Digital Satellite Remote Sensing for Terrestrial Coastal Zone Management

By

Cindy Pretorius

Thesis presented in partial fulfilment of the requirements for the degree of

MASTER OF ARTS

at the

UNIVERSITY OF STELLENBOSCH.

Supervisor: Prof. H.L. Zietsman

March 2002

Declaration

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

Abstract

The unique and often fragile environment of the coastal zone is placed under increasing pressure by human development. It is expected that three quarters of the world's population will be living within 60km of the coast by the year 2020. Thorough planning and management are required to prevent coastal degradation. In South Africa, coastal management efforts are being promoted through the implementation of a White Paper for sustainable coastal development. A Coastal Decision Support System (CDSS) was developed to empower local authorities to demarcate and manage sensitive coastal areas by giving them access to relevant botanical and physical information.

Land cover/use information for the CDSS was previously mapped manually from hardcopy aerial photography. This method was found to be time-consuming and costly. This study investigated the potential for digital satellite imagery as primary source of data for populating the land cover/use information of the CDSS. A methodology was designed utilising semi-supervised isodata clustering for extracting relevant information for a study area covering 40x20km of coast along the southern coastal sector of South Africa. Digital mapping of SPOT 4 multispectral satellite data was used successfully to map land cover/use information such as wetlands, coastal lakes, dune vegetation, urban areas, forest plantations, natural forest and agricultural areas.

A cost comparison was also made between the digital mapping method from satellite imagery used in this research project and the manual mapping from aerial photography. Digital mapping from satellite imagery was found to be more cost-effective in terms of both data and human resource costs. The method outlined and discussed in the research project should provide sufficient guidance for future application of the techniques in populating the CDSS with land cover/use information.

Opsomming

Die unieke en dikwels sensitiewe landskap in die kussone is onder aansienlike druk weens ontwikkeling deur mense. Daar word verwag dat 'n derde van die wêreldbevolking teen die jaar 2020 binne 60km van die kus woonagtig sal wees. Dit sal deeglike beplanning en bestuur verg om die agteruigang van hierdie gebied te bekamp. Kussonebestuur word in Suid Afrika aangemoedig deur die implementering van 'n Witskrif vir volhoubare kussone-ontwikkeling. 'n Kusgebied-besluitnemingsondersteuningstelsel (KBOS) is ontwikkel in 'n poging om plaaslike owerhede te bemagtig om sensitiewe kusgebiede af te baken en te bestuur. Die KBOS verleen plaaslike owerhede toegang tot toepaslike inligting oor botaniese en fisiese omstandighede.

Grondbedekkinginligting vir die KBOS is in die verlede vanaf hardekopie lugfoto's gekarteer. Hierdie metode is tydrowend en duur. Die potensiaal van digitale satellietbeelde as hoof databron om grondbedekkinginligting vir die KBOS te voorsien is in hierdie studie ondersoek. 'n Metode word in die tesis uiteengesit om 'semi-supervised isodata clustering' te gebruik om die nodige inligting uit die data te onttrek. Die studiegebied sluit 'n area van 40x20km langs die suid kus van Suid Afrika in. Digitale kartering vanaf SPOT 4 multispektrale satellietdata is suksesvol gebruik om grondbedekkingsinligting soos vleilande, kusmere, duin-plantegroei, stedelike gebiede, bosbou, natuurlike bos en landbougebiede te karteer.

'n Kostevergelyking is gedoen tussen die digitale karteringsmetode vanaf satellietbeelde in vergeleke met handkartering vanaf lugfotografie. Die digitale karteringsmetode blyk meer koste-effektief te wees beide in terme van die datakoste sowel as die koste verbonde aan mannekrag. Die omskrywing van die metode in die tesis behoort as goeie riglyn te dien vir die toepassing van die tegniek om grondbedekkinginligting voor te berei vir die KBOS.

Acknowledgements

I have been privileged to receive guidance and assistance from many colleagues and friends while undergoing this research and preparing the thesis. In particular I have to acknowledge my supervisor Prof. Larry Zietsman and my mentor over the past couple of years, Mark Thompson. Financial support was provided by the CSIR Parliamentary Research Grant.

It is the love and dedicated encouragement from friends and family that gave me the strength to complete the thesis long after I have completed the technical learning curve.

Table of Contents

List of Tables

List of Figures

List of Appendices

Abbreviations

CDSS	- Coastal Decision Support System
DEA&T	– Department of Environmental Affairs and Tourism
DSS	– Decision Support System
EIA	– Environmental Impact Assessment
GIS	– Geographical Information System
ICZM	– Integrated Coastal Zone Management
KBOS	- Kussone-besluitnemingsondersteuningstelsel
ODSS	- Outeniqua Decision Support System
SCA	– Sensitive Coastal Area

CHAPTER 1: INTRODUCTION

1.1 Background

1.1.1 Introduction

The coastal zone[1] is recognised as a unique and often fragile environment that requires thorough planning and management (Barale & Folving, 1996; Rakodi & Treloar, 1997). It is expected that three quarters of the world's population will be living within 60km of the coast by the year 2020 (UN, 1993). This implies that an increasing number of human activities – ranging from recreation and residential use to agriculture and industry – will be competing for limited space and resources in the coastal zone. It has been recognised internationally that strategic and proactive management of this environment is of utmost importance for the promotion of sustainable development[2].

1.1.2 White Paper for sustainable coastal development in South Africa

In South Africa, focused coastal management efforts at a national level began in the 1980s, culminating in a White Paper for sustainable coastal development in South Africa, which was launched on 6 June 2000 (CMO, 2000). The White Paper document sets out a new policy that aims to achieve sustainable coastal development through Integrated Coastal Zone Management (ICZM). One of the goals set out in the White Paper is 'to maintain an appropriate balance between built, rural and wilderness coastal areas'. A specific objective of this goal is to proactively identify and retain wilderness areas (i.e. coastal areas valued for their natural character) (CMPP, 1999).

---

[1] 'The coast can be defined as an area with a landward and a seaward boundary that includes:
- coastal waters, which extend from the low water mark into the sea, up to the point where these waters are no longer influenced by land and land-associated activities,
- the coastline or sea shore, which is the area between the low and high water marks,
- coastlands, which are inland areas above the high water mark that influence or are influenced in some way by their proximity to coastal waters (these areas may stretch many kilometers inland).' (CMPP, 1999). This study focuses on mapping of coastal lands, referred to as the terrestrial coastal zone.

[2] During an international workshop on Integrated Coastal Zone Management (ICZM) in the Mediterranean and Black Sea (Ozhan, 1997), the following were listed as important tools for ICZM: strategic planning, Decision Support Systems (DSSs), Geographical Information Systems (GISs), Environmental Impact Assessment (EIA) and economic instruments.

Information requirements are highlighted as one of the key elements of the proposed plan of action to implement the Policy. These information requirements are discussed in relation to:

- a monitoring and evaluation system – auditing current coastal monitoring initiatives and assessing future monitoring needs,
- an information and Decision Support System (DSS)[3] - assessing the need for a DSS, developing and designing a system to link with existing information systems, and
- research – coordination of research efforts to promote sustainable coastal development (CMPP, 1999).

1.1.3 Sensitive Coastal Areas (SCAs) and the Coastal Decision Support System (CDSS)

Regulations were promulgated in 1996 to prohibit activities such as earthworks, disturbance of vegetation, dredging and dune de-stabilisation within demarcated SCAs. The initial test case was the Outeniqua SCA, extending from the Tergniet to the Kaaimans Rivers along the South African Garden Route coast. Further regulations were promulgated in 1998 for an extention of the Outeniqua SCA to the Bloukrans River, as well as establishment of another test area at Pennington and Umtamvuna on the KwaZulu-Natal South Coast (CMO, 2000; Urban Management, 1997). This initiative laid the foundation for promoting one of the goals in the White Paper for sustainable coastal development in South Africa, namely – 'to maintain an appropriate balance between built, rural and wilderness coastal areas' (CMPP, 1999). Demarcation and effective management of SCAs accentuate the importance of these areas, often in need of protection from encroaching development.

The Outeniqua Decision Support System (ODSS) was implemented in 1995 as a joint project of the Department of Environmental Affairs and Tourism (DEA&T) and the CSIR. The objective was to produce a prototype system that could empower local authorities to demarcate and manage SCAs by giving them access to relevant botanical and physical information for determining environmental sensitivity (Raal *et al.*, 1995).

---

[3] The term decision support system (DSS) is defined as 'information and procedures that aid informed decision-making' in the draft white paper (CMPP, 1999).

The following features are used in identifying SCAs:

- physical sensitivity (steep slopes, mobile dunes, etc.),
- natural vegetation,
- archaeological resources, and
- other information (such as rare and/or endangered species, visual importance, cultural resources and socio-economic aspects) (DEA&T, 1998).

The DEA&T has revised and improved the ODSS in consultation with decision-making authorities. The ODSS, now called the Coastal Decision Support System (CDSS), is being promoted by the DEA&T as a tool to assist applicants and decision-making authorities in the implementation of SCA regulations (CMO, 2000). Decision-making authorities in the Outeniqua SCA successfully adopted the system, and systems are currently being populated for the SCAs in KwaZulu-Natal.

1.2 Problem statement

The maintenance of the information provided in the ODSS was mentioned as the key area of concern by participants at both the initial scoping meeting to determine user requirements and a later workshop to present enhanced physical sensitivity features of the ODSS to local authorities (Brown, 1998).

The DEA&T has expressed the need to identify a cost-effective method for populating, updating and maintaining land cover information provided in CDSSs (Malan, 1999). The DEA&T suggested that the land cover information will have to be updated every three to five years, but a set interval has not been specified. The rate of change in the natural environment as well as changes caused by development in each SCA, will determine the time frame for updating and maintenance of land cover information for the CDSSs. End users will have to take ownership of the CDSS for their area, and could, for example, focus on fast changing areas within their SCA when updating information. The DEA&T has also indicated that they would like to extend the concept of the CDSSs, which is currently being implemented in sensitive coastal areas, to cover the whole coastline of South Africa (Jumat, 1999). This will be done in accordance with goals and guidelines for addressing information needs in the South African coastal zone, as outlined in the White Paper for sustainable coastal development in South Africa.

Land cover[4] information (such as vegetation, wetlands, coastal lakes and agricultural areas) for the ODSS was derived from visual interpretation of 1:10 000 scale colour aerial photography acquired in 1987. The features were mapped onto clear acetate and the 1:10 000 scale ortho-photo map series (dated 1973/1989) was used for spatial correction. A minimum mapping unit of 1ha, representing an area of 1x1cm on the 1:10 000 scale photos, was used (Burns, 1999). The overlays were digitised, mosaiced and edge-matched to provide a continuous digital information layer as input to the ODSS. Manual mapping from aerial photography was found to be time-consuming and costly. The DEA&T has indicated that this method will be unsuitable for populating, updating and maintaining land cover information for CDSSs in South Africa, especially if the CDSSs were extended to cover the whole coastline of South Africa. Hence, the following problem statement has been identified:

Manual, paper-based mapping from aerial photography for populating, updating and maintaining land cover information for the Coastal Decision Support System is time-consuming and costly.

1.3 Aims and objectives

Johannsen and Sanders (1982) stated in their assessment of remote sensing options for coastal zone management in the United States that airborne photography is a better way to keep inventory and develop maps at scales of less than 1:24 000, but that repeat coverage of large areas becomes expensive and time-consuming. They suggested that satellite remote sensing offers unique inventory and change-detection possibilities, as it provides large-area, repeat-coverage capability. Various authors such as Houhoulis Smith (2001) and Phinn *et al.* (2000) have demonstrated the efficient application of satellite remote sensing towards mapping coastal environments.

It was decided to assess digital satellite remotely sensed imagery as potential alternative primary source of data for mapping land cover information for the CDSS. The large area

[4] Land cover can be defined as 'the vegetational and artificial coverings of the land surface' (Burley, 1961), or in Thompsons' (1996) words 'all the natural and man-made features that cover the earth's immediate surface'. This includes 'vegetation (natural or planted), human constructions (buildings, roads etc.), water, ice and bare rock or sand surfaces' (Di Gregorio, 1996). Land use includes human activity that is associated with a specific land-unit, in terms of utilization, impact, or management practices (Clawson & Steward, 1965; Thompson., 1996). A point on the earth's surface can have one land cover type with several land uses (e.g. a 'grassland' may be used for communal grazing within a conservancy area) (Thompson *et al.*, 1996).

synoptic view provided by satellite imagery minimises the need for mosaicing images to cover the study area. Furthermore, digital analysis was chosen, as the CDSS requires digital information as the final product format. Less time will therefore be spent on converting data formats than would be the case with manual mapping from hardcopy imagery.

The aims of this study are therefore:

- *to assess digital satellite imagery as primary source of data, in terms of quality of information and cost, for terrestrial coastal zone mapping,*
- *to assess digital mapping from satellite imagery as an alternative method to manual mapping from hardcopy aerial photography for populating land cover information for the Coastal Decision Support System.*

The following objectives have been addressed in order to meet the above aims:

- review satellite remote sensing as a source of spatial data, providing background information on its potential as primary source of data for this study,
- investigate the characteristics of the Outeniqua SCA and information needs of the CDSS to define an appropriate land cover classification system for extracting information from satellite imagery for the study area,
- assess information derived through digital mapping from satellite imagery in this study in terms of its thematic/classification accuracy and cost and compare the method with manual mapping from aerial photography, and
- draft guidelines and recommendations for the application of digital satellite remote sensing for terrestrial coastal zone mapping.

The detailed characteristics of the CDSS will not be discussed, nor will the CDSS be evaluated in this study. The focus of the study is on the methodology for digitally capturing land cover information from satellite imagery as input to a digital DSS[5], such as the CDSS.

---

[5] According to Sprague & Carlson (1982) the key characteristics of a DSS is a computer based system that:
- incorporates both data and models,
- is designed to assist managers in semi-structured or unstructured tasks,
- supports rather than replace management judgment, and
- improves the efficiency with which decisions are made.

1.4 Research framework

Figure 1.1 provides a conceptual framework of the methodology of this research in order to realise the aims mentioned in the previous section. The study consisted of three main elements:

- a review of relevant, current literature,
- the process of digitally extracting land cover information from satellite imagery for incorporation with the CDSS, and
- a cost assessment of this process, which was also compared to the process of manual mapping from aerial photographs to determine its applicability as an alternative method for populating, updating and maintaining information for the CDSS.

The process of digitally extracting land cover information from satellite imagery for incorporation with the CDSS involved the following steps:

- land cover information that should be extracted from digital satellite imagery for incorporation into the CDSS was identified through consultation with the client (the DEA&T) and a field orientation visit to the study area,
- digital satellite imagery as primary source of data, ancillary data and field data were obtained for the chosen area of study and used to digitally derive land cover information for the study area, and
- the land cover map compiled for the study area was evaluated in terms of its thematic accuracy and processed for incorporation with the CDSS.

This process involved close liaison with local specialists.

The findings of the study are presented in this thesis as guidelines and recommendations for the application of digital satellite remote sensing for terrestrial coastal zone management. A summary of the thesis can be viewed at http://www.csir.co.za/environmentek/index.html. The results of the study was presented as a paper at the 27th International Symposium for Remote Sensing of the Environment, which was held in Somerset West, South Africa in March 2000.

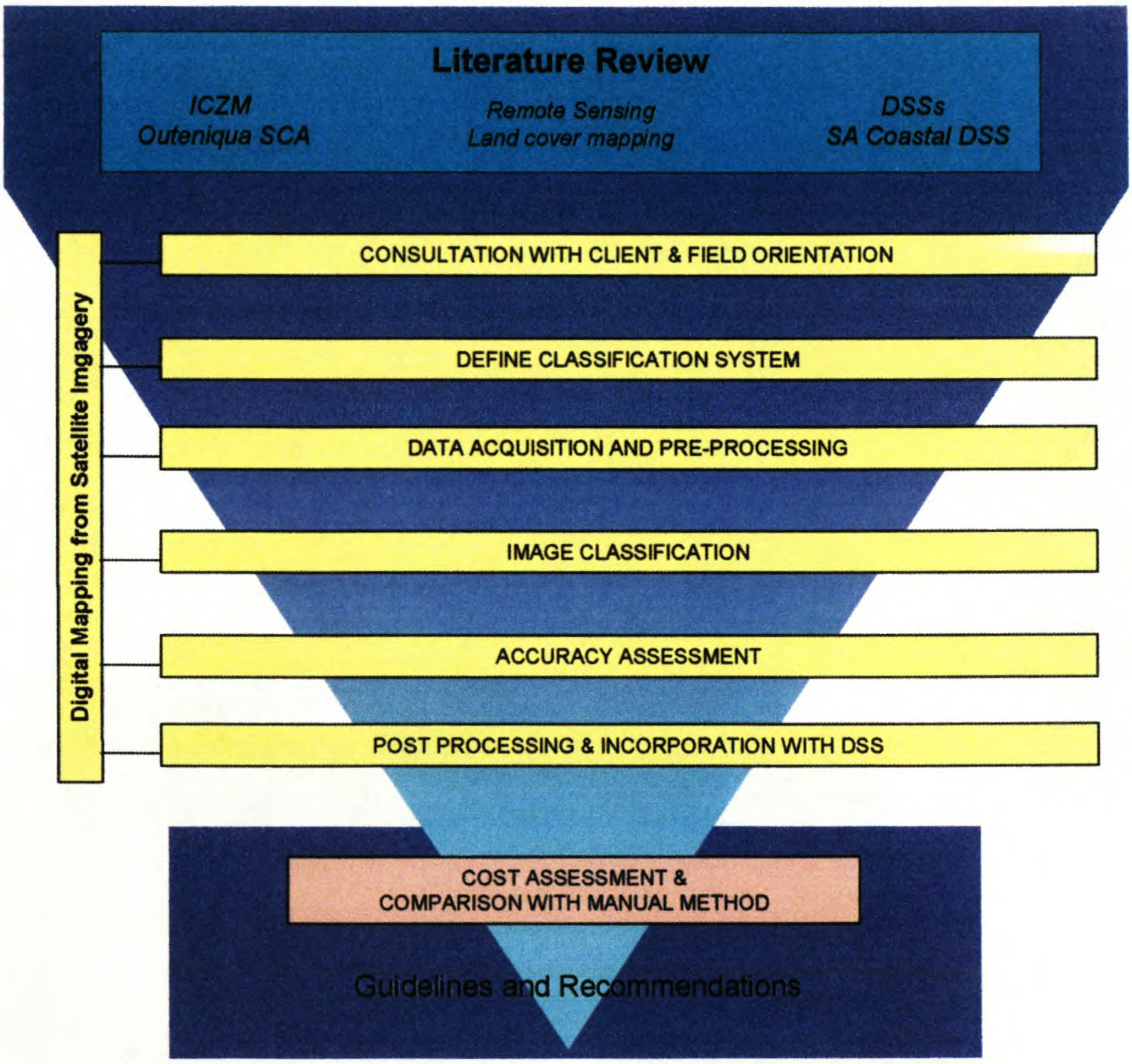


Figure 1.1 Diagrammatic outline of the research methodology.

1.5 Thesis structure

This thesis is structured as follows:

Chapter 1 consists of a brief introduction and background to the study and describe the characteristics of the study area. Chapter 2 follows with an overview of remote sensing and its applications to land cover mapping. The acquisition and processing of data for the project is explained in Chapters 3 and 4 with a discussion of the results in Chapter 5. Chapter 6 provides a summary of the thesis as well as concluding remarks and recommendations for the application of digital satellite remote sensing as primary source of mapping land cover information as input to the CDSS.

1.6 The study area

1.6.1 General location and spatial extent

The area surrounding the Sedgefield and Wilderness urban centres - which is located on the southern coastal plain of South Africa - was chosen as study area for this study in consultation with the client (the DEA&T). Most of the environmental features mapped for the ODSS are represented here. The general location of the study area is between 33° 56′ 00″S and 34° 05′ 20″S latitude and 22° 34′ 00″E and 22° 58′ 00″E longitude as shown in Figure 1.2.

The study area, which lies within the Outeniqua SCA, comprises an area of approximately 40km along the coastline extending approximately 20km inland. The Outeniqua SCA stretches approximately 155 km between the Tergniet and the Bloukrans rivers and extends 5 to 20km inland from the high water mark (South Africa, 1998a; South Africa, 1998b).

Figure 1.2 The general location of the study area within the Southern Cape Coastal Zone.

1.6.2 Physiographical description of the Outeniqua SCA

Geological variation and the associated soils together with spatial rainfall variations are largely responsible for the diversity of vegetation types that occur along the South African coastline (CSIR, 1991). The Southern Cape coastline is characterised by a series of half-heart shaped embayments with the adjacent coastal hinterland filled with Cretaceous to Recent sediments. The area is furthermore characterised by the presence of Pleistocene and Holocene dunes with the imbricate parabolic dune system at Groenvlei serving as a spectacular example (CSIR, 1991; Strydom, 1992). The above-mentioned area extends between 5 to 40km inland and is backed by west-east trending sub-parallel quartzite mountain ranges (Tinley, 1985). The topography between the coastline and the mountain ranges varies from undulating to hilly.

Martin (1962) and Chunnet (1964) describe the Wilderness lakes area as having formed a shallow embayment, which became cut off from the sea through the development of dune systems (mentioned above) that formed during low sea level phases. The marine system was subsequently transformed into a number of tidal lagoons or brackish fresh water lakes.

Recent (younger than 150 million years) deposits of aeolian sand, fixed dunes and dune sand (the dune systems) and alluvium (associated with the lake systems as described above) dominate the lithology of the study area (Figure 1.3). A deposit of Porphyritic biotite-muscovite granite is found in the northwestern section of the study area with bands of rocks and soils associated with the Gamtoos group (their age is estimated to be approximately 800 million years) extending between the dune systems and the Outeniqua mountain range. The Cape Supergroup is the backbone of the Cape Fold Belt mountains (Rust, 1998), which includes the Outeniqua range. See Appendix A for an overview of the geological succession in the Southeastern Cape coastal zone.

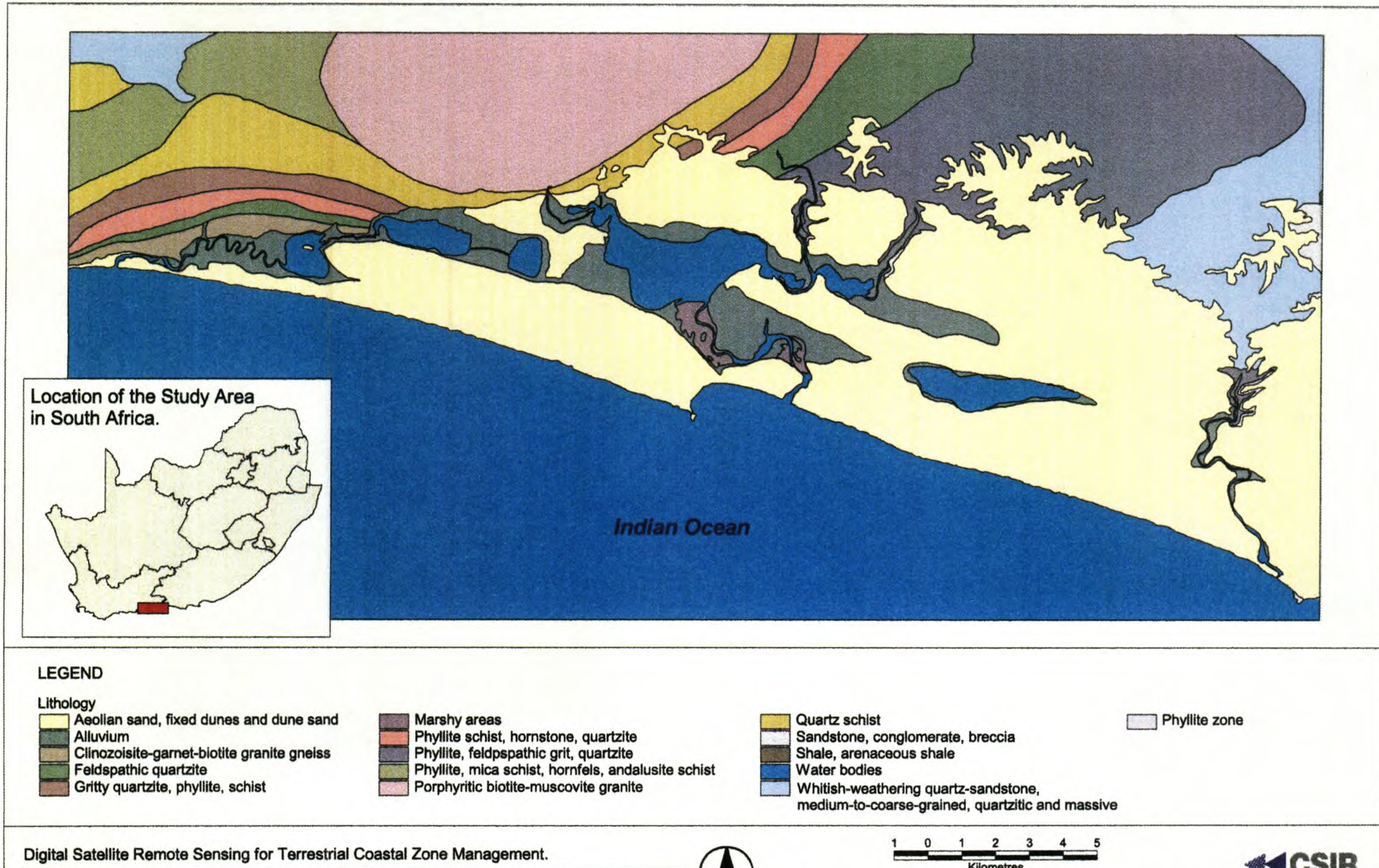


Figure 1.3 The lithology of the study area.

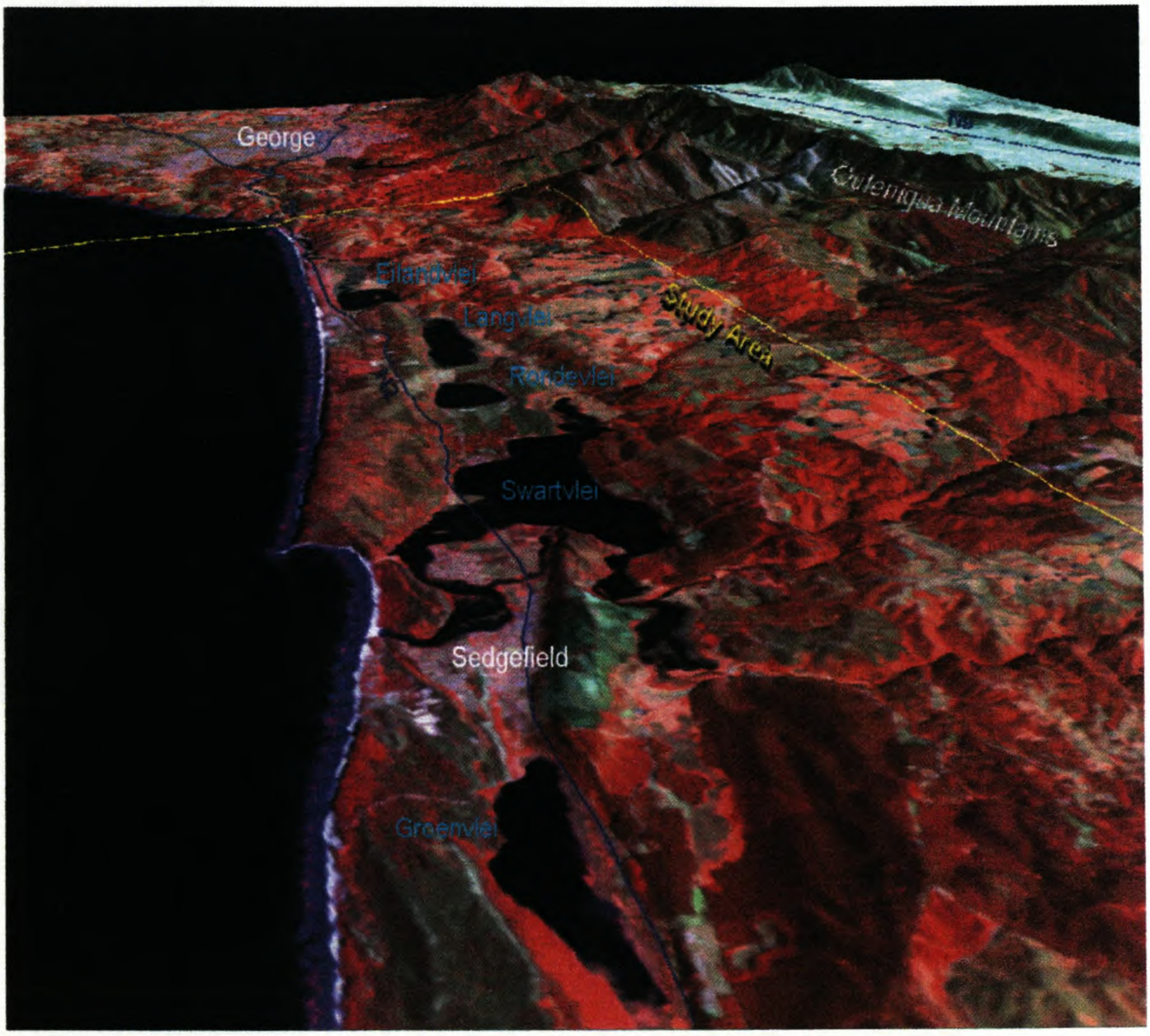


Figure 1.4 SPOT 4 image (band combination RGB = 3,4,2) draped over a 20m DEM of the study area.

1.6.2.1 Climate

i Rainfall distribution

The average annual rainfall for the study area is 684mm with an all-year rainfall distribution showing a slight increase in precipitation in March and October (Figure 1.5). The rainfall data for the study area, obtained from the South African Weather Bureau, are presented in Appendix B.

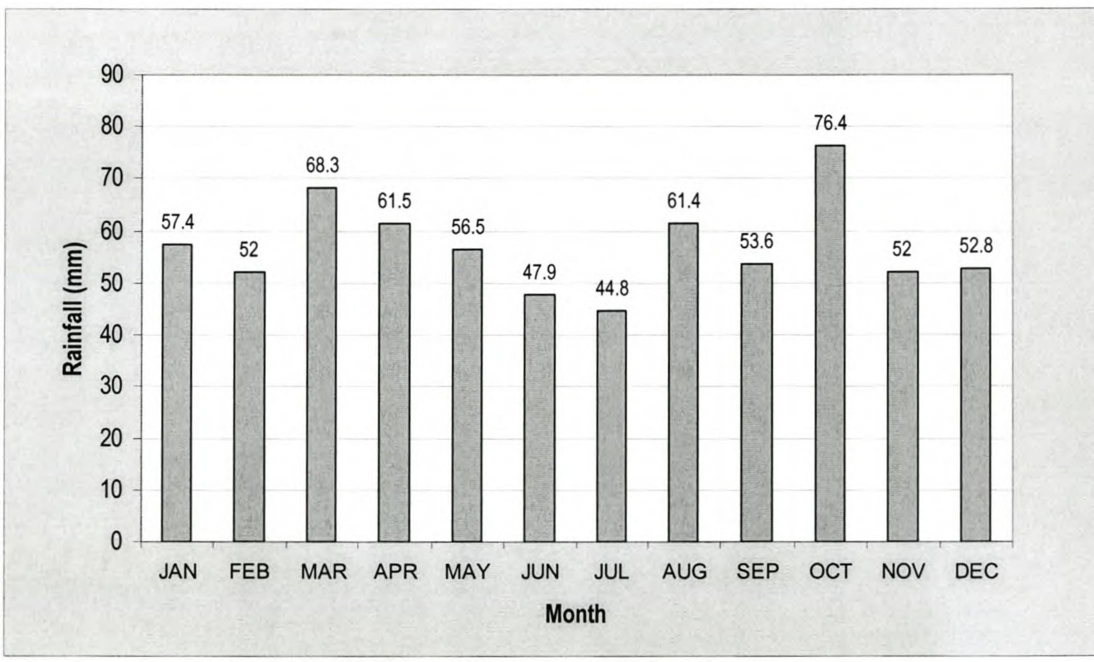


Figure 1.5 Long term monthly average rainfall for the Sedgefield/Wildernes area (Swartvlei weather station).

ii Temperature

The Cape South Coast experiences a warm temperate climate (Heydorn & Tinley, 1980; Tinley, 1985). Temperatures along the coast are moderate due to the proximity of cold inshore waters, high humidity values, high cloud cover and the cooling effect of the coastal wind regimes.

iii Wind

The entire South Coast is exposed to relatively strong winds that tend to be aligned roughly to the east-west coastline orientation. The westerly, low pressure cyclonic winds tend to occur throughout the year, while the high pressure, anticyclonic easterlies have a higher frequency of occurrence during spring and summer. The windiest season is from midwinter to spring (CSIR, 1991; Preston-Whyte & Tyson, 1988).

1.6.2.2 Land cover in the study area

The distribution of vegetation is affected directly by climatic effects such as solar radiation, temperature and moisture, and indirectly through the influence of soil conditions (Shantz & Marbut, 1923) and fire regime (Cowling *et al.*, 1997). The study area falls within the Cape phytogeographical[6] region, where one would commonly expect to find fynbos on the nutrient deficient soils and shrubland in the drier intermontane valleys. Patches of thicket (Tongaland-Pondoland) are to be found along the coast, whereas afromontane forest occur at the base of the wetter, coastal mountains (Cowling *et al.* 1997). Coastal lakes, wetlands and saltmarshes also characterise the area (these are described in Section 4.3). Intervention by man introduced urban uses, agricultural lands and forest plantations.

1.7 Summary

It is expected that three quarters of the world's population will be living within 60km of the coast by the year 2020. In South Africa, focussed coastal management efforts at a national level are being promoted through the White Paper for sustainable coastal development in South Africa. Information (including spatial information) is key to the success of the sustainable development aims as outlined in the White Paper. The Coastal Management Office of the South African Department of Environmental Affairs and Tourism has initiated a CDSS for South Africa. This study investigates the use of digital satellite remote sensing as primary source of data to populate, update and maintain the land cover information in the aforementioned decision support system. The appropriateness of the technology will be evaluated against manual mapping from hardcopy aerial

---

[6] Phytogeography is the study of the geographical distribution of plants (Holmes, 1979).

photography, a technique that has been used in the past to map land cover information for the prototype decision support system as developed by the Department of Environmental Affairs and Tourism. The terrestrial coastal environment around Sedgefield and Wilderness on the southern coast of South Africa will be used as study area as this provides a typical sensitive coastal environment under pressure from human impact and development.

CHAPTER 2: REMOTE SENSING: HISTORY AND FUNDAMENTAL CONCEPTS

2.1 Introduction

This chapter provides an overview of the origin and evolution of satellite-based earth observation sensors as well as fundamental concepts related to satellite remote sensing. It also addresses the applicability of satellite remote sensing as data source for land cover mapping. Data quality elements, which are discussed in following chapters of this thesis, are introduced.

2.2 Origin and evolution of remote sensing

For the purpose of this thesis, remote sensing is defined as:
'the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface' (Campbell, 1996: 5).

A few milestones in the history of remote sensing (1800 – 1990s) that trace the evolution of the field are presented in Table 2.1. According to Curran (1985) and Elachi (1987), aerial photography can be seen as the first method of remote sensing. Cameras strapped to the breasts of pigeons were used in the nineteenth century to obtain photographs of Paris. The first man-made platform used for gathering remotely sensed information was a hot air balloon with a hand-held camera as the sensor. Gaspard Tournachon took the first known aerial photograph at a height of 80m over the town of Bievre in 1858 (Lillesand and Kiefer, 1994).

Following the initiation of the field of remote sensing as depicted above, the next milestone is the use of powered airplanes as platforms for aerial photography in the 1900s. During World War II (1939 – 1945) use of the electromagnetic spectrum was extended from almost exclusive emphasis on the visible spectrum, to other regions such as the infrared and microwave regions. The 1960s saw the launch of the first meteorogical satellite (TIROS-1) that provided the basis for later development of earth observation satellites. Landsat 1, launched in 1972, was the first of many of these earth-orbiting satellites designed for observation of the earth's land areas. A new generation of Landsat sensors, along with sensors such as SPOT (the French Observation Satellite) providing a higher level of spatial detail was launched in the 1980s. During the 1990s sensors with even higher spatial resolution was introduced. This includes the first commercial high resolution satellite Ikonos that was launched on 24 September 1999. Radar instruments and hyperspectral imaging instruments were also introduced in the 1990s. Another feature of the 1990s is the rapid advances being made in image processing software and hardware capabilities (Campbell, 1996; Konecny, 1987; Aronoff, 1989).

Table 2.1 Milestones in the history of remote sensing.

1800	Discovery of infrared region of electromagnetic spectrum by Sir William Herschel
	Beginning of practice of photography
1839	Infrared spectrum shown by A.H.L. Fizeau and J.B.L. Fouault to share properties
1847	with visible light
	Photography from balloons
1850-1860	Theory of electromagnetic energy developed by James Clerk Maxwell
1873	Photography from airplanes
1909	World War I: aerial reconnaissance
1910 – 1920	Development of initial applications of aerial photography and photogrammetry
1920 – 1930	Development of radar in Germany, United States and United Kingdom
1930 – 1940	World War II: applications of non-visible portions of electromagnetic spectrum;
1940 – 1950	training of persons in acquisition and interpretation of airphotos
	Military research and development
1950 – 1960	Colwell's research on disease detection with infrared photography
1956	First use of term 'remote sensing'
1960 – 1970	TIROS weather satellite
	Skylab remote sensing observations from space
	Launch of Landsat I
1972	Rapid advances in digital image processing
1970 – 1980	Landsat 4: new generation of Landsat sensors
1980 - 1990	(SPOT) French Earth Observation Satellite
1986	Seasat Synthetic Aperture Radar (SAR) imaging satellite launched in 1978
1980s	Development of hyperspectral sensors
	SAR imaging satellites launched (ERS, RADARSAT, JERS)
	Landsat 7 launched on 15 April 1999 – new data and pricing policy promoting the
1990s	use of satellite data
	First commercial high resolution satellite IKONOS launched on 24 September
	1999
	MODIS hyperspectral imaging instrument launched aboard the Terra (EOS AM-1)
	satellite on 18 December 1999
	Major advances in image processing software and hardware

Source: *Adapted from Campbell, 1996; Landsat 7, 2001; IKONOS, 2001; MODIS, 2001.*

2.3 Satellite remote sensing basics

2.3.1 Spectral resolution

Satellite systems are either 'passive' or 'active' in their observation of the earth's surface:

- 'passive' systems sense the naturally available energy (the sun acts as source of illumination for these systems),
- 'active' satellites, such as radar systems, provide their own source of energy to illuminate features of interest.

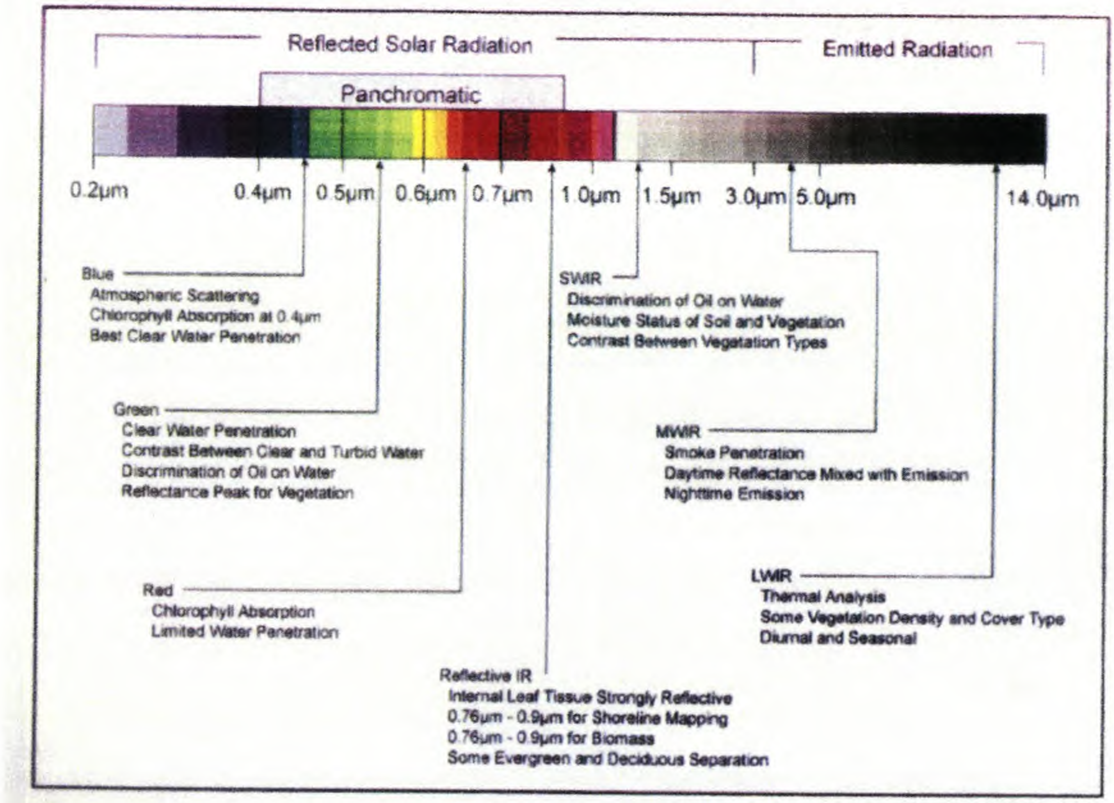
This study will focus on passive systems that are currently more commonly used for land cover mapping (Lillesand & Kiefer, 1994).

Satellite systems detect energy reflected or emitted from features on the earth in the form of electromagnetic radiation. The electromagnetic spectrum ranges from the shorter wavelengths (including gamma and x-rays) to the longer wavelengths (including microwaves and broadcast radio waves). Regions of the electromagnetic spectrum that are useful for earth observation remote sensing are the:

- visible spectrum,
- infrared region, and
- microwave region.

Figure 2.1 illustrates regions between the ultraviolet and long wave infrared regions (visible spectrum and infrared region) of the electromagnetic spectrum, as used for remote sensing. Microwaves are the longest wavelengths commonly used in remote sensing. They are from 1nm to 1m in wavelength. Microwaves (as used in radar) are capable of penetrating the atmosphere under virtually all conditions, whereas typical wavelengths used by optical sensors are limited to cloud-free periods for image acquisition (White, 1977; Lillesand & Kiefer, 1994; Scheepers, 1998).

Satellite sensors are designed to record specific portions of the electromagnetic spectrum, which are referred to as bands or spectral channels. The ability of sensors to record electromagnetic radiation within specific wavelength intervals is described as the sensors' spectral resolution (Morain & Lopez Baros, 1996).



Source: *Morain & Lopez Baros, 1996.*

Figure 2.1 Commonly used regions of the electro magnetic spectrum between the ultraviolet (0.2um) and long wavelength infrared (14um).

2.3.2 Spatial resolution, pixel size and scale[7]

Woodcock & Strahler (1987) stated that 'remotely sensed data are restricted to specific working scales by the very structure of the data, since it is a combination of the spatial structure of the image and the viewed environment that determine the appropriate scales of observation'.

Spatial resolution of passive optical satellite sensors, e.g. SPOT and Landsat TM, depends primarily on their Instantaneous Field of View (IFOV). IFOV is the angular cone of visibility of a sensor determining the area on the earth's surface viewed by an instrument from a given altitude at a particular moment in time. This area on the ground is called the resolution cell, indicating the sensor's maximum spatial resolution (CCRS, 2000).

---

[7] These guidelines refer to digital satellite imagery. For hardcopy print imagery the relationship between image resolution, print scale and printer resolution should also be taken into account (Thompson *et al.*, 1996; Fowler, 1997).

Digital satellite imagery consists of a matrix of picture elements, or pixels – the smallest part of an image. This minimum area determines the spatial detail that can be displayed on an image or mapping resolution. When an image is displayed at full resolution, the pixel size of the image will equal the spatial resolution of the sensor, i.e. an image from a 20m - resolution sensor is displayed with each pixel representing 20x20m. In well-designed sensors, the IFOV is equal to the resolution cell/pixel and the spatial resolution (ERDAS, 1997).

Scale[8] can be defined as the number of metric units in the space of the real world that are represented by a unit in the space of the map model (Cromley, 1992). Deane *et al.* (1989) suggested that the maximum advisable scale for use with any imagery is in the order of '1:3 000 x ground resolution (pixel size) of the imagery'. Approximate guidelines by Thompson (1994) based on local (South African) experience are very similar (see Table 2.2).

Table 2.2 Recommended maximum (cartographic) scales for RS data

Sensor/data	**Guidelines for maximum (cartographic) operating scale**	
	After Deane *et al.*, 1989	**After Thompson, 1994**
SPOT Pan (10m)	1:30 000	1:40 000
SPOT XS (20m)	1:60 000	1:50 000
Landsat TM (30m)	1:90 000	1:70 000
Landsat MSS (80m)	1:240 000	1:100 000

Source: *Thompson et al., 1996.*

[8] The convention is that a small-scale map has a relatively small size ratio (for example 1:100 000) and a large-scale map has a relatively large size ratio (for example 1:10 000) (Foody & Curran, 1994; Fowler, 1997).

2.3.3 Minimum mappable unit

In the context of this thesis, minimum mapping units are defined as the smallest spatial unit within which the dominant land cover to be mapped for the CDSS can be consistently and repetitively mapped, and only landscape elements that exceed a given minimum mapping unit will be classified (Thompson, 1999; Lunetta, 1999; Stuckens *et al.*, 2000).

The minimum mappable unit of digital satellite data depends on the sensors' maximum spatial resolution or ground resolution (resolution cell), as well as the size, shape and spectral characteristics of the features being observed. The ground resolution of a sensor and the size and shape of the features observed result in digital images comprising a range of 'pure' (containing spectral information on a single feature) and 'mixed' pixels (containing spectral information on more than one feature). The ratio of these will vary according to whether the pixels are larger or smaller than the features being viewed (Cao & Lam, 1997).

Since a land cover unit/feature must contain at least one complete/'pure' image pixel unit to be identified, the effective minimum mappable unit of a sensor is considered to be 3x3 pixels (assuming pixel = ground resolution) (Thompson, 1994). This rule of thumb compares well with information presented by Lunetta (1999) that the spatial resolution (i.e. pixel size) of imagery should be approximately one order of magnitude smaller than the required theoretical minimum mapping unit. This is not a hard and fast rule since certain features with distinct spectral characteristics such as dams might, for example, be discernable even though they are smaller than the spatial resolution – this is due to the 'spectral saturation' of an entire pixel (Townshend and Justice, 1988).

2.4 Earth observation by satellites

According to Stoney & Hughes (1998) and Scheepers (1998) there are over 30 earth-viewing satellites in orbit providing data with spatial resolutions of 30 meters or less. These sensors can be classified into four groups:

- satellites that offer broad area coverage, with spatial resolution of 5 to 30 meters or more in multiple colour bands,

- high spatial resolution satellites, with spatial resolution of 1 meter or less as panchromatic images in visible as well as near-infrared parts of the electromagnetic spectrum,
- hyperspectral sensors, with 30 meter spatial resolution, and
- radar, with 5 to 10 meter spatial resolution.

2.4.1 Satellite remote sensing for land cover mapping

Satellite remote sensing has a multitude of uses in application fields such as plant sciences, earth sciences and hydrospheric sciences (Campbell, 1996; Nikolaos, 1988; Johnston & Barson, 1993). The application of satellite imagery for land cover mapping is of special interest to this study. Satellite imagery is seen as a suitable source of primary data to undertake such a land inventory. Studies by Gastellu-Etchegorry (1990), Tateishi & Mukouyama (1987), Katsch & Vogt (1999) and Hill *et al.* (1998) demonstrate the successful use of Landsat and SPOT data for this purpose. More specifically relevant to this study Kunte & Wagle (1994) and Klemas (2001) used digital image processing of SPOT data and Landsat data respectively to show that coastal information such as estuarine, vegetation and near shore features can be identified and mapped from SPOT imagery. Kovacs *et al.* (2001) used Landsat 5 imagery successful for mapping land cover information classes in a coastal environment. Multi-date imagery furthermore provides the temporal information required to monitor land management practices (Skidmore *et al.*, 1997).

2.5 Data quality

Bernhardsen (1992) stated that good data descriptions and specifications of accuracies are two of the best assurances of proper data use. According to Veregin & Hargitai (1995) data quality assessment, in the context of geographical databases, are usually based on two dimensions:

- 'geographical observations are defined in terms of space, time and theme. Each of these dimensions can be treated separately (but not independently) in data quality assessment, and

- data quality is an amalgam of overlapping components, including accuracy, resolution, completeness and consistency. The quality of geographical databases can not be adequately described with a single component'.

These two dimensions are also applicable in the description of satellite data and derived information, which are usually incorporated into a geographical database. The quality of satellite data used in this study and the derived information/maps for incorporation into the CDSS is primarily described in terms of the data quality components of accuracy and resolution. These two quality components are addressed in the following sections:

- spatial accuracy - Section 5.2,
- temporal accuracy - Section 3.3.2,
- thematic accuracy/classification accuracy - Section 5.3,
- spatial resolution -Sections 2.3.2, 3.3.2 and 5.2,
- temporal resolution - Section 3.2, and
- thematic resolution relates to the classification levels as defined for the Classification System in Section 4.3.

Completeness and consistency are not specifically addressed in this study, but aspects of these data quality components are reflected in the accuracy and resolution descriptions. According to Bernhardsen (1992) data completeness describes how completely data on an object type has been entered. In mapping applications such as this study, errors of omission could, for example, result from elimination of features that are smaller than the minimum mapping unit size.

Consistency is a measure of the internal validity of a database and refers to the fidelity or integrity of the database (DCDSTF, 1988). Veregin & Hargitai (1995) provides geographical database-related descriptions of spatial, temporal and thematic consistency that are not relevant to the understanding of the accuracy of the satellite data and derived information/maps for this study. In remote sensing mapping applications the Kappa statistic is often utilized to report chance agreement and give an additional measure of classification accuracy – to give an indication of the scientific repeatability of the mapping exercise (see Section 5.3). Relevant aspects of the quality of ancillary data used in this study are described in Section 3.4.

2.6 Summary

Remote observation of the land surface dates back as far as the nineteenth century when cameras were strapped to the breasts of pigeons to obtain photographs of Paris. Since then both the sensors used for observation as well as the platforms have changed considerably. Satellites are now routinely used to mount sensors for observation of the earth. This thesis will focus on sensors that utilise the visible and infrared region of the electromagnetic spectrum for observation. Reports in literature indicate a high degree of success when utilising these sensors for land cover mapping. It is of relevance to understand the nature of the data source and of equal importance to understand and describe the quality of the derived information, as this will influence the effective utilisation of the end products. The data quality components introduced in this chapter will be elaborated on in chapters three, four and five of this thesis.

CHAPTER 3: ACQUISITION AND PREPROCESSING OF DATA

3.1 Introduction

Digital satellite imagery as primary source of data for this study is described in this chapter with regard to factors such as end user data requirements, the effect of spectral and spatial resolution, timing of data acquisition and cost-effectiveness of remotely sensed data. The characteristics of the primary satellite image acquired for the project are outlined. Ancillary data, which include digital topographical data, data on geological features, additional remotely sensed data and information from the South African national land cover database, are presented. The field data that were collected for the thematic accuracy assessment, along with the procedure for collecting the sample data, are also discussed. The hardware and software used for manipulation of the data are listed along with the procedures for preprocessing the primary and ancillary data.

3.2 The Satellite Application Centre (SAC)

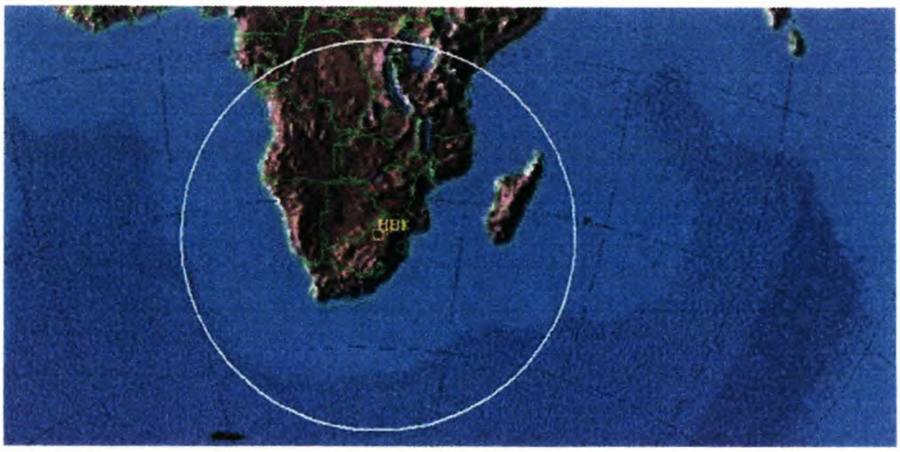
The Satellite Application Centre (SAC) was established in 1976 (then known as the Satellite Remote Sensing Centre (SRSC)) for reception of geo-information from satellites and became part of the world wide tracking network in 1983. International ground stations such as the SAC provide essential communication with satellites in terms of:

- receiving health-and-status reports from the satellite, uploading commands to image particular regions of the planet, and uploading new software[9], and
- down-linking (receiving) satellite data.

The SAC is situated approximately 60km north west of Johannesburg and 90km west of Pretoria, South Africa. Figure 3.1 provides an indication of the operational area covered by the SAC, also called a 'footprint'. The study area for this study falls within the footprint of the SAC. The SAC provided sponsorship of the satellite imagery used in this

[9] These functions are normally referred to as Telemetry, Tracking and Control (TT&C).

study and the selection of satellite data was thus focussed on the SAC portfolio of sensors[10].



Source: *SAC, 2002.*

Figure 3.1 The Satellite Application Centre (SAC) coverage area/footprint.

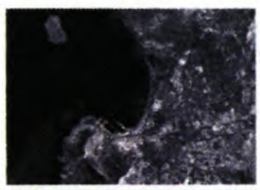
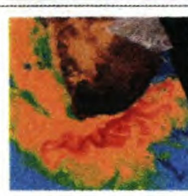
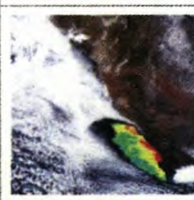
Earth obsaervation data from the following satellites is available from the SAC:

- Landsat,
- SPOT,
- ERS,
- NOAA
- EROS (SAC, 2002; SAC News, 2002).

The SAC is also a distributor for Radarsat imagery and has a re-seller agreement to distribute Ikonos data (SAC News, 2000.) Table 3.1 provides an overview of the SACs satellite data and image product portfolio as well as examples of applications the data are suitable for.

10 The SAC portfolio of data and products is constantly adapting to the needs of the earth observation community requiring data from the SAC footprint and the availability of new sensors. The SAC portfolio has changed since the selection of satellite data for this study was made including for example sensors with higher spatial resolution (such as SPOT 5). New sensors, providing higher spatial and / or spectral resolution provides opportunities to enhance the methodology described in this thesis. The findings presented in this thesis in terms of the potential of the specific primary data source (SPOT 4) evaluated however, remains valid.

Table 3.1 SAC satellite data and image product portfolio (2000).

Description	Sample Image	Applications
SPOT (Spot Image) Archive-1989 to present <u>Standard products:</u> Levels 1A, 1B and 2A Mono/XI merges and quarter scenes for SPOT 4 <u>Image products :</u> Levels 2B, and also, image tiles, Pan/Xs merges, image maps Output in CAP format **Landsat** (Space Imaging) Archive-1980 to present <u>Standard products:</u> Level 5, full and standard quarter scenes Level 8 in full or partial floating scenes Output is EOSAT FF <u>Image products:</u> Levels 9 and also image tiles, merges, image maps	 This Spot image of the northern parts of Pretoria, Gauteng, South Africa was acquired by the SPOT 4 satellite. Urban areas in cyan. The rectangular shape of smallholdings in the area (on the right of the image) - with agricultural activity and crops in different stages of growth - are clearly visible.  The rocky mountain formation (stemming from pre-volcanic activity and upliftment) for which the Pilanesberg area in South Africa's Northwest Province has become known, is captured by this Landsat image. Also visible is overgrazing and informal settlements in the north and Sun City and its golf courses nestled in the mountains. Mining activities are evident - see the blue patches towards the north west	**SPOT and Landsat data suitable for applications in:** **Agriculture** (precision farming, crop/forest harvests/biomass determination/soil conditions/habitat assessment/insect infestation) **Land Use and Mapping** (urban growth/transportation networks/flood plains/socio-economic impact) **Geology** (classifying rock types/volcanic surface deposits/ indications of mineral and petroleum resources/geomorphic maps) **Hydrology** (surface water areas/floods and flood plain characteristics/glacial features/lake inventories & health/snow melt runoff/tropical rainfall/watersheds) **Coastal Resources** (patterns and extent of turbidity/shoreline changes/ lanes/beach erosion and flooding/coral reef health/coastal circulation patterns/sea surface temperatures/red tides) **Environmental Monitoring** (deforestation/volcanic flow/water pollution/natural disasters/oil spills/mine waste pollution/volcanic ash plumes)
ERS (European Space Agency) Archive-1994 to present The portfolio exists of RAW, SLC, PRI and GEC standard products. All are available in CEOS format on CD Rom	 This ERS image of Cape Town clearly shows the harbour and ships on a calm/windless sea with Robben Island top left. Storage tanks are visible as a white triangle slightly inland.	**Environmental monitoring** (man-made illegal or accidental ocean spills) **Marine Climatology** (wave Forecasting) **Ice Monitoring** **Tropical monitoring of crops** **Geology** (geological features as result of ability to penetrate vegetation to a certain extent)
NOAA (National Oceanographic and Atmospheric Administration of the USA) Archive-1984 to present <u>Standard products:</u> Raw data in a TDF format (Seaspace system) on CD-Rom or via FTP Level 1B is provided in LAC	 A NOAA image which demonstrates the fusion of the warm Agulhas stream off the South African West Coast and the cold Benguela stream lining the east coast from Mozambique southwards.	**Weather** (warnings, conditions, hurricanes, tornadoes) **Oceanography** (coral reefs, tides and currents, buoys, marine sanctuaries, estuaries, diving, oil and chemical spills) **Fisheries** (fish statistics and economics, seafood inspection, fishery market news, law enforcement) **Climate** (El Niño & La Niña, global warming, drought, climate prediction, environmental data, paleoclimatology) **Research** (air quality, atmospheric processes, climate and human interactions) **Coasts** (coastal services and products, sustainable seas expedition, state of the coast, coastal zone management) **Charting & Navigation** (nautical and aeronautical charts, ocean mapping, safe navigation and transportation)
Orbview 2 (Orbimage) Archive-1998 to present Seawifs data are distributed only to scientists registered with NASA Data is available on CD-Rom and via FTP RAW or Level 1A formats.	 This image of the West Coast of South Africa indicates upwelling and the phytoplankton presence along the coast line.	**Environmental monitoring** (ocean plankton concentration/sediment concentration/ red-tide tracking) **Weather forecasting** **Fishery** (linked to plankton)

Source: *SAC News, 2000, 4 - 5.*

3.3 Satellite imagery as primary data source

When choosing remotely sensed imagery as the primary data source, care must be taken to ensure that the specific characteristics of both the platform and the sensor are appropriate for the objectives of the study. The platform is the supporting structure that houses the imaging sensor. It is a combination of the physical positioning of the platform (i.e. aircraft or satellite), and the sensor design that will influence the spatial, spectral and temporal[11] characteristics of the imagery (Thorpe, 1996; Celentano, 1999).

Depending on the sensor design, imagery may be recorded either photographically or digitally. In either case, imagery can be presented to end-users as either hardcopy (i.e. paper-prints) or in digital format. Since hardcopy imagery is presented in a fixed format, it is important that the spatial, spectral and scale-related specifications are suitable for the end-user's requirements. Digital imagery allows the end-user the opportunity to spatially and spectrally manipulate the data during analysis. These product types have a varied price range, often dependent on the level of preprocessing[12] of the data (Forseman, 1999; Budge & Morain, 1995).

3.3.1 Factors determining the choice of remotely sensed data

Thompson *et al.* (1996) described the evaluation of data needs in terms of the following criteria:

- end user data requirements,
- spectral resolution,
- spatial resolution,
- speed of user access,
- aerial coverage,
- long term monitoring requirements,
- timing of data acquisition,

---

[11] Temporal resolution refers to the time lapse between successive revisits of the same area of the earth's surface by an orbiting satellite.

[12] Preprocessing functions involve those operations that are normally required prior to the main data analysis and extraction of information, and are generally grouped as radiometric or geometric corrections. Radiometric corrections include correcting the data for sensor irregularities and unwanted sensor or atmospheric noise, and converting the data so it accurately represents the reflected or emitted radiation measured by the sensor. Geometric corrections include correcting for geometric distortions due to sensor-earth geometry variations, and conversion of the data to real world coordinates (e.g. latitude and longitude) on the earth's surface' (CCRS, 2000).

- the cost-effectiveness of remotely sensed data, and
- cost constraints.

3.3.1.1 End user data requirements

As indicated in Chapter 1, manual land cover mapping for the CDSS from hardcopy aerial photography was found to be time-consuming and costly. Time (which also relates to manpower cost) had to be spent on converting the multiple hardcopy maps (corresponding to the hardcopy aerial photographs from which they were mapped) into a digital format, and mosaicing the digital maps to provide a continuous digital dataset for incorporation to the CDSS. This study assesses digital satellite remotely sensed imagery as potential alternative primary source of data. Digital image analysis was chosen, as the CDSS requires digital information, and because less time will be spent on converting data formats. The synoptic large area view provided by satellite imagery should furthermore minimise the need for mosaicing data to cover the study area.

The client (the DEA&T) indicated that the minimum mapping unit should be approximately 1ha. This relates to the minimum mapping unit that was used for mapping land cover from hardcopy aerial photography for inclusion in the ODSS (Jumat, 1999; Burns, 1999). SCAs in South Africa, for which the CDSS provides information, currently stretch between 5 and 20km inland and varies in terms of their extent along the coastline. The CDSS is to be used for long term monitoring and management. It is expected that the land cover information provided in the system will have to be updated every three to five years depending on the rate of change in the natural environment, as well as changes caused by development in each SCA. Certain SCAs or areas within SCAs might, for example, need to be updated more frequently, such as areas surrounding expanding informal settlements compared to areas surrounding established formal settlements (where the rate of change in the landscape caused by development is significantly slower).

Land cover change mapping is not specifically addressed in this thesis. Satellite remote sensing is however an ideal tool for monitoring land cover change. This can be done through both post-classification change mapping as well as well as change analysis from original satellite data. The final maps presented in this thesis could potentially be used as input for post-classification change mapping where appropriate land cover maps exists for the study area (Brown & Arbogast, 1999; Mouat *et al.*, 1993; Chavez & MacKinnon, 1994).

3.3.1.2 Spectral resolution

Of the satellite data provided by the SAC, data from the Landsat and SPOT sensors are most commonly used for land cover mapping. Both the Landsat (TM and ETM+) and SPOT (1,2 and 4) sensors provide the necessary spectral information for mapping terrestrial coastal features as they cover the visible, near infrared and mid-infrared sectors of the electro-magnetic spectrum. The main characteristics of these satellite systems are provided in Table 3.2.

It is important to note that Landsat TM, ETM+ and SPOT 4 imagery contains a shortwave infrared (SWIR) band in addition to the spectral information provided by SPOT 1 and 2. The SWIR band detects moisture content in vegetation and soil, which enhances the mapping capabilities for the purpose of this study, and also helps to distinguish between snow and cloud.

Landsat 7 (ETM+) was launched after data were acquired for this study. The sensor characteristics are, however, included in this discussion, as the sensor holds potential for future application of the methodology described in the thesis.

Table 3.2 Summary of the key sensor characteristics for Landsat and SPOT satellite systems.

Satellite	Landsat 5	Landsat 7	SPOT 1,2	SPOT 4
Sensor (s)	Thematic mapper (TM)	Enhanced TM plus (ETM+)	HRV Pan	HRV Pan
Status	Operational (1984)	Operational (1999)	Operational (1990)	Operational (1998)
Resolution (m): - multispectral - panchromatic	 30x30 n/a	 30x30 15x15	 20x20 10x10	 20x20 10x10
Image area (kms) (at nadir)	185x185	185x185	60x60	60x60
Update cycle (at nadir)	16 days	16days	26days	26days
Update cycle (off-nadir)	n/a	n/a	2/3 days	2/3 days
Stereo capability	No	No	Yes	Yes
Spectral resolution (nm)				
Blue	450-520 B	450-520 B		
Green	520-600 G	520-600 G	500-590 G	500-590 G
Red	630-690 R	630-690 R	610-680 R	610-680 R
Near Infrared	760-900 NIR	760-900 NIR	790-890 NIR	790-890 NIR
Middle Infrared	1550-1750 SWIR	1550-1750 SWIR		1500-1750 SWIR
Thermal Infrared	10400-12500 TIR	10400-12500 TIR		
Short Wave Infrared	2080-2350 SWIR	2080-2350 SWIR		
Panchromatic		500-900 Pan	510-730 Pan	510-730 Pan

Source: *Adapted from Thompson et al., 1996.*

3.3.1.3 Spatial resolution

A comparison of the pixel/ground resolution with the minimum mappable unit for the SPOT (1,2 and 4) and Landsat (TM and ETM+) systems is provided in Table 3.3. The minimum mappable units presented in the table indicate that all the sensors offer a minimum mappable unit appropriate (approximately 1ha) for classifying land cover information from digital satellite imagery as input to the CDSS.

Table 3.3 Comparison of pixel/ground resolution and minimum mappable unit for digital, per pixel classification of SPOT (1,2 and 3) and Landsat (TM and ETM+) sensors.

Sensor type	Pixel/ground resolution (m)	Equivalent area (approximate)	Effective minimum mappable unit (m)	Equivalent area (approximate)
SPOT Panchromatic	10x10	0.01ha	30x30	0.09ha
SPOT Multispectral	20x20	0.04ha	60x60	0.36ha
Landsat ETM+ Panchromatic	15x15	0.03ha	45x45	0.2ha
Landsat ETM+ Multispectral	30x30	0.09ha	90x90	0.8ha
Landsat TM	30x30	0.09ha	90x90	0.8ha

Source: *Adapted from Thompson et al., 1996.*

'Lower spatial resolution' data (e.g. SPOT 4, 20m multispectral bands) can be combined with 'higher spatial resolution' data (such as a coregistered SPOT 4, 10m mono-spectral/panchromatic band) to produce imagery with the best characteristics of both, namely high spatial and high spectral resolution. This process is known as multisensor merging, fusion or sharpening (of the lower resolution image) (Schowengerdt, 1997). On-board registration of a SPOT 4 10m monospectral/panchromatic scene (M) with a 20m multispectral (Xi) scene imaged at the same time by the same instrument allows for a multispectral (four band), simulated 10m ground resolution image to be generated (SPOT Image, 1999; Ehlers, 1991; Price, 1987; Ranchin & Wald, 2000; Chliche *et al.*, 1985).

The SAC offered sponsorship of a SPOT 4 (M + Xi merge) - image to be investigated as primary data source in this study. This offer was accepted as a SPOT 4 (M + Xi merge) - image presents the spectral and spatial resolution required for mapping land cover as input to the CDSS.

3.3.1.4 Temporal coverage

The SPOT 4 satellite system is designed to follow a near-polar orbit[13]. This orbital path of the satellite system in conjunction with the earth's rotation (west-east) allows the system to cover most of the earth's surface over a certain period of time. The system crosses a particular area on the earth's surface nominally every 26 days.

SPOT 4 also has an oblique viewing capability, which is used in three ways:

- to acquire imagery, in response to programming requests, anywhere within an observable corridor extending 450km to either side of the satellite ground track/nadir[14], corresponding to oblique viewing between the extreme angles of +/- 27°,
- to acquire any given scene from two viewing angles to yield a stereopair for stereo restitution and relief mapping, and
- to move to a position enabling the instrument to look at a calibration source (SPOT Image, 1999).

The first point mentioned above allows for the programming of the instrument to capture imagery outside the fixed orbital paths of the satellite system. This implies that the usual 26 days needed for repeat coverage of a specific area on the earth's surface could be less. It may also, as in the case of this study, reduce the number of images required to cover a specific area of study by allowing imagery that does not correspond to the fixed orbital paths followed by the satellite system to be captured.

3.3.1.5 Spatial coverage

The shape (i.e. uniform, linear, irregular) and size of the area to be covered determines the number of satellite images needed from a specific sensor to cover the area. Sensitive Coastal Areas in South Africa currently stretch between 5 and 20km inland, along the coastline. The SPOT 4 sensor has a swath width[15] of 60km. Imagery is provided for areas representing 60x60km of the earth's surface and along orbital tracts as standard product. This implies that only a portion of a 60x60km SPOT image will be utilised for extracting

---

[13] Near-polar orbits are so named for the inclination of the orbit relative to a line running between the North and South poles (CCRS, 2000).

[14] Nadir is defined as the point of the celestial sphere that is directly opposite the zenith and vertically downward from the observer (CCRS, 2000).

[15] A swath is referred to as the portion of the earth's surface 'seen' and imaged by a sensor as a satellite revolves around the earth.

land cover information and that more than one image might be required should the area extend across orbital tracks.

The study area, for example, (although only 40x20km in size) extends across two orbital tracks due to its shape and alignment. If standard imagery, e.g. archived data[16] were to be used for this study, it would have implied that two images would have had to be acquired. However, by providing an optimal scene centre, the SPOT 4 satellite system could be programmed to capture a single image covering the study area for this study.

The client (the DEA&T) also indicated that they would like to extend the concept of the CDSS, which is currently being implemented in Sensitive Coastal Areas, to cover the whole coastline of South Africa. The shape of the coastline and the spatial extent of the areas to be mapped often do not fit comfortably along the fixed orbital paths of satellite systems. Data needs should therefore be carefully examined to minimise the number of satellite images acquired – thereby reducing the data purchase costs.

3.3.1.6 Long term monitoring requirements

The availability of SPOT data will be maintained in the foreseeable future by the SPOT 4 satellite, which was launched in March 1998, and the SPOT 5 satellite that was launched on 4 May 2002 (SPOT Image, 1999). The system can thus support the long term monitoring requirements of the CDSS.

See Figure 3.2 for a graphical overview of the launching dates of the various satellites in the SPOT system. Of these satellites SPOT 1, SPOT 2, SPOT 4 and SPOT 5 are currently operational with SPOT 3 ceasing operation in early November 1996 (Boyle, 1996). The SPOT 5 sensor was launched after the findings of this study have been documented and data characteristics of this sensor are therefore not included in detail in this thesis.

---

[16] The SAC has been receiving and archiving SPOT 4 data on a daily basis since 1 May 1999 (Croft, 2000).

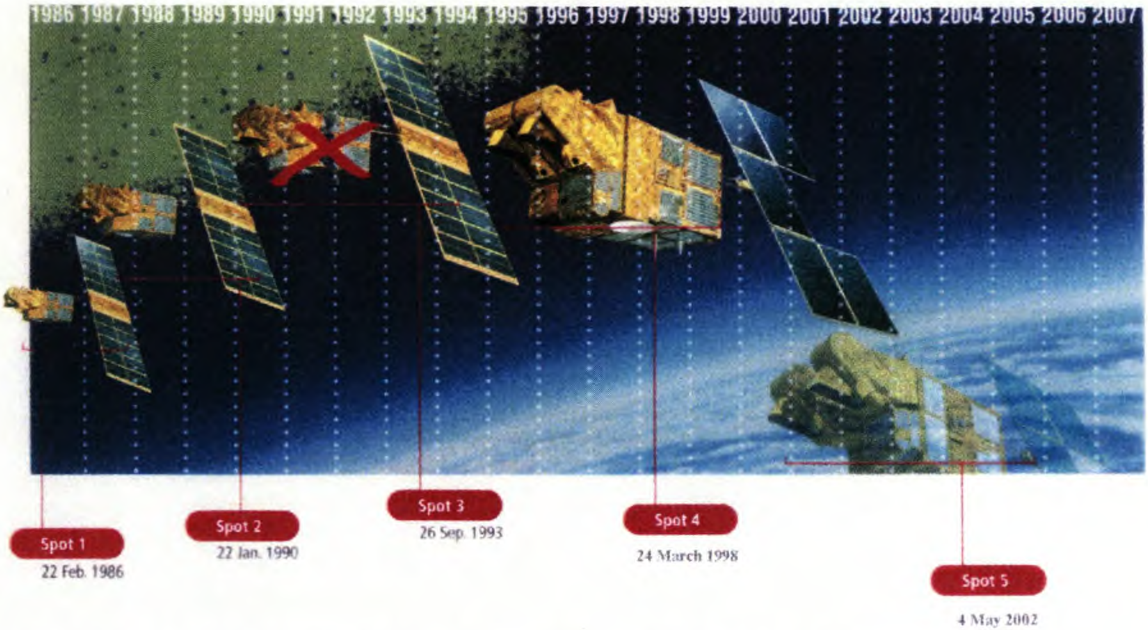


Figure 3.2 The launching dates of the various satellites in the SPOT satellite system.

3.3.1.7 Timing of data acquisition

The SPOT 4 satellite system is sun-synchronous. This implies that a specific area on the earth's surface is crossed at a constant local time of day, called local sun time. The position of the sun in the sky as the satellite passes over a specific area will thus be the same within the same season. This ensures consistent illumination conditions when acquiring images of a particular area over a series of equivalent julian dates, or in a specific season over successive years. It thereby minimises the need to correct such imagery for different solar illumination angles. Variable atmospheric conditions should however also be taken into account. This is an important factor for the future application of the methodology followed in this study where:

- the area to be mapped might extend across more than one satellite image from adjacent orbital paths (thus captured over a series of days) and requires the mosaicing of the imagery, and
- ongoing monitoring envisaged for the CDSS might require multitemporal images, or images from a specific season for change mapping.

The SPOT 4 satellite system has a fixed local overpass time over the study area of approximately 8:30am SA standard time. The early morning overpass time has an effect on the quality of data in terms of terrain shadowing. The ideal time of year for image acquisition for the study area (in terms of minimising the relief shadow effect) will be when the sun is the 'highest' in the sky at the time imagery is captured and thus providing the most direct illumination of the earth's surface. A table indicating the typical sunrise times for the study area over a period of a year is provided in Appendix C. The most appropriate time of year for image acquisition for the study area for minimizing the terrain shadowing effect is late November/early December (summer) when the sun rises at approximately 5:10am (3 hours 20 minutes before the overpass), with June/July (winter) being less favourable, as the sun rises at approximately 7:30am (only 1 hour before the overpass).

The time (during the year) of image acquisition must be chosen to optimally capture the characteristics of the features to be extracted from the data. There is little seasonal variation in the natural land cover in the study area, since it has an all-year rainfall pattern. None of the man-induced land covers in the study area, such as agriculture or built-areas, displays specific seasonal characteristics that need to mapped for this study. For this particular study, no specific optimum season for image capturing in terms of land cover characteristics was identified.

The all-year rainfall experienced by the study area does however place a constraint on capturing data for the study area, as optical satellite sensors such as SPOT cannot 'observe' through cloud cover. The average number of rain days per year for the study area is 110, with March and October showing a slight increase in precipitation. October has the highest number of rain days per month – an average of 11,5 days and May the lowest average number of rain days per month, namely 8,3 days (see Appendix B.). This marginal difference between the highest and lowest average number of rain days per month accentuates that no optimum month for image acquisition can be identified with confidence for the study area in terms of minimizing the risk of cloud cover. Rainfall is only one indicator of cloud cover over a specific area. Knowledge of the local weather conditions is important to identify the optimum window of opportunity for capturing cloud-free imagery, especially in coastal environments.

Furthermore, abnormal rainfall preceding the date of image acquisition could have an effect on the integrity of the data in terms of capturing data true to 'normal' conditions. Heavy rainfall, as an example, could result in flood conditions, which will obscure land cover information from the sensor and indicate water features where they are not 'normally' present. Long-term rainfall averages for the study area as well as rainfall data for the months preceding the date of image capture for this study was obtained and examined. The area experienced normal rainfall conditions prior to image capture.

3.3.1.8 Cost-effectiveness of remotely sensed data

Cost-effectiveness is a measure of both direct (i.e. data purchase costs) and indirect (i.e. data technical 'suitability') factors (Berry, 1993; Thompson *et al.*, 1996). The primary aim of this study was to assess the technical suitability of digital satellite imagery in terms of the information needs of the CDSS. A comparison of the cost-effectiveness of the digital mapping from satellite imagery applied in this study, in relation to the manual mapping from hardcopy aerial photography are done in Section 5.4. The comparison is based on data purchase costs and manpower costs related to extracting relevant information and preparing the information for inclusion in the CDSS.

3.3.2 Acquisition of project imagery

Work on this study started in February 1999 and a request was submitted for programming the SPOT 4 satellite to capture a non-standard image of the study area (by providing an optimal scene centre) during March (end of summer) 1999. The study area experiences a slightly higher level of rainfall than its average 'all-year' rainfall during March and October. Even though there is a high level of precipitation and cloud cover during March, it was possible to capture a cloud-free image for the study area.

One SPOT 4 monospectral/panchromatic (M) and multispectral (Xi) merged (through onboard registration) image was acquired on 14 March 1999 - scene ID 126-1-418 990314. Sunrise for the study area on 14 March 1999 was approximately 6:30am (2 hours before the image was captured) (see Appendix C). The study area experienced heavy but normal rainfall during the month preceding acquisition of the SPOT 4 image used in this study (see Appendix B). The sun azimuth was 51.3° and the sun elevation 46.8° at the time of image acquisition[17]. A summary of the data characteristics of this image is presented below.

3.3.2.1 Spectral and spatial resolution

The SPOT 4 (M+Xi merge) - image provides four multispectral bands at simulated 10m ground resolution (see Section 3.3.1) which provides the following spectral information[18]:

- visible band B1: 0.50-0.59 um (green),
- visible band B2: 0.61-0.68 um (red; chlorophyll absorption),
- visible band B3: 0.79-0.89 um (near infrared; atmospheric penetration), and
- shortwave infrared (SWIR) band B4: 1.58-1.75 um (moisture content in vegetation and soil, distinguish between snow and cloud) (CNES, 1998; Campbel, 1996).

3.3.2.2 Maximum operating scale and minimum mappable unit

The simulated 10m SPOT 4 (Xi+M merged) - image should allow for a *maximum operating scale* of approximately 1:30 000. Thompson (1994) presents guidelines based on local (South African) experience that advise a maximum (cartographic) operating scale of 1:40 000 for 10m pixel size imagery. The minimum mappable unit of the digital imagery is approximately 0.09ha.

3.3.2.3 Preprocessing

The SAC processed the SPOT 4 (M+Xi merge) - image to Level 2B. This includes geo-rectification by obtaining ground control points from the 1:50 000 South African topographical map series provided by the Chief Directorate Survey and Mapping (CDSM). To ensure high geometric accuracy it was essential to achieve a root mean square of about half a pixel (5m). The image was also registered to a Transverse Mercator projection using the Cape Datum[19] and a 23°E Central Meridian (the same as the information provided in the CDSS) (Meyer, 1999).

---

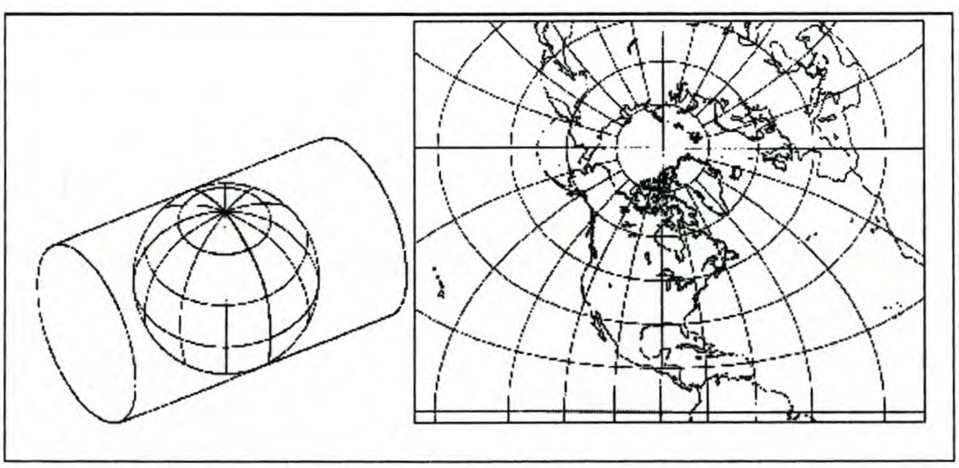
[17] This information is provided in the header file of the image.

[18] These bands provide the same spectral information as bands 2,3,4 and 5/7 of the LANDSAT system.

[19] The Surveyor General decided in 1992 that the existing Cape datum, referenced to the Clarke 1880 (modified) ellipsoid, should be changed to the World Geodetic System 1984 (also known as WGS 84) (Stadler, 1998). The changeover was scheduled to begin after this study was initiated. It was decided to complete the project in the coordinate system as described in the section above (the Cape datum) to conform to the other spatial information currently provided in the Coastal DSS.

A map projection is a system for the representation of a curved surface (the earth) on a plane (the map). The Transverse Mercator projection displays the same characteristics as the Gauss Conform projection used in the National Maps Series of South Africa (Le Grange, 1987). Van Brakel (1989) lists the following characteristics of the Gauss Conform Projection:

- zones are 2^{o} wide in longitude,
- the central meridian for that zone is in contact with the ellipsoid i.e. the scale is true along the central meridian,
- conformal projection - correct representation of shapes,
- equator projects as a straight line,
- meridians are equally spaced along the equator and converge to a point at the poles,
- parallels are curved lines, intersecting the meridians at right angles, curvature increase towards the pole, and
- used for the 1:10 000 ortho-photo maps, the 1:50 000 and 1:250 0000 topographical maps as well as for the South African coordinate system.



Source: *Moore, 1997.*

Figure 3.3 Graphic presentation of the Transverse Mercator projection

A subset of 40x20km (22MB) covering the study area was 'clipped' from the original 60x60km SPOT 4 (M+Xi merge) image (220MB). Working with a subset reduces computer storage space needed to save data as well as computer memory needed for processing data - saving time and effort for the analyst (Campbell, 1996; Ahearn & Wee, 1991).

3.4 Ancillary data

Ancillary data are used as an aid for extracting information from the primary data source. Ancillary data can be used for manual interpretation as well as digital analysis of satellite imagery. Ancillary data could include data from maps, field observations, reports and personal experience. In this study, supporting data were used for orientation, identification and refinement of the land cover features mapped from the digital SPOT 4 image subset, and for mapping and checking field data site locations (Anuta, 1976; Vogelman *et al.*, 2001).

To facilitate the overlay of the ancillary data with the primary data for this project and the information provided in the CDSS, the digital ancillary data were projected to the Transverse Mercator projection using the Cape Datum and a 23 °E Central Meridian. The data were mosaiced and/or 'clipped' to create continuous datasets covering the study area and incorporated into an ArcView project as themes[20].

Data obtained and used in the study include the following:

- 1:50 000 scale digital topographical data for the study area,
- a 1:50 000 scale digital map showing geological features for the study area,
- archived 1:10 000 scale hardcopy aerial photography, 1:10 000 scale hardcopy ortho-photos and digital SPOT 2 satellite imagery of the study area, and
- 1:250 000 scale digital South African national land cover data for the study area.

Two of the land cover features in the study area – indigenous forest areas and plantation areas – are known to display similar spectral characteristics. Digital data indicating boundaries for either of these features can aid in refining the final map for the study area. However, neither the Thessen Company who owns and manages the plantation areas in the study area nor the Department of Water Affairs and Forestry who manages the indigenous forest areas possess digital data for these areas (Viljoen, 2000; Baard, 1999). The hardcopy format of these datasets is also not in an 'easy to use'/accessible format[21] and was not obtained. It was decided to rely on visual interpretation of the satellite and other data for mapping these features, as converting hardcopy data to a digital format would have

[20] A theme represents a distinct set of geographic features in a particular geographic data source (ESRI, 1994).
[21] Most of the plantation boundaries are not in 'map' format, but in the form of legal documents verbally describing the boundaries of the areas. The indigenous forest boundary maps are incomplete. DWAF has, however, initiated a process of updating these boundaries and converting the data to a digital format.

been too time-consuming and costly. Should the data however become available in digital format, it could be incorporated in the methodology to assist in delineating the plantation mask (see Section 4.4.2).

3.4.1 Digital topographical data

The digital topographical data were used for orientation as well as refining the land cover classification by providing information on the slope, aspect and shaded relief of the area. Digital topographical data covering the study area were obtained from the CDSM. This includes contour data at 20m intervals as well as roads, dams, rivers and lakes captured from 1:50 000 scale topographical-map sheets.

The contour data were imported to ERDAS Imagine image processing software to build a 20m elevation surface/digital elevation model (DEM)[22] for the study area. The DEM of the study area was integrated into the Arcview project, and Spatial Analyst[23] was used to perform the following topographical analyses:

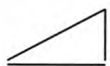
- Slope: The slope categories used in the CDSS area shown in Table 3.4. The categories relate to the erodability of soils and suitability for development. The slope analysis for the study was set to the same class intervals than those used in the CDSS. The slope map was used to visually aid interpretation of the satellite imagery by identifying/eliminating the possibility of particular land cover types according to slope suitability e.g. large water features such as estuaries are expected on flat slopes and can not be found on very steep slopes.

---

[22] Methods of storing Z-value information (elevation dimension) are collectively known as digital elevation models (Demers, 1997).

[23] Spatial Analyst is the raster GIS extension for ArcView.

Table 3.4 Slope gradient categories used in the CDSS.

Appearance	Description	Ratio	Percentage
	Very steep	More than 1:4	More than 25%
	Steep	1:6 – 1:4	16 – 25%
	Gently sloping	1:20 – 1:6	5 – 16%
	Flat	Less than 1:20	Less than 5%

Source: *DEA&T, 1998.*

- Aspect: The aspect function in Spatial Analyst identifies the steepest down-slope direction from each cell to its neighbours, with the output grid theme presenting the compass direction of the aspect (ESRI, 1996). The aspect map provided useful guidance in the visual interpretation of the satellite imagery, e.g. it was found that afromontane forests on westfacing slopes show similar spectral characteristics to pine plantations on eastfacing slopes.
- Shaded relief: A common type of visual output used to portray the effect of shining a light (e.g. the sun) onto a 3-dimentional surface (e.g. the earth) is termed a shaded relief image or model (Aronoff, 1989). The azimuth (51.3°) and elevation (46.8°) of the sun at the time the image was captured were used as input values to create a shaded relief image of the study area which indicates the relief shading effect that could be expected on the SPOT 4 satellite image. This shaded relief image was used for visual interpretation of the SPOT 4 image subset, e.g. to identify areas that could be expected to give a poor spectral response due to 'shadow effect' caused by local relief.

Figure 3.4 to Figure 3.6 show the derived slope, aspect and shaded relief images used in this study.

LEGEND

Slope gradients
- Less than 5% (Flat)
- 5 - 16% (Gently sloping)
- 16 - 25% (Steep)
- More than 25% (Very steep)

Digital Satellite Remote Sensing for Terrestrial Coastal Zone Management.

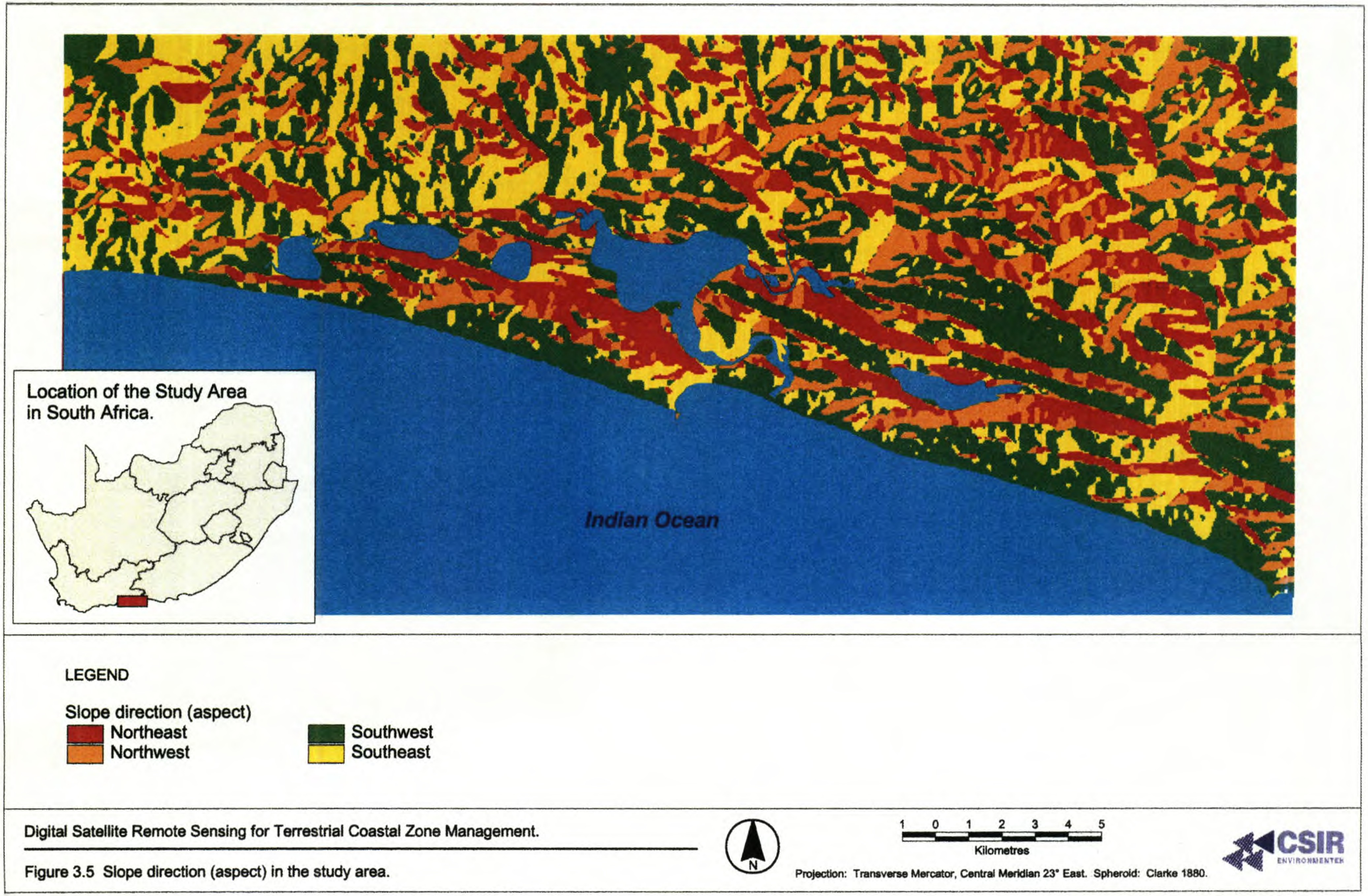
Figure 3.4 Slope gradients in the study area.

N

1 0 1 2 3 4 5
Kilometres

Projection: Transverse Mercator, Central Meridian 23° East. Spheroid: Clarke 1880.

CSIR ENVIRONMENTEK



Digital Satellite Remote Sensing for Terrestrial Coastal Zone Management.

Figure 3.5 Slope direction (aspect) in the study area.

LEGEND

Shaded relief

Full shade

Full illumination

Digital Satellite Remote Sensing for Terrestrial Coastal Zone Management.

Figure 3.6 Shaded relief map of the study area (Sun azimuth: 51.3; Sun elevation: 46.8).

Projection: Transverse Mercator, Central Meridian 23° East. Spheroid: Clarke 1880.

CSIR ENVIRONMENTEK

3.4.2 Geological features

Geological information was used for orientation in terms of the overall geological structure as well as visual interpretation of the SPOT 4 image subset. For example, the lithological information was used to demarcate dune areas in order to distinguish dune vegetation from land cover classes that have similar spectral characteristics but are spatially located elsewhere. Geological information from the CDSS captured for the Outeniqua SCA was obtained from the client (the DEA&T). The data were captured at 1:50 000 scale using standard geological mapping techniques (Croukamp, 1999). The data do not cover the full north-south extent of the study area. However, it cover the area extending up to the Outeniqua mountain range providing sufficient information for use in the study.

The geological dataset contains the following attribute data:

- formation,
- group,
- sub-group,
- lithology, and
- engineering implications (for development).

Figure 1.3 provides a view of the lithology data, which is the main set of geological information used in the study.

3.4.3 Aerial photography, ortho-photos and satellite imagery

Aerial photos, ortho-photos and additional archived satellite imagery (made available by SAC for the duration of the study) were used for orientation during field visits, visual aid for the interpretation of the SPOT 4 image subset, mapping the position of sample points during field visits as well as for allocating additional sample points in remote areas. Selected 1:10 000 scale hardcopy color aerial photographs captured in 1987 and 1990 (from the CSIR's archive) as well as scanned aerial photos for a portion of the study area captured in 1996 (obtained from the client, (the DEA&T)) were used. 1:10 000 scale hardcopy ortho-photos compiled in 1973 and 1989 (from the CSIR's archive) were also used.

The SAC provided the following additional satellite images:

- *SPOT 2 XS (December 1989), Multispectral – 20m pixel size.*

 This image was geo-referenced, enhanced for visual display (resampled, filtered and histogram matched[24]), 'clipped' to fit the study area and a hardcopy at a scale of 1:20 000 was produced by the SAC,

- *SPOT 2 XS (6 April 1998 and 16 April 1998), Multispectral – 20m pixel size.*

 These images were geo-referenced, histogram matched, mosaiced and 'clipped' to fit the study area,

- *SPOT 2 P (23 December 1997 and 23 December 1997), Panchromatic – 10m pixel size.*

 These images were geo-referenced, histogram matched, mosaiced and 'clipped' to fit the study area. A 1:40 000 scale SpaceMap[25] (hardcopy) was produced by the SAC. This provided a 'manageable' map in terms of format, (physical) size and spatial resolution to use for orientation during an initial field visit to the study area in February 1999. The map was also used for mapping the position of the sample points during field visits in July and August 1999.

The additional satellite imagery was specifically helpful in providing synoptic multitemporal views of the study area. 'Older' imagery was used to distinguish between land cover features that displayed similar spectral characteristics on the SPOT 4 image subset. For example, some plantation areas that were recently cleared before the SPOT 4 image was captured in 1999 showed similar spectral characteristics to fynbos. These areas could clearly be identified as mature plantation areas on the 1989, 1997 and 1998 satellite imagery and were mapped accordingly.

3.4.4 '96 South African National Land Cover Database

The study area falls within the Oudtshoorn 3322 1:250 0000 South African national land cover database map sheet tile. Appendix D contains an extract from the database for the area covering the study area. The information was mainly used for orientation as it indicates the broad land cover classes present in the study area.

---

[24] Histogram matching – the process of determining a lookup table that will convert the histogram of one band of an image or one colour gun to resemble another histogram (ERDAS, 1997).

[25] A spacemap is a geo-referenced satellite image with latitude and longitude marked on it and presented in the form of a map (Marais, 1996).

3.5 Field data

Knowledge about local conditions and experience in identifying land cover features from remotely sensed data enhances an analyst's capability to produce an accurate map. For this reason a conservation biologist with in-depth knowledge about the land cover in the study area as well as a botanist with experience in mapping land cover features in the study area from hardcopy aerial photos were approached for assistance. They assisted in field orientation, field data collection for the thematic accuracy assessment, the design of the land cover classification system (outlined in Section 4.3) as well as the interpretation of the SPOT 4 image subset.

An orientation visit to the study area was undertaken in February 1999. Field data to be used in the thematic accuracy assessment of the final land cover map for the study area were collected in July (26 sample points) and August (31 sample points) 1999. It is preferable to collect field data as close as possible to the date of image acquisition to avoid potential land cover changes during this time. July 1999 was the first available time for field data collection after the image for the study was captured in March 1999. Unfavourable weather conditions however necessitated the field data collection exercise to be abandoned. The help of a local conservation biologist was summoned and he managed to collect field data during August 1999.

Sample points were randomly determined in the field by driving along most of the accessible roads in the study area and sampling where a suitable sample site could be identified. A sample site had to be homogeneous with an approximate minimum area of 1ha (the desired minimum mapping unit as indicated by the client (the DEA&T). In most cases the sample site exceeded 1ha.

A reference slide was photographed for each sample point (weather permitting). The location of each sample site was located and mapped on a 1:40 000 scale geo-referenced SPOT Panchromatic SpaceMap of the area along with the direction in which the slide was photographed. General field notes (e.g. areas where alien vegetation occurs and areas where mixtures of land cover types were prominent) were also mapped onto this SpaceMap. The date, latitude (Y) and longitude (X) coordinates (Global Positioning

System[26] reading) / position on the earth's surface, land cover type and slide reference number were recorded for each of the 57 sample points.

Twenty five sample points were located from aerial photographs, ortho-photos and ancillary satellite imagery of the study area. The sample points from these sources were located randomly to ensure coverage of remote, inaccessible regions not reached by field sampling. A total of 82 sample points were used in the thematic accuracy assessment of the final land cover map.

Using the X and Y coordinates from the field sample data, a 'X Y event table' was created and integrated into the ArcView project. The additional 25 sample points were also added to the field data theme in the ArcView project.

The reference slides were digitally scanned. An active link (called a 'hot link') between the point data and the individual scanned images was created in ArcView. This 'hot link' allows the user to view the local environment as observed during the field data collection exercise by 'clicking' on a point (sample site) in the ArcView project. The viewing direction from each sample point when the reference slide was captured is indicated in the legend of the field data theme in the ArcView project. The reference slides were used to verify the land cover class allocated to each sample point. See Figure 3.7 for an example of the field data theme with an associated reference slide for the sample point displayed.

3.6 Hardware and Software

Data processing was done at the CSIR and the hardware and software used in this project was thus governed by the availability of resources at the CSIR. The data were processed on a Dell Cpi-series notebook with a Pentium (ii) processor and 64MB RAM. Data volumes were kept to a minimum by working with a subset of the SPOT 4 image[27]. The digital ancillary data sets were also 'clipped' to fit the study area. This aided in limiting the storage space needed as well as processing time.

---

[26] GPS (Global Positioning System) is a satellite navigation system designed for, funded and controlled by the United States Department of Defense. GPS provides specifically coded satellite signals that can be processed in a GPS receiver, enabling the receiver to compute position, velocity and time (Dana, 1999).

[27] The average size of a SPOT 4 (M+Xi merge) – image (containing 4 bands of spectral information) is 220MB. The SPOT 4 (M+Xi merge) – image subset (containing 4 bands of spectral information) for the study area is 22MB.

ERDAS Imagine V3.8.1 for Microsoft Windows '98 (raster image processing software) was used for the processing of the SPOT 4 imagery. ArcView version 3.2 (a desktop vector-based Geographical Information System (GIS) software package) was used to compile ancillary data into an easy accessible project for visual interpretation and analysis. ArcView's Spatial Analyst extension was used to analyse ancillary raster data. ArcInfo 8 was used for vectorizing the derived land cover information for input to the CDSS. The ERDAS Image Vector module could also have been utilised, but the CSIR was not in possession of this module at the time the raster to vector conversion was performed.

Both the ERDAS Imagine and the ArcView software products are widely used by remote sensing and GIS specialists (Congalton, 2000; Comentz, 2000) and the software packages were thus used with confidence for the purpose of the study.

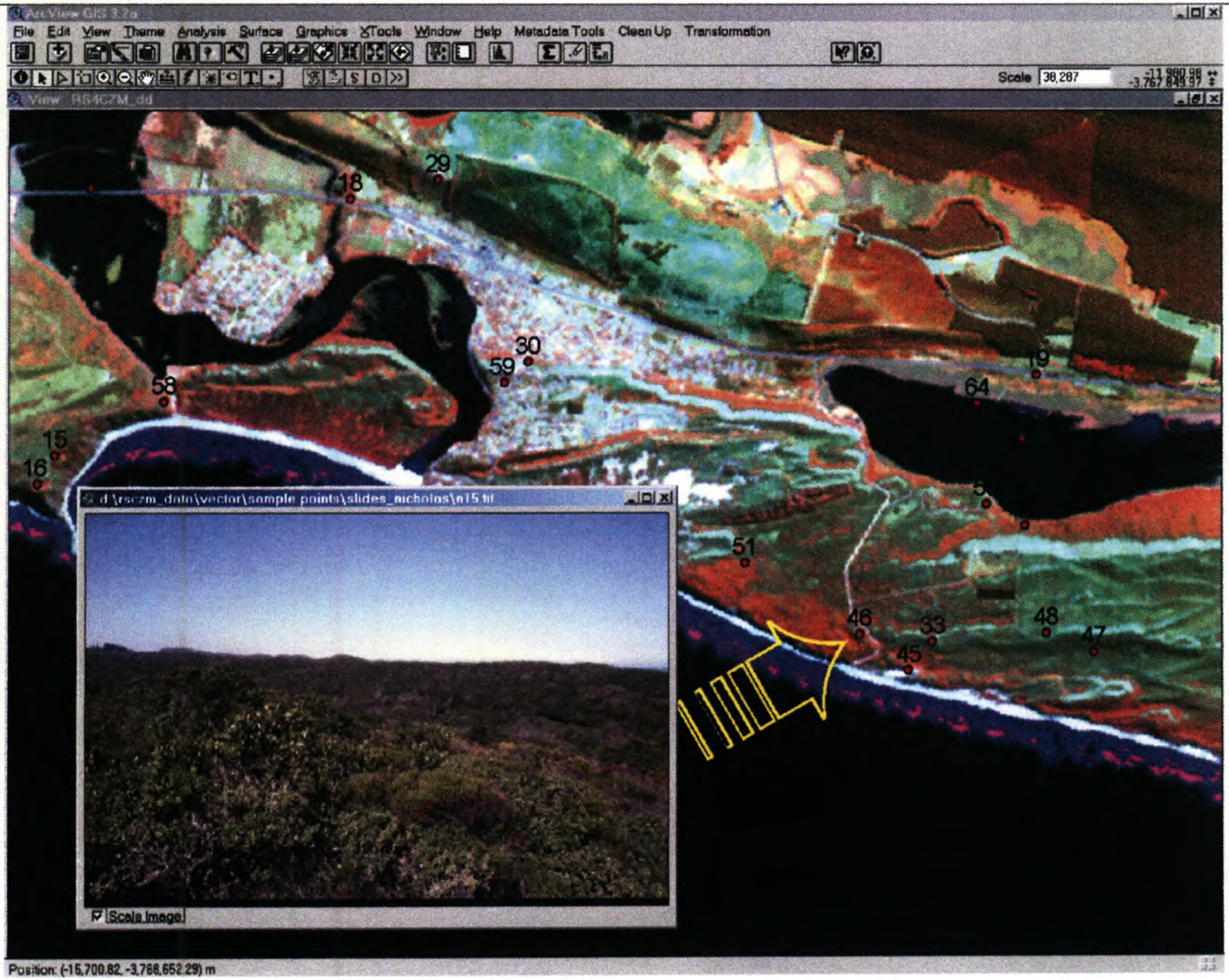


Figure 3.7 An example of a reference slide displayed as a 'hot link' to the relevant sample point and SPOT 4 image (RGB + 4,3,2) as backdrop.

3.7 Summary

The SAC sponsored a SPOT 4 (M + Xi) – merged image acquired on 14 March 1999 as primary data source for this study. A SPOT 4 (M + Xi) merged scene provides four multispectral bands at simulated 10m ground / spatial resolution. The spectral information provided in the image includes green, red, near infrared and shortwave infrared bands. The spatial as well as spectral characteristics of this image should be adequate to map land cover information for the study area at the required approximately 1ha minimum mapping unit. Various ancillary datasets were obtained to aid in the interpretation of the primary data source. Datasets include digital topographical data, information about the geological features, archived aerial photography, orhto-photos and satellite imagery as well as the South African national land cover data. Local experts were involved to assist in a field orientation visit to the study area as well as in the collection of field data be used in the thematic accuracy assessment of the final land cover map. All the datasets for the study were registered to a Transverse Mercator projection using the Cape Datum and a 23°E Central Meridian (to match the existing data in the CDSS) and assembled in an ArcView project.

CHAPTER 4: IMAGE CLASSIFCATION AND POSTPROCESSING

4.1 Introduction

The basic concepts in digital image classification are defined in this chapter. The land cover classification system designed for the study along with the definitions for each land cover class are presented. This is followed by the digital image classification procedure for deriving land cover information from satellite imagery. Postprocessing involved in converting the final land cover map to digital vector format for inclusion in the CDSS is also presented.

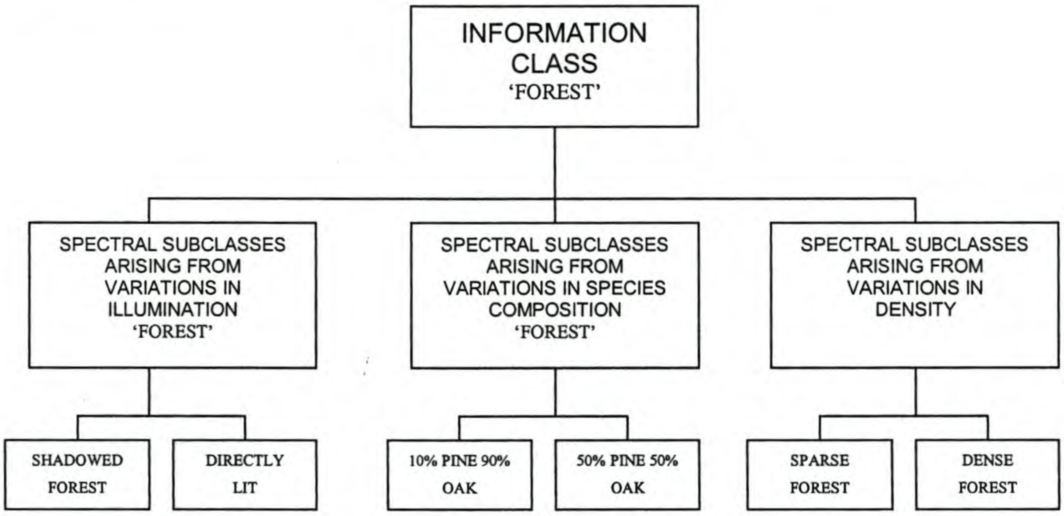
4.2 Digital image classification

Image classification is the process of assigning the pixels of a continuous raster image to discrete categories (ERDAS, 1997). An analyst can use either visual interpretation or digital classification to identify homogeneous groups of pixels that represent features of land cover classes of interest. Visual interpretation is limited by the fact that only three bands of spectral information can be displayed at once in producing image data for interpretation. Elements such as shape, size, shadow, pattern and texture are used to supplement the spectral information available during visual interpretation (Holz, 1985). During digital image classification however, the spectral information of each pixel, represented by digital numbers for any number of spectral bands, is used to classify or assign each pixel to a feature of a land cover class. The elements mentioned above for visual interpretation can also be included during digital classification. Various techniques exists and are being researched to include these and other criteria to refine classifications (Chan *et al.*, 2001; Gumbricht *et al.*, 1996).

4.2.1 Information and spectral classes

Information classes are the categories of interest to the user of the data, e.g. for this study the information classes relate to land cover classes such as vegetation types, agriculture and built-up areas. Spectral classes are groups of pixels that are uniform with respect to brightness in specific spectral channels (bands). The objective during image classification is to match the spectral classes in the data with the user-defined information classes.

Information classes are often composed of numerous spectral subclasses, as depicted in Figure 4.1. In this example it is shown how the information class 'forest' is composed of various spectral subclasses. The spectral subclasses are caused by variations in the illumination conditions, species composition and density of the forested areas (Robinove, 1981; Campbell, 1996).



Source: *Campbell, 1996.*

Figure 4.1 Example of an information class that is comprised of spectral subclasses

4.2.2 Supervised and unsupervised image classification

Various techniques and algorithms exist for digital classification of satellite imagery. This include per-pixel classification of digital data (such as utilised in this study) to more advanced techniques that employ fuzzy logic, neural networks and object-oriented classification (Hubert-Moy *et al.*, 2001; Robbins & Maddock, 2000). It was not within the scope of this study to investigate the more advanced techniques for land cover mapping in detail but rather to employ proven techniques which can be transferred to local users of the CDSS for future update of the land cover information for the CDSS. Because cost is a consideration for the adoption of the proposed technique by the client (the DEA&T), a primary data source and mapping methodology suitable to address their needs at minimal cost had to be investigated. Cognisance is however taken that there are advanced satellite sensors (spatial and spectral resolution) as well as mapping techniques that could be employed to further improve on the methodology as outlined in this thesis. These advanced sensors and mapping techniques were either not available or well known and researched at the time of inception of this study and are therefore not included in detail in the thesis.

Digital image classification can be achieved through either supervised or unsupervised classification techniques. An analyst guides a supervised classification by identifying homogeneous representative samples of the information classes of interest. The sample areas are known as training areas. The digital numerical information of the pixels comprising the training areas is used to determine a numerical 'signature' for each training class. Once the computer has determined the signatures for the training/information classes, each pixel in the image is compared to the signatures and labelled as the information class it most closely 'resembles' (Lillesand & Kiefer, 1994; Townshend, 1981). A simplified example of this procedure is presented in Figure 4.2.

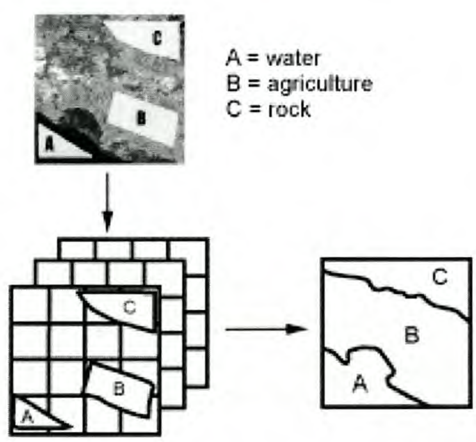


Figure 4.2 Simplified illustration of supervised image classification.

In an unsupervised classification, pixels are first aggregated according to their spectral information and subsequently matched to information classes (if possible) by the analyst. The analyst usually specifies the number of clusters the computer should identify in the data. Subsequent to the clustering process the analyst might also combine or subdivide some of the clusters further in an attempt to match the spectral classes identified by the computer with the information classes to be mapped (Lillesand & Kiefer, 1994) (see Figure 4.3). Clustering algorithms are used to determine the statistical groupings of the digital numerical values of the pixels. The ERDAS Imagine image processing software used in this project uses ISODATA clustering which was described as functional for land cover mapping by Cihlar *et al.* (2000) as well as Vogelman *et al.* (1996).

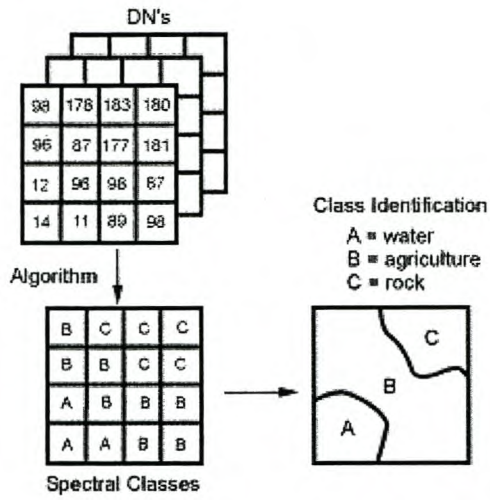


Figure 4.3 Simplified illustration of unsupervised image classification.

Campbell (1996) describes the following advantages and disadvantages of unsupervised image classification (relative to supervised classification):

Advantages:

- less detailed prior knowledge of the region is required than with supervised classification,
- the opportunity for human error is minimised, and
- unique spectral classes are recognised as distinct units.

Disadvantages:

- the spectrally homogeneous classes do not necessarily correspond to the information categories that are of interest to the analyst,
- the analyst has limited control over the menu of classes and their specific identities, and
- spectral properties of specific informational classes could change over time. The relationships between the information and spectral classes could thus change over time.

According to Richards (1986) supervised image classification can be more time-consuming than unsupervised classification, due the demand on the analyst's time in training a supervised procedure. Studies investigating the relative accuracies of alternative classification techniques by Kelton *et al.* (1985) were in favour of unsupervised methods, while work by Schmidt (1984) indicated slightly better results for supervised techniques. An evaluation done by Fukue *et al.* (1998) suggested that unsupervised classification techniques are preferable when using high ground resolution imagery in detailed land use areas (as is the case in this study). A statement by Campbell (1996) summarises the above by saying that there are no rules to define with confidence which classification technique will be more effective for a specific application or landscape. Given the advantages and disadvantages of the two approaches, intermediate hybrid methods have been suggested (Flemming, 1977). The methodology described in this thesis is such a hybrid method.

4.3 Land cover classification system for the study

A classification system structures and defines the information classes that are extracted from the satellite imagery. A classification system can either be developed on *a-priori* or *a-posteriori* basis. *A-priori* design implies a predetermined classification system that is designed before any image data are classified. The image analyst, along with the end-user, is able to ensure that the final classification structure and definitions are appropriate for the specific mapping objectives. *A-posteriori* design is when the classification scheme is constructed after the data have been classified. The actual data and mapping techniques are used to define the final classes. This can result in a very accurate map in terms of the final classes recorded, but could result in problems to the end-user since the content of the final map is unknown until the product is completed (Thompson, 1996).

An *a-priori* classification system design approach was followed in this study. The land cover classification system designed for this study relates to the standard land cover classification for remote-sensing applications in South Africa[28], and was modified to suit the local conditions/requirements of the study area. The information requirements for the CDSS were also taken into consideration.

[28] Thompson (1996) presented a hierarchical framework for the classification of remotely sensed data, designed to suit the South African environment. This framework, which relates to classification systems or codes that have been used within various organisations, is based on known land cover classes that can be derived from high-resolution remotely sensed data such as Landsat (TM) or SPOT.

A structured hierarchical format offers a high degree of flexibility and formed the basic framework for international and national classification systems such as the US Geological Survey's (USGS) land cover classification system designed by Anderson *et al.* (Lindgren, 1985), the FAO's land cover classification system for the AFRICOVER project (United Nations, 1993), the British (Fuller & Groom, 1993) and Dutch (Thunissen *et al.*, 1993) national land cover maps as well as the South African National land cover classification system (Thompson, 1999).

The classification system designed for this study consists of two hierarchical levels:

Level I: 11 broad land cover types that can be identified with minimal use of ancillary data, and

Level II: 20 land cover subclasses that require the use of ancillary data to be delineated.

The land cover classification system for the study along with the definition for each of the land cover classes are presented in Table 4.1

Table 4.1 Land cover classification system and class definitions used in this study

Level I	Description	Level II	Description
Forest	Wooded area with tree canopy cover >70%. A multi-strata community, with interlocking canopies, composed of canopy, sub-canopy, shrub and herb layers. Essentially indigenous species[29], growing under natural or semi-natural conditions (although it may include some localised areas of self-seeded exotic species). Excludes commercial plantations (and woodlots).	**Afromontane forest**	Afromontane forest is restricted to temperate, moist sites. In areas with a marginal climate, the forest is confined to drainage lines and river courses. The forest is mainly evergreen, with projected tree canopy cover of at least 75% and a canopy height varying between 5 and 30 m (McKenzie & Moll, 1986). The forest can be stratified into one or more tree, shrub and herb layers.
		Dune forest	Dune forest is found on Pleistocene and Holocene dunes (dune/alluvium soil types), often on lower dune slopes and in inter-dune troughs.
Thicket, scrub forest and high fynbos	Communities typically composed of tall, woody, self-supporting, single and/or multi stemmed plants (branching at or near the ground), with, in most cases no clearly definable structure. Total canopy cover >10%, with canopy height between 2-5m. Essentially indigenous species, growing under natural or semi-natural conditions (although it may include some localised areas of self-seeded exotic species, especially along riparian zones).	**Dune thicket**	Areas of densely interlaced trees and shrub species (often forming an impenetrable community). Composed of multi-stemmed plants with no clearly definable structure or layers, with > 70% cover. Dune thicket communities occur on Pleistocene and Holocene dunes where the seasonal rainfall distribution is suitable for their establishment. The vegetation is essentially a subtropical thicket type of relatively low species diversity and is dominated by trees and shrubs that are mostly of Tongaland-Pondoland origin (Moll & White, 1978). Some species have strong Afromontane affinities (Cowling, 1983; Cowling 1984).
		Scrub forest	Vegetation intermediate in structure between true forest and thicket. A multi-layered community with interlocking canopies, with >70% cover.
Fynbos	Communities dominated by low, woody, self-supporting, multi-stemmed plants branching at or near the ground, between 0.2 – 2m in height. Total tree cover <1.0%. A shrubby complex of Cape species – proteaceous plants, heaths, ericas, restios – which are found on nutrient-poor soils, and often in winter rainfall areas (Lubke & de Moor, 1998).	**Lowland fynbos**	In the study area, this includes Dune Fynbos, which incorporates a variety of communities that occur on leached, nutrient poor calcareous dune sands. The typical form of this vegetation is dominated by ericoid, evergreen shrubs and rhizomatous plants 0.75 – 1.5 m tall. Taller shrubs of up to 2.5m high increase towards the margins of the Dune Fynbos where moisture is less limiting. Restionaceae are common in the lower strata and herbs and geophytes occur throughout. Although generally considered to have an open structure, Dune Fynbos communities normally are quite dense with a canopy in mature stands usually from 65 – 80% (Raal & Burns, 1991).

[29] Indigenous refers to in all cases to plant species that occur naturally within southern Africa.

			Dune Fynbos is more uniform in species composition than mountain Fynbos and is also composed of more grass species and annuals (Taylor, 1983).
		Mountain fynbos	Mountain Fynbos is common at higher altitudes on rocky mountain slopes (Lubke & de Moor, 1998).
Forest plantations	All areas of systematically planted, man-managed tree resources, composed of primarily exotic species (including hybrids). Category includes both young and mature plantations that have been established for commercial timber production, seedling trials, and woodlots/windbreaks of sufficient size to be identified on satellite imagery. Unless otherwise stated, Levels 1 & 2 include clear-felled stands *within* plantations. Excludes all non-timber based plantations as well as orchards used in the production of citrus or nut corps. Level 1 category will include associated land cover such as roads, fire-breaks and building infrastructure if these are too small to be clearly mapped off the satellite imagery.	**Pine plantation**	Areas planted with parent and/or hybrid pine species (*Pinus* spp.).
		Eucalyptus plantation	Areas planted with parent and/or hybrid eucalypt species (*Eucalyptus* spp.).
		Alien invasion	This category includes areas where natural vegetation and transformed environments have been invaded by alien plant species. For the study area, this mainly includes the invasion of Dune Fynbos and thicket by *Acacia cyclops*. Exotic species invasion (dominantly pine, eucalyptus and wattle – not plantation areas) is found in agricultural areas and along the river courses.
Agricultural lands	This includes grasslands (planted grassland, containing either indigenous or exotic species, growing under managed conditions for grazing, hay or turf production, recreation etc.) and Cultivated Land (areas of land that are ploughed and/or prepared for raising crops (excluding timber production). This category includes areas currently under crops, fallow land, and land being prepared for planting. Low density small-holdings, including buildings and other human-made structures are also mapped as agriculture.		
Barren lands	Non-vegetated areas, or areas of very little vegetation cover (excluding agricultural fields with no crop cover) where the exposed soil substratum is clearly apparent.	**Transformed land**	Permanent or seasonally transformed land of very low vegetation cover (i.e. where tree, bush and/or herbaceous cover has been removed) in comparison with the surrounding environment. Examples include agricultural fields that are not actively being cultivated and cleared plantation areas that could not be positively identified as being part of a plantation.

		Bare rock/soil	Natural areas of exposed sand, soil or rock with no, or very little, vegetation cover during any time of the year, (excluding agricultural fields with no crop cover). Examples would include rock outcrops, dune and beach sand, dry river bed material, and gravel plains.
Water bodies	Areas of (generally permanent) open water. This category includes natural and human-made water bodies, which are either static or flowing; fresh, brackish and salt water bodies, and features such as rivers and dams (i.e. reservoirs, permanent pans, lakes, lagoons and coastal waters).	**Coastal waters**	This includes the ocean, at its interface with the land.
		Lakes and estuaries (lagoons)	Estuaries occur at the transitions between river systems and coastal waters, i.e. where rivers enter the sea. They experience tidal effects and exhibit salinity changes from salt- to fresh-water conditions. Coastal lagoons are areas of relatively shallow water that have been partly or wholly sealed off from the sea by the formation of depositional barriers (Bird, 1984).
		Dams	This category includes constructed dams, reservoirs and impoundments.
Wetlands	Natural or artificial areas where the water level is permanently or temporarily at (or very near) the land surface, typically covered in either herbaceous or woody vegetation cover. The category includes fresh, brackish and salt-water conditions. Examples include salt marshes, pans with non-permanent water cover and reed-swamps.	**Vleis**	Emergent, semi-aquatic and vegetation fringing the lake systems.
		Salt marsh	Similar to vleis, but established under brackish conditions, e.g. at estuaries.
Urban/ Built-up land	Areas where there are a permanent concentration of buildings and other man-made structures from large village to city scale. The urban boundary includes open areas within the built-up region (i.e. vegetated or non-vegetated areas with few or no structures).		
Shadow areas	Areas where relief shadowing does not allow positive identification of the relevant land cover. This is not a generally recognised land cover class. For final land cover map preparation the appropriate land cover class for these areas has to be verified from ancillary sources such as aerial photographs or field data. For the purpose of the study these areas were mapped as 'shadow areas' to indicate the extent of the effect.		

Recently burned	Areas with little or sparse vegetation due to fire scar. Unless specified as an end-user requirement in the event of mapping burn scars, for final land cover map preparation the appropriate land cover class for these areas has to be verified from ancillary sources such as aerial photographs or field data. For the purpose of the study these areas were left as 'recently burned' areas to indicate the extent of the effect.		

'Shadow areas' and 'recently burned areas' information classes, included in the land cover classification system for this study, are not commonly recognised and mapped as land cover classes. However, extremely steep, shadowed areas such as the south facing cliff-areas along the coastline in the study area often present difficulty in digital classification of satellite imagery. The standard practice is to re-code such areas to the appropriate information class during the final preparation of a land cover map. The appropriate land cover class could be identified and labelled either through local knowledge, field verification or input from other sources of remotely sensed data. It was decided to map these areas as a separate 'land cover' class (shadow areas) in the final map presented in the thesis to illustrate the impact of such shadow effect during digital image classification.

Furthermore, it was anticipated that the effect of a burn would still be evident north of the Sedgefield urban centre when the SPOT 4 image was captured and when field data were collected for the thematic accuracy assessment of the final map. It was decided to include a specific 'recently burned areas' class for classification of the SPOT 4 image subset to illustrate the mapping capability of SPOT 4 data. End-users of the CDSS might choose to include 'recently burned areas' as a class for aiding local decision-making and management. For general land cover purposes it would however be more appropriate to map these areas as barren/degraded land or the land cover class(es) known to cover the area. This will depend on the end-user requirements.

4.4 Image classification procedures followed

A hybrid / semi-supervised procedure was used to prepare the land cover map for the study area. The procedure is based on an unsupervised classification of the SPOT 4 image subset with subsequent manual modification using ancillary data, visual interpretation of the imagery and area specific masking (areas of interest).

4.4.1 Unsupervised classification of the SPOT 4 image subset

The SPOT 4 image subset was classified into 100 spectral classes using ERDAS Imagine image processing software. ERDAS Imagine utilises the ISODATA algorithm[30] to cluster digital information into spectral classes. Work by Vogelman *et al.* (1996) has indicated that relatively little unique land cover information is derived using more than a 100 clusters when performing unsupervised classification.

4.4.2 Recoding of the unsupervised classification into land cover classes for the study

The spectral classes were grouped to 'best fit' the information (land cover) classes, as defined in the land cover classification system for the study. During this process it became evident that several of the information (land cover) classes consisted out of more than one spectral class and that some of the spectral classes were present in more than one information (land cover) class. A table was compiled noting which of the spectral classes related to each of the information (land cover) classes. An extract of this table is provided in Appendix E as example.

Manually determined area-specific masks were delineated (on-screen) through visual interpretation of the SPOT 4 image subset. Specific information (land cover) classes, which shared spectral classes with other information (land cover) classes, were isolated[31]. The masks were used to selectively separate the spectral classes that were shared between information (land cover) classes into the appropriate information (land cover) classes. The masks were used as areas of operation in which to recode the spectral classes under question. It is important to note that these masks are not delineated to precisely fit an information class, but that the masks are drawn 'roughly' with the aim of differentiating these areas from other areas where the involved spectral classes relate to other information (land cover) classes. Masks were created for the following information (land cover) classes:

- plantations,
- wetlands,

---

[30] The ISODATA (Iterative Self-Organising Data Analysis Technique) method uses minimum spectral distance to assign a cluster for each candidate pixel (ERDAS Imagine, 1997).

[31] An area of interest (AOI) is a point, line or polygon that is selected as training sample or as the image area to be used in an operation (ERDAS, 1997). In the case of the study a mask is an 'area of interest' polygon used in an operation.

- recently burned,
- transformed,
- built-up areas,
- dunes,
- lakes,
- dams,
- shadow areas, and
- agricultural areas.

For example, afromontane forest on west-facing slopes showed similar spectral characteristics to plantation areas on east facing slopes. This is probably due to the low sun-angle at the time the image was captured (8:29am) and the resulting relief-shading effect. A mask was created to selectively recode those spectral classes that indicated afromontane forest as plantations in areas known to be plantation areas. Figure 4.4 provides an illustration of the area-specific 'Plantation'-mask (white polygons) used to recode spectral classes representing east-facing plantation areas (purple areas within the white polygons) and west-facing afromontane forest areas (purple areas outside of the white polygons) to the appropriate information (land cover) classes.

Ancillary data were used extensively by the analyst to recode the spectral classes into the appropriate information (land cover) classes and in the delineation of the area-specific masks. In a study by Vogelman *et al.* (1998) digital slope, aspect and hillshade (shaded relief) maps were used as ancillary data to resolve confusion in spectral classes that represented two or more targeted land cover categories. They found shaded relief, which contains elements of both slope and aspect variables, to be more powerful for eliminating confusion than either slope or aspect data layers used separately.

Aspect and the shaded relief maps created for this study provided the most useful guidance in the recoding process. The aspect map, for example proved helpful in establishing that the spectral response of afromontane forest on west-facing slopes (shadow areas) showed similar spectral characteristics to pine plantations on east-facing slopes (being more directly illuminated).

The hillshade map gave an indication of the areas that could be expected to give poor spectral response due to 'shadow effect' caused by local relief. An example of an extreme case is the very steep, coastal cliffs facing southwest. These areas were mapped as shadow areas, as no unique spectral response that relates to any of the other information (land cover) classes could be distinguished.

Lithological information (see Section 3.4.2) was used to delineate a 'dune'-mask in order to separate spectral classes which were shared between information (land cover) classes present on dune systems and other information (land cover) classes which displayed similar spectral characteristics. As an example, dune fynbos displays similar spectral characteristics to mountain fynbos. The 'dune'-mask was demarcated to include aeolian sand, fixed dunes and dune sand.

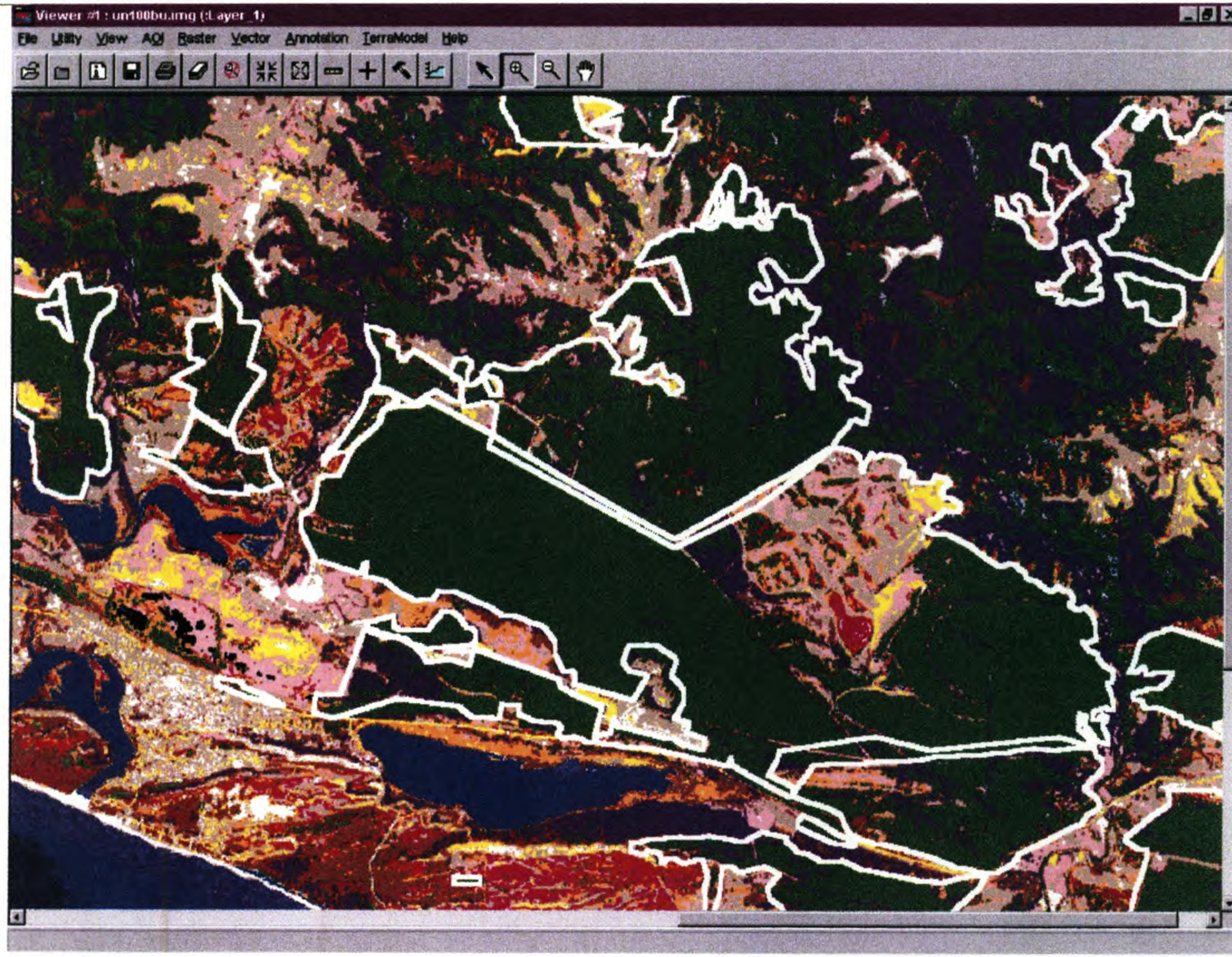


Figure 4.4 An illustration of the area-specific 'Plantation'-mask (indicated as white polygons).

4.5 Postprocessing

Postprocessing is applied to digitally derived classified information for preparing the data for integration with other vector datasets. The two postprocessing techniques most often applied are post classification smoothing / filtering and raster to vector conversion.

Classified data often manifest a salt-and-pepper appearance due to the inherent spectral variability encountered by a classifier when applied on a pixel-by-pixel basis. In such cases digitally derived thematic classifications are spatially filtered to remove the 'salt and pepper' effects. Postclassification smoothing improves the overall homogeneity of the classified image (without loss of classified information), enhancing the presentation of information and aiding in the transformation of the data from raster[32] to vector[33] format (as required by the CDSS) (Lillesand & Kiefer, 1994).

Various combinations of a majority filter[34] were applied to the classified SPOT 4 image subset. These filtered land cover classifications were vectorised and are displayed in Figure 4.5[35]. Table 4.3 presents total number of polygons before and after applying majority filters to the classified image.

As displayed in Figure 4.5 the 5x5 majority filter and the 7 x 7 majority filter had the most significant effect on the visual appearance of the data. It will appear that the 5x5 and 7x7 are more effective in eliminating the salt-and-pepper effect from the data. However, these filters seem to manipulate the data by making the corners of certain features appear 'rounded' and altering the shape of some of the features significantly. This is not the case when applying the 3x3 majority filter.

The data provided in Table 4.2 indicates that the number of polygons is reduced by 70% when applying a 3x3 majority filter to the classified image, 86% for a 5x5 majority filter

32 Raster data, such as digital satellite imagery is a series of uniform spatial elements providing thematic rather than linear representations of ground cover. The data are organised in a grid of columns and rows (a matrix) (ERDAS, 1997).

33 Vector data is 'data that represent physical forms (elements) such as points, lines, and polygons' (ERDAS, 1997).

34 In a majority filter, a moving window is passed through a classified data set and the majority class within the window is determined. The center value (continually using the original class codes) is changed to the majority class in the window. If there is no majority class the value is not changed (Lillesand & Kiefer, 1994)

35 The raster to vector conversion was performed using ArcView Spatial Analyst functionality. The software converts all adjacent grid cells of an image into contiguous polygons. The polygons smaller than 1ha were eliminated using ArcInfo 8 software.

and 92% for a 7x7 majority filter. When considering the trade-off between the differential gain in the reduction of number of polygons, 23% (92% - 69%) and the effect on the visual appearance of the classification, applying a 3x3 majority filter to the final land cover classification is the preferred method for reducing the salt-and-pepper effect for this study. The 3x3 majority filter provides a significant reduction in the total number of polygons (size of the vector file) and improves the overall appearance and homogeneity of the data without loosing the integrity of the data.

Table 4.2 Effect of spatial filtering / smoothing on the total number of polygons.

Majority Filter	Total number of polygons	% Reduction in size
Final classification (no filter)	125203	
3 x 3	38222	69
5 x 5	17756	86
7 x 7	10238	92

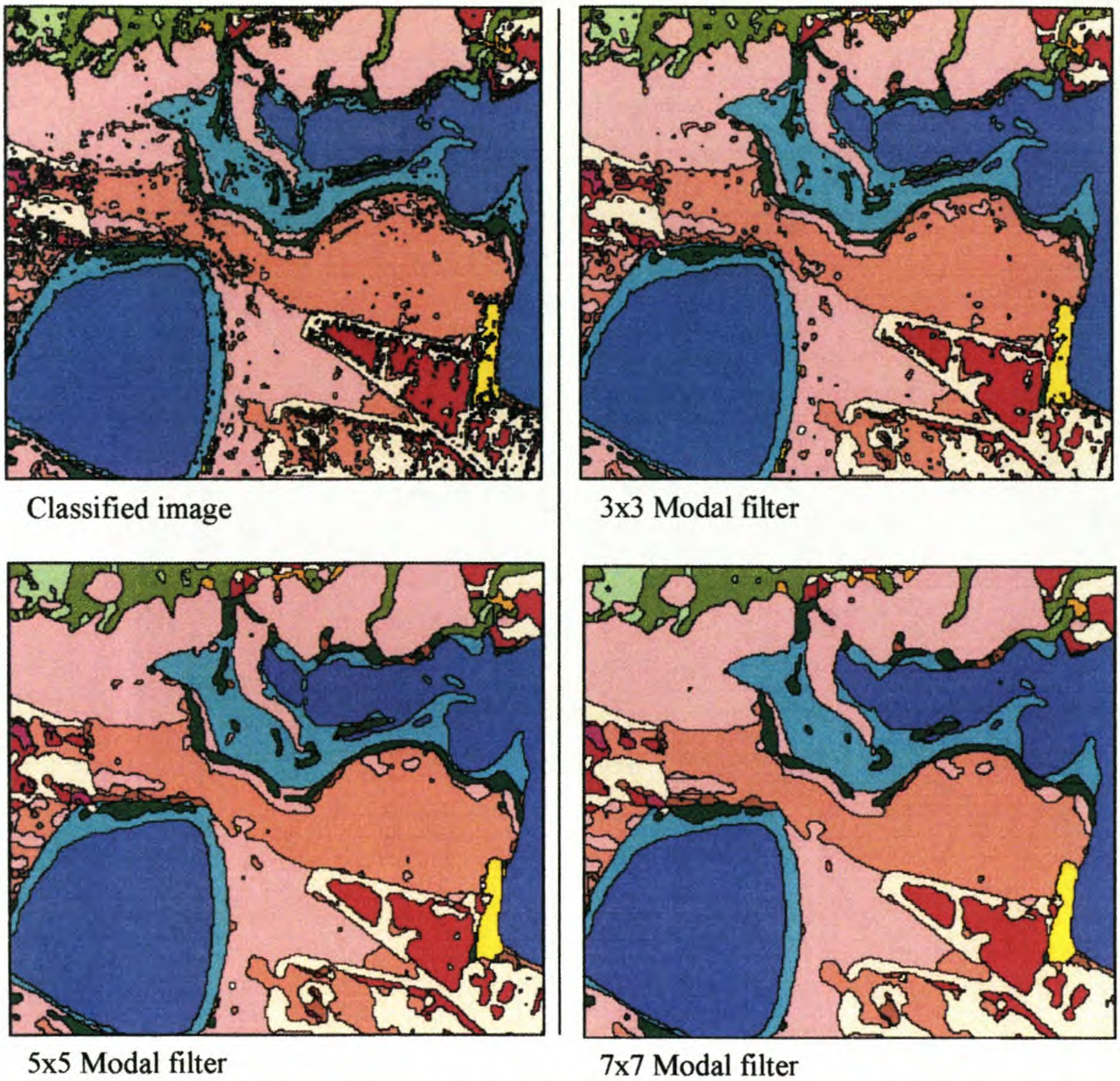
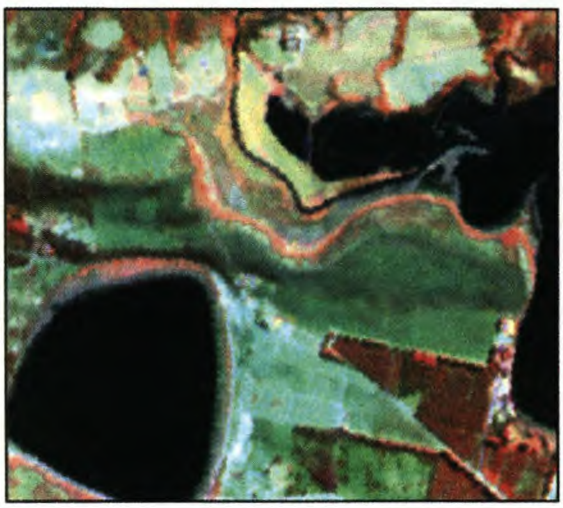


Figure 4.5 Illustration of the effect of post-classification filtering to reduce the salt-and-pepper effect (scale approximately 1:20 000).

The client (the DEA&T) requested a minimum mapping unit of 1ha. It was therefore decided to eliminate all the polygons smaller than 1ha from the 3x3 filtered classified image in preparation of the final land cover map for the study area. The visual effect of this elimination is presented in Figure 4.6 along with a subset of the original SPOT 4 image from which the land cover map was derived. A total number of 35 989 polygons smaller than 1ha were eliminated. This infers a further reduction of almost 30% from the original 125 203 polygons in the classified image before filtering, and a 94%

reduction in the number of polygons from the 3x3 majority filtered classification. Only 6% of the total number of polygons in the classified image is thus left.

The smaller number of polygons and thus size of digital files will imply easier manipulation of the final dataset for modelling and other purposes. It is suggested that should the client (the DEA&T) prefer not to eliminate the polygons smaller than 1ha that the original raster dataset (before vectorisation) is used for data manipulation and integration with other datasets as a raster dataset is typically smaller in file size and easier to navigate than its counter-part vector dataset.



SPOT 4 image (RGB = 3,4,2)

3x3 Modal filter; < 1ha

Figure 4.6 Subset of original SPOT 4 image and final land cover map with polygons smaller than 1ha eliminated from the 3x3 majority filtered classification (scale approximately 1:20 000).

4.6 Final land cover map

The final land cover map for the study area is presented in Figure 4.7 . The polygon count and associated area of cover for each of the individual land cover classes are listed in Table 4.3.

'Coastal waters' was included in the land cover classification system for the study area to provide a continuous land cover classification as represented by the SPOT 4 image subset. A large portion of the image subset (37%) is covered by 'coastal waters' - the study area is situated on the South African southern coast which borders the Indian Ocean. When this large area of 'coastal waters' is included with the calculations for percentage cover for each of the land cover classes it provides an unbalanced view of the terrestrial environment. For this reason the percentage cover for each of the land cover classes is also provided in Table 4.3 with the 'coastal waters' excluded from the equation. Percentage cover mentioned below refers to the terrestrial environment (excluding the 'coastal waters').

Almost half of the study area (48%) has been transformed through human intervention (forest plantation, agricultural land, transformed land and urban / built-up land). The natural vegetation that covers the largest portion of the study area is afromontane forest (25%) with 6% consisting of lowland fynbos and 5% of dune thicket. The lakes, vleis and salt marsh land cover classes jointly constitutes 7% of the study area. It was not possible to identify alien infestation from the SPOT 4 image with the methodology followed in this study.

LEGEND

Land Cover Classes

Afromontane forest	Mountain fynbos	Bare rock/soil	Saltmarsh
Dune forest	Pine plantations	Coastal waters	Urban/ Built-up land
Scrub forest	Eucalyptus plantations	Lakes	Shadow areas*
Dune thicket	Agricultural lands	Dams	Recently burned areas*
Lowland fynbos	Transformed land	Vleis	

* These classes are not generally recognised land cover classes but were incorporated in the land cover map for illustrative purposes.

Digital Satellite Remote Sensing for Terrestrial Coastal Zone Management.

Figure 4.7 Land cover map of the study area.

1 0 1 2 3 4 5

Kilometres

Projection: Transverse Mercator, Central Meridian 23° East. Spheroid: Clarke 1880.

CSIR ENVIRONMENTEK

Table 4.3 Total number of polygons and cover for each of the land cover classes presented in the final land cover map for the study area.

Land Cover Class	Number of polygons	Area (m^2)	Area (ha)	% Cover	% Cover without coastal waters
Afromontane forest	205	101 748 900	10174.89	15.79	25.17
Dune forest	190	10 784 700	1078.47	1.67	2.67
Pine plantations	146	54 827 500	5482.75	8.51	13.56
Eucalypt plantations	15	690 700	69.07	0.11	0.17
Alien species invasion	0	0	0	0.00	0.00
Dune thicket	242	19 368 500	1936.85	3.01	4.79
Scrub forest	234	8 579 300	857.93	1.33	2.12
Lowland fynbos	212	22 896 400	2289.64	3.55	5.66
Mountain fynbos	242	4 796 900	479.69	0.74	1.19
Agricultural lands	250	89 878 900	8987.89	13.95	22.23
Bare rock / soil	98	7 261 100	726.11	1.13	1.80
Transformed land	247	40 439 700	4043.97	6.28	10.00
Coastal waters	1	240 102 600	24010.26	37.26	
Lakes	20	21 284 800	2128.48	3.30	5.27
Dams	20	577 000	57.7	0.09	0.14
Vleis	35	8 353 200	835.32	1.30	2.07
Slatmarsh	5	177 900	17.79	0.03	0.04
Urban / Built-up land	46	8 640 400	864.04	1.34	2.14
Shadow areas	22	1 074 400	107.44	0.17	0.27
Recently burned areas	1	2 872 300	287.23	0.45	0.71
TOTAL	**2231**	**644 355 200**	**64435.52**	**100**	**100**

4.7 Summary

A hierarchical land cover classification system consisting of two levels was designed for the study area. Level I of the land cover classification system consists of 11 broad land cover types that can be identified with minimal use of ancillary data whereas Level II consists of 20 subclasses that require the use of ancillary data to be delineated. A semi-supervised procedure was used to prepare the land cover map for the study area. Unsupervised ISODATA clustering was used to classify 100 spectral classes for the study area. A series of manually derived area specific masks were used to facilitate the allocation of the spectral classes into the land cover classes for the study area. A 3 x 3 modal filter was used to eliminate the salt-and-pepper effect in the final classified data. The data were vectorised and all polygons smaller than 1ha eliminated from the final map. Nearly half of the study area (48%) has been converted through human intervention. Various natural land cover classes however remains with afromontane forest representing the largest total area of coverage (35%).

CHAPTER 5: DISCUSSION OF RESULTS AND COST ASSESSMENT

5.1 Introduction

The spatial and thematic accuracy of the final map produced for the study area is discussed in relation to the requirements of the CDSS. Estimated costs involved in producing this final map are outlined and compared to an estimated cost of producing land cover information by manual mapping from hardcopy aerial photographs. The cost estimation argues the contribution of data as well as manpower cost in producing a land cover map.

5.2 Spatial resolution compliance

The maximum advisable scale for use with digital satellite imagery is in the order of 1:3 000 times the ground resolution of the imagery. The minimum mappable unit of digital remotely sensed data is essentially 9 times (3x3) the pixel size of an image. The simulated 10m SPOT 4 (M+Xi merge) - image used in this study should thus allow for a maximum operating scale of approximately 1:30 000 and a minimum mappable unit of 0,09 ha.

This minimum mappable unit is in fact smaller than the minimum mapping unit of approximately 1ha that was stated as a requirement by the client (the DEA&T). For the final map preparation polygons smaller than 1ha were removed from the dataset. This step reduced the data volume to only 6% of the data volume of the final classified image before filtering, allowing easier transfer and future manipulation / use of the dataset.

5.3 Thematic accuracy assessment

Congalton (1991), Steele *et al.* (1998) and Edwards *et al.* (1998) describe various techniques available for assessing the thematic accuracy of land cover maps. Choice of assessment technique can substantially influence the outcome of an accuracy assessment, emphasising the importance of the conclusion made by Gong and Howarth (1990) that 'until a standardized approach becomes available, any accuracy assessment should clearly specify the procedures used'.

The three basic components of an accuracy assessment according to Stehman & Czaplewski (1998) are:

- the sampling design used to select the reference sample (described in Section 3.5 for this study),
- the response design used to obtain the reference land cover classification for each sampling unit, and
- the estimation and analysis procedures.

The above-mentioned components are affected by constraints as outlined by Fairbanks and Thompson (1996), namely:

- technological constraints,
- logistical constraints, and
- financial constraints.

Technological constraints include all forms of potential measurement error relating to observation of 'ground truth' and may include failure of equipment such as GPS systems or reference slides that get damaged. Logistical constraints may include the practical considerations in visiting sample points. For this study, sample points were randomly determined in the field by driving along most of the accessible roads in the study. Sampling measurements had also been made from aerial photography for 'inaccessible areas' / remote areas to supplement the data obtained through field visits. Financial constraints experienced in this study relate to limited funding for field visits. Weather conditions during a field visit in July 1999 did not allow for the collection of sufficient sample data for thematic accuracy assessment of the final map. The project budget did not support a follow-up field trip to the study area, however, a local conservation biologist assisted by gathering more field sample data during August 1999. This saved on travelling costs, and allowed for the sampling to be carried out when the weather permitted it.

5.3.1 Thematic accuracy assessment results

The final land cover map compiled for the study area from the SPOT 4 image subset was tested against 82 sample points for both levels of the land cover classification system. The results of the accuracy assessments of the land cover map of the study area are presented as contingency[36] matrices in Table 5.1 and Table 5.2. Data are presented for both the Level I and Level II hierarchical classifications levels although the land cover map of the study area is only presented at Level II for inclusion in the CDSS.

[36] A contingency table is a matrix that contains the number and percentages of pixels that were classified as expected (ERDAS, 1997).

Table 5.1 Contingency table for the land cover map of the study area (Level I).

		Land cover map (Level I) being evaluated														
		Forest	Forest plantations	Thicket, scrub forest & high fynbos	Fynbos	Agricultural lands	Barren lands	Waterbodies	Wetlands	Urban/Built-up land	Shadow areas	Recently burned areas	**Totals**	**PA%**	**EO%**	**EC%**
Actual Land Cover (Field)	Forest	14	0	0	0	0	0	0	0	0	0	0	14	100.0	0.0	35.7
	Forest plantations	2	9	0	0	1	0	0	0	0	0	0	12	75.0	25.0	0.0
	Thicket, scrub forest & high fynbos	3	0	8	0	0	0	0	0	0	0	0	11	72.7	27.3	9.1
	Fynbos	0	0	1	8	1	1	0	1	0	0	0	12	66.7	33.3	0.0
	Agricultural lands	0	0	0	0	6	0	0	0	0	0	0	6	100.0	0.0	33.3
	Barren lands	0	0	0	0	0	4	0	0	0	0	0	4	100.0	0.0	50.0
	Waterbodies	0	0	0	0	0	0	7	0	0	0	0	7	100.0	0.0	0.0
	Wetlands	0	0	0	0	0	1	0	9	0	0	0	10	90.0	10.0	10.0
	Urban/Built-up land	0	0	0	0	0	0	0	0	5	0	0	5	100.0	0.0	0.0
	Shadow areas	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0	0.0
	Recently burned areas	0	0	0	0	0	0	0	0	0	0	1	1	100.0	0.0	0.0
	Totals	19	9	9	8	8	6	7	10	5	0	1	**82**			
	CA%	73.7	100.0	88.9	100.0	75.0	66.7	100.0	90.0	100.0	0.0	100.0				

PA% - Producer's accuracy, EO% - Errors of omission, EC% - Errors of commission, CA% - Consumer's accuracy.

Table 5.2 Contingency table for the land cover map of the study area (Level II).

		Image to be evaluated: Level II																							
		Afromontane forest	Dune forest	Pine plantations	Eucalypt plantations	Alien species invasion	Dune thicket	Mountain thicket	Dune fynbos	Mountain fynbos	Agricultural lands	Bare rock/soil	Transformed land	Coastal waters	Lakes	Dams	Vleis	Saltmarsh	Urban Built-up land	Shadow areas	Recently burned areas	Totals	PA%	EO%	EC%
	Afromontane forest	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	85.7	14.3	85.7
	Dune forest	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	100.0	0.0	133.3
	Pine plantations	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	100.0	0.0	0.0
	Eucalypt plantations	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3	33.3	66.7	0.0
	Alien species invasion	5	0	0	0	0	3	1	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0.0	100.0	0.0
Actual	Dune thicket	0	3	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	50.0	50.0	50.0
Land	Mountain thicket	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	100.0	0.0	200.0
Cover	Dune fynbos	0	0	0	0	0	0	0	8	0	1	0	1	0	0	0	1	0	0	0	0	11	72.7	27.3	0.0
(Field)	Mountain fynbos	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.0	100.0	0.0
	Agricultural lands	0	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	6	100.0	0.0	33.3
	Bare rock/soil	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	3	100.0	0.0	33.3
	Transformed land	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	100.0	0.0	100.0
	Coastal waters	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	100.0	0.0	0.0
	Lakes	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	5	100.0	0.0	0.0
	Dams	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	100.0	0.0	0.0
	Vleis	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	8	0	0	0	0	9	88.9	11.1	11.1
	Saltmarsh	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	100.0	0.0	0.0
	Urban/Built-up land	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	5	100.0	0.0	0.0
	Shadow areas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	100.0	0.0
	Recently burned areas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	100.0	0.0	0.0
	Totals	12	7	8	1	0	6	3	8	0	8	4	2	1	5	1	9	1	5	0	1	**82**			
	CA%	50.0	42.9	100.0	100.0	0.0	50.0	33.3	100.0	0.0	75.0	75.0	50.0	100.0	100.0	100.0	88.9	100.0	100.0	0.0	100.0				

PA% - Producer's accuracy, EO% - Errors of omission, EC% - Errors of commission, CA% - Consumer's accuracy.

A summary of the results is outlined below in Table 5.3. The following statistical indices are presented:

- Map accuracy: Overall classification accuracy based on correctly identified sites versus the number of sites assessed, expressed as a percentage,
- Confidence interval: Reports how confident one should be of the reported map accuracy (%) using a two-tailed test. Provides a variance range of confidence around the reported map accuracy, based in this instance on 90% confidence limits,
- Ommission error: Index of the amount of misclassification, when one class is mis-identified as another,
- Kappa statistic[37]: Reports chance agreement and provides an additional measure of classification accuracy. An indication of the scientific repeatability of the mapping exercise, where values greater than 70 are normally taken as 'acceptable' (Thompson, 1999).

Table 5.3 Summary of the thematic accuracy assessment results for the final land cover map of the study area.

	Level I	Level II
Overall map accuracy:	86.59%	75.61%
90% confidence limit:	81.66 – 91.51	69.45 – 81.77
Ommission Error:	13.41	24.39
Kappa Index:	84.72	73.63

High percentages overall map accuracies and kappa indices were obtained for both levels of classification. As would be expected because of the more specific land cover classes evaluated, the Level II classification shows a lower overall mapping accuracy than the Level I classification. The misclassifications can be ascribed to information (land cover) classes displaying similar spectral characteristics and an inadequacy of the methodology

[37] Kappa (K) is estimated by $\hat{K}$ 'k hat'. $\hat{K}$ adjusts the percentage correct by subtracting the estimated contribution of chance agreement. As the percentage correct approaches 100, and as the contribution of chance agreement approaches 0, the value of $\hat{K}$ approaches +1.0, indicating perfect effectiveness of the classification. Values near 0 suggest that the classification process yields no better results than would a chance assignment of pixels to information classes. $\hat{K}$ assumes a negative value for increased chance agreement with decreased percentage correct (Campbell, 1996).

followed in this study to perfectly separate the spectral classes into the appropriate information (land cover) classes. It is also possible that the primary data source (SPOT 4 image) does not contain sufficient spectral information to be able to differentiate and map the required land cover classes at better thematic accuracy than achieved in this study.

Overall map accuracy can further be improved by more thorough delineation of the masks used to recode the unsupervised classification. Masks should however be employed with caution, as incorrect use may lead to a very generalised map where variations in the landscape are erroneously recoded to one specific information (land cover) class. No fixed parameters are stated for the delineation of the masks for this study. The analyst subjectively defined the masks based on visual interpretation of the ancillary data. To improve on this technique and aid in consistent repeatable application of the methodology it is recommended that the delineation of masks be based on well-defined parameters for fixed features such as relief or aspect. These parameters will have to be defined in consultation with local experts.

All the assessed Level I information classes, except fynbos, were mapped with accuracies greater than 70%. Fynbos was mapped with 66% accuracy. Due to the heterogeneous spectral characteristics of fynbos, it was also mapped as thicket/scrub forest, agriculture, wetlands and barren lands. Some forest plantations and thicket/scrub forest areas were erroneously mapped as forests. The boundaries between the spectral signatures of, for example, the thicket/scrub forest and the forest classes are difficult to define as it can be seen as an ecotonal gradient rather than a distinct line.

For the Level II classifications, the alien invasive class as well as the mountain fynbos could not be accurately mapped from the SPOT 4 data. Only one reference sample site was available to assess the accuracy of the mountain fynbos class. This site was mapped as scrub forest. This is most probably due to the heterogeneous spectral characteristics of mountain fynbos.

The alien invasive class was mainly mapped as afmontane forest or dune thicket. This again is most likely due to the similarities in the physiological structure of these classes and the resulting similar spectral characteristics. Alien invasive species might be mapped more accurately by acquiring satellite imagery during their flowering season. This could differentiate their spectral signature from the vegetation classes they are infesting and/or the classes with which they share physiological structure.

A very small percentage of the study area was mapped as shadow areas. These are mainly the extremely steep cliffs facing southeast along the shoreline as well as a few smaller areas, including the mountainous area in the northwestern corner of the image (foothills of the Outeniqua mountain range). 'Shadow areas' as mapped for this study are the result of local topography, sun azimuth and angle at the time the image was captured. A hillshade map can be used to locate and demarcate such 'shadow areas' and 'sample sites' for a thematic accuracy assessment. However, time constraints on the study did not allow for the extraction of 'shadow area' sample sites from the hillshade map. Furthermore, 'shadow areas' is not a recognised land cover class and should not be mapped as such in future application of the methodology proposed in this thesis.

5.4 Cost assessment[38]

A cost-estimate was made of the main elements contributing to the cost of compiling a land cover map for the study area through manual mapping from hardcopy aerial photography (referred to in this chapter as the manual method). A cost-estimation was also made of compiling a land cover map from digital satellite imagery such as SPOT 4 (referred to in this chapter as the digital method), and the two methods were compared in terms of cost-effectiveness.

Maguire (1991) outlines the basic elements of a GIS in an institutional context as:

- hardware,
- software,
- data, and
- liveware/people.

These elements also contribute to the costs of compiling information as input to a system such as the CDSS. The cost implications of these elements to the manual and digital methods are discussed below.

---

[38] The initial cost estimate for inclusion in this thesis was made in the first quarter of 2000. Although prices quoted in this thesis might have changed since the information was included it is expected that the general trend indicated in this chapter will still be the same.

5.4.1 Hardware and software

Hardware and software needs are determined by the complexity of tasks that need to be performed. Both the manual and digital methods for populating the land cover layer require specialised hardware and software. For example, manual mapping from hardcopy aerial photography specifically requires digitising equipment whereas the digital mapping from satellite imagery requires image-processing software. The hardware and software options and price range are too broad to include in this discussion. However, it has to be noted that easy to use, 'affordable' software packages and improved processing capabilities of PCs (which also includes innovative ways to minimise data space volumes) should encourage local authorities to take ownership of the maintenance of the CDSS in the long run. For most organisations with a spatial technologies department, hardware and software should be included in their infrastructure and will not specifically add to the cost of compiling the land cover information layer.

5.4.2 Data costs

Table 5.4 provides an estimate of the data costs involved for the manual and digital methods. A set of 1:10 000 scale hardcopy, project specific colour aerial photographs for the study area (40kmx20km) 800km^2 will cost R61/ km^2. The quote used for this cost estimate was based on colour aerial photography flown at a scale of 1:20 000. A set of prints at 1:10 000 is then produced by 2 x color enlargement from the negatives (Tanner, 2000). This price estimate is for project specific data acquisition, i.e. an aircraft would specifically be commissioned for this project. The costs might be reduced if the data acquisition coincides with data acquisition by the aerial survey company at locations close to the study area. The aforementioned costs could be affected by delays caused, for example, by local weather conditions. Archived 1:10 000 scale hardcopy, black and white ortho-photos are available at a minimal cost of R1/ km^2 from the CDSM. The ortho-photos available from the CDSM for the study area were compiled in 1973 and 1989.

Digital SPOT 4 imagery provided at a Level 2B processing level (such as acquired for this project) costs R6/ km^2. One scene covers an area of (60kmx60km) 3600km^2. Only 22% of the SPOT 4 scene was utilised to cover the study area which increases the cost to R26/ km^2. For land cover mapping in the study area, digital SPOT 4 data provided a cheaper option than hardcopy aerial photographs.

The cost of ancillary data is not provided in this estimate as the availability, potential use and cost of these datasets vary considerably. The use of ancillary data is however imperative for both the manual and the digital methods in enhancing the quality of land cover maps. Ancillary data sources should be used discerningly, as it can influence the total cost of the project substantially.

Table 5.4 Data cost estimates for the conventional manual and proposed digital methods.

Data source	**Data costs estimates (including 14% VAT)**	**R/Km^2 (approximate)**
1:10 000 colour aerial photography (hardcopy)	Project Specific (total area – 40km x 20km) **R48 878**	**R61**
1:10 000 ortho-photos (hardcopy)	Black & White, 1973/1989 (per photo – 4x5km) **R18**	**R1**
SPOT 4 archived and programmed imagery (digital)	Xi +M merge (Level 2B) (per scene – 60 x 60km) (22% of scene utilised – 40km x 20km) **R21 150**	**R6** **R26**

5.4.3 Manpower

The estimated manpower costs involved in preparing a land cover map for the study area are outlined in Table 5.5. Manual mapping from hardcopy aerial photography costs approximately R39/ km^2 and digital mapping from satellite imagery costs approximately R11/ km^2. The main reason for this price structure is the various tasks involved during each method (outlined in the table below) to compile a seamless, digital map as required for input to the digital CDSS.

Digital mapping from satellite imagery saves time (which relates to cost) by eliminating the need for converting hardcopy maps to digital format, as required by manual mapping from hardcopy aerial photography. Significantly less time is also spent on 'edge-matching' the multiple 1:10 000 mapped sheets needed to cover the same area as one satellite image[39]. This emphasises the added benefit of satellite imagery, providing a synoptic map-like view of an area.

The costs involved with field trips for orientation and ground truthing are not included in the calculations, as this can be expected to be the same for both methods. The extent and the type of terrain that needs to be assessed and method followed will determine the cost of obtaining this ancillary data. As a rough estimate R5 000 to R7 000 per visit can be added for collecting field data in an area the size of the study area[40]. This estimate includes human resource and running expenses and is based on the cost of the field visit conducted for this study.

Digital mapping from satellite imagery is a cheaper option in terms of labour cost than manual mapping from hardcopy aerial photographs.

[39] A 1:10 000 scale ortho-photo covers 20 km^2. The study area covers 800 km^2. 40 x 1:10 000 scale ortho-photo map sheets are required to cover the study area. A SPOT 4 satellite image covers an area of 3600 km^2.

[40] This estimated cost if for a field visit lasting three days, including the cost of a return-flight from Cape Town to George.

Table 5.5 Manpower cost estimate.

Method	Tasks involved for mapping an area of +/- 40x20km (800 km^2)	Estimated labour cost[41]	R/km^2 (approximate)
Conventional manual mapping from aerial photos	• Manual mapping onto 40 overlays	40h @ R250 = R10 000	
	• Digitise, geo-rectify, mosaic and edge-match 40 map sheets	120h@ R170 = R20 400 4h@ R250 = R1 000	
	Total:	**R31 400**	**R39**
Proposed digital mapping from satellite imagery	• Unsupervised classification	2h @ R250 = R500	
	• Recoding (with masks)	30h @ R250 = R7 500 4h @ R250 = R1 000	
	• Postprocessing	**R9 000**	**R11**
	Total:		

5.5 Summary

Digital mapping from a SPOT 4 image provided a land cover map with an acceptable thematic accuracy and suitable spatial resolution to be included in the CDSS. Both hierarchical levels of land cover classes could be mapped at an overall map accuracy of more than 70% with a high degree of confidence and repeatability. Digital mapping from satellite imagery is a cheaper option than manual mapping from hardcopy aerial photographs both in terms of data and labour cost.

[41] The following estimates of hourly rates (based on CSIR experience) were used: R250/h for an experienced analyst to do photo/image interpretation, and R180/h for an experienced technical assistant to do digitising. The estimate does not include the cost of training should the required capacity not be available.

CHAPTER 6: SUMMARY AND CONCLUSIONS

6.1 Introduction

This chapter provides an overview of the information presented in the thesis. The aims of the study are revisited along with the relevant remote sensing history and fundamental concepts. The acquisition and preprocessing of the primary and ancillary data sources for the study are discussed. The preparation of the final land cover map for the study area are outlined, including both the design of the land cover classification system for the study area as well as the processing and postprocessing of the data. An evaluation of the suitability of the final land cover map for inclusion in the CDSS is included along with the associated costs. In conclusion recommendations are made for the future application of the proposed methodology in this thesis.

6.2 Revisiting the aims of the study

6.2.1 Background and introduction

The coastal zone is recognised as a unique and often fragile environment that requires thorough planning and management. It is expected that three quarters of the world's population will be living within 60km of the coast by the year 2020. In South Africa, focused coastal management efforts at a national level began in the 1980s, culminating in a White Paper for sustainable coastal development in South Africa, which was launched on 6 June 2000. The White Paper document sets out a new policy that aims to achieve sustainable coastal development through ICZM. Information requirements are highlighted as one of the key elements of the proposed plan of action to implement the Policy.

In support of information requirements as mentioned in the White Paper for coastal development a CDSS is being promoted by the DEA&T. A prototype of the CDSS was introduced for the Outeniqua SCA as a tool to assist applicants and decision-making authorities in the implementation of SCA regulations. Land cover information (such as vegetation, wetlands, coastal lakes and agricultural areas) for the ODSS was derived from visual interpretation and manual mapping of 1:10 000 scale hardcopy colour aerial photography acquired in 1987. Even though this method was successful for populating the ODSS is was found to time-consuming and costly.

The aims of this study are:

- *To assess digital satellite imagery as primary source of data, in terms of quality of information and cost, for terrestrial coastal zone mapping.*
- *To assess digital mapping from satellite imagery as an alternative method to manual mapping from hardcopy aerial photography for populating land cover information for the Coastal Decision Support System.*

6.2.2 The study area

The area surrounding the Sedgefield and Wilderness urban centres - which is located on the southern coastal plain of South Africa - was chosen as study area for this study in consultation with the client (the DEA&T). Most of the environmental features mapped for the ODSS are represented here. The study area, which lies within the Outeniqua SCA, comprises an area of approximately 40km along the coastline extending approximately 20km inland. The general location of the study area is displayed in Figure 1.2.

The distribution of vegetation in the study area is affected directly by climatic effects such as solar radiation, temperature and moisture, and indirectly through the influence of soil conditions and fire regime. The study area falls within the Cape phytogeographical region, where one would commonly expect to find fynbos on the nutrient deficient soils and shrubland in the drier intermontane valleys. Patches of thicket (Tongaland-Pondoland) are to be found along the coast, whereas afromontane forest occur at the base of the wetter, coastal mountains. Coastal lakes, wetlands and salt marshes also characterise the area. Intervention by man introduced urban uses, agricultural lands and forest plantations.

6.3 Remote sensing: history and fundamental concepts

For the purpose of this thesis, remote sensing is defined as:

'the practice of deriving information about the earth's land and water surfaces using images acquired from an overhead perspective, using electromagnetic radiation in one or more regions of the electromagnetic spectrum, reflected or emitted from the earth's surface'.

Remote observation of the land surface dates back as far as the nineteenth century when cameras were strapped to the breasts of pigeons to obtain photographs of Paris. Since then both the sensors used for observation as well as the platforms have changed considerably. Satellites are now routinely used to mount sensors for observation of the earth.

Satellite sensors detect energy reflected or emitted from features on the earth in the form of electromagnetic radiation. Regions of the electromagnetic spectrum that are useful for earth observation remote sensing are the:

- visible spectrum,
- infrared region, and
- microwave region.

Satellite sensors are designed to record specific portions of the electromagnetic spectrum, which are referred to as bands or spectral channels. The ability of sensors to record electromagnetic radiation within specific wavelength intervals is described as the sensors' spectral resolution.

The suggested maximum advisable scale for use with any imagery is in the order of '1:3 000 x ground resolution (pixel size) of the imagery'. The minimum mappable unit of digital satellite data depends on the sensors' maximum spatial resolution or ground resolution (resolution cell), as well as the size, shape and spectral characteristics of the features being observed. Since a land cover unit/feature must contain at least one complete/'pure' image pixel unit to be identified, the effective minimum mappable unit of a sensor is considered to be 3x3 pixels (assuming pixel = ground resolution). This is not a hard and fast rule since certain features with distinct spectral characteristics such as dams might, for example, be discernable even though they are smaller than the spatial resolution – this is due to the 'spectral saturation' of an entire pixel.

Remote sensing has a multitude of uses in application fields such as plant sciences, earth sciences and hydrospheric sciences. The application of satellite imagery for land cover mapping is of special interest to this study. Satellite imagery is seen as a suitable source of primary data to undertake such a land inventory. Various studies have demonstrated the successful use of Landsat and SPOT data for this purpose, and more specifically SPOT data have been used to identify and map coastal information such as estuarine, vegetation and near shore features.

6.4 Acquisition and preprocessing of data

6.4.1 Primary data source

The SAC sponsored a SPOT 4 (M + Xi) – merged image acquired on 14 March 1999 as primary data source for this study - scene ID 126-1-418 990314. A SPOT 4 (M + Xi) merged (onboard) scene provides four multispectral bands at simulated 10m ground / spatial resolution. The spectral information provided in the image includes green, red, near infrared and shortwave infrared bands. Sunrise for the study area on 14 March 1999 was approximately 6:30am (2 hours before the image was captured). The study area experienced heavy but normal rainfall during the month preceding acquisition of the SPOT 4 image used in this study. The sun azimuth was 51.3° and the sun elevation 46.8° at the time of image acquisition. The simulated 10m SPOT 4 (Xi+M merged) - image should allow for a maximum operating scale of approximately 1:30 000 – 1:40 0000 and a minimum mapping unit of approximately 0.09ha.

The SAC processed the SPOT 4 (M+Xi merge) - image to Level 2B. This includes geo-rectification by obtaining ground control points from the 1:50 000 South African topographical map series provided by the Chief Directorate Survey and Mapping (CDSM). To ensure high geometric accuracy it was essential to achieve a root mean square of about half a pixel (5m). The image was also registered to a Transverse Mercator projection using the Cape datum and a 23°E Central Meridian (the same as the information provided in the CDSS).

6.4.2 Ancillary data

To facilitate the overlay of the ancillary data with the primary data for this project and the information provided in the CDSS, the digital ancillary data were projected to the Transverse Mercator projection using the Cape Datum and a 23 °E Central Meridian. The data were mosaiced and/or 'clipped' to create continuous datasets covering the study area and incorporated into an ArcView project as themes.

Ancillary data obtained and used in the study includes the following:

- 1: 50 000 scale digital topographical data for the study area,
- a 1:50 000 scale digital map showing geological features for the study area,

- archived 1:10 000 scale hardcopy aerial photography, 1:10 000 scale hardcopy ortho-photos and digital SPOT 2 satellite imagery of the study area, and
- 1: 250 000 scale digital '96 South African National Land Cover Database for the study area.

Digital topographical data covering the study area were obtained from the CDSM. This includes contour data at 20m intervals captured from 1:50 000 scale topographical-map sheets. The contour data were used to build a 20m elevation surface/digital elevation model (DEM) for the study area and derive slope, aspect and hillshade maps for the study area.

6.4.3 Field data

Knowledge about local conditions and experience in identifying land cover features from remotely sensed data enhances an analyst's capability to produce an accurate map. For this reason a conservation biologist with in-depth knowledge about the land cover in the study area as well as a botanist with experience in mapping land cover features in the study area from hardcopy aerial photos were approached for assistance. They assisted in field orientation, field data collection for the thematic accuracy assessment, the design of the land cover classification system as well as the interpretation of the SPOT 4 image subset.

Following a field orientation visit to the study area in February 1999, field data to be used in the thematic accuracy assessment of the final land cover map for the study area were collected in July (26 sample points) and August (31 sample points) 1999.

6.4.4 Hardware and Software

Data processing was done at the CSIR and the hardware and software used in this project was thus governed by the availability of resources at the CSIR. The data were processed on a Dell Cpi-series notebook with a Pentium (ii) processor and 64MB RAM. ERDAS Imagine V3.8.1 for Microsoft Windows '98 (raster image processing software), was used for the processing of the SPOT 4 imagery. ArcView version 3.2 (a desktop vector-based GIS software package) was used to compile ancillary data into an easy accessible project for visual interpretation and analysis. ArcView's Spatial Analyst extension was used to analyse ancillary raster data. ArcInfo 8 was used for vectorizing the derived land cover information for input to the CDSS.

6.5 Image classification and postprocessing

6.5.1 Land cover classification system

An *a-priori* classification system design approach was followed in this study. The hierarchical land cover classification system designed for this study relates to the standard land cover classification for remote-sensing applications in South Africa, and was modified to suit the local conditions/requirements of the study area. The information requirements for the CDSS were also taken into consideration. The main classes of the land cover classification system for the study area is shown in Table 6.1.

Table 6.1 Land cover classification system for the study area.

Level I	Level II
Forest	Afromontane forest Dune forest
Thicket, scrub forest and high fynbos	Dune thicket Scrub forest
Fynbos	Lowland fynbos Mountain fynbos
Forest plantations	Pine species Eucalypt species Alien species invasion
Agricultural lands	Agricultural lands
Barren lands	Bare rock/soil Transformed land
Waterbodies	Coastal waters Lakes Dams
Wetlands	Vleis Saltmarsh
Urban/Built-up land	Urban/Built-up land
Shadow areas	Shadow areas
Recently burned areas	Recently burned areas

'Shadow areas' and 'recently burned areas' information classes, included in the land cover

6.5.2 Land cover classification methodology

A semi-supervised procedure was used to prepare the land cover map for the study area. This procedure is based on an unsupervised classification of the SPOT 4 image subset with subsequent modification using ancillary data, visual interpretation of the imagery and area specific masking (areas of interest). The SPOT 4 image subset was classified into 100 spectral classes using ERDAS Imagine image processing software. The spectral classes were grouped to 'best fit' the land cover classes, as defined in the land cover classification system for the study. During this process it became evident that several of the land cover classes consisted of more than one spectral class and that some of the spectral classes were present in more than one land cover class.

Manually determined area-specific masks were delineated (on-screen) through visual interpretation of the SPOT 4 image subset. Specific land cover classes, which shared spectral classes with other land cover classes, were isolated. The masks were used to selectively separate the spectral classes that were shared between land cover classes into the appropriate land cover classes. The masks were used as areas of operation in which to recode the spectral classes under question. It is important to note that these masks are not delineated to precisely fit an information class, but that the masks are drawn 'roughly' with the aim of differentiating these areas from other areas where the involved spectral class relates to other land cover classes.

Three different modal filters were tested in an attempt to remove the salt-and-pepper effect from the classified image. A 3 x 3 modal filter was found to provide the best solution as it induced a significant reduction in the total number of polygons (size of the vector file) and improved the overall appearance and homogeneity of the data without loosing the integrity of the data. The data were vectorised and all polygons smaller than 1ha eliminated from the final map as the minimum mapping unit for the final land cover map for the study area is 1ha.

Nearly half of the study area (48%) has been converted through human intervention. Various natural land cover classes however remains with afromontane forest representing the largest total area of cover (25%). The final land cover map for the study area is presented in Figure 4.7.

6.6 Final land cover map suitability and cost assessment

6.6.1 Spatial resolution compliance

The simulated 10m SPOT 4 (M+Xi merge) - image used in this study should allow for a maximum operating scale of approximately 1:30 000 and a minimum mappable unit of 0,09 ha rendering it suitable in terms of spatial resolution to be used for land cover mapping as input to the CDSS. This minimum mappable unit is in fact smaller than the minimum mapping unit of approximately 1ha that was stated as a requirement by the client (the DEA&T). For the final map preparation polygons smaller than 1ha were removed from the dataset. This step reduced the data volume to 6% of the data volume of the classified image before spatial filtering, allowing easier transfer and future manipulation / use of the dataset.

6.6.2 Thematic accuracy

High percentages overall map accuracies and kappa indices were obtained for both levels of the classification system. As would be expected because of the more specific land cover classes evaluated, the Level II classification shows a lower overall mapping accuracy than the Level I classification. The misclassifications can be ascribed to information (land cover) classes displaying similar spectral characteristics and an inadequacy of the methodology followed in this study to perfectly separate the spectral classes into the appropriate information (land cover) classes. It is also possible that the primary data source (SPOT 4 image) does not contain sufficient spectral information to be able to differentiate and map the required land cover classes at better thematic accuracy than achieved in this study. A summary of the thematic accuracy assessment results is presented in Table 5.3.

6.6.3 Cost assessement

A set of 1:10 000 scale hardcopy, project specific colour aerial photographs for the study area (40kmx20km) 800km^2 will cost R61/ km^2. This price estimate is for project specific data acquisition, i.e. an aircraft would specifically be commissioned for this project. The costs might be reduced if the data acquisition co-insides with data acquisition by the aerial survey company at locations close to the study area. The aforementioned costs could be affected by delays caused, for example, by local weather conditions. Archived 1:10 000 scale hardcopy, black and white ortho-photos are available at a minimal cost of R1/ km^2 from the CDSM. The ortho-photos available from the CDSM for the study area were compiled in 1973 and 1989.

Digital SPOT 4 imagery provided at a Level 2B processing level (such as acquired for this project) costs R6/ km^2. One scene covers an area of (60kmx60km) 3600km^2. Only 22% of the SPOT 4 scene was utilised to cover the study area which increases the cost to R26/ km^2. For land cover mapping in the study area, digital SPOT 4 data provided a cheaper option (R26/ km^2) than hardcopy aerial photographs (R61/ km^2).

The estimated manpower costs involved in preparing a land cover map for the study area using manual mapping techniques from hardcopy aerial photography costs approximately R39/ km^2 and digital mapping from satellite imagery costs approximately R11/ km^2. Digital mapping from satellite imagery saves time (which relates to cost) by eliminating the need for converting hardcopy maps to digital format, as required by manual mapping from hardcopy aerial photography. Significantly less time is also spent on 'edge-matching' the multiple 1:10 000 mapped sheets needed to cover the same area as one satellite image. This emphasises the added benefit of satellite imagery, providing a synoptic map-like view of an area. Digital mapping from satellite imagery is a cheaper option in terms of labour cost than manual mapping from hardcopy aerial photographs.

6.7 Concluding remarks and recommendations

6.7.1 Concluding remarks

Digital mapping from a SPOT 4 image provided a land cover map with an acceptable thematic accuracy and suitable spatial resolution to be included in the CDSS. Both hierarchical levels of land cover classes could be mapped at an overall map accuracy of more than 70% with a high degree of confidence and repeatability. Digital mapping from satellite imagery is a cheaper option than manual mapping from hardcopy aerial photographs both in terms of data and labour cost.

6.7.2 Recommendations

Manual mapping from hardcopy aerial photography and digital mapping from digital satellite remotely sensed data present two opposite ends of a continuum of possible methods to do land cover mapping. Digital aerial photography or mapping from hardcopy satellite imagery are examples of two additional/alternative data sources that may also be utilised. Using alternative data sources implicates variability in the data and human resource costs for mapping land cover information. It was not within the scope of this study to evaluate all the various options in detail. It might prove useful to perform a broad level cost estimate of the other options when applying the method as described in the thesis.

The application of the methodology described in this thesis to the full extent of the Outeniqua SCA (larger than the chosen study area) and/or an expansion of the concept of the CDSS to the complete coastline of South Africa will necessitate careful consideration of the following issues:

- Images acquired to cover the full extent of the area will have to be seasonally and climatically standardised. This is important to maximise information on vegetation cover types and minimise temporal effects and land cover variability between adjacent images captured on different dates.

- Data volumes will play an important role in terms of storage space and computer processing capabilities. There are various ways to reduce storage space, including compression software such as Lizartech's MrSID data compression algorithm or ER Mapper's ECW compression system. Such software should be considered if data volume becomes a deterrent in adapting the proposed methodology and utilised if they are found to be suitable for application.

- The specific end-users' information requirements as well as the characteristics of the various coastal sections mapped will have to be clearly understood and defined. Local knowledge is essential to enhance the final quality of the derived information. This in turn accentuates the need for close co-operation with the end-users who have intimate knowledge of the areas they manage.

- The proposed method is not a stand-alone technology, but a tool to aid and improve traditional mapping techniques. Satellite remotely sensed data can be used along with other sources such as aerial photography and videography to provide a set of tools in mapping land use and monitoring change.

Efficient mapping of land cover information as input to the CDSS and the management of our precious coastal environment will be promoted by:

- improved mapping resolution and spectral discrimination of future satellites,
- lower cost of data as more users utilise the technology, and
- the integration of remote sensing platforms such as digital aerial imagery and videography.

Reference List

Ahearn, SC & Wee, C 1991. Data Space Volumes and Classification Optimization of SPOT and Landsat TM Data. *Photogrammetric Engineering & Remote Sensing* 57, 1: 61-65.

Anuta, PE 1976. Digital Registration of Topographic Data and Satellite MSS Data for Augmented Spectral Analysis. In *Proceedings, 42nd Annual Meeting, American Society of Photogrammetry.* Falls Church, VA: American Society of Photogrammetry, pp. 180-187.

Aronoff, S 1989. *Geographic Information Systems: A Management Perspective*. Ottawa: WDL Publications.

Baard, J 1999. Information given to C. Pretorius during a personal communication in 1999.

Barale, V & Folving, S 1996. Remote sensing of coastal interactions in the Mediterranean region. *Ocean & Coastal Management* 30, 2-3: 217-233.

Bernhardsen, T 1992. *Geographic Information System*. Norway: Viak IT.

Berry, JK 1993. *Beyond Mapping: Concepts, Algorithms, and Issues in GIS.* Fort Collins, CO: GIS World, Inc.

Bird, ECF 1984. Coasts – *An introduction to Coastal Geomorphology.* 3rd ed. New York: Basil Blackwell.

Boyle, T 1996. Supply of SPOT data not affected by demise of SPOT 3 satellite. *SAC News* 12: 6.

Brown, R 1998. Information given to C. Pretorius during a personal communication in 1998.

Brown, DG & Arbogast, AF 1999. Digital Photogrammetric Change Analysis as Applied to Active Coastal Dunes in Michigan. *Photogrammetric Engineering & Remote Sensing* 65,4:467-474.

Budge, AM & Morain, SA 1995. Access Remote Sensing Data for GIS. *GIS World,* February: 45-49.

Burley, TM 1961. Land use or land utilization? *Professional Geographer* 13: 18-20.

Burns, ME 1999. Information given to C. Pretorius during a personal communication in 1999.

Campbell, JB 1996. *Introduction to remote sensing.* 2nd ed. London: Taylor & Francis. 622p.

Cao, C & Lam, NS-N 1977. Understanding the scale and resolution effects in remote sensing and GIS. In Quattrochi, DA & Goodchild, MF (Eds.) *Scale and Remote Sensing and GIS*, pp57-72. New York, NY: Lewis Publishers.

CCRS 2000. [Online]. Available: http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/indexe.html [20.12.2000].

Celentano, A 1999. Remote Sensing in the 21st Century: more precision, more choice, more applications. *GEOEurope,* November: 28-29.

Chan, JC-W, Chan, K-P & Yeh, AG-O 2001. Detecting the Nature of Change in an Urban Environment: A Comparison of Machine Learning Algorithms. *Photogrammetric Engineering & Remote Sensing* 67, 2: 213-255.

Chavez, Jr., PS & MacKinnon, DJ 1994. Automatic Detection of Vegetation Changes in the Southwestern United States Using Remotely Sensed Images. *Photogrammetric Engineering & Remote Sensing* 60, 5: 571-583.

Chliche, G, Bonn, F & Teillet, P 1985. Integration of the SPOT panchromatic channel into its multispectral mode for image sharpness enhancement. *Photogrammetric Engineering & Remote Sensing* 3: 311-316.

Chunnet, EP 1964. *The deterioration of the Wilderness system.* Pretoria: CSIR (Special Report No. MEG. 306).

Cihlar, J, Latifovic, R & Beaubien, J 2000. Comparison of Clustering Strategies for Unsupervised Classifcation. *Canadian Journal of Remote Sensing* 26, 5: 446-454.

Clawson, M & Steward, CL 1965. *Land use information. A critical survey of U S statistics including possibilities for greater uniformity.* Baltimore, MD: Johns Hopkins University Press for Resources for the Future.

CMO 2000. See Coastal Management Office.

CMPP 1999. See Coastal Management Policy Programme.

Coastal Management Office 2000. Coastal Management Policy Programme. [Online]. Available: http://www.environment.gov.za/sacoast/ [7.7.2000].

Coastal Management Policy Programme 1999. Progress Report. Progress with implementation of the draft white paper for sustainable coastal development in South Africa. Coastal management policy programme. [Online]. Available: http://www.cmpp.co.za/Update.htm [7.9.1999].

CNES 1998. Official SPOT 4 web site: They eyes of SPOT 4. [Online]. Available: http://spot4.cnes.fr/spot4_gb/hrvir.htm [18/12/1999].

Comentz, J 2000. ERDAS Imagine 8.4, Image Processing with Class. *GeoSpatial Solutions*, November: 46-49.

Congalton, RG 1991. A review of assessing the accuracy of classifications of remotely sensed data. *Remote Sensing of Environment* 37:35-46.

Congalton, RG 2000. ERDAS Imagine 8.4, Image Processing with Class. *GeoSpatial Solutions*, October: 48-51.

Cowling, RM 1983. Phytochorology and vegetation history in the south-eastern Cape, South Africa. *Journal of Biography* 10: 393-419.

Cowling, RM 1984. A syntaxonomic and synecological study in the Humansdorp region of the Fynbos biome. *Bothalia* 15, 1&2: 175 – 228.

Cowling, RM, Richardson, DM & Pierce, SM 1997. V*egetation of Southern Africa*. Cambridge, UK: Cambridge University Press.

Croft, L 2000. Information given to C. Pretorius during a personal communication in 2000.

Cromley, RG 1992. *Digital Cartography*. New Jersey: Prentice Hall.

Croukamp, L 1999. Information given to C. Pretorius during a personal communication in 1999.

CSIR 1991. *The mapping and conservation importance rating of the Cape coastal vegetation as an aid to development planning – Southern Cape Coast*. Stellenbosch: CSIR (Report No. EMA – C 89153A).

Curran, PJ 1985. *Principles of remote sensing*. Hong Kong: Longman Group Limited.

Dana, PH 1999. Global Positioning System Overview. The Geographer's Craft Project. [Online]. Available: http://utexas.edu/depts/grg/gcraft/notes/gps/pgs.html [19.2.2000].

DCDSTF 1988. See Digital Cartographic Data Standards Task Force.

DEA&T 1998. See Department of Environmental Affairs and Tourism.

Deane, GC, Bradbury, PA & Barr, WMC 1989. The Choice of Imagery And Interpretation Techniques For Operational Remote Sensing, Technical contents of 15th Annual Conference of the Remote Sensing Society, 1989.

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

Department of Environmental Affairs and Tourism, 1998. *Guidelines for the control and management of activities in sensitive coastal areas: Document 2 – Guidelines and definitions*. Cape Town: Department of Environmental Affairs and Tourism Coastal Management.

Digital Cartographic Data Standards Task Force, 1988. The proposed standard for digital cartographic data. *The American Cartographer* 15: 7-140.

Di Gregorio, A 1996. AFRICOVER Land Cover Classification. Proposal for the International working Group Meeting, Dakar, 29 – 31 July.

Edwards, TC, Moisen, GG & Cutler, DR 1998. Assessing map accuracy in a remotely sensed, eco-region scale cover map. *Remote Sensing of Environment* 63:73-83.

Ehlers, M 1991. Multisensor image fusion techniques in remote sensing. *ISPRS Journal of Photogrammetry and Remote Sensing* 46: 19-30.

Elachi, C 1987. *Introduction to the physics and techniques of remote sensing.* New York: John Wiley & Sons, Inc.

ERDAS Imagine 1997. *ERDAS Field Guide.* 4th Ed. Atlanta: ERDAS Inc.

ESRI 1994. *Introduction to ArcView.* ESRI: USA.

ESRI 1996. *ArcView spatial analyst: advanced spatial analysis using raster and vector data.* Redlands: Environmental Systems Research Institute, Inc.

Fairbanks, DHK & Thompson, MW 1996. Assessing land-cover map accuracy for the South African Land-Cover Database. *South African Journal of Science* 92:465-470.

Flemming, MD 1977. *Computer-aided analysis techniques for an operational system to map forest lands utilizing Landsat MSS data.* West Lafayette, Indiana: Laboratory for Applications in Remote Sensing, Purdue University (Technical Report No. 112277).

Foody, GM & Curran, PJ 1994. Scale and environmental remote sensing. In Foody, GM & Curran, PJ (eds.) *Environmental Remote Sensing from Regional to Global Scales,* pp223-232. Chichester: Wiley.

Forseman, TW 1999. Government and Planning Applications for Remote Sensing. *Earth Observation Magazine,* April: 30-33.

Fowler, RS 1997. Map specifications (Part II). *Earth Observation Magazine,* November: 33-35.

Fukue, K, Shimoda, H, Matumae, Y, Yamaguchi, R & Sakata, T 1998. Evaluations of unsupervised methods for Land-cover/use classifications of Landsat TM data. *Geocarto International* 2: 37 – 44.

Fuller, R & Groom, G 1993. The land cover map of Great Britain. *GIS Europe,* October: 25-28.

Gastellu – Etchegorry, JP 1990. An assessment of SPOT XS and Landsat MSS data for digital classification of near-urban land cover. *International Journal of Remote Sensing* 11, 2: 225 – 235.

Gong, P & Howarth, PJ 1990. An assessment of some factors influencing multi-spectral land cover classification. *Photogrammetric Engineering and Remote Sensing* 56, 5: 597-603.

Gumbricht, T, McCarthy, J & Mahlander, C 1996. Digital interpretation and management of land cover – a case study of Cyprus. *Ecological Engineering* 6: 273-279.

Heydorn, AEF & Tinley, KL 1980. *Estuaries of the Cape: Part I. Synopsis of the Cape Coast. Natural features, dynamics and utilization.* Stellenbosch: CSIR/National Research Institute for Oceanology (Report No. 380).

Hill, MJ, Peter, JV, Furnival, EP & Donald, GE 1998. Pasture Land Cover in Eastern Australia from NOAA-ACHRR NDVI and Classified Landsat TM. *Remote Sensing of Environment* 67:32-50.

Holmes, S 1979. *Henderson's dictionary of biological terms.* London and New York: Longman.

Holz, RK 1985. *The surveilant science: Remote Sensing of the Environment.* 2nd ed. New York: John Wiley & Sons.

Houhoulis Smit, P 2001. Maximizing information content of Landsat imagery for coastal zone applications. *Photogrammetric Engineering & Remote Sensing* 67, 7: 769-775.

Hubert-Moy, L, Cotonnec, A, Le Du, L, Chardin, A & Perez, P 2001. A Comparison of Parametric Classification Procedures of Remotely Sensed Data Applied on Different Landscape Units. *Remote Sensing of Environment* 75: 174-187.

IKONOS 2001. IKONOS home page. [Online].
Available: http://www.spaceimaging.com/ [23.11.2001]

Johannsen, CJ & Sanders, JL (eds.) 1982. *Remote sensing for resource management.* Iowa: Soil Conservation Society of America.

Johnston, RM & Barson, MM 1993. Remote sensing of Australian Wetlands: An evaluation of Landsat TM data for inventory and classification. *Australian Journal for Marine and Freshwater Resources* 44: 235 – 252.

Jumat, MZ 1999. Information given to C. Pretorius during a personal communication in 1999.

Katsch, C & Vogt, H 1999. Remote sensing from space – present and future applications in forestry, nature conservation and landscape management. *Southern African Forestry Journal* 185: 14-26.

Kelton, K, Shain, WA & Nix, L 1985. Supervised and Unsupervised methods of spectral classification of vegetative types in the South Carolina coastal plain.

Klemas, VV 2001. Remote Sensing of Landscape-Level Coastal Environmental Indicators. *Environmental Management* 27, 1: 47-57.

Konecny, G 1987. Development and art of remote sensing. In Damen, MCJ, Smit GS, Verstappen, HTH (eds.) *Remote Sensing for Resource Development and Environmental Management*, pp969-972. Rotterdam: Balkema.

Kovacs, JM, Wang, J & Blanco-Correa, M 2001. Mapping disturbances in a Mangrove Forest Using Multi-Date Landsat TM Imagery. *Environmental Management* 27, 5: 763-776.

Kunte, PD & Wagle, BG 1994. Analysis of Space-borne data for coastal zone information extraction of Goa Coast, India. *Ocean & Coastal Management* 22: 187 – 200.

Landsat 7 2001. Landsat 7 homepage. [Online].
Available: http://landsat7.usgs.gov/index.php [20.11.2001]

Le Grange, J 1987. *Opmeetkunde vir stads – en streeksbeplanning.* Potchefstroom: Potchefstroom University for Christian Higher Education.

Lillesand, TM & Kiefer, RW 1994. *Remote Sensing and Image Interpretation.* 3rd ed. New York, Chichester, Brisbane and Toronto: John Wiley and Sons.

Lindgren, DT 1985. Land use/cover; inventory and change. In Lindgren, DT (ed.) *Land use planning and remote sensing,* pp101-115. Dordrecht: Martinus Nijhoff.

Lubke, RA & de Moor, I (eds.) 1998. *Field guide to the Eastern & Southern Cape coasts.* Rondebosch: University of Cape Town Press.

Lunetta, RS 1999. Application, project formulation and analytical approach. In Lunetta, RS & Elvidge, CD (eds.) *Remote Sensing and Change Detection: Environmental Monitoring Methods and Applications*, pp1-20. London, UK:Taylor and Francis Ltd.

Maguire, DJ 1991. An Overview and Definition of GIS. In Maguire, DJ, Goodchild, MF & Rhind, DW (eds.) *Geographical Information Systems,* pp9-20. New York: John Wiley & Sons, Inc.

Malan, DE 1999. Information given to C. Pretorius during a personal communication in 1999.

Marais, I 1996. SpaceMaps at cost. *SAC News* 12: 6.

Martin, ARH 1962. Evidence relating to the Quaternary history of the Wilderness lakes. Transactions of the Geological Society of South Africa *Proceedings of the Geological Society of South Africa* 65:19-42.

McKenzie, B & Moll, E 1986. The forest – a distinct biome. *Veld & Flora* 72, 3: 79-82.

Meyer, B 1999. Information given to C. Pretorius during a personal communication in 1999.

MODIS 2001. MODIS home page. [Online]. Available: http://modis.gsfc.nasa.gov/ [24.11.2001]
Moll, EJ & White, F 1978. The Indian Ocean coastal belt. In Werger, MJA (ed.) *Biography and ecology of southern Africa.* The Hague: W Junk.

Moore, L 1997. Transverse Mercator Projections and U.S. Geological Survey Digital Products. [Online]. Available: http://mcmcweb.er.usgs.gov/drg/mercproj/ [29/9/2000].

Morain, S & Lopez Baros, S (eds.) 1996. *Raster Imagery in Geographic Information Systems*. USA: Onward Press.

Mouat, DA, Mahin, GG & Lancaster, J 1993. Remote Sensing Techniques in the Analysis of Change Detection. *Geocarto International* 2: 39-50.

Nikolaos, S 1988. Visual and Digital classification of Landsat TM data for soil, physiography and land use mapping in Axios alluvial plant, Thessaloniki, Greece. *Geocarto International* 4: 55 – 65.

Ozhan, E 1997. Recent developments and announcements – International MEDCOAST workshop on the state-of-the-art of integrated coastal zone management in the Mediterranean and Black Sea: Immediate needs for research, education/training, and Implementation (MED and Black Sea ACZM 96) 2-5 November 1996, Sarigerme, Turkey. *Ocean & Coastal Management* 33, 3: 227-232.

Phinn, SR, Menges, C, Hill, GJE, & Stanford, M 2000. Optimizing remotely sensed solutions for monitoring, modelling and managing coastal environments. *Remote Sensing of Environment* 73: 117–132.

Preston-Whyte, RA & Tyson, PD 1988. *The atmosphere and weather of Southern Africa.* Cape Town: Oxford University Press.

Price, JC 1987. Combining Panchromatic and Multispectral Imagery from Dual Resolution Satellite Instruments. *Remote Sensing of Environment* 21: 119-128.

Raal, P & Burns, M 1991. *The mapping and conservation importance rating of the Cape coastal vegetation as an aid to development planning – Southern Cape Coast.* Stellenbosch: CSIR (Report No. EMA – C 89153A).

Raal, PA, Burns, MER & Davids, H 1995. Beyond GIS: Decision Support for coastal development, A South African example. – In *CoastGIS '95: International symposium on GIS and computer mapping for coastal zone management*. Cork: University College.

Rakodi, C & Treloar, D 1997. Urban development and coastal zone management – An international review. *Third World Planning Review* 19, 4: 401-424.

Ranchin, T & Wald, L 2000. Fusion of High Spatial and Spectral Resolution Images: The ARSIS Concept and Its Implementation. *Photogrammetric Engineering & Remote Sensing* 66, 1: 49-61.

Richards, JA 1986. *Remote Sensing Digital Image Analysis: An Introduction*. Berlin: Springer-Verlag.

Robbins, PR & Maddock, T 2000. Interrogating Land Cover Categories: Metaphor and Method in Remote Sensing. *Cartography and Geographic Information Science* 27, 4: 295-309.

Robinove, CJ 1981. The Logic of Multispectral Classification and Mapping of Land. *Remote Sensing of Environment* 11: 231-244.

Rust, IC 1998. Geology and geomorphology. In Lubke, RA & de Moor, I (eds.) *Field guide to the Eastern & Southern Cape coasts*. Rondebosch: University of Cape Town Press.

SAC 2002. Official web-site of the Satellite Application Centre. [Online]. Available: http://www.sac.co.za/ [26.2.2000].

SAC News 2000. SAC Satellite data and image product portfolio. *SAC News* 20 (September/October): 4-5.

SAC News 2002. Building up EROS data over South Africa. *SAC News* 22 (July/August): 1.

Shantz, HL & Marbut, CF 1923. The vegetation and soils of Africa. *American Geographical Society Research Series No. 13*. New York: National Research Council & American Geographical Society.

Scheepers, F 1998. Putting you in the picture. *Geoinformation Africa* 3: 18-24.

Schowengerdt, RA 1997. *Remote Sensing: Models and Methods for Image Processing*. 2nd ed. San Diego: Academic Press.

Schmidt, L 1984. A Comparison of Classification Techniques Using Landsat Thematic Mapper and Multispectral Scanner Data, for Landcover Classification of a Portion of Calloway and Graves Counties, Kentucky. MSc thesis. Murray: Murray State University.

Skidmore, AK, Bijker, W, Schmidt, K & Kumar, L 1997. Use of remote sensing and GIS for sustainable land management. *ITC Journal* 3, 4: 302 – 315.

South Africa 1998a. Intent to identify activities which may have a detrimental effect on the environment under Section 21 (1) of the Environment Conservation Act, Act 73 of 1989. Outeniqua sensitive coastal area extension. Government Gazette of the Republic of South Africa 18666, 23.2.1998: 392.

South Africa 1998b. Intent to identify activities which may have a detrimental effect on the environment under Section 21 (1) of the Environment Conservation Act, Act 73 of 1989. Outeniqua sensitive coastal area extension. Government Gazette of the Republic of South Africa 19493, 27.11.1998: 401.

SPOT Image 1999. SPOT Image homepage. [Online].

Available: http://www.spotimage.fr/spot-us.htm [20.12.2000].

Sprague, RH & Carlson, ED 1982. *Building effective decision support systems.* Prentice-Hall Inc Englewood Cliffs.

Stadler, C 1998. Grid Expectations. *Geoinformation Africa* 7: 28-30.

Steele, BM, Winne, JC & Redmond, RL 1998. Estimation and mapping of misclassification probabilities for thematic land cover maps. *Remote Sensing of Environment* 66: 192-202.

Stehman, SV & Czaplewksi, RL 1998. Design and Analysis for Thematic map Accuracy Assessment: Fundamental Principles. *Remote Sensing of the Environment* 64: 331-344.

Stoney, WE & Hughes, JR 1998. New Space Race is On! *GIS World* 11, 3.

Strydom, S 1992. A Classification of Southern Cape coastal dunes and the associated vegetation. MSc Dissertation. Port Elizabeth: University of Port Elizabeth.

Stuckens, J, Coppin PR & Bauer, ME 2000. Integrating contextual in-formation with per-pixel classification for improved land cover classification. *Remote Sensing of Environment* 71: 282-296.

Tanner, C 2000. Information given to C. Pretorius during a personal communication in 2000.

Tateishi, R & Mukouyama, Y 1987. Land Cover Classification Using SPOT data. *Geocarto International* 2: 17 – 29.

Taylor, HC 1983. The vegetation of Cape of Good Hope Nature Reserve. *Bothalia* 14, 3&4: 779-784.

Thompson, MW 1994. *The use of current RS technology to support wetland inventory and monitoring – Feasibility and application in South Africa (Part 1 – Guidelines for the use of RS in the mapping and monitoring of wetlands in South Africa).* Pretoria: CSIR (Report No. FOR-DEA 736).

Thompson, MW 1996. Standard Land-Cover Classification Scheme for Remote Sensing Applications in South Africa. *South African Journal of Science* 92: 34-42.

Thompson, MW 1999. *South African National land-cover database project: Data users manual, final report (Phase 1,2 and 3).* Pretoria: CSIR (Report No. ENV/P/C 98136 version 3.1).

Thompson, MW, Adam, MP, Fairbanks, D & Thomas, M 1996. Regional Remote Sensing Workshop: Practical Remote Sensing Training, 30 September – 4 October, 1996, CSIR, Pretoria.

Thorpe, J 1996. Aerial Photography and Satellite Imagery: Competing or Complementary? *Earth Observation Magazine*, June: 35-39.

Thunissen, HAM, van de Boogaard, PJ & Ullenbroeck, HPT 1993. Operational land cover classification in the Netherlands using satellite images and other geographical information. Proceedings Operationalisation of Remote Sensing, 19-23 April 1993, ITC Enschede, the Netherlands. Vol. 3, pp. 9-20.

Tinley, KL 1985. *Coastal dunes of South Africa.* Pretoria: CSIR/National Research Foundation, South African National Scientific Programmes (Report No. 109).

Townshend, JRG 1981. *Terrain analysis and remote sensing*. London: George Allen & Unwin.

Townshend, JRG & Justice, CO 1988. Selecting the spatial resolution of satellite sensors required for global monitoring and land transformations. *International Journal of Remote Sensing* 9, 2: 187-236.

United Nations 1993. Towards international classification systems for land use and land cover. A preliminary proposal prepared for UNEP and FAO, March 1994. In *Annex V, Report of the UNEP/FAO expert meeting on harmonizing land cover and land use classifications.* 23-25 November. Geneva.

Urban Management 1997. CMC to support new coastal protection initiative. 28, 10: 20.

Van Brakel, JP 1989. Inleidende kartografie. Diktaat 88/90. Potchefstroom: Departement Sentrale Publikasies PU vir CHO.

Veregin, H & Hargitai, P 1995. An evaluation matrix for geographical data quality. In Guptill, SC & Morrison, JL (eds.) *Elements of spatial data quality,* pp167-188. Oxford: Elsevier.

Viljoen, N 2000. Information given to C. Pretorius during a personal communication in 2000.

Vogelman, JE, Howard, SM, Yang, L, Larson, CR, Wylie, BK & Van Driel, N 2001. Completion of the 1990s National Land Cover Data Set for the Conterminous United States from Landsat Thematic Mapper Data and Ancillary Data Sources. *Photogrammetric Engineering & Remote Sensing* 67, 6: 685.

Vogelman, JE, Seevers, PM & Oimoen, M 1996. Effects of selected variables for discriminating land cover: multi-seasonal data, different clustering algorithms, and varying numbers of clusters. In *Proceedings of the 13th Pecora Conference*. Sioux Falls, South Dakota.

Vogelman, JE, Sohl, T & Howard, SM 1998. Regional characterization of land cover using multiple sources of data. *Photogrammetric Engineering & Remote Sensing* 64, 1: 45-57.

White, LP 1977. Current systems and services for remote sensing in relation to common user requirements. In Barrett, EC & Curtis, LF (eds.) *Environmental remote sensing 2: practices and problems,* pp12-24. London: Edward Arnold.

Woodcock, CE & Strahler, AH 1987. The factor of scale in remote sensing. *Remote Sensing of the Environment* 21: 311-32.

Appendix A An overview of the geological succession in the South-eastern Cape coastal zone.

Era		Geological epoch/period*		Geological group, formation, etc.		Dominant rock type
CENOZOIC	QUARTERNARY	HOLOCENE	0.01	Algoa Group	Schelmhoek Formation	modern dunes
CENOZOIC	QUARTERNARY	PLEISTOCENE	2	Algoa Group	Nahoon Formation Salnova Formation	aeolianite beach deposits
CENOZOIC	TERTIARY	PLIOCENE		Algoa Group	Nanaga Formation	sandy limestone, aeolian
CENOZOIC	TERTIARY	MIOCENE	25	Algoa Group	Alexandria Formation	sandy limestone, beach deposits
CENOZOIC	TERTIARY	OLIGOCENE EOCENE PALAEOCENE	65		Bathurst Formation	sandy limestone, marine
MESOZOIC		CRETACEOUS	140	Uitenhage Group	Sundays River Formation Kirkwood Formation Enon Formation	marine mudstone fluvial mudstone, sandstone conglomerate
					GONDWANA BREAKUP	
MESOZOIC		JURASSIC	210	Karoo Supergroup	Suurberg Group Karoo Intrusives	basalt, rhyolitic ash dolerite
MESOZOIC		TRIASSIC	250	Karoo Supergroup	'Stormberg Series'	not exposed in our area
				Karoo Supergroup	Beaufort Group	shale, mudstone, sandstone
PALAEOZOIC		PERMIAN	290	Karoo Supergroup	Ecca Group	shale, sandstone
PALAEOZOIC		CARBONIFEROUS	360	Karoo Supergroup	Dwyka Group	tillite, shale
PALAEOZOIC				Cape Supergroup	Witteberg Group	quartzite, shale
PALAEOZOIC		DEVONIAN	410	Cape Supergroup	Bokkeveld Group	shale, sandstone
PALAEOZOIC		SILURIAN	440	Cape Supergroup	Table Mountain Group	quartzite, shale
PALAEOZOIC		ORDOVICIAN	500	Cape Supergroup		
PALAEOZOIC		CAMBRIAN	590		Cape Granite Suite	granite
		LATE PRECAMBRIAN	800	Pre-Cape	Kaaimans/Kango/ Gamtoos Groups	quartzite, phyllite, marble, skarn

* Numbers refer to age in millions of years

Reference: Rust, IC 1998. Geology and geomorphology. In Lubke, RA & de Moor, I (eds.) *Field guide to the Eastern & Southern Cape coasts*. Rondebosch: University of Cape Town Press.

Appendix B Rainfall data Sedgefield: Swartvlei and Rondevlei weather stations.

Table B.1 Long-term rainfall data for the Sedgefield/Wildernes area - Swartvlei weather station (Latitude: -34 00, Longitude: 22 45). Data available from 1955 – 1992.

MONTH	AVE	ST DEV	N DAY RAIN	NUM MON	RAINFALL FREQUENCY (MM)						MAX. R DAY	MAX. RAIN DATE
					1-5	5.1-10	10.1-20	20.1-50	50.1-100	100.0-900		
JAN	57.4	31.9	9.2	36	4	1.4	0.9	0.6	0.1	0	69.5	24/01/1981
FEB	52	26.9	9.5	33	3.9	1.3	0.9	0.5	0	0	77	21/02/1955
MAR	68.3	43.7	10.3	34	4.1	1.5	1.4	0.5	0.1	0	132	07/03/1963
APR	61.5	43	9.1	36	3.5	1.5	1.3	0.4	0.1	0	82.2	14/04/1987
MAY	56.5	48.8	8.3	35	3.4	0.9	0.9	0.6	0.1	0	105.5	29/05/1981
JUN	47.9	30.1	7.9	36	2.8	1.5	0.7	0.6	0	0	55	15/06/1969
JUL	44.8	36	7.3	35	3.2	0.9	0.5	0.6	0	0	53	29/07/1971
AUG	61.4	44.5	8.8	33	3.7	1.4	0.8	0.6	0.2	9	85.5	01/08/1959
SEP	53.6	42.1	9.6	36	3.6	1.6	0.7	0.4	0.1	0	69	14/09/1964
OCT	76.4	45.3	11.5	34	4.6	2.2	1	0.7	0.2	0	86	09/10/1959
NOV	52	31.6	9.8	37	3.8	1.4	0.9	0.5	0	0	102	01/11/1978
DEC	52.8	39.2	8.8	37	3.5	1.4	1	0.4	0.1	0	124	06/12/1970

AVE: Average rainfall for month
ST DEV: Standard deviation from the normal
N DAY RAIN: Average number of rain days per month

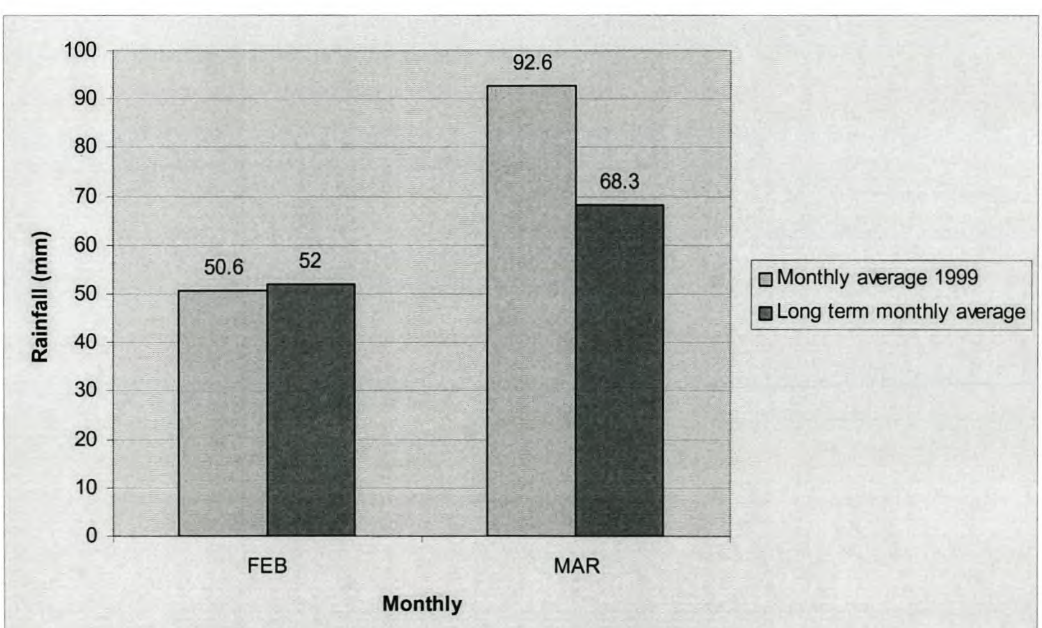
NUM MON: Number of months used in calculation
MAX R DAY: Maximum rainfall that occurred over a 24-hour period
MAX RAIN DATE: Date maximum rain day occurred.

Source: *Data acquired from the South African Weather Burro.*

Table B.2 Daily rainfall data for the Sedgefield/Wildernes area - Rondevlei weather station (Latitude: -34.0, Longitude: 22.43). Data for the period 01/02/1999 - 31/03/1999.

RONDEVLEI LATITUDE: -34.0 S LONGITUDE: 22.43 E, HEIGHT ABOVE MEAN SEA LEVEL: 14 m			
FEBRUARY 1999		**MARCH 1999**	
Date	**Rainfall**	**Date**	**Rainfall**
1	13.5 mm	8	40.4 mm
2	13.6 mm	11	10.5 mm
7	5.5 mm	14 (date of image acquisition)	16.5 mm
10	1.8 mm	15	0.4 mm
14	0.5 mm	16	0.1 mm
16	1.2 mm	22	4.7 mm
18	1.4 mm		
21	0.2 mm		
22	6.4 mm		
23	0.1 mm		
28	6.4 mm		
MONTHLY TOTAL	**50.6 mm**	**MONTHLY TOTAL**	**92.6 mm**

Source: *Data acquired from the South African Weather Burro.*



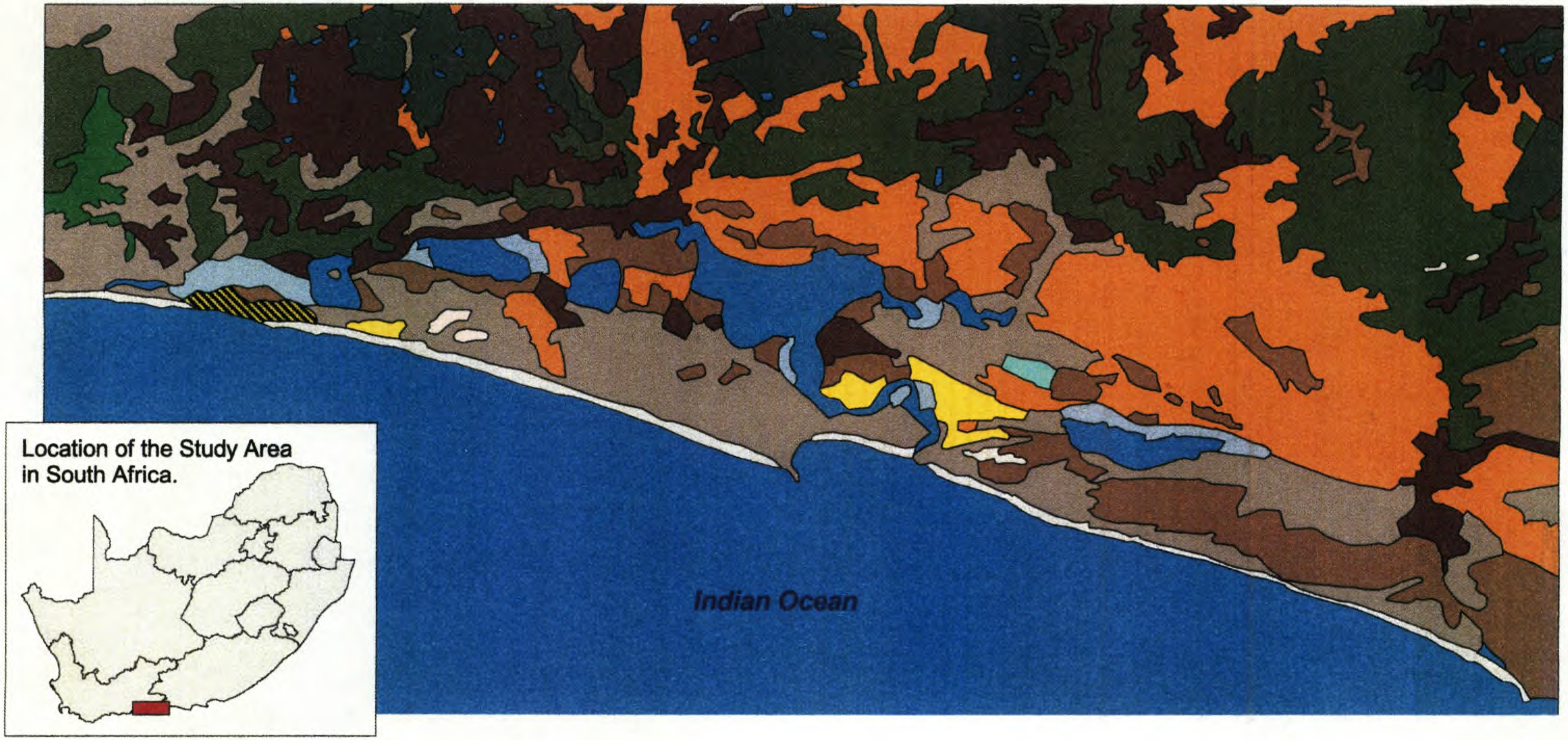
Source: *Data acquired from the South African Weather Burro.*

Figure B.1 Long term monthly and 1999 monthly rainfall averages for February and March.

Appendix C Mean annual daily sunrise (SR) and sunset (SS) at: Sedgefield, Lat - 34.0, Long 22.7, Time zone 30.0E.

MONTH		01	03	05	07	09	11	13	15	17	19	21	23	25	27	29	31
JAN	SUNRISE	05:22	05:23	05:25	05:26	05:28	05:30	05:32	05:34	05:35	05:37	05:39	05:41	05:43	05:45	05:47	05:49
JAN	SUNSET	19:42	19:43	19:43	19:43	19:43	19:43	19:42	19:42	19:41	19:41	19:40	19:39	19:38	19:37	19:36	19:34
FEB	SUNRISE	05:50	05:52	05:54	05:56	05:58	06:00	06:02	06:03	06:05	06:07	06:09	06:11	06:13	06:14		
FEB	SUNSET	19:34	19:32	19:31	19:29	19:27	19:25	19:23	19:21	19:19	19:17	19:15	19:12	19:10	19:07		
MAR	SUNRISE	06:16	06:18	06:19	06:21	06:23	06:24	06:26	06:27	06:29	06:31	06:33	06:34	06:36	06:37	06:39	06:40
MAR	SUNSET	19:05	19:03	19:00	18:57	18:55	18:52	18:49	18:47	18:44	18:41	18:39	18:36	18:34	18:31	18:28	18:26
APR	SUNRISE	06:41	06:42	06:44	06:45	06:47	06:48	06:50	06:51	06:53	06:54	06:56	06:57	06:59	07:00	07:02	
APR	SUNSET	18:24	18:22	18:19	18:16	18:14	18:11	18:09	18:06	18:04	18:01	17:59	17:57	17:54	17:52	17:50	
MAY	SUNRISE	07:03	07:05	07:06	07:08	07:09	07:11	07:12	07:14	07:15	07:16	07:18	07:19	07:20	07:22	07:23	07:24
MAY	SUNSET	17:48	17:46	17:44	17:43	17:41	17:39	17:38	17:36	17:35	17:34	17:33	17:32	17:31	17:30	17:29	17:28
JUN	SUNRISE	07:25	07:26	07:27	07:28	07:29	07:30	07:31	07:31	07:32	07:33	07:33	07:33	07:34	07:34	07:34	
JUN	SUNSET	17:28	17:28	17:27	17:27	17:27	17:27	17:27	17:27	17:27	17:27	17:28	17:28	17:29	17:29	17:30	
JUL	SUNRISE	07:34	07:34	07:34	07:33	07:33	07:33	07:32	07:31	07:30	07:29	07:28	07:27	07:26	07:25	07:23	07:22
JUL	SUNSET	17:31	17:32	17:33	17:34	17:35	17:36	17:37	17:38	17:39	17:40	17:42	17:43	17:44	17:46	17:47	17:48
AUG	SUNRISE	07:21	07:19	07:18	07:16	07:14	07:12	07:10	07:08	07:05	07:03	07:01	06:58	06:56	06:54	06:51	06:48
AUG	SUNSET	17:49	17:50	17:52	17:53	17:54	17:56	17:57	17:59	18:00	18:01	18:03	18:04	18:06	18:07	18:08	18:10
SEP	SUNRISE	06:47	06:44	06:42	06:39	06:36	06:34	06:31	06:28	06:25	06:22	06:20	06:17	06:15	06:12	06:09	
SEP	SUNSET	18:10	18:12	18:13	18:14	18:16	18:17	18:18	18:20	18:21	18:23	18:24	18:25	18:27	18:28	18:30	
OCT	SUNRISE	06:06	06:04	06:01	05:58	05:56	05:53	05:50	05:48	05:45	05:43	05:41	05:38	05:36	05:34	05:32	05:30
OCT	SUNSET	18:31	18:33	18:34	18:36	18:37	18:39	18:40	18:42	18:44	18:45	18:47	18:49	18:50	18:52	18:54	18:56
NOV	SUNRISE	05:29	05:27	05:25	05:23	05:22	05:20	05:19	05:18	05:16	05:15	05:14	05:14	05:13	05:12	05:12	
NOV	SUNSET	18:57	18:58	19:00	19:02	19:04	19:06	19:08	19:10	19:11	19:13	19:15	19:17	19:19	19:21	19:22	
DEC	SUNRISE	05:12	05:11	05:11	05:11	05:11	05:12	05:12	05:13	05:13	05:14	05:15	05:16	05:17	05:18	05:20	05:21
DEC	SUNSET	19:24	19:26	19:27	19:29	19:31	19:32	19:33	19:35	19:36	19:37	19:38	19:39	19:40	19:41	19:41	19:42

Source: *Data acquired from the South African Weather Burro.*



LEGEND

'96 National Land Cover Database

- Forest
- Thicket & bushland (etc)
- Shrubland and low Fynbos
- Unimproved grassland
- Improved grassland
- Forest plantations
- Waterbodies
- Wetlands
- Barren rock
- Cultivated: permanent - commercial irrigated
- Cultivated: temporary - commercial dryland
- Cultivated: temporary - commercial irrigated
- Urban / built-up land: residential
- Urban / built-up land: residential (small holdings: bushland)

Digital Satellite Remote Sensing for Terrestrial Coastal Zone Management.

Appendix D '96 National Land Cover database clipped to the study area.

N

1 0 1 2 3 4 5
Kilometres

Projection: Transverse Mercator, Central Meridian 23° East. Spheroid: Clarke 1880.

CSIR ENVIRONMENTEK

Appendix E Table with notes on an extract of the 100 spectral classes and their information class(es).

17	Plantation	Old pine	Not so dense? " "
18	Plantation	Old pine	East " West facing "
19	Plantation	~~Pine~~	~~Shadow side along river courses~~ Pine North Facing, Shadow Afro nacre
20	Plantation	Eucalyps	
21	Degraded/Barren		(Totally) cleared in plantation / agric / Wetland / mntn Sparse veg
22	Shrubland and Low Fynbos		Fynbos 1 Dune Fynbos | Cleared Plantation areas / (Wetland) Weedlet
23	Shrubland and Low Fynbos		Fynbos Dune fynbos) (Cleared Pl areas | (Wetland)
24	~~Plantation~~ Forest	~~Pine~~	~~Young Pine, South Facing~~ Young/Sunlit Pine, Afro in shadow
25	Dune Forest and Thicket		Alien Invasive (1) / Young growing plantation Rooikrantz / pine } Dune Thicket | Afro Shadow forest | Young plantations
26	Fore...		