.870'	29° 14.438'			6.3	Mxd. Acacia –B. foet Shrblnd.
68	22° 3.340'	29° 3.482'			8.2	C. apic. – C. mop. Wdlnd.
69	22° 4.027'	28° 59.993'			9.2	C. mopane Woodland

Table D-2 - Venetia - Limpopo Nature Reserve

Qd #	GPS Latitude	GPS Longitude	VT #	Vegetation Type
1	22° 24.88	29° 16.31	1.3	C. mopane Riparian Woodland
2	22° 18.38	29° 15.37	1.1	A. tort.- C. meg. Riparian Gallery Wdlnd.
3	22° 17.01	29° 15.46	13	Sesamothamnus Woodland
4	22° 16.52	29° 15.53	13	Sesamothamnus Woodland
5	22° 16.66	29° 15.05	1.1	A. tort.- C. meg. Riparian Gallery Wdlnd.
6	22° 17.48	29° 15.41	4.1	C. mop.-Salvadora Shrblnd. on Sandy Soils
7	22° 18.04	29° 15.45	14.1	C. mop.-T. prun. Shrblnd. on Sandstone. Hills
8	22° 18.48	29° 16.00	3.1	Salvadora - C. mop. Wdlnd. on Bottomlands
9	22° 24.82	29° 16.26	1.3	C. mopane Riparian Woodland
10	22° 24.99	29° 16.53	5	C. mopane Woodland on Colluvial deposits
11	22° 23.96	29° 16.09	1.3	C. mopane Riparian Woodland
12	22° 23.78	29° 16.03	1.3	C. mopane Riparian Woodland
13	22° 24.10	29° 15.51	5	C. mopane Woodland on Colluvial deposits
14	22° 24.32	29° 15.43	14.3	C. mop.- T.prun. Wdlnd. on Dykes / Outcrops
15	22° 20.79	29° 15.29	5	C. mopane Woodland on Colluvial deposits
16	22° 18.94	29° 21.43	15.1	C. apic.– C. mop. Wdlnd. on Escrpmt. Sands
17	22° 17.85	29° 21.81	4.2	C. mop. Shrubland on Sandy Soils on slopes
18	22° 21.39	29° 22.30	15.1	C. apic.– C. mop. Wdlnd. on Escrpmt. Sands
19	22° 20.15	29° 21.03	12	A. senegal – T. prun. - C. mop. on Calcrete
20	22° 19.17	29° 21.65	15.1	C. apic.– C. mop. Wdlnd. on Escrpmt. Sands
21	22° 16.96	29° 21.73	15.1	C. apic.– C. mop. Wdlnd. on Escrpmt. Sands
22	22° 17.67	29° 20.53	8.1	C. mop.-T. prun. Shrblnd. on Escrpmnt.
23	22° 24.75	29° 22.42	9	C. mop.-T. prun. Shrbld. On Calcrete
24	22° 25.61	29° 22.72	7	C. mop.-T. prun.-D. cin. Mxd. Decid. Wdlnd.
25	22° 24.15	29° 22.37	15	C. mop.-T. prun.-D. cin. on Old Fields
26	22° 23.47	29° 22.08	15.1	C. mop.-C. apic.-T. prun.-D. cin.
27	22° 20.42	29° 20.65	8.1	C. mop.-T. prun.
28	22° 24.24	29° 14.83	4.3	C. mop. Shrblnd. on Sandy Quartzitic Soils
29	22° 23.95	29° 15.09	11	C. merkerii Woodland on bottomlands
30	22° 23.67	29° 15.99	1.1	A. tort.- C. meg. Riparian Gallery Wdlnd.
31	22° 23.24	29° 15.22	1.3	C. mopane Riparian Woodland
32	22° 23.08	29° 15.78	3.2	C. mop.- Salvadora Wdlnd. on Bottomlands
33	22° 22.03	29° 16.65	3.2	C. mop.- Salvadora Wdlnd. on Bottomlands
34	22° 21.52	29° 15.76	1.1	A. tort.- C. meg. Riparian Gallery Wdlnd.
35	22° 21.31	29° 15.99	5	C. mopane Woodland on Colluvial deposits
36	22° 21.11	29° 15.82	1.3	C. mopane Riparian Woodland
37	22° 20.58	29° 16.44	5	C. mopane Woodland on Colluvial deposits
38	22° 20.50	29° 16.28	1.3	C. mopane Riparian Woodland

39	22° 20.12	29° 16.77	3.2	C. mop.- Salvadora Wdlnd. on Bottomlands
40	22° 19.99	29° 16.79	3.1	Salvadora - C. mop. Wdlnd. on Bottomlands
41	22° 24.32	29° 13.99	15.2	C. apic.– C. mop. Wdlnd. - Sandy Clay Loams
42	22° 24.10	29° 13.79	4.3	C. mop. Shrblnd. on Sandy Quartzitic Soils
43	22° 23.54	29° 13.17	4.3	C. mop. Shrblnd. on Sandy Quartzitic Soils
44	22° 22.64	29° 13.23	1.3	C. mopane Riparian Woodland
45	22° 22.29	29° 13.09	4.3	C. mop. Shrblnd. on Sandy Quartzitic Soils
46	22° 21.49	29° 13.52	14.4	C. apic. Wdlnd. on Sandstone Ridges
47	22° 20.79	29° 12.92	1.3	C. mopane Riparian Woodland
48	22° 20.07	29° 13.24	5	C. mopane Woodland on Colluvial deposits
49	22° 20.05	29° 13.72	1.3	C. mopane Riparian Woodland
50	22° 20.32	29° 14.15	4.3	C. mop. Shrblnd. on Sandy Quartzitic Soils
51	22° 21.21	29° 17.39	1.2	Mxd. Acacia Drainage Line Fringe Wdlnd
52	22° 21.41	29° 18.07	3.1	Salvadora - C. mop. Wdlnd. on Bottomlands
53	22° 21.64	29° 18.23	1.3.1	C. mopane – A. nigrescens Riparian Woodland
54	22° 22.03	29° 18.47	13	Sesamothamnus Woodland
55	22° 22.63	29° 18.26	5	C. mopane Woodland on Colluvial deposits
56	22° 22.83	29° 18.50	16	C. apiculatum Mixed Woodland on Quartz
57	22° 22.67	29° 17.99	4.3.1	C. mop. Shrblnd. on Sndy. Quartzitic Soils
58	22° 22.43	29° 17.69	1.3	C. mopane Riparian Woodland
59	22° 22.39	29° 17.32	4.1	C. mop.(-Salvadora) Shrblnd. on Sandy Soils
60	22° 20.45	29° 16.98	1.3	C. mopane Riparian Woodland
61	22° 20.90	29° 16.84	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
62	22° 20.85	29° 17.84	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
63	22° 20.41	29° 17.62	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
64	22° 20.57	29° 18.95	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
65	22° 21.85	29° 21.35	8.1	C. mop.-T. prun. Shrblnd. on Escrpmnt.
66	22° 22.53	29° 21.06	8.1	C. mop.-T. prun. Shrblnd. on Escrpmnt.
67	22° 23.07	29° 20.77	8.2	C. mop.-Commiphora Shrblnd. on Escrpmnt.
68	22° 23.42	29° 20.53	1.3	C. mopane Riparian Woodland
69	22° 23.49	29° 19.35	15.1	C. apic.– C. mop. Wdlnd. on Escrpmt. Sands
70	22° 22.83	29° 19.70	8.1	C. mop.-T. prun. Shrblnd. on Escrpmnt.
71	22° 21.00	29° 20.21	13	Sesamothamnus Woodland
72	22° 19.78	29° 18.69	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
73	22° 19.40	29° 18.80	5	C. mopane Woodland on Colluvial deposits
74	22° 19.02	29° 19.20	14.3	C. mop.- T.prun. Wdlnd. on Dykes / Outcrops
75	22° 18.67	29° 19.12	1.3	C. mopane Riparian Woodland
76	22° 19.38	29° 18.02	5	C. mopane Woodland on Colluvial deposits

77	22° 18.71	29° 18.12	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
78	22° 17.29	29° 17.59	17.1	Mxd. Acacia Wdlnd. in Hydrmrphc. Grslnd.
79	22° 16.73	29° 16.91	2	Acacia stuhlmannii – Salvadora Open Woodland
80	22° 19.29	29° 17.62	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
81	22° 19.21	29° 16.86	1.3	C. mopane Riparian Woodland
82	22° 25.54	29° 15.96	5	C. mopane Woodland on Colluvial deposits
83	22° 25.86	29° 16.09	5	C. mopane Woodland on Colluvial deposits
84	22° 26.25	29° 16.91	16	C. apiculatum Mixed Woodland on Quartz
85	22° 26.58	29° 16.97	1.1	A. tort.- C. meg. Riparian Gallery Wdlnd.
86	22° 27.04	29° 17.33	5	C. mopane Woodland on Colluvial deposits
87	22° 27.59	29° 16.72	1.3	C. mopane Riparian Woodland
88	22° 27.47	29° 16.29	4.1	C. mop.-Salvadora Shrblnd, Sandy Clay Loams
89	22° 27.95	29° 17.25	1.3	C. mopane Riparian Woodland
90	22° 27.63	29° 17.63	16	C. apiculatum Mixed Woodland on Quartz
91	22° 25.57	29° 17.25	4.4	C. mop. –Commiphora - T. prun Shrblnd.
92	22° 17.71	29° 14.70	17.1	Mxd. Acacia Wdlnd. in Hydrmrphc. Grslnd.
93	22° 17.86	29° 14.84	17.1	Mxd. Acacia Wdlnd. in Hydrmrphc. Grslnd.
94	22° 17.86	29° 14.83	17.1	Mxd. Acacia Wdlnd. in Hydrmrphc. Grslnd.
95	22° 17.96	29° 15.13	1.1	A. tort.- C. meg. Riparian Gallery Wdlnd.
96	22° 18.08	29° 15.03	17.1	Mxd. Acacia Wdlnd. in Hydrmrphc. Grslnd.
97	22° 16.97	29° 15.28	17.2	Mxd. Acacia Wdlnd. in Hydrmrphc. Grslnd.
98	22° 16.96	29° 15.92	2	Acacia stuhlmannii – Salvadora Open Woodland
99	22° 16.97	29° 16.56	3.2	C. mop.- Salvadora Wdlnd. on Bottomlands
100	22° 19.73	29° 16.95	1.2	Mxd. Acacia Drainage Line Fringe Wdlnd
101	22° 19.70	29° 16.90	1.3	C. mopane Riparian Woodland
102	22° 19.44	29° 15.89	4.2	C. mop. Shrubland on Sandy Soils on slopes
103	22° 18.42	29° 16.10	1.3	C. mopane Riparian Woodland
104	22° 17.23	29° 19.15	4.4	C. mop. – Commiphora - T. prun Shrblnd.
105	22° 16.61	29° 19.42	6	C. mop. – Dichro – Grewia on Fine Sand
106	22° 17.07	29° 19.88	6	C. mop. – Dichro – Grewia on Fine Sand
107	22° 17.00	29° 19.83	14.2	C. apic. – C. mop. Wdlnd. on Sandstone Ridges
108	22° 16.55	29° 19.89	8.1	C. mop.-T. prun. Shrblnd. on Escrpmnt.
109	22° 17.13	29° 14.28	1.3	C. mopane Riparian Woodland
110	22° 17.12	29° 14.29	1.3	C. mopane Riparian Woodland
111	22° 17.35	29° 13.32	6	C. mop. – Dichro – Grewia on Fine Sand
112	22° 17.79	29° 12.86	6	C. mop. – Dichro – Grewia on Fine Sand
113	22° 17.79	29° 13.60	14.1	C. mop.-T. prun. Shrblnd. on Sandstone. Hills
114	22° 18.25	29° 14.09	1.3	C. mopane Riparian Woodland
115	22° 18.66	29° 13.27	5	C. mopane Woodland on Colluvial deposits

Appendix E - Classified Vegetation Image

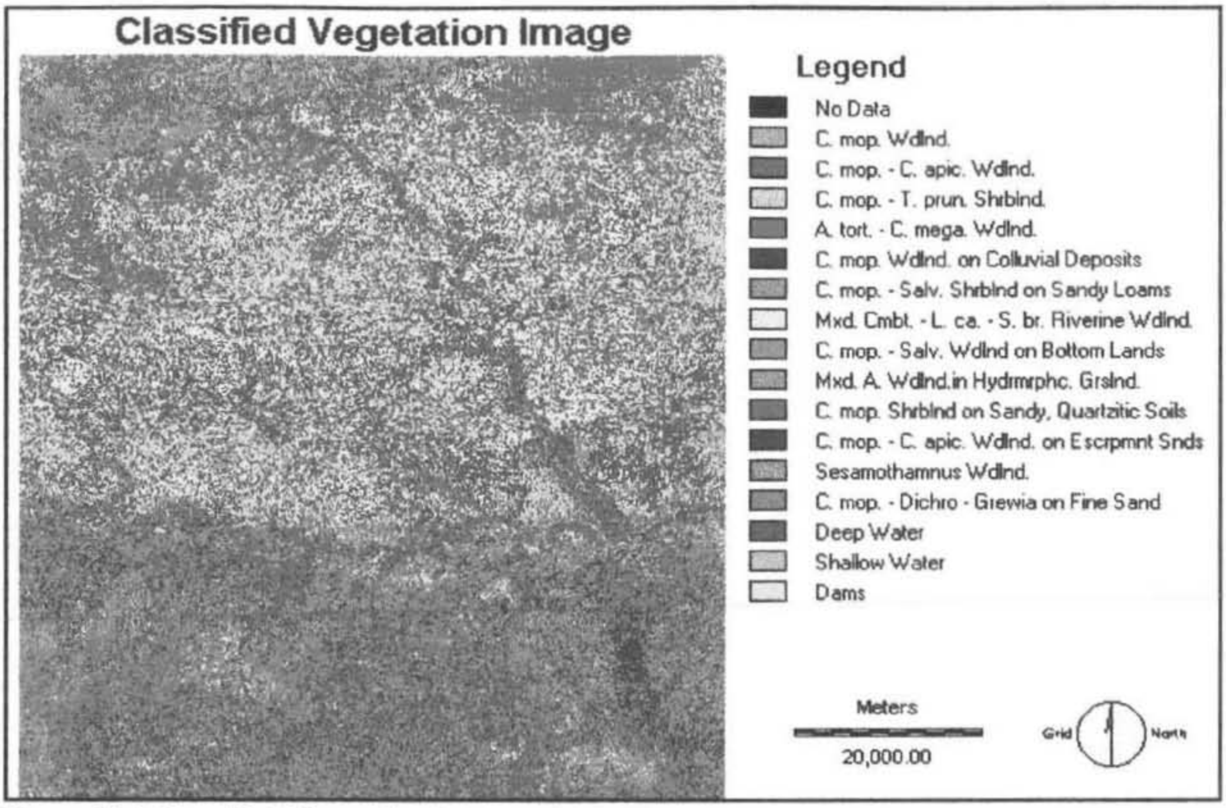

Figure E-1 Classified Vegetation Image

Appendix F - Rainfall Station Positions

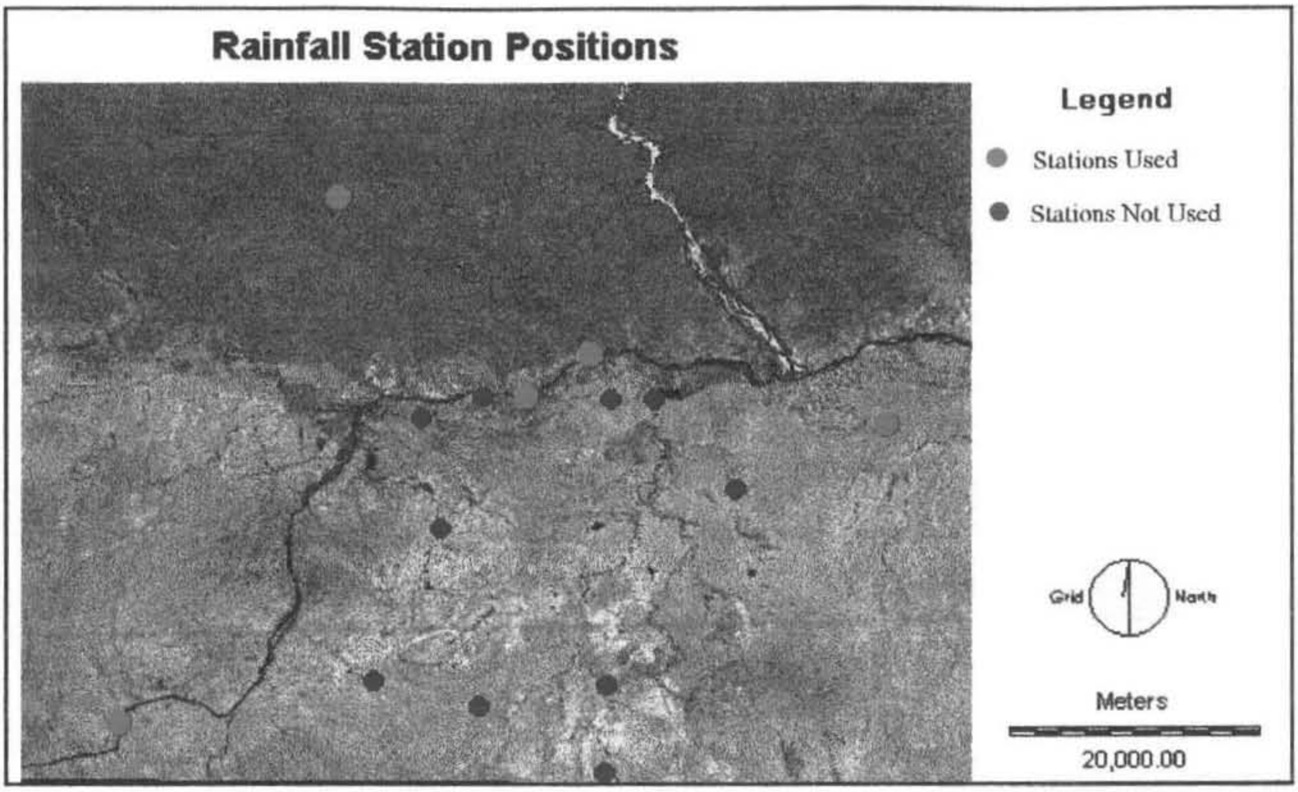

Figure F-1 Rainfall Station Positions

References

Allred, G.K. (n.d.), *Maintaining Professional Competency*, Chair, Commission 1, International Federation of Surveyors.

Barry, M. (1994), *A Part Time Post-Graduate Education Programme in GIS at UCT*, in Proceedings of the Second Workshop on Surveying Education in Southern Africa, R.Floreck and C.Martin (Eds.), Cape Town.

Brown, J.H. (1994), Grand Challenges in Environmental Research, in Michener, W.K., Brunt, J.W. and Stafford, S.G. (eds.), *Environmental information Management and Analysis: Ecosystem to Global Scales*, Taylor and Francis Ltd., Great Britain.

Budlender, G. and Latsky, J. (1991), Unravelling rights to land in rural race zones, in M.de Klerk (ed.) *A Harvest of Discontent: The Land Question in South Africa*, IDASA, Cape Town.

Burrough, P.A. (1990), *Principles of Geographic Information Systems for Land Resources Assessment*, Clarendon Press, Oxford.

Canters, F. (1997), Evaluating the Uncertainty of Area Estimates Derived from Fuzzy Land-Cover Classification, *Photogrammetric Engineering and Remote Sensing*, **63**(4), 403-414.

Chavez, P.S., Jr. and MacKinnon, D.J. (1994), Automatic Detection of Vegetation Changes in the Southwestern United States Using Remotely Sensed Images, *Photogrammetric Engineering and Remote Sensing*, **60**(5), 571-583.

Chen, J. and McLaughlin (1992), Strategic directions of surveying and mapping - a perspective, *ASPRS-ACSM/RT Technical Papers*, **1** - Global change and education, 254-261.

Cheng, T. and Molenaar, M. (1999), Objects with Fuzzy Spatial Extent, *Photogrammetric Engineering and Remote Sensing*, **65**(7), 797-801.

Claassens, A. (1991), For whites only - land ownership in South Africa, in M.de Klerk (ed.) *A Harvest of Discontent: The Land Question in South Africa*, IDASA, Cape Town.

Cross, C. (1991), Informal tenures against the state: landholding systems in African rural areas, in M.de Klerk (ed.) *A Harvest of Discontent: The Land Question in South Africa*, IDASA, Cape Town.

Dale, P. and McLaughlin, J. (1988), *Land Information Management*, Clarendon, Oxford.

Eastman, J.R. (1997), *Idrisi for Windows Version 2.0 Tutorial Exercises*, Clark University.

Eastman, J.R. (1997a), *Idrisi for Windows Version 2.0 User's Guide*, Clark University.

Forbes, A.M., (1999 - 2000) personal communication.

Fourie, C. (1994), Possible trends in the implementation of state policy, in *Land Use and Land Administration in the New South Africa*, The Centre for Adult Education, University of Natal, Durban.

Fourie, C. (1997), Geomatics, Unpublished mimeo.

Goodwin, D.P. (1992), *Appropriate Cadastres for Southern Africa: the Case of Zimbabwe*, Paper presented at CONSAS, Cape Town.

Gosz, J.R. (1994), Sustainable Biosphere Initiative: Data Management Challenges, in Michener, W.K., Brunt, J.W. and Stafford, S.G. (eds.), *Environmental information Management and Analysis: Ecosystem to Global Scales*, Taylor and Francis Ltd., Great Britain.

Green, K., Kempka, D., Lackey, L. (1994), Using Remote Sensing to Detect and Monitor Land-Cover and Land-Use Change, *Photogrammetric Engineering and Remote Sensing*, **60**(3), 331-337.

Greene, O.M. (1994), *Profile of a Surveyor in the Year 2000*, in Proceedings of the Second Workshop on Surveying Education in Southern Africa, R.Floreck and C.Martin (Eds.), Cape Town.

Haines, R.J. and Cross, C.R. (1988), An historical overview of land policy and tenure in South Africa's black areas, in C.R.Cross and R.J.Haines (eds.), *Towards Freehold? Options for Land and Development in South Africa's Black Rural Areas*, Cape Town, Juta.

Heo, J. and FitzHugh, T.W. (2000), A Standardized Radiometric Normalization Method for Change Detection Using Remotely Sensed Imagery, *Photogrammetric Engineering and Remote Sensing*, **66**(2), 173-181.

Hindson, D. and McCarthy, J. (1994), *Here to Stay: Informal Settlements in KwaZulu-Natal*, Indicator, University of Natal, Durban.

http://edcdaac.usgs.gov/gtopo30/hydro

Jelinski, D.E., Goodchild, M.F., Steyaert, L.T. (1994), Multiple Roles for GIS in Global Change Research: Towards a Research Agenda, in Michener, W.K., Brunt, J.W. and Stafford, S.G. (eds.), *Environmental information Management and Analysis: Ecosystem to Global Scales*, Taylor and Francis Ltd., Great Britain.

Jenkins, D., Scogings, D., Margeot, H., Fourie, C. and Perkin, P. (1986), Investigation of the Emerging Patterns of Zulu Land Tenure and the Implications for the Establishment of Effective Land Information and Administrative Systems as a Base for Development, Project for the National Programme for Environmental Sciences, Human Needs, Resources and the Environment of the H.S.R.C., Department of Surveying, University of Natal (Durban), Unpublished.

Jones, K. and Ellis, G. (1994), *The Challenge of Meeting the Professional Education Demands of a Changing Society*, Paper presented at FIG XX Congress, Melbourne, Australia.

Kennedy, E.A. and Woolnough, D.F. (1994), *Canada Breaks New Ground in Geomatics Education and Training*, Paper presented at FIG XX Congress, Melbourne, Australia.

Larsson, G. (1991), *Land Registration and Cadastral System Tools for Land Information Management*, Longman.

Lyon, J.G., Yuan, D., Lunetta, R.S. and Elvidge, C.D. (1998), A Change Detection Experiment Using Vegetation Indices, *Photogrammetric Engineering and Remote Sensing*, **64**(2), 143-150.

Macleod, R.D. and Congalton, R.G. (1998), A Quantitative Comparison of Change-Detection Algorithms for Monitoring Eelgrass from Remotely Sensed Data, *Photogrammetric Engineering and Remote Sensing*, **64**(3), 207-216.

Marcus, T. (1991), National, class and gender issues in land reform, in M.de Klerk (ed.) *A Harvest of Discontent: The Land Question in South Africa*, IDASA, Cape Town.

Margerison, C. and McCann, D. (1990), *Team Management: Practical New Approaches*, Mercury Books, Great Britain.

McCloy, K.R. (1995), *Resource Management Information Systems: Process and Practice*, Taylor and Francis, London.

Merry, C.L. (1994), *The Surveyor in the Year 2000*, in Proceedings of the Second Workshop on Surveying Education in Southern Africa, R.Floreck and C.Martin (Eds.), Cape Town.

Michalek, J.L., Wagner, T.W., Luczkovich, J.J., Stoffle, R.W. (1993), Multispectral Change Vector Analysis for Monitoring Coastal Marine Enviroments, *Photogrammetric Engineering and Remote Sensing*, **59**(3), 381-384.

Michener, W.K., Brunt, J.W. and Stafford, S.G. (1994), *Environmental Information Management and Analysis: Ecosystem to Global Scales*, Taylor and Francis Ltd., Great Britain.

Michener, W.K. and Houhoulis, P.F. (1997), Detection of Vegetation Changes Associated with Extensive Flooding in a Forested Ecosystem, *Photogrammetric Engineering and Remote Sensing*, **63**(12), 1363-1374.

Muchoney, D.M. and Haack, B.N. (1994), Change Detection for Monitoring Forest Defoliation, *Photogrammetric Engineering and Remote Sensing*, **60**(10), 1243-1251.

Ormeling, F. (1994), *Joint Course Curricula in the Surveying and Mapping Field*, Paper presented at FIG XX Congress, Melbourne, Australia.

Oxford Paperback Dictionary, Oxford University Press.

Page, B.R. (1997), Learning About the Interaction Between Elephants and Their Habitats: Twenty One Years of The Tuli Elephant Project, *Journal of the Rhino and Elephant Foundation*, **11**, 31-34.

Page, B.R. (1999 - 2000), personal communication.

Parker, G.M. (1990), *Team Players and Team Work: The New Competitive Business Strategy*, Jossey-Bass Publishers, San Francisco.

Price, K.P., Pyke, D.A., Mendes, L. (1992), Shrub Dieback in a Semiarid Ecosystem: The Integration of Remote Sensing and Geographic Information Systems for Detecting Vegetation Change, *Photogrammetric Engineering and Remote Sensing*, **58**(4), 455-463.

Richards, J.A. (1986), *Remote Sensing Digital Image Analysis: An Introduction*, Springer-Verlag, Berlin.

Rouch, J. and DeLoach, S. (1994), *Technical Education of Surveyors in an Era of Push Button Technology*, Paper presented at FIG XX Congress, Melbourne, Australia.

Rudd, R. (1974), Remote Sensing of Natural Resources, in Estes, J.E. and Senger, L.W., *Remote Sensing: Techniques for Environmental Analysis*, Hamilton Publishing Company, California.

Rüther, H. (n.d.), *Trends and Needs in Surveying Education*.

Sader, S.A. (1995), Spatial Characteristics of Forest Clearing and Vegetation Regrowth as Detected by Landsat Thematic Mapper Imagery, *Photogrammetric Engineering and Remote Sensing*, **61**(9), 1145-1151.

Simpson, K.W. and Sweeney, G.M.J. (1973), *The Land Surveyor and the Law*, University of Natal Press, Pietermaritzburg.

Stafford, S.G., Brunt, J.W. and Michener, W.K. (1994), Integration of Scientific Information Management and Environmental Research, in Michener, W.K., Brunt, J.W. and Stafford, S.G. (eds.), *Environmental information Management and Analysis: Ecosystem to Global Scales*, Taylor and Francis Ltd., Great Britain.

Star, J. and Estes, J. (1990), *Geographic Information Systems: An Introduction*, Prentice-Hall Inc., New Jersey.

UNEP/FAO (1993), *Report of the UEP/FAO Expert Meeting on Harmonizing Land Cover and Land Use Classifications*, Geneva.

University of New South Wales Annual Report (1994), *Geomatics*, Sydney.

van Gysen, H. (1994), *What Technological Change Can Do for Appropriate Land Tenure*, in Land Use and Land Administration in the New South Africa, The Centre for Adult Education, University of Natal, Durban.

van Gysen, H. (1997), Geomatics and Land Management, Unpublished mimeo.

Viitanen, K. (1994), *New Challenges to the Education of Surveyors in Finland*, Paper presented at FIG XX Congress, Melbourne, Australia.

West, C.N. (1981), *The Private-Practicing Land Surveyor - How He Renders a Service to his Community*, Paper presented at FIG XVI, International Congress, Montreux, Switzerland.

www.fao.org (1997)

www.funet.fi (1992)

www.ncgia.ucsb.edu (1996)

Young, F.R. (1994), *Flexible Education for the Future Generic Surveyor/Cartographer*, Paper presented at FIG XX Congress, Melbourne, Australia.

Zhang, J. and Kirby, R.P. (1999), Alternative Criteria for Defining Fuzzy Boundaries Based on Fuzzy Classification of Aerial Photographs and Satellite Images, *Photogrammetric Engineering and Remote Sensing*, **65**(12), 1379-1387.