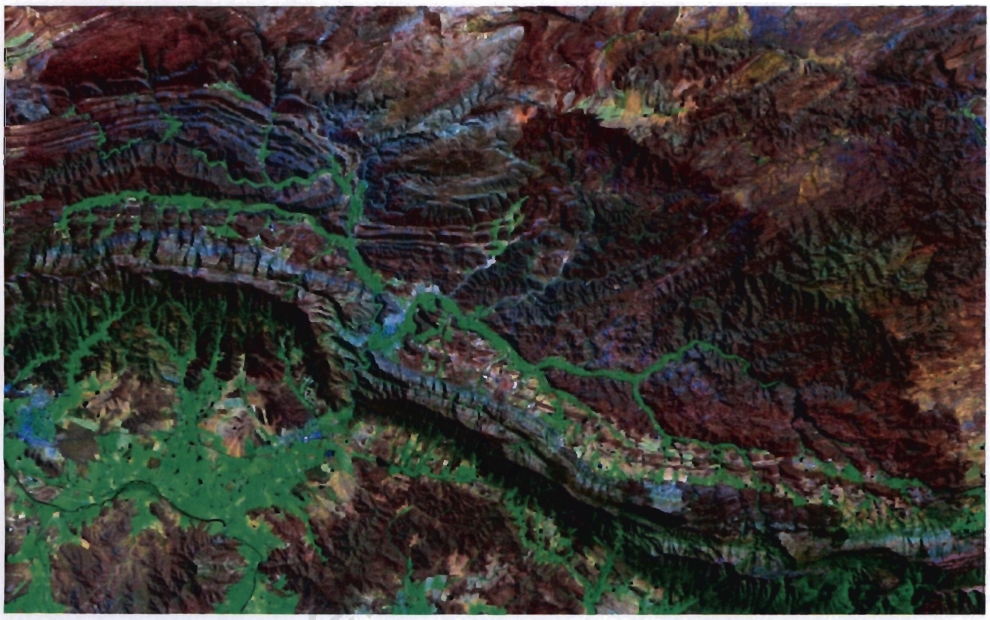
Analysis of Land-Cover Change in the Kogmans River (H3) Secondary Catchment: Impact of Land Degradation and River Management on Flood Severity



Kogmans River Catchment, Landsat TM, November 2003 (RGB 741)

by

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ABSTRACT

This study aims to understand what role the landscape, and the management thereof, played in the March 2003 floods in the Kogmans River catchment.

The Kogmans River (H3) secondary catchment is situated in the Klein (Little) Karoo region of the Western Cape, approximately 170km east of the city of Cape Town. With an area of approximately 1205km^2, this mountainous, largely agricultural catchment forms part of the greater Breede River basin. Two relatively small towns, Montagu and Ashton with a combined total population of 23 100 people (DWAF, 2003c), are located on either side of the Kogmanskloof which cuts through the Langeberg mountains.

On Sunday March 23, a cut-off low, fed by moist tropical air from an extensive inland low pressure intensified causing intense rainfall over the much of the south Cape area, including the Kogmans (H3) River catchment. The heaviest 24-hour rainfall in 23 years caused the Kingna River to break its banks and flood the towns of Monatgu and Ashton. The 2003 flood caused significant damage to primary infrastructure (bridges, roads, electricity, sewage), houses, orchards, vineyards and irrigation systems and forced the evacuation of more than 500 households in Montagu and the local Primary School (DiMP,2003).

Three main areas were investigated to determine their possible effects on the flood severity of the March 2003 floods. Urban expansion, land degradation and the management of the river ecosystem with particular focus on the riparian zone and in-stream vegetation. The study revealed that all three areas played a role in the flooding of the Kogmans River catchment, but the prolific growth of *Phragmites australis* reed beds, caused by agricultural nutrient supply, water abstraction and diversion and exacerbated by drought, was most significant in influencing the severity of the floods.

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TABLE OF CONTENTS

GLOSSARY

Catchment. A catchment is all the land that drains into a particular river system i.e. a drainage basin (King, 1988). In South Africa, catchments are described as primary, secondary, tertiary and quaternary (DEAT, 2004). Primary catchments constitute the catchment areas of all the major rivers in the country (DEAT, 2004). The topography of these drainage regions are such that all rainfall that falls in these catchments will eventually drain into the major river flowing through the catchment (DEAT, 2004). Primary river catchments are, in turn, subdivided into contributing secondary catchments (DEAT, 2004). Secondary catchments are subdivided into even smaller tertiary catchments and finally, tertiary catchments are subdivided into quarternary catchments, the smallest catchment units used in the management and planning of water resources at a national level (DEAT, 2004).

Cut-off Low. A cut-off low is a cold-cored depression, which starts as a trough in the upper westerlies and deepens into a closed circulation extending downward to the surface and which becomes displaced equatorward out of the basic westerly current. Cut-off Lows are unstable, baroclinic systems associated with strong convergence and vertical motion (Preston-Whyte and Tyson, 1988). The frequency of Cut-off Lows that produce heavy rainfall are highest between March and May and September and November (Preston-Whyte and Tyson, 1988).

Donga. A steep-sided gulley resulting from severe soil erosion (Mayhew, 1997).

Drainage Region Classification for South Africa. There are 22 drainage regions in South Africa. Each drainage region is assigned a letter of the alphabet, for example 'H' which represents the Breede River Basin. This drainage region is also referred to as the primary catchment. The secondary catchment is assigned the letter of the primary catchment as well as a numerical number depending on how many secondary catchments exist within the primary catchment. For example, the Kogmans River catchment is assigned the code 'H3.' Using the same logic, the secondary catchments are subdivided into tertiary and quarternary catchments by assigning a '0' and and additional alphabetic symbol (A,B,C etc.) respectively , for example H30A.

Electromagnetic Spectrum. Electromagnetic radiation occurs a continuum or spectrum of wavelengths and frequencies from short wavelength, high frequency gamma rays to long wavelength, low frequency radio waves (Curren, 1985) including the visible light spectrum (**Figure A**).

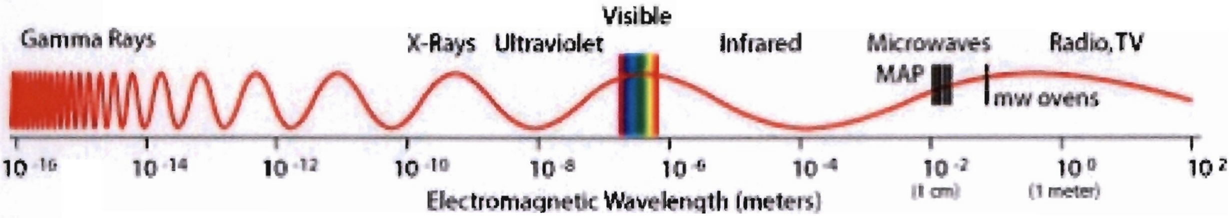


Figure A: The electromagnetic spectrum (Source: http://map.gsfc.nasa.gov/).

Flood Frequencies (return periods). Flood frequency is the calculation of the statistical probability that a flood of a certain magnitude for a given river will occur in a certain period of time (Mayhew, 1997). These calculations are expressed as return periods, which are described in terms of the particular flood being a 2, 5, 10, 20, 50, 100 or 200-year flood (DIMP, 2003). A 2-year flood relates to a 50% probability of the estimated flood occurring in a given year (DIMP, 2003). A 10-year flood relates to a 10% probability, a 20-year flood relates to a 5% probability and so on (DIMP, 2003).

Geometric correction. Geometric correction is the process by which a distorted raw, remotely sensed image is corrected for errors of skew, rotation, and perspective in data (Gibson, 2000)

Hydrograph. A hydrograph is a graph that illustrates the stage flow and velocity of water with respect to time (ASCE, 1996). Hydrographs can be plotted for hours, days and even months (Mayhew, 1997).

Hydrology. Hydrology is concerned with the basic physical processes governing the occurrence, distribution and movement of water on or below the Earth's surface (Ward and Robinson, 1990).

Hydrological Cycle. The hydrological cycle is the movement of water and its transformation between gaseous, liquid and solid forms (Mayhew, 1997). The major components of the cycle are condensation by which precipitation is formed, the movement and storage of water overland and underground, evaporation and the horizontal movement of water (Mayhew, 1997).

The hydrological cycle can be expressed in a simplified form as:

$$P = Et + Q \pm S$$

Where

P = precipitation

Et = evapotranspiration of catchment vegetation

Q = streamflow

S = underground storage of water

(Bosch, 1988).

Land-cover. The term land-cover relates to the type of feature present on the surface of the earth e.g. corn fields, lakes, forests, and highways (Lillesand and Kiefer, 2000).

Land Degradation. Land degradation is “the reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:

(i) soil erosion caused by wind and/or water;

(ii) deterioration of the physical, chemical and biological or economic properties of soil; and

(iii) long-term loss of natural vegetation.”

(UNO, 1994, p.5)

Land-use. The term land-use relates specifically to the human activity or economic function associated with a specific tract of land (Lillesand and Kiefer, 2000).

Normalised Difference Vegetation Index (NDVI). The Normalised Difference Vegetation Index is a ratio image used in vegetation studies produced by subtracting the red band from the infrared band and dividing it by the sum of the red band and the infrared band (Gibson, 2000) i.e.

$$\text{NDVI} = (\text{IR} - \text{R}) / (\text{IR} + \text{R})$$

Radiometric Correction. Radiometric correction addresses variations in pixel intensity that are caused by differing sensitivities or malfunctioning of detectors, topographic effects and atmospheric effects (ERDAS, 1999).

Remote Sensing. Remote sensing is the use of electromagnetic radiation sensors to acquire images of the environment which can be interpreted to yield useful information (Curren, 1985).

Riparian Zone. The riparian zone has been loosely defined as the area adjacent to a river or stream (Snaddon, 1999). In South Africa, zones 20m wide on either side of streams and rivers are defined as riparian (Bosch and King, 1988).

Root-Mean-Square error (RMSe). The Root-Mean-Square error (RMSe) defines the degree of correspondence between the computed values and the original values for a particular variable. The lower the RMSe value, the better the degree of correspondence between the computed and actual values (ERDAS, 1999). The RMSe is commonly applied to determine the positional accuracy of a satellite image in relation to the Earth's surface.

Spectral Band. A spectral band is a wavelength range measured by a remote sensing system (Gibson, 2000) e.g. the red band of a Landsat Thematic Mapper (TM) image has a wavelength range of 0.63 –0.69µm.

Standard Deviation. The standard deviation is a statistical measure of the spread or dispersion of data values about the mean (Gibson, 2000).

Sun-synchronous Satellite. A Sun-synchronous satellite has a polar or near polar orbit that always crosses the equator at the same local time (Drury, 1990).

Tasseled Cap Vegetation Index. A Tassled Cap transformation is an enhancement technique used to optimize data for vegetation studies using Landsat Multispectral Scanner (MSS) and Landsat Thematic Mapper (TM) images (ERDAS, 1999). Using Landsat MSS images, the output of a Tasseled cap transform consists of a soil brightness index (SBI), a green vegetation index (GVI), a yellow stuff index (YVI), and a non-such index (NSI) associated with atmospheric effects (ENVI, 2000). Using Landsat TM imagery, the Tasseled cap vegetation index consists of three factors, Brightness, Greenness and "Third." The Brightness and Greenness are equivalent to the MSS tasseled cap SBI and GVI indices and the "Third" component is related to soil features, including moisture status (ENVI, 2000).

Topographic Normalisaton. Topographic normalization or topographic correction refers to the use of normalization algorithms to correct different solar illuminations within an image scene caused by the irregular shape of the terrain (Riaño *et al,* 2003). Examples of topographic normalization algorithms include the Cosine method, the Minnaert Constant and C-factor correction.

ABBREVIATIONS LIST

ARC	Agricultural Research Council
ASCE	American Society of Civil Engineers
BRBS	Breede River Basin Study
CDSM	Chief Directorate of Surveys and Mapping
CSIR	Council for Scientific and Industrial Research
DEAT	Department of Environmental Affairs and Tourism
DiMP	Disaster Mitigation for Sustainable Livelihoods Programme
DWAF	Department of Water Affairs and Forestry
ENPAT	Environmental Potential Atlas
EOSAT	Earth Observation Satellite
ETM	Enhanced Thematic Mapper
FAO	United Nations Food and Agriculture Organisation
GEO - 2000	Global Environmental Outlook – 2000
GIS	Geographical Information Systems
GLCF	Global Land Cover Facility
HEC - HMS	Hydrological Engineering Corp – Hydrological Modelling System
IGBP	International Geosphere-Biosphere Programme
IHDP	International Human Dimensions Programme on Global Environmental Change
IIASA	International Institute for Applied Systems Analysis
ISCW	Institute for Soil, Climate and Water
LUCC	Land Use and Land Cover Change Project
MODIS	Moderate Resolution Imaging Spectroradiometer
MSDI	Moving Standard Deviation Index
MSS	Multispectral Scanner
NASA	National Aeronautics and Space Administration
NBI	National Botanical Institute
NDVI	Normalised Vegetation Index
PACD	Plan of Action to Combat Desertification
PLAAS	Programme for Land and Agrarian Studies
RMSe	Root-Mean-Square error

SAC	Satellite Applications Centre
SADC	Southern African Development Community
SAPIA	South African Plant Invader Atlas
SAWS	South African Weather Service
SRTM	Shuttle Radar Topography Mission
StatsSA	Statistics South Africa
TM	Thematic Mapper
UNCCD	United Nations Convention to Combat Desertification
UNCOD	United Nations Conference on Desertification
UNEP	United Nations Environment Programme
UNO	United Nations Organisation
USDA	United States Development Agency
USGS	United States Geological Society
WCNC	Western Cape Nature Conservation

Chapter One

Introduction

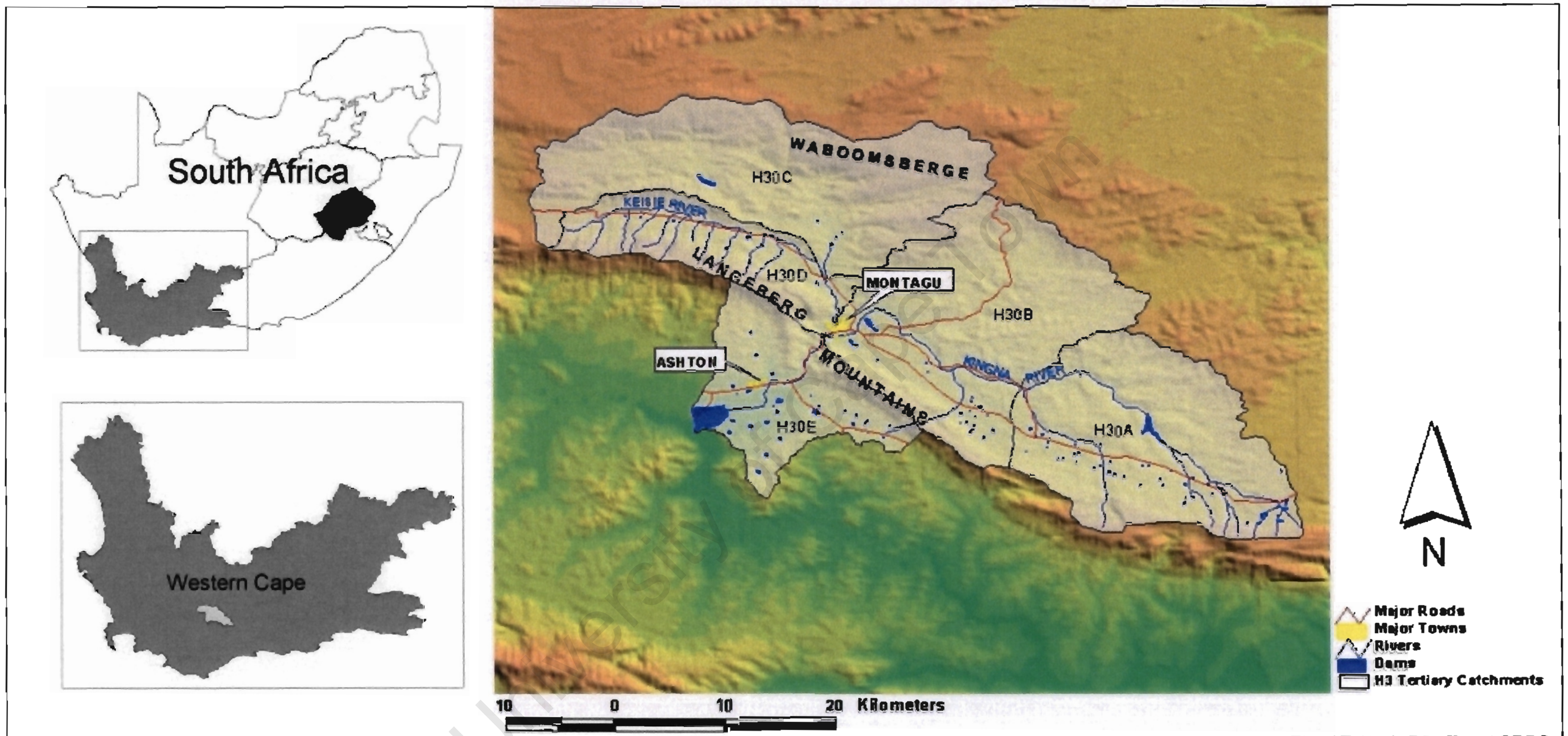
The Kogmans River (H3) secondary catchment (**Figure 1.1**) is situated in the Klein (Little) Karoo region of the Western Cape, approximately 170km east of the city of Cape Town. With an area of approximately 1205km², this mountainous, largely agricultural catchment forms part of the greater Breede River basin. Two relatively small towns, Montagu and Ashton (**Figure 1.1**) with a combined total population of 23 100 people (DWAF, 2003c), are located on either side of the Kogmanskloof which cuts through the Langeberg mountains.

The Kogmans River catchment has experienced a number of high magnitude flood events (1867, 1885, 1906, 1948, 1981, 1983) since the towns of Montagu and Aston were established in the catchment in the mid-1800s, and Montagu, in particular, has been highly vulnerable during such flood events.

The geographical location of the town, at the confluence of the Kingna and Keisie Rivers at the base of the mountainous catchment (**Figure 1.1**), coupled with its urban expansion across both rivers has made Montagu increasingly at risk to large-scale damage and potential loss of life as a result of major flooding.

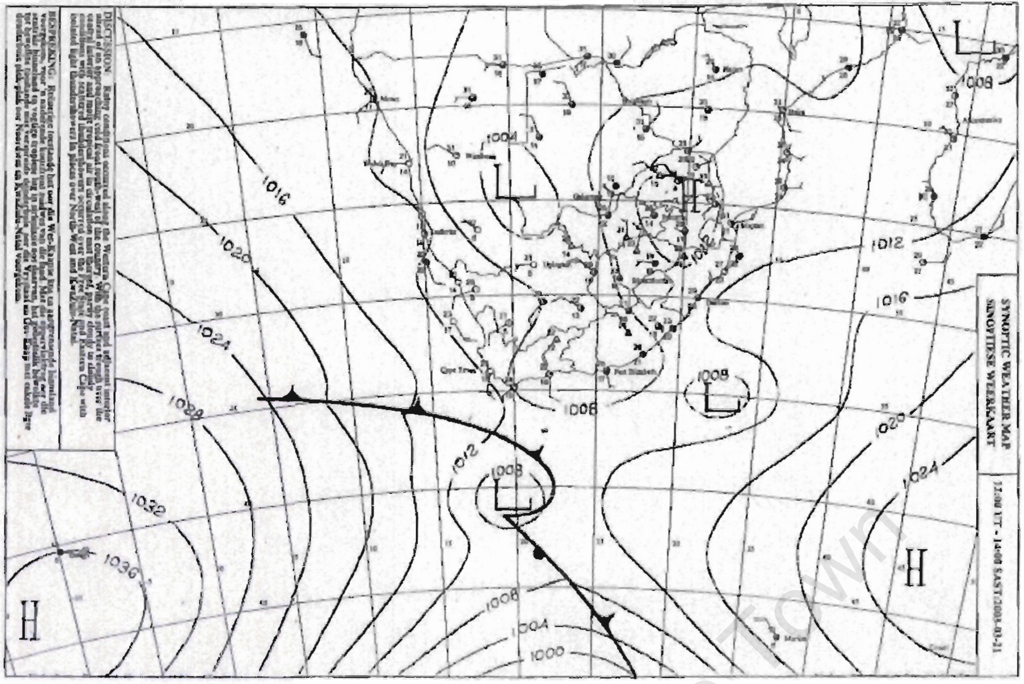
On the 21st of March 2003, a large frontal system moved towards South Africa from the south Atlantic Ocean (**Figure 1.2**). As the front crossed the south coast of the Western Cape the following day (**Figure 1.2**), the low pressure system closed itself, becoming a 'cut-off low' (DiMP, 2003). On Sunday March 23, the cut-off low, fed by moist tropical air from an extensive inland low pressure intensified and by late Sunday, the strong pressure gradient induced instability in the system, causing high wind speeds, low temperatures and record rainfall over much of the south coast and adjacent interior (DIMP, 2003).

The South African Weather Service's (SAWS) rainfall station in Montagu measured 178mm of rainfall over the 24-hour period of the 23rd to 24th of March. The intense rainfall, the highest recorded in a 24 hour period for more than 23 years, triggered the Kingna River to break its banks early on Monday morning, and flood the towns of Monatgu and Ashton.



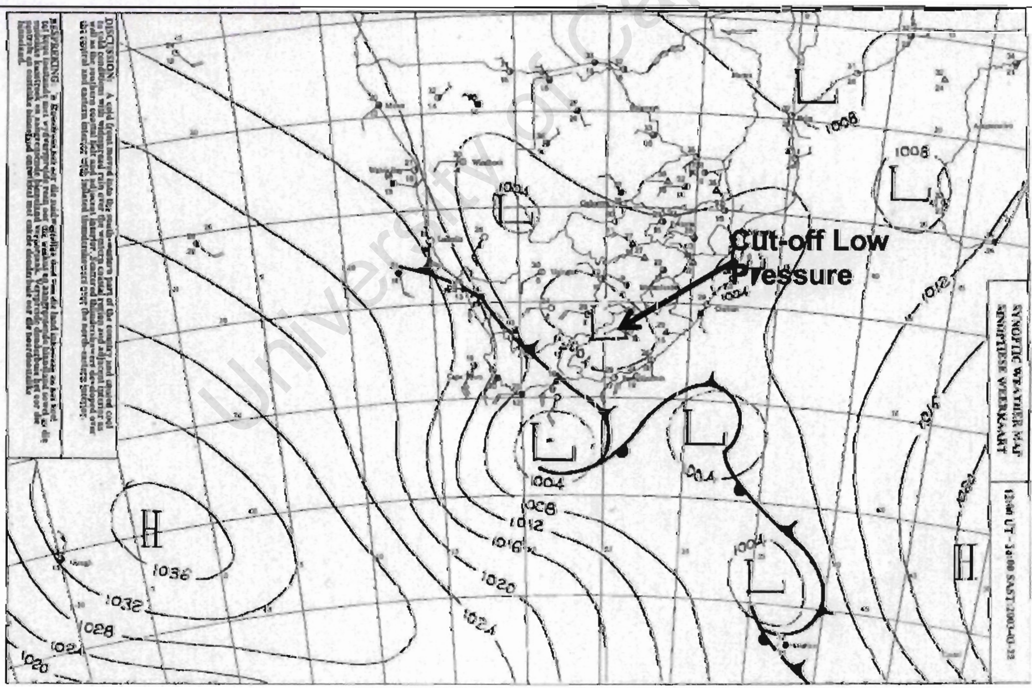
Source: ENPAT 1999, DEAT and BRBS

Figure 1.1: The Kogmans River catchment , Western Cape Province, South Africa.



Source: SAWS

March 21, 2003



Source: SAWS

March 22, 2003

Figure 1.2: Movement of the low pressure over South Africa and the formation of a 'cut-off low': 22-23 March 2003.

It was the worst flood event in the area since the devastating flood of January 1981, which had caused the death of 13 people. The 2003 flood caused significant damage (**Figure 1.4**) to primary infrastructure (bridges, roads, electricity, sewage), houses, orchards, vineyards and irrigation systems and forced the evacuation of more than 500 households in Montagu and the local Primary School (DiMP,2003). Fortunately there was no loss of life, however the rain, storm water run-off and flood damage caused widespread human hardship, particularly to the more impoverished communities in the catchment (**Figure 1.3**) – Ashbury (Montagu North), Zolani (just outside Ashton) and farm labourers living along the banks of the Kingna River and Kogmans River. Extensive damage was also recorded in the town of Ashton on the southern side of the Kogmanskloof that cuts through the Langeberg Mountains (**Figure 1.4**). The financial cost of the 2003 floods in the Kogmans River catchment was conservatively estimated at approximately R65 690 000 (excluding costs incurred by the Department of Agriculture as the specific figure for the Kogmans River catchment is not available). On the 4th of April, a national state of disaster was declared, by the State President, in the Magisterial Districts of Montagu, Robertson and Swellendam.

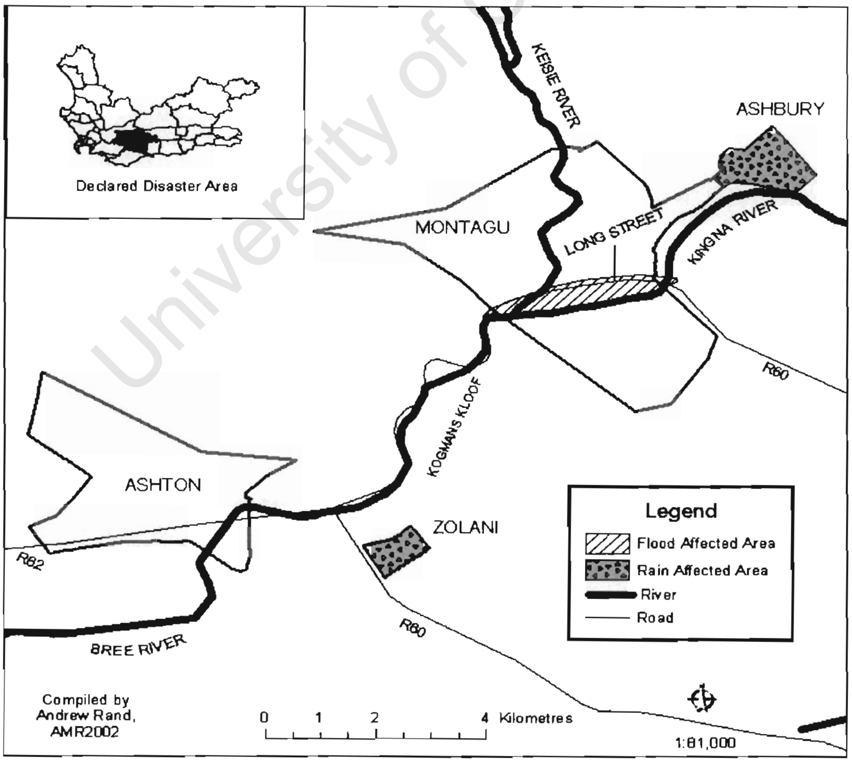


Figure 1.3: Areas affected by rain and flood damage in the Kogmans River Catchment (DiMP, 2003).

Source: Montagu Library

Vineyards flooded, Kingna River

Source: Montagu Library

Montagu Primary school

Source: Die Burger

Kogmans River, Ashton

Source: Field visit, April 2003

Bridge across the Kogmans River, Ashton

Source: Montagu Library

Bridge at the confluence of the Kingna and Keisie Rivers, Montagu

Source: Montagu Library

Road (R60) through the Kogmanskloof, Montagu

Figure 1.4: Damage caused by the floods in the Kogmans River Catchment, March 2003.

1.1 Rationale

In the wake of the March 2003 floods in Montagu and the storm and flood damage sustained by much of the south Cape region, the Department of Social Services and Poverty Alleviation of the Provincial Government of the Western Cape, along with the Provincial Development Council and the United Nations Food and Agricultural Organisation (FAO) took the initiative to co-finance research in order to document the March 2003 meteorological situation, resultant flooding and its associated impacts (DiMP, 2003). Part of the study, conducted by a multi disciplinary team formed by the Disaster Mitigation for Sustainable Livelihoods Programme (DiMP), included research into the nature and extent of land-use and land-cover change in the Kogmans River catchment.

Time-series analysis revealed that the town of Montagu had increased in area by approximately 112.6% from 5.76km² in 1960 to 12.25km² in 1999 (DiMP, 2003). In the same 39-year period, land under cultivation remained relatively stable, decreasing by 0.74% or 0.85km² from 114.6km² in 1960 to 113.75km² in 1999 (DiMP, 2003), largely as a result of Montagu's urban expansion encroaching on the fringe of agricultural land. Similar results were obtained for Ashton and surrounds. The analysis of the aerial photography is explained in further detail in Chapter 5.

Although the analysis provided some insight into the nature, extent and significance of land-use change in Montagu and the surrounding agricultural sector, some key questions remained unanswered, particularly those relating to land-cover change in the catchment area itself, and the nature and extent of land degradation and the management of the riparian zone.

Land degradation was evident in parts of the catchment visited during a field visit to Montagu and Ashton, in early April 2003, shortly after the floods. Significant evidence of erosion was noted at Johandal and Warmwater farm (**Figure 1.5**) in the east of the catchment, along the R62. Degraded land, approximately 10-15% vegetated, was also noted along R62 (in the direction of Barrydale), particularly within approximately 30km of Montagu (**Figure 1.5**). The issue of the riparian zone management was raised in interviews conducted by DiMP with farmers in the catchment, where it emerged that mismanagement of the riparian zone and the prolific growth of naturalised reed species and the invasion of alien reed species may have influenced the severity of the flooding (MacGregor, H., DiMP, personal communication, 2003).

Source: Field visit, April 2003

Evidence of significant erosion at Johandal and Warmwater farm on the R62 between Montagu and Barrydale.

Source: Field visit, August 2004

Degraded land along the R62 just outside Montagu in the East of the catchment.

Source: Field visit, August 2004

“Badlands” along the R62 just outside Montagu.

Source: Field visit, August 2004

“Badlands” along the R62 just outside Montagu.

Figure 1.5: Evidence of land degradation in the Kogmans River Catchment.

1.2 Broad Aim and Objectives

1.2.1 Broad Aim

The broad aim of this study is to establish the relationship between catchment land-use, land cover change and flood frequency and magnitude in the Kogmans River Catchment. This relationship will be explored in the context of urban expansion, land degradation, and changes in the riparian zone.

1.2.2 Objectives

The following major objectives have been identified:

- to determine the nature and extent of land use and land cover changes within the catchment that may impact on the flood hydrograph;
- to describe current management practices with regard to riparian zone management; to determine the influence of the riparian zone on the flooding in the Kogmans River catchment, with reference to the record 2003 floods;
- Apply a hydrological model to the Kogmans River Catchment to determine the effect of changes in land-use/land-cover on the total discharge of the catchment; and
- recommend possible mitigating practices.

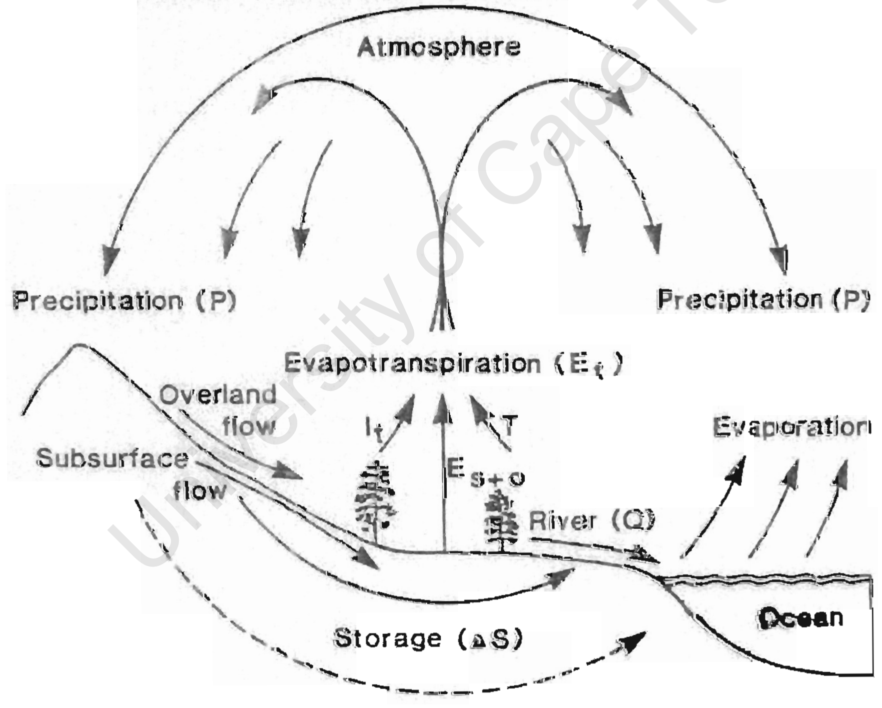
1.3 Overview of Study

Chapter One introduces the rationale, the broad aim and objectives of this study, and provides a brief overview of the scope of the research undertaken and the issues involved. Chapter Two explores the appropriate literature to provide a conceptual and theoretical basis for this study, with particular focus on land-cover and land-use, land degradation and the riparian zone and the relationship between these landscape characteristics and catchment hydrology. Chapter Three provides a detailed description of the study area to establish a sound geographical context for this research. Chapter Four provides an in-depth account of the flood event of March 2003. Chapter Five and Six deal primarily with methodology, results and discussion of the aerial photography analysis, the application of remote sensing, the investigation of the current state and management of the riparian zone and the hydrological modelling component of this research. Finally, Chapter Seven outlines the conclusions of this study and provides recommendations for further study.

Chapter Two

Land-Cover & Land-Use Change, Land Degradation, the Riparian Zone and Catchment Hydrology

The hydrology of a catchment is driven by various natural and anthropogenic forces that exert their influence on the catchment landscape over time. Climate (including seasonal variation in precipitation, evaporation and temperature), the composition and extent of land-use and land-cover, the structure and depth of soils, vegetation, and the stability and health of river ecosystems all influence the functioning of the landscape component of the hydrological cycle (**Figure 2.1**), and the manner (speed and intensity) in which water behaves when it reaches the Earth's surface.



Unnamed symbols are:

I_t – interception loss by evaporation;

T – transpiration lost by evaporation;

E_{s+o} – evaporation from soil and water surfaces

Figure 2.1: The hydrological cycle (King, 1988).

To better understand how the issues of land-cover and land-use change, land degradation and riparian zone and wetland management affect the severity of flooding, a review of the relevant literature pertaining to these issues is essential.

2.1 Land-cover and Land-use Change

There is an intimate relationship between the state of a river's catchment and the quality of its water and its flow (Rabie and Day, 1999). In addition, the state of a catchment is decisively influenced by the condition of the soil, which in turn is directly related to land-cover and land-use (Rabie and Day, 1999).

Land-cover and land-use change is an important component of environmental change that is studied and monitored globally by various academic, state and non-governmental research institutions. The United Nations Food and Agriculture Organisation (FAO), Africover Initiative, Land-use Initiative, the United Nations Environment Programme (UNEP), the NASA Land Cover Land Use Change Program, the International Institute for Applied Systems Analysis (IIASA), the Land-use Change Project, the International Geosphere-Biosphere Programme (IGBP), the International Human Dimensions Programme on Global Environmental Change (IHDP), and the Land Use and Land Cover Change Project (LUCC), are but a few of the major projects and programmes dealing with the issues of land-cover and land-use change around the world.

The term land-cover (**Figure 2.2**) refers to the biophysical state of part of the Earth's surface and immediate subsurface described in terms of broad categories such as crop fields, lakes, forests, grassland, settlements and highways (Schulze, 2000). These land-cover categories can be altered by natural factors, such as long-tern climate change or climatic persistence, or by naturally occurring episodic events such floods and fire (Schulze, 2000). However, land-cover can also be altered by human activity on the land, and it is this conversion and modification of the landscape that introduces the term land-use as distinct from land-cover (Schulze, 2000).

The term land-use (**Figure 2.2**) relates specifically to the human actions or economic functions associated with a specific tract of land (Lillesand and Kiefer, 2000). For example, a piece of land on an urban fringe may be described as urban, single family, residential in terms of its land-use (Lillesand and Kiefer, 2000). Land-use thus refers to the utilization, human inputs and management levels, driven by production and consumption dynamics, and is subject also to social, political and economic factors (Schulze, 2000).

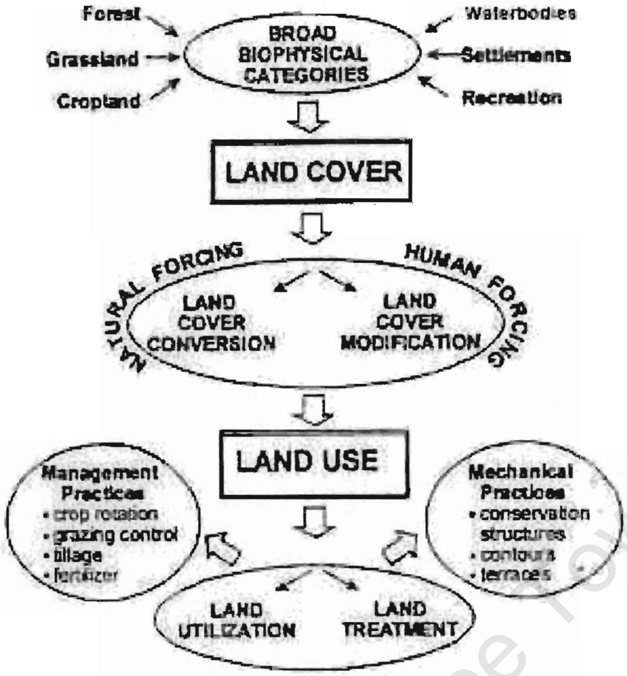


Figure 2.2: Relationship between land-cover and land-use (Schulze, 2000).

2.1.1 Land-cover and Land-use Change and Hydrology

Interest in land-cover and land-use stems from their direct relationship with many of the Earth's fundamental characteristics and processes (de Sherbinin, 2002). These include the productivity of the land, biodiversity, and biochemical and hydrological cycles (de Sherbinin, 2002). In terms of the latter, there are various links between land surface characteristics and the water cycle (de Sherbinin, 2002). Water that falls within a catchment may (a) evaporate, (b) run straight into a river channel, (c) infiltrate into the soil and eventually percolate into groundwater storage or into a river channel or (d) be lost through evapotranspiration in plants (O'Keeffe, Uys and Brunton, 1999). Land-cover or land-use can affect both the rate of infiltration and the extent of run-off following a rainfall event (de Sherbinin, 2002). Secondly, the degree of vegetation cover and the type of land-use can have an affect on the albedo of the surface, which, in turn, can affect the rate of evaporation, the level of humidity and cloud formation (de Sherbinin, 2002). Land-use and the modification of natural vegetation cover therefore play an important role in determining how much rainfall reaches each part of the system (O'Keeffe, Uys and Brunton, 1999).

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Streamflow, one of the major components of the hydrological cycle, is generated and sustained by two primary sources. The first is baseflow, which consists of water from previous rainfall events which has infiltrated the soil and percolated through to the groundwater zone and contributes as a delayed flow to streams in a catchment. And the second is runoff generated at and/or near (subsurface) the soil surface of a catchment in response to a specific rainfall event when infiltration is not possible. (Schultze, 2000). Subsurface flow in the Western Cape, in particular, is likely to contribute a significant proportion of the total runoff in response to a storm event (Migley and Scott, 1993; New and Schulze, 1996). Natural land cover has various properties that help to regulate the flow of water above and below the Earth's surface (de Sherbinin, 2002). Changes to the land-cover, by human or natural influence can therefore significantly affect the behaviour of water and its interaction with the soil surface of a catchment, either enhancing or retarding infiltration, thereby reducing or encouraging stormflow generation (Schulze, 2000).

For example, vegetation promotes infiltration by intercepting raindrops, by improving the soil structure and providing infiltration channels down deep root systems. It also helps to stabilise soils and reduce erosion as well as run-off, since evapotranspiration is directly related to plant biomass (O'Keeffe, Uys and Brunton, 1999). However, reduction in the vegetation cover, especially on steep slopes, means that less water will be intercepted or held in the soil by plants during a rainfall event (Davies and Day, 1998). Furthermore, the removal or alteration of vegetation in the riparian zone effectively neutralises an important buffer that, under natural conditions, helps reduce sediment loads, and the speed at which runoff reaches a stream (de Sherbinin, 2002). (More on the importance of the riparian zone can be found in section 1.2.3)

The hardening of a catchment, as a consequence of urban development, also has an effect on hydrological behaviour. An urbanising catchment is one in which impervious surfaces cover, or will soon cover, a considerable area (USDA, 1986). An increase in impervious area reduces the ability of soils in urban areas to absorb water falling as rain (Davies and Day, 1998). The elements that contribute to a hardening of a catchment include the construction of roofs, paths, tarred roads, pavements and parking lots (Davies and Day, 1998).

The negative effects of increased top soil losses, gully and donga formation and riverbank erosion are related to overstocking, abuse of natural grazing, injudicious ploughing, veld burning and vegetation clearance as well as poor river management (Görgens and Hughes, 1986). Thus, land-cover and land-use change is, in many cases, a primary driver of land degradation. Overgrazing, vegetation clearance and drought, all leading to decreased vegetation cover, are just some examples of land-use practices and land-cover changes that can cause land degradation in its many forms.

2.2 Land Degradation

The worldwide increase of human populations and the consequent increase in the level and intensity of resource utilisation, has led to the realisation that large areas of the earth's surface are environmentally degraded (Johnson and Lewis, 1995). Land degradation is widely regarded as a major environmental issue in scientific, political and even popular circles (Thomas and Middleton, 1995). It is of particular concern in arid, semi-arid and sub-humid environments, where the process has long been associated with the term desertification, and manifests itself in a variety of different forms, including soil erosion and the reduction of biological diversity. This is evidenced, for example, by the invasion of indigenous Fynbos species by exotic plant species in the south-western Cape of South Africa (Meadows, 1998a).

The concept of desertification was first introduced into the scientific lexicon in 1949 by André. Aubréville, a perceptive and well-informed botanist and ecologist, who used the term in his report entitled Climats, Forêts et Désertification l'Afrique Tropicale (Dregne, 1986) to describe the way in which an expanding Sahara desert was thought to be engulfing marginal savanna grasslands (Middleton and Thomas, 1997). However, it was only in the 1970s, in the wake of a severe drought in the Sahel region of Africa, that serious attention was given to the concept of desertification.

In August - September 1977, the United Nations Conference on Desertification (UNCOD) was held in Nairobi, Kenya, and attended by official representatives from 95 countries, 50 UN offices and a variety of NGOs (Thomas and Middleton, 1995). According to Thomas and Middleton (1995) UNCOD was the start of the period when the word desertification entered popular, political and scientific vocabularies as a term for a major environmental problem. It was also the beginning of an ongoing debate about what defines desertification, what causes it and where it occurs (Thomas and Middleton, 1995).

So, what is desertification? And how does it relate to the concept of land degradation? The literature is filled with contradictions and generalisations on the matter and the cause for the lack of agreement with regard to what defines desertification is complex. The scant availability of data, uncertainties stated as fact (Thomas and Middleton, 1995), as well as national, bureaucratic and institutional bias (Glantz and Orlofsky, 1983) have all contributed to the dozens of definitions of desertification in the literature. Glantz and Orlovsky (1983) identified over one hundred definitions for the phenomenon (Thomas and Middleton, 1995) and since then many more have been offered up.

Aubréville was the first to provide an explanation of desertification - its identity, nature and distribution. Based on his work in the humid and sub-humid tropics of Africa, Aubréville thought of desertification as the process by which productive land steadily changed into desert as a result of human-induced soil erosion (Dregne, 1986). Deforestation, the indiscriminate use of fire and cultivation, all of which exposed the soil to erosion by both water and wind, were amongst the causes cited by Aubréville (Dregne, 1986). Aubréville viewed desertification primarily as a process, but also as a product or the end state of degradation (Glantz and Orlofsky, 1983). He was quite clear in his conclusions that desertification occurred only in the humid and sub-humid tropics, that it was a result of human activity on the land, and was not influenced in any way by climate change (Dregne, 1986).

Today, Aubréville's work defines the debate that continues around the concept of desertification. Central to widespread disagreement of what constitutes desertification is the fact that some researchers view desertification as a process of change while others view it as the end result of a process of change (Glantz and Orlofsky, 1983). In addition, different definitions focus on changes of different elements of the landscape (Glantz and Orlofsky, 1983). Some focus on soil (e.g. salinization), others on vegetation (e.g. decrease in density of biomass), water (e.g. waterlogging), or air (e.g. increased albedo) as the main indicator of desertification (Glantz and Orlofsky, 1983).

There is also no universal agreement about where desertification can take place (Glantz and Orlofsky, 1983). Many researchers regard arid, semi-arid and sometimes sub-humid regions as areas where desertification can occur (Glantz and Orlofsky, 1983). Others imply that areas outside arid, semi-arid and sub-humid regions are equally at risk through the use of descriptive words such as "extension", "expansion" and "spread", to explain the emergence of desert characteristics into non-desert environments (Glantz and Orlofsky, 1983).

The introduction of the term "land degradation" was born out of the afore mentioned debate on desertification, and only began to appear in the literature in more recent times. Thus, it is a relatively new word in our scientific vocabulary (Johnson and Lewis, 1995) and, like the concept of desertification, its definition is fraught with misinterpretation and inappropriate popular imagery (Mainguet, 1994).

To get a better understanding of the various interpretations of desertification and related land degradation, it is useful to review the evolution of some of the definitions offered over the years from UNCOD in Nairobi in1977 to the adoption of the United Nations Convention to Combat Desertification (UNCCD) in Paris in 1994 and beyond.

At the end of UNCOD a Plan of Action to Combat Desertification (PACD) was adopted wherein desertification was defined as:

> "The diminution or destruction of the biological potential of the land, and can lead ultimately to desert-like conditions. It is an aspect of the widespread deterioration of ecosystems, and has diminished or destroyed the biological potential, i.e. plant and animal production, for multiple use purposes at a time when increased productivity is needed to support growing populations in quest of development." (UNCOD, 1978, p.6)

This definition was simple, straightforward and unambiguous and specified both the general process as well as the consequences of desertification (Thomas and Middleton, 1995). However, this definition failed to be universally adopted, since it was rendered impractical in terms of any attempts to quantify desertification and not being confined to any specific biome, it was seen as blanket definition for any form of degradation that reduces productivity (Thomas and Middleton, 1995).

The picture was further complicated in 1984 by the Food and Agriculture Organisation (FAO) / United Nations Environment Programme (UNEP) which provided a definition from a more human perspective and included reference to the general contributory factors, the areas affected and the environmental outcome of desertification (Thomas and Middleton, 1995). The FAO/UNEP definition defined desertification as:

> “A comprehensive expression of economic and social processes as well as those natural and induced ones which destroy the equilibrium of soil, vegetation, air and water, in the areas subject to edaphic and/or climatic aridity. Continued deterioration leads to a decrease in, or destruction of the biological potential of the land, deterioration of living conditions and an increase of desert landscape.” (Thomas and Middleton, 1995, p.9)

The lack of a definitive explanation of desertification created controversy and conflict of opinion resulting in differing interpretations as the academic and scientific community also began to weigh in on the debate. Dregne (1986) asserted that desertification should be recognized as a land degradation process that involves a continuum of change, from slight to very severe vegetation and soil resource degradation due to human activity alone. His definition was as follows:

> “Desertification is an impoverishment of terrestrial ecosystems under the impact of man. It is the process of deterioration in these ecosystems that that can be measured by reduced productivity of desirable plants, undesirable alterations in the biomass and the diversity of the micro and macro fauna and flora, accelerated soil deterioration, and increased hazards for human occupancy.” (Dregne, 1986, p.2)

In contrast, Barrow (1991) asserted that a precise definition of land degradation was impossible, given the many factors that may be responsible, and offered the following classic definition:

> “Land degradation may be defined as the loss of utility or potential utility or the reduction, loss or change of features or organisms which cannot be replaced.” (Barrow, 1991, p.1)

In 1990, in response to the furious debate and requests to clarify its position (Thomas and Middleton, 1995), UNEP developed a definition in preparation for the United Nations Conference on Environment and Development (UNCED) in Brazil, 1992 (Dahlberg, 1994). The following definition of desertification was adopted in the UN World Atlas of Desertification in 1991 (Thomas and Middleton, 1995):

> "Desertification is land degradation in arid, semi-arid and dry sub-humid area resulting mainly from adverse human impact." (Middleton and Thomas, 1997, p.viii)

The phenomenon of "land degradation" in the above definition was defined as:

> "The reduction of the resource potential by one or a combination of processes acting on the land, including water and wind erosion, sedimentation and siltation, long-term reduction in the level of diversity in natural vegetation, crop yields, soil salinization and sodification." (Middleton and Thomas, 1997, p.viii)

Unlike the earlier UNCOD definition, the UNEP definition specified the environments in which land degradation could be termed desertification (Thomas and Middleton, 1995). It also shifted the focus from drought and climatic factors as primary causes, to what is the dominant view today – that people are the main cause of desertification (Thomas and Middleton, 1995).

In June 1994, as a result of the agreements reached at UNCED in Rio de Janeiro, the Convention to Combat Desertification was adopted in Paris. The definition adopted was slightly different to UNEP definition adopted in 1991:

> "Desertification means land degradation in arid, semi-arid and dry sub-humid area resulting from various factors, including climatic variations and human activities." (UNO, 1994, p.5)

Land degradation, in turn, was defined as:

> "The reduction or loss, in arid, semi-arid and dry sub-humid areas, of the biological or economic productivity and complexity of rain-fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes, including processes arising from human activities and habitation patterns, such as:
> (i) soil erosion caused by wind and/or water;
> (ii) deterioration of the physical, chemical and biological or
> economic properties of soil; and
> (iii) long-term loss of natural vegetation." (UNO, 1994, p.5)

Despite the widespread disagreement around the issue of desertification, a recent examination of the literature by Johnson and Lewis (1995) seemed to imply that there is, in fact, general consensus around two critical elements of land degradation. Firstly, land degradation is defined as a substantial decrease in the biological productivity of a land system; and, secondly, that this decrease is the result of processes attributed to human activities rather than natural events (Johnson and Lewis, 1995).

Consequently, Johnson and Lewis (1995) defined land degradation as follows:

> "The substantial decrease in either or both of an areas productivity or usefulness due to human interference." (Johnson and Lewis, 1995, p.2)

Johnson and Lewis (1995), went on to say:

> "Because biological productivity is determined not only by attributes of the land but also water properties, land degradation incorporates those aspects of the hydrologic domain that are significant to a given area." (Johnson and Lewis, 1995, p.2)

In the context of this research, a slightly different interpretation of land degradation needs to be adopted. The rainfall-runoff relationship of catchment hydrology needs to be addressed.

Working on the 1994 UNEP definition of land degradation, the following statement needs to be added:

> ...the effects of which alters the natural rainfall-runoff relationship in mountainous catchments, and may, as a result, contribute to the increased likelihood of flooding or influence the flood magnitude.

2.2.1 Land degradation in Southern and South Africa

Land degradation is a serious problem throughout Africa and not least affected is southern Africa (UNEP, 1999). It is estimated that 500 million hectares of land have been affected by degradation since 1950, including an estimated 65% of all agricultural land in Africa (UNEP, 1999).

In South Africa, only about 13,5% of South Africa is arable, although 80% of the land is used for agriculture (Hoffman and Ashwell, 1999a). Many centuries of exploitation and injudicious land policies have left large tracts of South Africa degraded (Hoffman and Ashwell, 1999a). Soil losses alone are estimated to be as high as 400 million tonnes annually in South Africa (UNEP, 1999) and costs the country an estimated R2 billion per annum (Hoffman and Ashwell, 1999a).

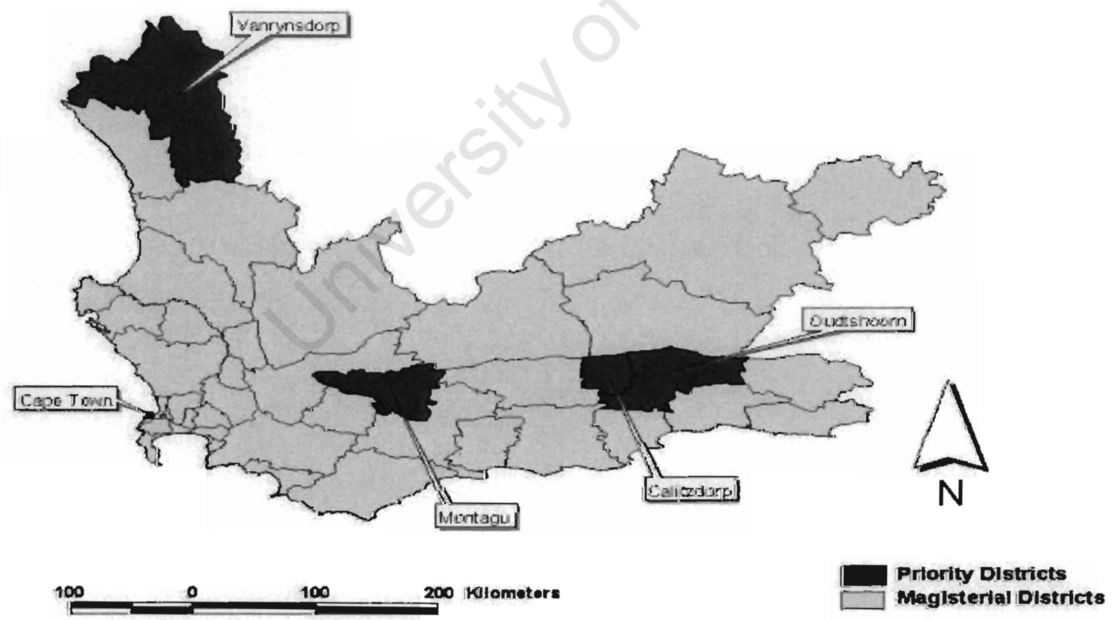
In January 1995, South Africa signed the United Nations Convention to Combat Desertification (UNCCD) (Hoffman and Ashwell, 1999a). As a result the Government, through the Department of Environmental Affairs and Tourism (DEAT), committed itself to developing a National Plan of Action to combat desertification (Hoffman and Ashwell, 1999a). The first stage of the National Plan was to gather information on the severity and extent of land degradation in South Africa (Hoffman and Ashwell, 1999a). The National Botanical Institute (NBI) and the Programme for Land and Agrarian Studies (PLAAS) where contracted to conduct a national research project on land degradation in 1997.

According to the national review of land degradation that was concluded in 1999, soil and veld (vegetation) degradation is most severe in communal farming areas, particularly in the steeply sloping grazing areas in the northern and eastern parts of the country in the Limpopo province, Kwazulu - Natal and the Eastern Cape (Hoffman and Ashwell, 1999a). The most degraded commercial farming areas are in the Northern and Western Cape (Hoffman and Ashwell, 1999a). The study found that the Western Cape has the second lowest level of soil degradation in South Africa (Hoffman and Ashwell, 1999b). The majority of the magisterial districts in the province show minor levels of soil degradation, with the exception of the districts of Montagu, Ladismith, Calitzdorp, Oudtshoorn and Uniondale in the Klein Karoo and the district of Vanrynsdorp to the north west of the province, which show moderate levels of soil degradation (Hoffman and Ashwell, 1999b).

The veld in the Western Cape shows evidence of moderate degradation (Hoffman and Ashwell, 1999b). Most districts have been well managed, with the exception of Hermanus on the south coast and Montagu, Calitzdorp and Oudtshoorn in the Klein Karoo (Hoffman and Ashwell, 1999b). In the arid interior the most common veld degradation issue relates to the change in plant species composition as a result of grazing or fire mismanagement (Hoffman and Ashwell, 1999b). Along the coast, and in the mountainous areas of the province, the spread of alien vegetation is the biggest threat (Hoffman and Ashwell, 1999b). With almost 29% of the land invaded by alien plant species, the Western Cape has the most serious alien vegetation problem in South Africa (Hoffman and Ashwell, 1999b). The invasion of the indigenous fynbos by communities of exotic trees and shrubs is widely regarded as one of the most serious forms of land degradation in the region (Meadows, 1998a).

The introduction of alien plant species to southern Africa and the Western Cape probably began one to two thousand years ago with the introduction of many species, including some which are invasive, such as *Cannabis sativa* (Meadows, 1998a). However the large majority of alien plant species only arrived after European colonisation in the mid-17th century and many of these have since become widespread and are highly invasive (Meadows, 1998a). The most prolific invaders are trees or large shrubs belonging to the genera *Acacia, Hakea* and *Pinus* (Meadows, 1998a). Their success and marked expansion in distribution has been attributed to their widespread intentional planting and effective natural dispersal (Meadows, 1998a).

The DEAT study on land degradation identified four priority districts (**Figure 2.3**) in the commercial farming areas of the Western Cape, all of which show moderate to severe soil and veld degradation (Hoffman and Ashwell, 1999b). The districts identified are Calitzdorp, Montagu, Outshoorn and Vanrynsdorp (Hoffman and Ashwell, 1999b).



Source: ENPAT 2000

Figure 2.3: Land Degradation in the Western Cape: Priority Districts.

Although degradation is widespread in the Western Cape, it is locally a problem. The extent to which the various forms of degradation influenced the floods in question, then, is an important issue to be addressed in this study

2.2.1.1 Causes of Land Degradation in South and Southern Africa

The most commonly accepted proximal causes of land degradation in southern Africa are over-cultivation, overgrazing, poor irrigation practices and deforestation (Dahlberg, 1994). According to the United Nations Environment Programme's (UNEP) Global Environmental Outlook 2000 (GEO-2000) (1999), the increasing rate of land degradation over the last decade can be ascribed to increased livestock numbers. Declining agricultural yields in the Southern African Development Community (SADC) have been attributed, in part, to water erosion, which accounts for 15% of land degradation (UNEP, 1999). A further 2% of soils in southern Africa are damaged by physical degradation, such as the sealing and crusting of topsoil, leading to a reduction of available soil water, the compaction of topsoil and waterlogging (UNEP, 1999). The recent national review on land degradation in South Africa found that areas with steep slopes, high temperatures, low annual rainfall, high stocking densities and high levels of unemployment were at greatest risk of becoming degraded.

However, the root causes of land degradation in southern Africa stem primarily from colonial imbalances in land distribution, lack of incentives for conservation, insecure land tenure, a failure to introduce diversified rural production systems and poverty (UNEP, 2002). In South Africa, policies, such as the Land Acts, beginning in 1913, whereby roughly 80 percent of the population were placed on marginal land, led to the creation of densely populated communal farming areas (Hoffman and Ashwell, 1999a). Poverty, inappropriate land use practices and a lack of government support in communal farming areas, resulted in the land becoming seriously degraded in these areas (Hoffman and Ashwell, 1999a). In contrast, financial incentives, agricultural extension services and farmer support groups helped to enhance productivity and the quality of the land in the more sparsely populated commercial, predominately white-owned farming areas (Hoffman and Ashwell, 1999a).

The expansion, broadly speaking, of agriculture in the last 30 years has seen the cultivation of marginal lands and the clearance of important natural habitats such as forests and wetlands (UNEP, 2002). Loss of natural habitat has reduced vegetation cover and exposed soils to both wind and water erosion (UNEP, 2002). Soil erosion reduces the productivity of land, and causes increased rates of siltation of dams and rivers, which significantly increases the risk of flooding in rivers and estuaries (UNEP, 2002).

Having explored the issue of land degradation in general, the effect of the disturbance of the riparian zone in particular is now examined.

2.3 Riparian Zone and Wetlands (Channel Vegetation)

Roman law identified three constituent parts of a river – the water or stream (flumen), the bed (alveus) and the banks (ripae) (**Figure 2.4**) (Rabie and Day, 1999). The riparian zone has been loosely defined as the area adjacent to a river or stream (Snaddon, 1999). In South Africa, zones 20m wide on either side of streams and rivers are defined as riparian (Bosch and King, 1988). The relationship between surface water ecosystems and the associated riparian zone is an intimate and dynamic one (Snaddon, 1999), and there is an increasing demand to include riparian vegetation in conservation, restoration and management plans (Muller, 1997).

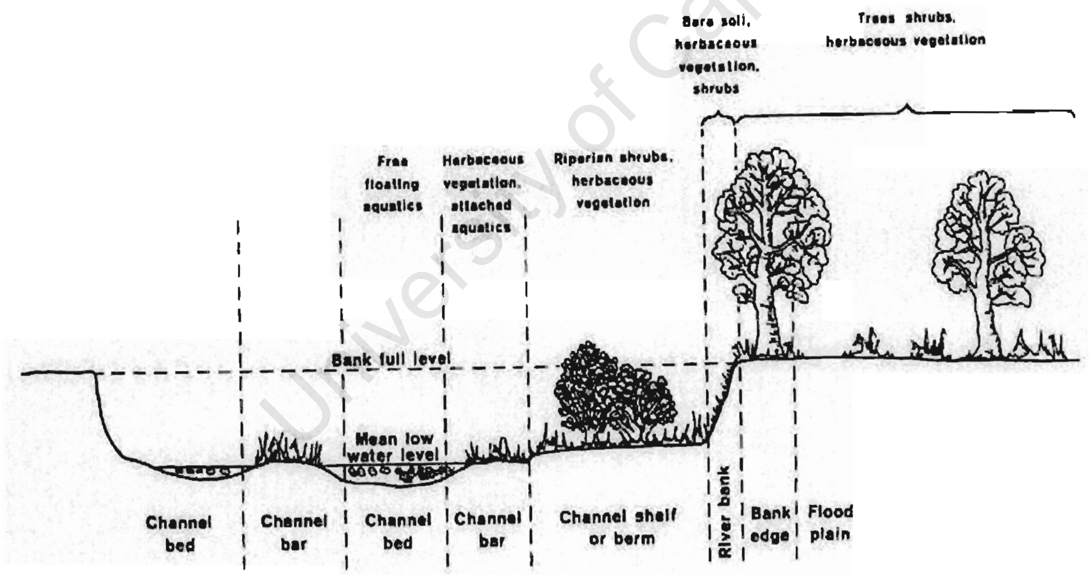


Figure 2.4: Riverine and riparian features and their associated vegetation (Rowntree, 1991).

In its natural state, the riparian zone acts as a physical and biological filter for sediments and nutrients from catchment run-off (Hoffman and Ashwell, 2001). Riparian vegetation induces local deposition on the banks by reducing the near-bank velocities, therefore decreasing the shear stress on banks and promoting sediment deposition on the channel shelf (du Plessis, 2000). In addition, it helps to stabilise riverbanks and soils, reducing erosion and the associated problems of turbidity and sedimentation (Hoffman and Ashwell, 2001). Preserving the riparian zone increases stream flow, improves water quality and enhances the functioning of aquatic ecosystems (Hoffman and Ashwell, 2001).

Wetlands are also important riverine features and are known to be remarkably effective flood-control agents. The dense stands of reeds and rushes help to reduce the force of the floodwaters, forcing the water to spread out, and thereby reducing its damaging effects on primary infrastructure (Davies and Day, 1998). Moreover, wetlands help to reduce the impacts of floods by storing and slowly releasing flood water into the river channel, reducing the flood-peak and increasing the lag period of run-off draining to the river (Davies and Day, 1998). Wetlands also serve as natural water filters, removing impurities and sediment from the river flow (de Sherbinin, 2002). However, wetlands are also highly sensitive to change. Rabie and Day (1999) note that an increase in sediment load has a detrimental effect on wetlands, and in some cases wetlands can be completely destroyed, having a direct influence on future flood events. Davies and Day (1998) assert that it is fairly certain that a significant loss of wetland in a river's catchment can lead to serious flooding in the lower reaches.

Stream banks are particularly prone to invasion by alien vegetation in comparison with terrestrial environments (Rowntree, 1991), as they are physically dynamic areas vulnerable to changes in land-use and land-cover in adjacent areas as well as changes in river flow. Floods, in particular, can alter the riverbeds and expose bare soil for colonisation by weeds (Le Maitre, 1999). Of particular concern are the so-called transformer species, which change the natural character of an ecosystem over a substantial area (Rowntree, 1991). Natural riparian zone vegetation has been found to be particularly vulnerable to invasion due to exposure to periods of natural and human related disturbance, the perennial availability of water, reliable dispersal of water and the role of stream banks as seed reservoirs (Rowntree, 1991).

The riparian zone also has a direct influence on the streamflow since riparian vegetation draws water directly from the supply that feeds the stream i.e. groundwater and surface run-off (Snaddon, 1999). Dense stands of alien woody species are known to have a marked influence on catchment hydrology (Meadows, 1998a). Recent studies by Van Wilgen, Cowling and Burgess in Meadows (1998a) have compared the effects on the hydrological output of two hypothetical mountain fynbos catchments, one with exotic tree removal as a management strategy, the other without (Meadows, 1998a). The results revealed a 30% improvement in run-off in the managed catchment (Meadows, 1998a).

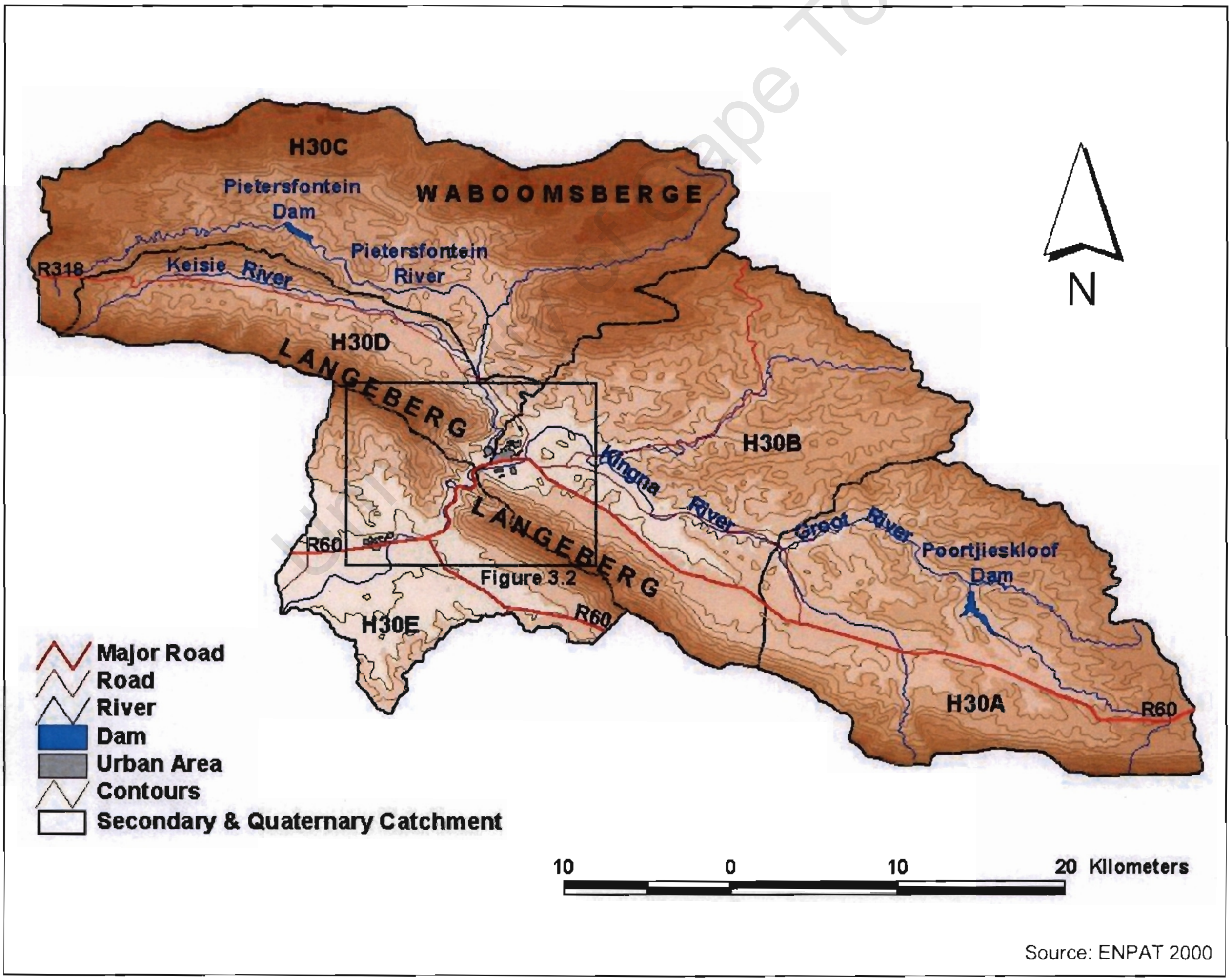
Riparian vegetation and wetlands are both important factors in the stability and flow of a river channel. The destruction, removal and the composition of these riverine features have a direct influence on streamflow (Snaddon, 1999). Therefore the management or mismanagement of the broader riverine ecosystem can play a significant role in the severity and magnitude of flood events within a given catchment.

This chapter has explored the theory and significance of land-cover and land-use change, land degradation and riparian zone management in the context of catchment hydrology. Chapter Three will introduce and describe the study area of this research – the Kogmans River catchment – in terms of its physical geography, land degradation, land-use and settlement history (with particular focus on Montagu).

Chapter Three

The Kogmans River (H3) Secondary Catchment

The Kogmans River (H3) catchment is situated in the Klein Karoo region of the Western Cape, between the Langeberg Mountains to the south and the Waboomsberge to the north (**Figure 3.1**). This secondary catchment is part of the greater Breede River catchment and drains into two perennial rivers, the Kingna River and the Keisie River (**Figure 3.1**). Two large irrigation dams provide water for the agricultural community within the catchment – Pietersfontein Dam in the north west and Poortjieskloof dam in the south east (**Figure 3.1**).



Source: ENPAT 2000

Figure 3.1: The Kogmans River catchment.

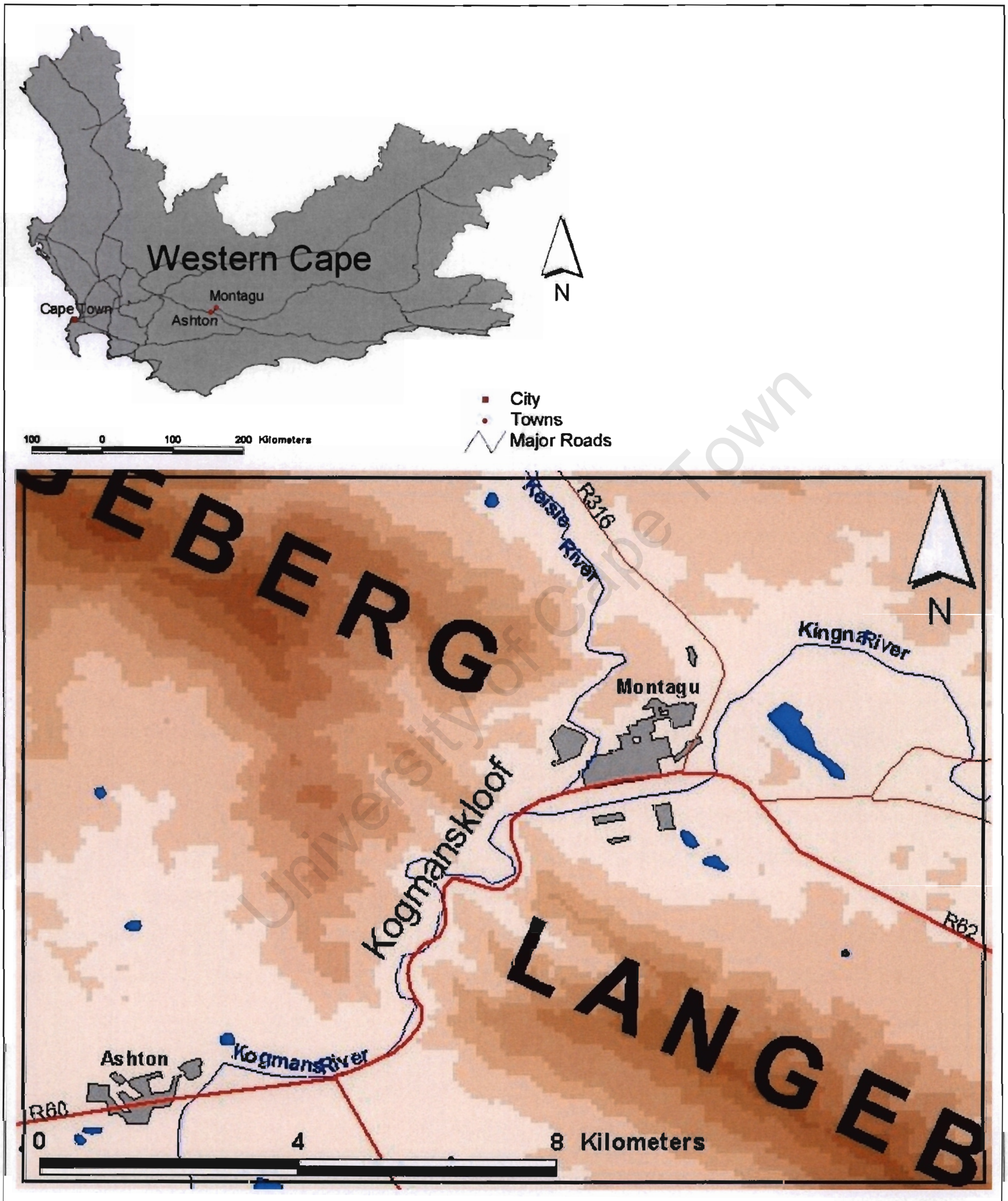
Two major towns are situated within the catchment – Montagu, to the north of the Langeberg and Ashton to the south (**Figure 3.2**).

Montagu was established in the mid-nineteenth century on the site of the farm De Uytvlugt, one of the first farms established in the area in 1744 (Burman, 1981). Situated 170km east of the city of Cape Town (**Figure 3.2**), the town has become a major tourist destination with an established hospitality and tourism industry catering for all manner of visitor. Montagu is also host to a thriving local wine industry that produces quality wine for both local and export markets.

Ashton was established in the late 1800s and served primarily to provide vital access to the railway for Montagu residents and surrounding communities not connected to the railway network (Burman, 1970). The establishment of the Breede River irrigation scheme saw Ashton become the centre of a rich fruit-yielding area, and in 1940 the Langeberg Cooperative built a fruit processing and canning factory in the town (Burman, 1970). Today, Ashton is an important wine and fruit-processing centre.

The confluence of the Kingna and Keisie River is situated at the southern entrance to the town of Montagu and the northern end of the narrow Kogmanskloof, which serves as a vital road link between Montagu to the north and Ashton to the south (**Figure 3.2**). The combined flow of the Kingna and Keisie Rivers forms the Kogmans River, which flows south, via the Kogmanskloof, through the town of Ashton (**Figure 3.2**) to the confluence with the Breede River at Goudmyn.

The macroscale development of the landscape has been clearly influenced by the lithology and stratigraphy of the area. In general, the resistant, folded Table Mountain Group rocks form the east-west orientated mountain ranges. The less resistant Bokkeveld Group shales to the north comprise undulating hilly areas of lower relief. Drainage lines, such as the Kogmans River, have been superimposed on the landscape, incising the Fold Mountains and thereby providing north-south drainage feeding into the Breede River.



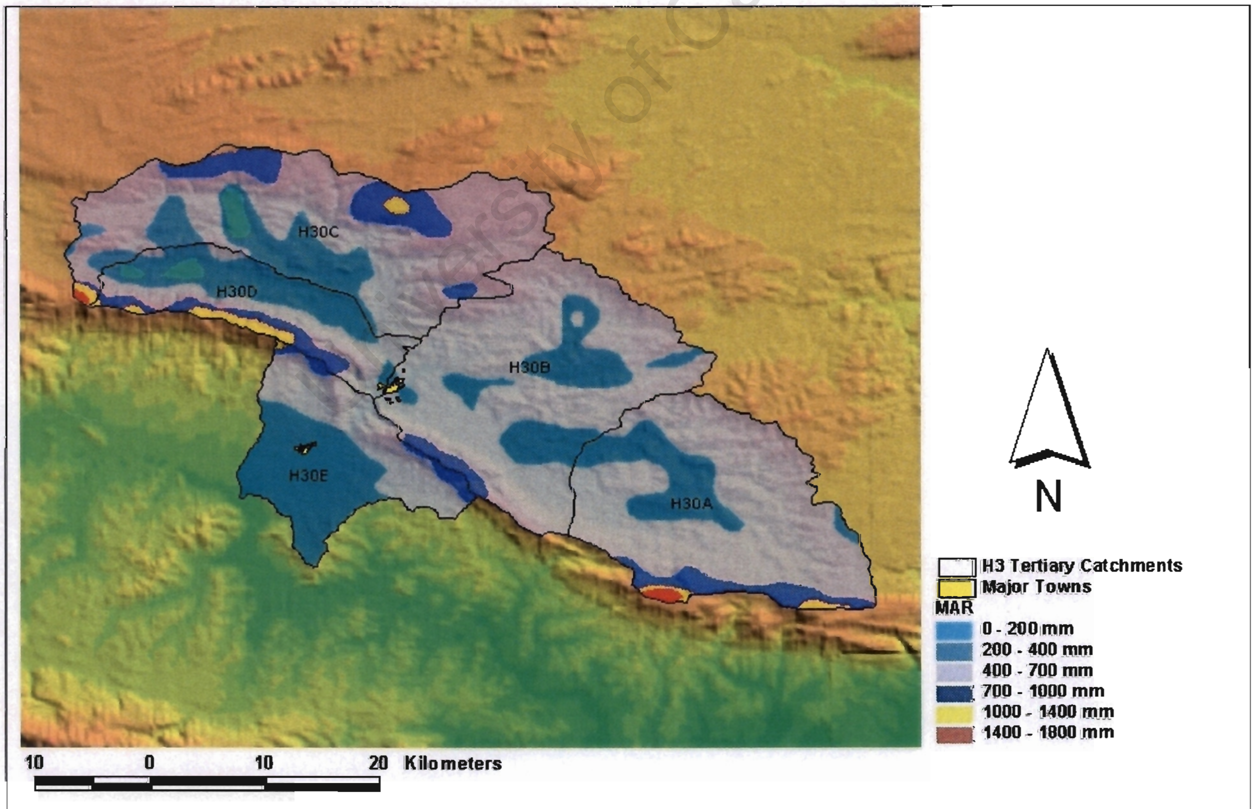
Source: ENPAT 2000

Figure 3.2: Montagu and Ashton.

3.1 Climate

The Kogmans River catchment is situated in the winter rainfall region of the Western Cape in a region called the Klein (Little) Karoo. Rainfall is the catchment is strongly seasonal, with approximately 80% of the annual precipitation falling between the months of April and September as a result of frontal systems that move over the area from the west (DWAFa, 2003). The rainfall pattern over the area varies considerably, mainly as a result of the topography (DWAFa, 2003). The highest mean annual rainfall occurs in the high-lying mountainous areas of the Langeberg and Waboomsberge while the low-lying valley below receives the lowest mean annual rainfall figures (**Figure 3.3**) (DWAFa, 2003).

Rainfall data for the catchment are available for three rain gauge stations, each administered by the South African Weather Service (SAWS), the Department of Water Affairs and Forestry (DWAF) and the Institute for Soil, Climate & Water (ISCW) respectively. However, not all of them have data for a given time of event. For example, of the nineteen stream gauges only six have data pertaining to the 2003 floods in Montagu.



Source: BRBS

Figure 3.3: Mean Annual Rainfall (MAR) in the Kogmans River Catchment (Source: BRBS).

Table 3.1 shows the average annual rainfall statistics for Montagu (Lat.: –33.7830; Long.: 22.1170; height ASL: 230m) for the period 1883 – 2003 as supplied by the South African Weather Service (SAWS).

Month	Mean	Mean±SD*	Ave. No. Days Rain	Num Mon**	Max r Day (mm)***	Max r Date****
Jan.	12.7	18.3	1.5	98	69.9	11/01/1912
Feb.	14.5	19.8	1.6	96	50.5	05/02/1972
Mar.	20.9	31.3	2.5	98	178.0	23/03/2003
Apr.	33.0	40.8	3.4	99	80.0	11/04/1993
May	35.5	33.7	4.3	102	137.2	14/05/1885
Jun.	34.2	23.8	4.8	103	78.0	08/06/1910
Jul.	35.1	27.3	4.5	101	76.2	23/07/1918
Aug.	38.5	31.2	4.9	98	78.7	12/08/1912
Sept.	26.1	25.1	3.7	98	59.2	09/09/1892
Oct.	24.1	21.5	3.4	100	57.7	10/10/1934
Nov.	23.6	22.8	2.7	100	54.6	08/11/1914
Dec.	15.4	26.4	1.8	96	116.0	14/12/1998
Year	313.7	------	39.2	------	------	------

* Mean±SD. represents the standard deviation from the mean

**Num Mon represents the number of months used in the calculation.

***Max r Day represents the maximum rainfall that occurred over a 24-hour period (08:00 – 08:00).

****Max r Date represents the date on which the maximum 24-hour rainfall occurred.

Source: SAWS

Table 3.1: Average rainfall statistics for Montagu: 1883 – 2003.

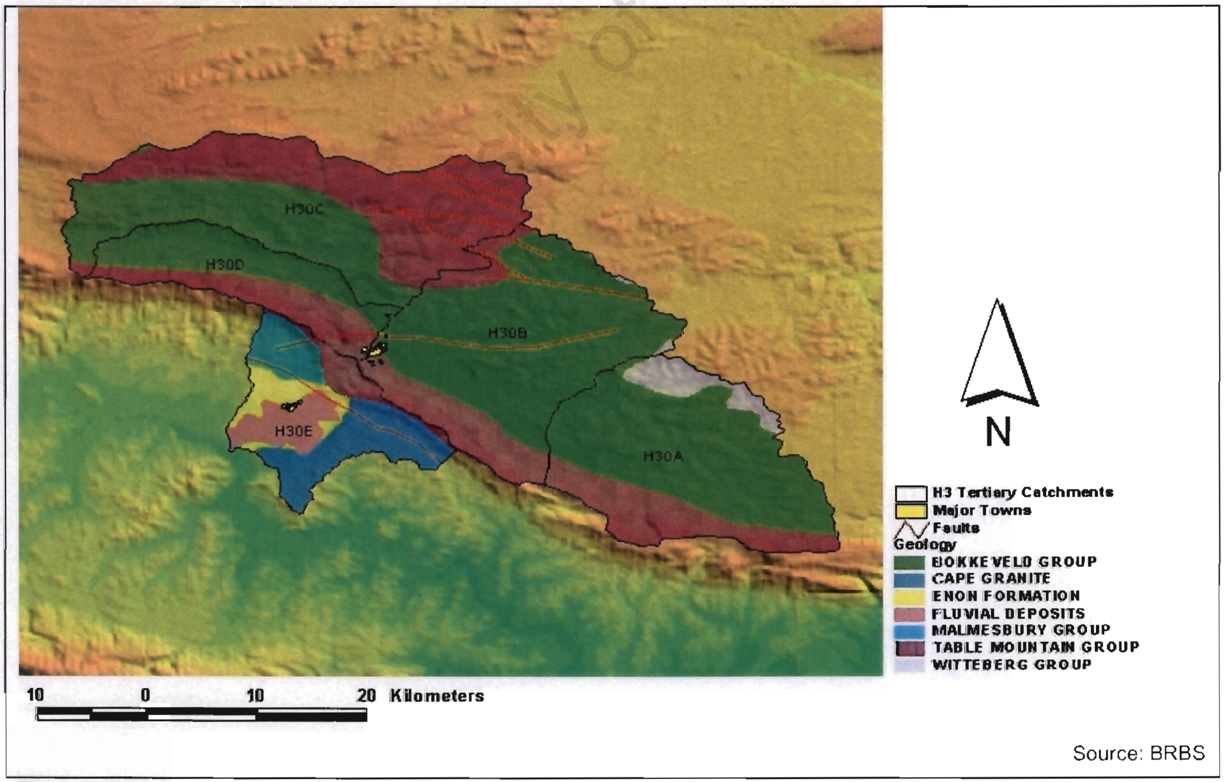
In accordance with seasonality of the rainfall within the catchment, the relative humidity is higher in winter than it is in summer (DWAF, 2002). The highest humidity ranges from 66% to 69% in the month of June, while the lowest humidity ranges from 62% to 66% in January (DWAF, 2002).

The Klein Karoo is characterised by very significant diurnal and seasonal fluctuations in temperature (Kotze, 2002). During the summer months, temperatures commonly reach 38° C during the day, and during the cold winter nights the temperature can drop below freezing point (Kotze, 2002). Daily average minimum and maximum temperatures for summer and winter range from 15°C to 42°C and -3°C to 18.5°C respectively (Kotze, 2002).

Summers tend to be dry and hot with generally high evaporation (DWAFa, 2003). The average annual evaporation varies from between 1760mm/a and 2050mm/a from west to east across the Klein Karoo (Kotze, 2002). The annual evaporation in the Kogmans River catchment is estimated at 1800 mm/a (DWAFa, 2003). Evaporation is approximately 50% less between the months of April and September (Kotze, 2002). Evapotranspiration values are therefore at a maximum between October and March, which is reflected by a drop in groundwater levels and spring flow (Kotze, 2002).

3.2 Geology

The geology of the Kogmans River catchment is predominately characterised by the Table Mountain and Bokkeveld Group, both of which are part of the Cape Supergroup (**Figure 3.4**). The Langeberg Mountains, on the southern boundary of the catchment, and the Waboomsberge on the northern boundary, are comprised mainly of Table Mountain Group sandstone, while the geology of the base of the catchment consists largely of Bokkeveld Group shales and siltstone. At the southern end of the Kogmanskloof yellowish-brown phyllites of the Malmesbury Group are dominant (Geological Society of South Africa, 1999). To the south of the catchment, in the vicinity of Ashton, conglomerate with thin sandstone, siltstone and mudstone beds of the Uitenhage Group form the underlying geology. Scree and alluvium border the mountain chains and major river channels respectively (Theron, Wickens and Gresse, 1991).



Source: BRBS

Figure 3.4: Geology of the Kogmans River catchment.

In the Kogmans River catchment, the Table Mountain Group, which comprises the lithology of much of the Cape Fold Belt (Visser, 1986), has a maximum thickness of 3000m and consists of five formations (Cedarberg/Pakhuis, Peninsula, Goudini, Skurweberg and Rietvlei) all of which are predominantly arenitic in character (Theron, Wickens and Gresse, 1991). The fossil content and large variety of structures indicate a marine depositional environment (Theron, Wickens and Gresse, 1991). The material was probably originally carried by rivers from a landmass to the north and deposited in a coastal environment some 400 million years ago (Viljoen and Reimold, 1999).

The Bokkeveld Group, in turn, consists of seven formations (Gydo, Gamka, Voorstehoek, Hex River, Tra-Tra, Boplaas and Waboomsberg) and is made up of a regular alternation of predominantly arenitic and pelitic units (Theron, Wickens and Gresse, 1991). The beds of the Bokkeveld Group underlie long strips between the mountains in the Kogmans River catchment (Visser, 1986).

Between 280 and 220 Million years ago, compressional forces in the Earth's crust folded the layers of the Table Mountain Group and uplifted the original Cape Fold Mountains (Viljoen and Reimold, 1999). Subsequently, a major east-west fracture also occurred, an example of which is the Worcester fault evident at the southern entrance to the Kogmanskloof (Viljoen and Reimold, 1999). As a result, various isolated occurrences of rocks from the Uitenhage Group, which vary from Jurassic to Cretaceous in age, are present on the southern side of the Langeberg (Theron, Wickens and Gresse, 1991).

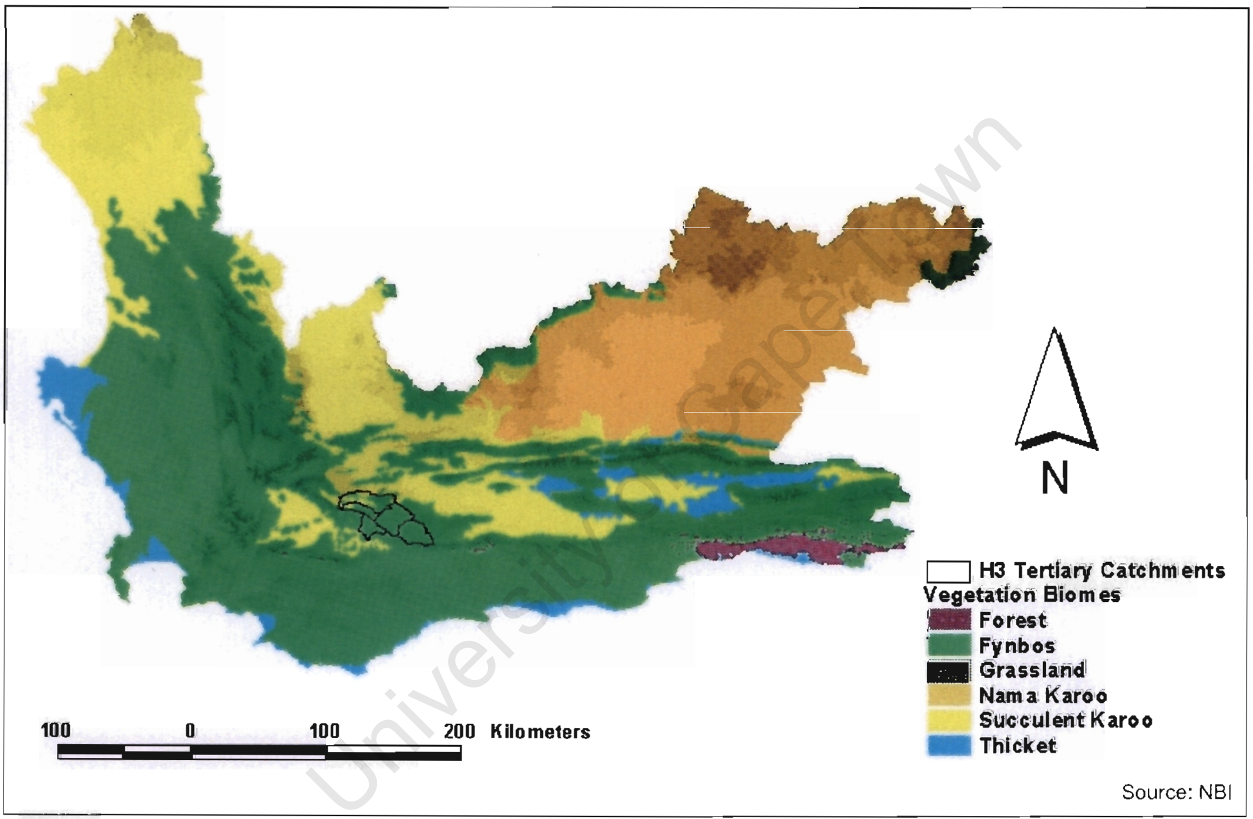
Hardly any significant mineral deposits occur in the area, except small deposits of gypsum, limestone and uranium (Theron, Wickens and Gresse, 1991).

3.3 Soils

The relationship of geology to soils is well established in this region (Watkeys, 1999). Most of the soils are shallow (<300mm), of pedologically young landscapes (Watkeys, 1999) and derived from the Bokkeveld Group that dominates the geology in most of the Kogmans River catchment. The majority of the soils are comprised of the Glenrosa and/or Mispah soil forms. Soils derived from Table Mountain Group rocks are shallow, quartzitic, and generally lacking in nutrients.

3.4 Vegetation

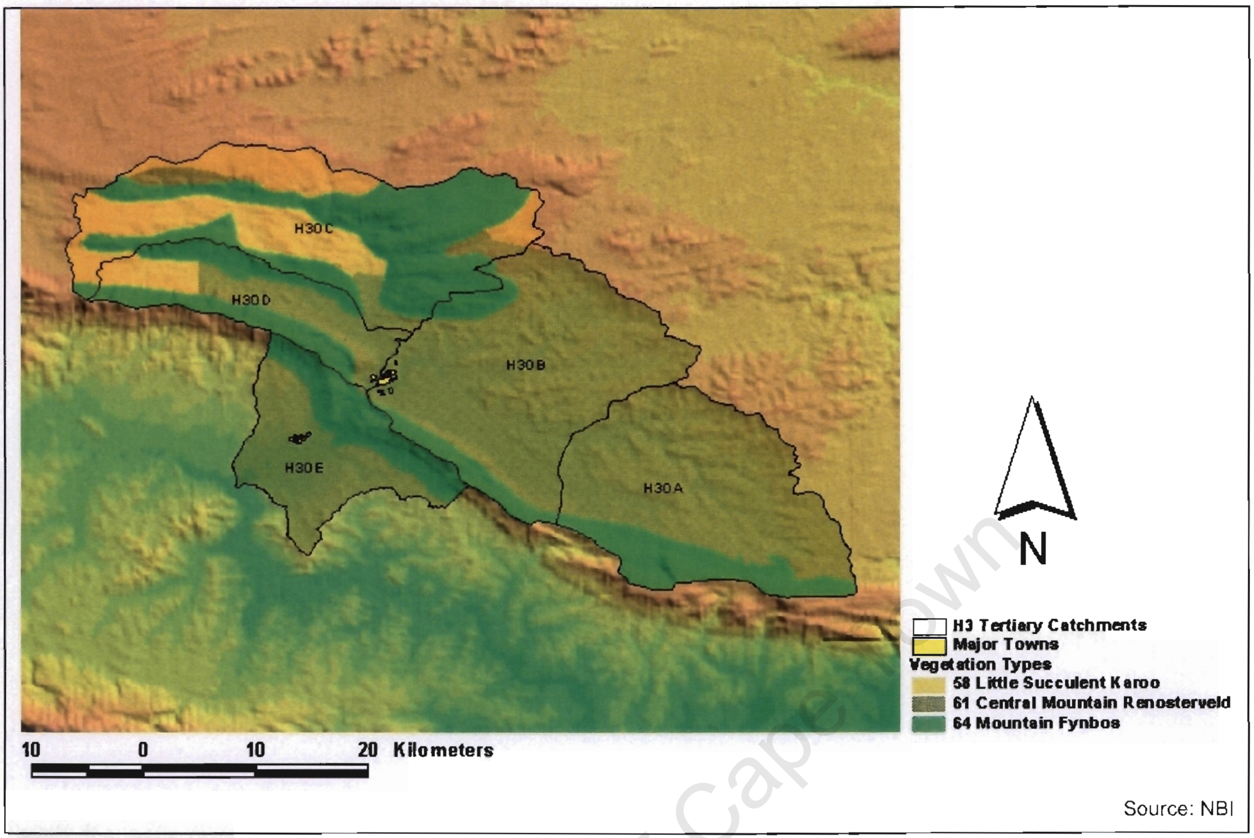
The Kogmans River catchment is situated predominantly within the fynbos biome (**Figure 3.5**) of the Western Cape. The fynbos biome, despite its small size (2.7% of southern Africa), has the richest flora of the southern African biomes (Cowling and Olivier, 1999). The north west area of the catchment is characterised by vegetation belonging to the Succulent-karoo biome (Cowling and Olivier, 1999).



Source: NBI

Figure 3.5: Vegetation biomes of the Western Cape.

The lower lying areas of the catchment is dominated by Central Mountain Renosterveld vegetation to the southeast, while the northwest boundary is dominated by the Little Succulent Karoo vegetation type (**Figure 3.6**). The Langeberg and Waboomsberge mountains are dominated by Mountain fynbos (**Figure 3.6**). The riparian vegetation is dominated by Fluitjiesriet (Phragmites australis) and Papkuil or Bullrush (Typha capensis).



Source: NBI

Figure 3.6: Vegetation types in the Kogmans River catchment.

The Central Mountain Renosterveld typically occupies rocky and hilly landscapes at elevations ranging from 300m-600m above sea level (Acocks, 1988). It is dominated by succulents, and dwarf trees and shrubs are widespread (Acocks, 1988). The low level of soil moisture partly explains the prevalence of succulents, while the better soil-water relations produced by the rocky, undulating landscape explains the dense distribution of shrubs (Acocks, 1988). More specifically, the Central Mountain Renosterveld is characterised by the scattered occurrence of Sweet Thorn (*Acacia karoo*), Bitter Aloe (*Aloe ferox*) and Common Guarri *Euclea undulata* and *Rhus* spp) (Rebelo, 1996a). The understorey lacks grasses when overgrazed and contains a fair number of herbaceous plants at various densities, with a high proportion of succulents (Rebelo, 1996a). Ashbush *Pteronia incana* is often dominant (Rebelo, 1996a).

The Little Succulent Karoo vegetation is characterised by a wide range of succulent (Thorn Vygie *Eberlanzia ferox*), non-succulent shrub (Hairbush *Hirpicium integrifolium* and Bankruptbush *Pteronia pallens*) and low tree species (Jacketplum *Pappea capensis*, Common Guarri *Euclea undulata* and Karoo Boerbean *Schotia afra*) (Hoffman, 1996). The vegetation is overwhelmingly dominated by dwarf succulent shrubs, while perennial grasses are scarce but annuals are prominent during spring (Cowling and Olivier, 1999).

In terms of floristics and structure, Mountain fynbos has not been rigorously defined (Rebelo, 1996b). Quite simply, therefore, Mountain fynbos is merely Fynbos that occurs in mountain environments in the fynbos biome (Rebelo, 1996b).

The dominant indigenous riparian plant within the fynbos biome is the Palmiet (*Prionium serratum*) or Cape river plant (Goldblatt and Manning, 2000). This robust, clonal fynbos shrub characteristically forms dense stands up to 2m tall (Boucher and Withers, 2004) and is endemic to much of the Western Cape and southern KwaZulu-Natal (Goldblatt and Manning, 2000). Perennial graminoids *Phragmites australis* or Common Reed and *Typha capensis*, commonly known as Bulrush, are also found along rivers within the fynbos biome, particulary where silt is actively deposited (Boucher, 1988).

The distribution of Palmiet in the Western Cape and Kwa-Zulu Natal is influenced markedly by water quality. In particular, Palmiet has been found to be totally intolerant of saline conditions (Boucher and Withers, 2004), which explains its absence from rivers in the Kogmans River catchment. The same can be said about *Typha capensis* which also shows an intolerance to saline conditions.

The geology of the Kogmans River catchment has been found to play an important role in determining the water quality of the rivers that drain the area (DWAF, 2002). Most of the run-off in the catchment is generated on the shallow soils and sandstone bedrock of the Langeberg mountains (DWAF, 2002). Although the run-off that originates from the sandstone geology is generally of high quality with a low total dissolved salt content, this quality deteriorates significantly by the time it reaches the main river channel due to the fact that it drains through the Bokkeveld shales at the base of the catchment (DWAF, 2002). In soils formed on Bokkeveld or Malmesbury shales and mudstone, the clays and mobile salts leach from the surface and accumulate in the lower part of the soil profile (DWAF, 2003b). As a result, water that drains from these soils is characteristically of poor quality and elevated salinity levels (DWAF, 2002), a condition that is exacerbated during low flow periods (during summer and periods drought).

In addition, the irrigation of soils on clay rich formations, such as those found on Bokkeveld Group rocks, generates significant salinity (DWAF, 2003b). Deep ripping of these soils during irrigation, flushes the accumulated salts into streams and rivers (DWAF, 2003b).

As a result, Palmiet is not found within the Kogmans River catchment and the riparian vegetation is dominated instead by *Phragmites australis*.

3.4.1 The Common Reed, *Phragmites australis*

The grass family or Poaceae is made up of 253 genera including the genus *Phragmites* Adans. *Phragmites* is represented by three species in Africa – *P. karka* (Retz.) Trin. Ex Steud., *P. mauritianus* Kunth and *P. australis* (Cav.) Trin. Ex Steud (Gordon-Gray and Ward, 1971). *P. mauritianus* and *P. australis* are indigenous to southern Africa, and while *P. mauritianus* occurs only in the northern parts of South Africa with a distribution that extends into the tropical belt, *P. australis* is found throughout South and southern Africa (Chippindall, 1955; James *et al.*, 2002) and is a common feature in South African rivers (James *et al.*, 2002).

P. australis or Common reed, also known locally as Fluitjiesriet (Chippindall, 1946), is a robust aquatic or semi aquatic, perennial and rhizomatous reed (Chippindall, 1955) that stands between 600mm and 4000mm tall (Gibb Russel *et al.*, 1990). It commonly occurs in dense stands (Gordon-Gray and Ward, 1971) in riverbeds and along the banks of streams and vleis (Scott, 1955) and is found predominantly in the Fynbos, Savanna, Grassland, Nama Karoo and Desert biomes (Gibb Russel *et al.*, 1990). Gordon-Gray and Ward (1971) observe that *P. australis* favours generally moist organically rich soil or clayey sand or mud. The abundance of *P. australis* reed beds is closely linked to water, and it has been found to grow most vigorously when the flow is just above the water table (Haslam, 1970, Ostendorp, 1991; James *et al.*, 2002).

3.4.2 Alien Vegetation

The term alien can be used to describe any species not naturally occurring in a specific area (Le Maitre, 1999). Humans have introduced a large variety of plant species to areas outside their natural geographic distribution (Le Maitre, 1999). Approximately 750 alien tree species and probably several thousand alien shrub and herbaceous species have been introduced to South Africa for use in horticulture, agriculture and forestry (Le Maitre, 1999). The Western Cape has a total area of 12 931 413 ha, of which 3 727 392 ha are invaded by alien plants species (Le

Maitre, 1999). This accounts for approximately 28% of the total area of the Western Cape, making the province the worst affected by alien plant invasion in South Africa. In addition, the Western Cape differs from the rest of the country in that the problem of invaders is one of both landscapes (i.e. entire catchments) and rivers, whereas riparian zone invasions dominate the problem in the rest of the country (Le Maitre, 1999).

The Kogmans River catchment is host to various alien species of grasses, saltbushes, trees and reeds that have invaded indigenous vegetation and capitalised on both natural and human induced landscape disturbances.

Winter-growing annual grasses (*Avena, Bromus, Hordeum, Stipa capensis*) and European forbs with soil-stored seedbanks, cold-cued germination and C_3 photosynthetic pathways have become abundant where indigenous shrubs have become reduced (Milton *et al.*, 1999). Localised soil disturbance, amelioration by ant or termites and selective grazing on such sites by livestock have generated a patchy distribution of alien grasses in the Klein Karoo (Milton *et al.*, 1999).

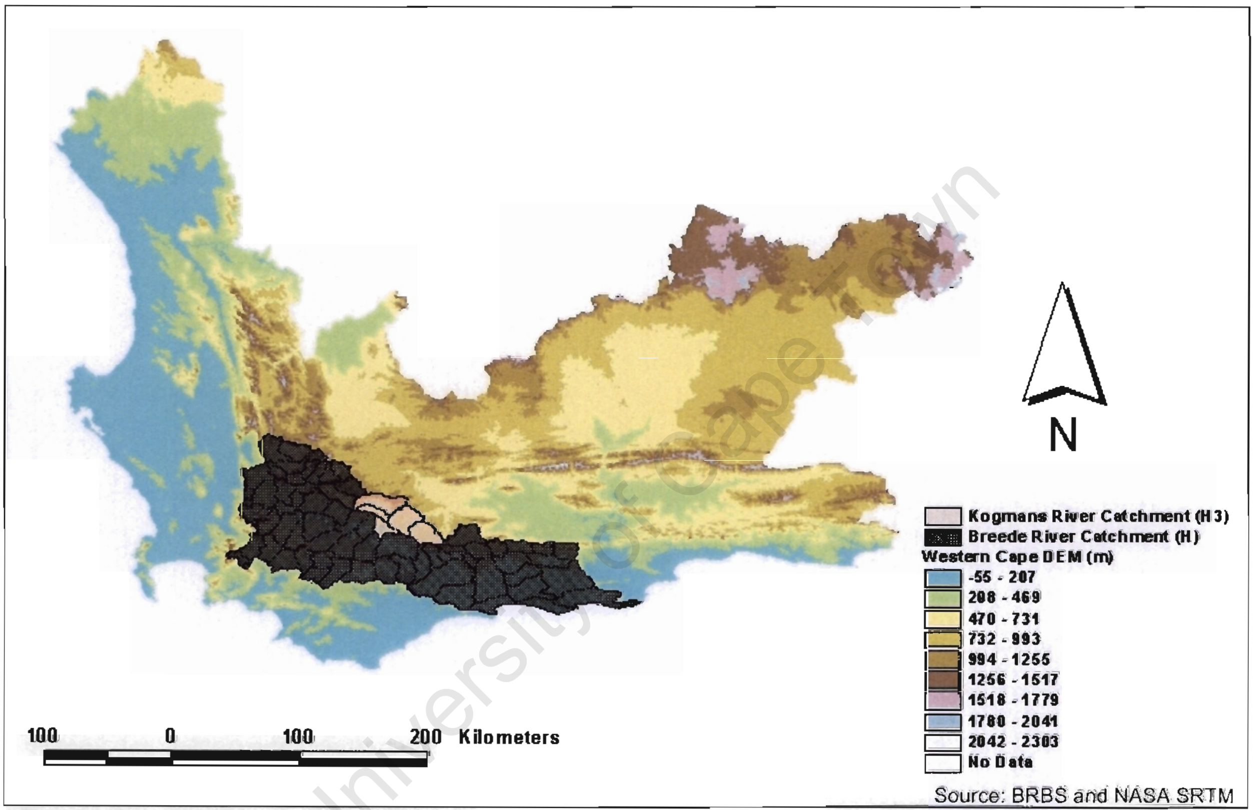
Australian desert saltbushes (*Atriplex* sp.), introduced to the area in the mid-1800s to provide pasture for small stock and ostriches, are particularly abundant in the succulent dominated vegetation of the Klein Karoo (Milton *et al.*, 1999).

All introduced saltbush species, including the herbaceous *Atriplex lindleyi*, *A. muelleri*, *A. semibacata* and shrubby *A. nummularia*, have since naturalised and are widespread on fine textured and saline soils (Milton *et al.*, 1999). Their efficient dispersal, large seedbanks, water and nitrogen-broken seed dormancy and rapid growth enable the herbaceous saltbush, particularly *A. lindleyi* ,to colonise natural disturbances on river banks as well as anthropogenic disturbances like abandoned fields, dry impoundments, road verges and livestock watering points (Milton *et al.*, 1999).

The riparian zone is particularly vulnerable to invasion, especially in areas where invaders are excluded from landcape invasions due to a limited moisture availability (Le Maitre, 1999) as is the case in the Kogmans River catchment.

3.5 Hydrology

The Kogmans River catchment (H3) is a secondary catchment forming part of the greater Breede River primary catchment (H) (**Figure 3.7**). The secondary catchment is divided into five tertiary catchments (H30A – H30E) and has a total area of 1205 km² .Two major rivers drain the Kogmans River catchment - the Kingna River to the south-east and the Keisie River to the north-west.



Source: BRBS and NASA SRTM

Figure 3.7: The Breede River Primary catchment (H) and the Kogmans River Secondary and Tertiary catchments.

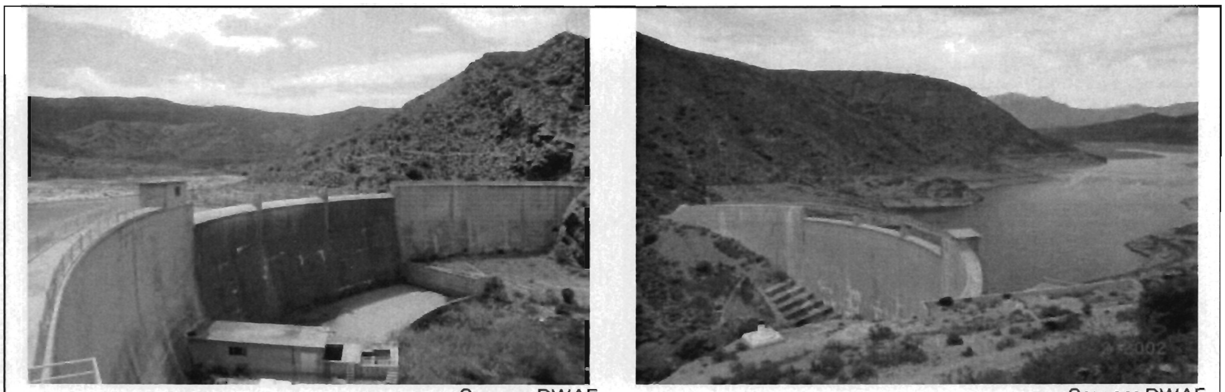
The confluence of the Kingna River and Keisie River is located at the start of the narrow Kogmanskloof, and the combined flow of the Kingna and Keisie Rivers join to form the Kogmans River, which flows south via the town of Ashton to the confluence with the Breede River at Goudmyn.

Two large dams, built, maintained and administered by the Department of Water Affairs and Forestry (DWAF) serve much of the agricultural sector in the catchment with irrigation water. Both the Pietersfontein Dam in the north west and Poortjieskloof dam in the east of the catchment (**Figure 3.8**) are Arch dams with heights of 29m and 35m respectively (DWAF, 2003c). The Pietersfontein dam was completed in 1968 on the Pietersfontein River (a major tributary to the Keisie River), and lies 18km north west of Montagu (DWAF, 2003c). The dam has a maximum storage capacity of 2 .097 million m³ and at full supply covers an area of 30.4ha (DWAF, 2003c). The Poortjieskloof dam lies 30km east of Montagu on the Groot River (that feeds the Kingan River) (DWAF, 2003c). The dam was completed in 1955 and has a maximum capacity of 9.855 million m³, which translates into a full supply area of 103ha (DWAF, 2003c). Two smaller dams – the Knipes Hope Dam (3.1 million m³) and Sarah's Dam (1.037 million m³) – supplement the dam storage capacity of the catchment (DWAF, 2002).

Stream gauge data from the Department of Water Affairs and Forestry is available for nineteen stream gauges within the catchment although not all of them have data for a given time of event. For example, of the nineteen stream gauges only six have data pertaining to the 2003 floods in Montagu.

The agricultural sector in the Kogmans River catchment is also serviced with irrigation water supplied by various irrigation boards who abstract water from various sources to store in a number of dams within the catchment (DWAF, 2003c). The irrigation boards in operation in the catchment are the Cogmanskloof Irrigation Board, who operate a pumping scheme that diverts water from the Breede River to Montagu; the Dwariga Irrigation Board, who utilise water from the Dwariga River (a tributary to the Kingna River); the Kingna Irrigation board, who divert water from the Kingna River and the Poortjieskloof dam; and the Baden Irrigation board, which manages groundwater supply in the Montagu area utilising a spring water from the Pietersfontein River valley (DWAF, 2003c).

The highest flood peak in the Kogmans River catchment, to date, was recorded on the 25th January 1981 at 1460 m³/s (Kovacs, 1988).



Source: DWAF Source: DWAF

Pietersfontein Dam. Poortjieskloof Dam.

Figure 3.8: Two major dams in the Kogmans River catchment.

Both the Keisie and the Kogmans River are listed by Cowen and van Riet (1998) in A Directory of South African Wetlands as rivers that support riverine wetlands. Riverine wetlands are defined as systems confined to a channel which include the following habitats: perrenial rivers and streams (including waterfalls), inland deltas, seasonal rivers and streams and riverine floodplains (Cowen and van Riet, 1998).

3.6 Settlement and Land-use History

The Karoo has a long history of human occupation, the earliest traces of which date back at least three million years (an estimated date based on comparable associated fauna from east Africa for the Taung skull, *Australopithecus africanus*) (Smith, 1999). According to Keller (1973), the early hunter-gatherer inhabitants of the Klein Karoo would have probably found it easiest to enter the region from the south, where the Langeberg forms the only barrier, or from the east where the mountain ranges do not extend all the way to coast. From the west entry would have been hindered by the du Toits mountain range, the Breede river valley and the Langeberg mountains (Keller, 1973). From the north, passage into the region would have been navigated along the maze of rivers and passes cut into the mountain ranges (Keller, 1973). Migration into this area was most likely driven by resource requirements in response, primarily, to seasonal variations in plant foods (Humphreys, 1987).

Since then, human use of the Karoo landscape has continued uninterrupted (Smith, 1999) from the early Stone Age (1.6 to 1.4 million years ago), middle Stone Age (1.3 million to 40 000 years ago) and late Stone Age (30 000 to 2 000 years ago), to the appearance of the first agricultural peoples of southern Africa roughly 2000 years ago and, finally, to the arrival of European colonists approximately 300 years ago. While much of the Klein Karoo remains to be explored archaeologically (Smith, 1999) the continuum of human activity and occupation in the Kogmans River catchment is comprehensively represented by Archaeological evidence from the Montagu Cave and the historical record that documents the colonial agricultural settlement of the catchment through to the present day.

3.6.1 Pre-colonial Settlement and Occupation of the Kogmans River Catchment

Located in the side of a small ravine cut through the Table Mountain Sandstone on the northern side of the Langeberg mountains, near the town of Montagu (Butzer, 1973), the "discovery" of the Montagu cave was first reported by European settlers in the 1880s (Keller, 1973). Since then, the cave has been excavated twice and has provided a rich artefact assemblage charting the cave's occupation through the early, middle and late Stone Age.

The cave was first excavated by Dr. S.H. Haughton and Dr. K.H. Barnard from the South African Museum between 1919 and 1920 and later, between 1964 and 1965, by C. M Keller from the University of California.

Haughton and Barnard excavated an estimated three quarters of the cave and reported four artefact-bearing layers. The bottom three layers revealed, what Haughton and Barnard described as "Earlier Stone Age" occupation of the cave, whilst the uppermost layer attested to more recent "Later Stone Age" utilization of the cave (Keller, 1973). A full account of their work and details regarding the stratigraphy and artefacts recovered can be found in Goodwin (1929).

Building on the work done by Haughton and Barnard, Keller (1973) excavated an area 20 feet by 25 feet in size on the south side of the cave that had not been excavated previously by Haughton and Barnard in the early twentieth century (Keller, 1973). Keller (1973) excavated six levels within the cave and reported artefact assemblages from the late Archeulean tradition (early Stone Age), the late Stone Age, as well as the Howiesons' Poort industry (middle Stone Age). The artefact assemblage of Montagu Cave revealed the change in stone tool technology from the hand axe and cleaver of the Archeulean tradition to the flakes and blade technology of the middle Stone Age (Smith, 1999) that were later refined and reduced in size during the later Stone Age. The changes is stone tool technology are significant as they are mirrored by the biological development of our human ancestors from *Homo erectus* to archaic *H. sapiens* and, finally, to modern *H. sapiens* who appeared in southern Africa around 40 000 years ago during the late Stone age (Smith, 1999). In addition, these archaeological assemblages together with their associated phases in Human evolution help provide a better understanding human-environment interactions and their possible impacts on the landscape from prehistoric occupation through to the present day.

While the impact of humans would have been minimal for most of the three million years since their first appearance in the archaeological record, the extent to which early human occupation and use of the Karoo landscape impacted this environment is not conclusive (Meadows, 1998b). The evidence pointing to the availability of fire suggests a potentially high level of influence on the landscape however, this influence is deemed almost negligible by the small population number of these early human communities (Meadows, 1998b). The same cannot be said for later Stone Age hunter-gatherer societies who are more widely accepted to have had an impact on surrounding vegetation communities (Meadows, 1998a).

Increasing population numbers towards the later Stone Age (Meadows, 1998b) and the development of new skills to modify and manipulate the environment, through the use of, for example, fire, meant that humans played an ever increasing role in the health of the land and distribution of plants and animals (Smith, 1999). It has been noted, for example, that around prehistoric hunter campsites in the Karoo, disturbances to the surface have altered plant communities in the vacinity (Smith, 1999).

In addition, archaeological evidence suggests that around 10 000 years ago hunter-gatherer societies functioned more as "dedicated patch foragers" (Deacon, 1992), using "fire-stick farming" methods to encourage the growth of natural fields of geophytes (perennial plants, bulbs, tubers etc.) (Meadows, 1998a). The argument for significant human impact on the environment during the later Stone Age is further supported by proxy evidence, gathered from archaeological sites around the western Cape, that indicates that population numbers during the Holocene (around 10 000 years ago) were close to carrying capacity for the region (Deacon, 1992).

Around 2000 years ago, the hunter-gatherer lifestyle of the later Stone Age peoples of southern Africa changed fundamentally (Hilton–Barber and Berger, 2002) with the arrival of the first agricultural peoples of southern Africa. These migrants from central Africa brought with them a radical new way of life (Smith, 1999) and their arrival is marked in the archaeological record by the appearance of pottery and the bones of domestic animals such was goats and cattle (Humphreys, 1987). The significance of the arrival of these pastoral communities goes beyond the introduction of domestic animals and plants. The new immigrants brought with them a far more structured society with leaders as well as the concept of private ownership (Smith, 1999) reflected in the importance of domestic stock as inheritable assets (Hoffman *et al.*, 1999) or control over land for grazing and the cultivation of domestic plants (Smith, 1999). With the rise of importance of cattle herding, hunter-gatherer foragers would have found themselves increasingly marginalized by this dominant society (Smith, 1999) and the land-use patterns would have been altered significantly by this new society of pastoralists. For example, palynological evidence from studies in the western Cape suggests significant impacts on vegetation communities due to heavy grazing pressure (Meadows, 1998a). Further impacts involved amended fire intervals relative to the natural fire regime and increased soil erosion due to a reduction in vegetation cover (Deacon, 1992).

It is evident that, since the appearance of modern humans 40 000 years ago, the Karoo has been subject to a variety of impacts due to anthropogenic activity on the landscape. However, there is little doubt that the scale of landscape alteration increase markedly following the arrival of European settlers in the area over 300 years ago (Meadows, 1998a).

3.1.2 Colonial Settlement in Kogmans River Catchment

The first trekboers arrived in this part of the Klein Karoo from the west via the Kogmanskloof in the mid-eighteenth century. For over a century following their arrival, the Kogmans River catchment contained only isolated farms (Burman, 1981). Initially, most farmers who had applied for loan farms in the area had done so purely for grazing cattle (Burman, 1981). However, the environment proved to be less than ideal for this sort of activity and many farmers were forced to leave and find better grazing elsewhere (Burman, 1981). Those who remained or subsequently settled on the vacant farms soon realised, however, that there was great potential for crop farming on the banks of both the Kingna and Keisie rivers and their tributaries (Burman, 1981). Both vineyards and fruit orchards were planted, and later Lucerne was cultivated to provide food for the Ostrich farm industry within the catchment (Burman, 1981).

The arrival of European settlers signalled a new phase in human utilization of the Klein Karoo that brought significant changes to both social and natural environment within the Kogmans River catchment. Hoffman *et al.* (1999) argues that the European settlement and colonization disrupted indigenous social formations through direct competition for land and grazing, the penetration of mercantile capital and the imposition (ultimately) of new forms of state power and administration. European settlers also brought with them the notion of individual ownership with respect to land, and introduced a land tenure system that would have promoted overstocking, overgrazing and mismanagement of the landscape through burning at too frequent an interval, all of which must have had serious consequences for indigenous vegetation (Deacon, 1992). Fynbos has proved vulnerable to the inescapable role played by encroaching activities of people (Baxter and Meadows, 1994). For example, vineyards and orchards, established on suitable soils during the eighteenth and nineteenth century, were planted at the expense of various fynbos communities (Meadows, 1998a). Added to these substantial impacts, the disturbance caused by roads, dams and urban expansion (Deacon 1992) and the introduction of alien vegetation (Baxter and Meadows, 1994) further exacerbated the impact of colonial settlement on the natural environment.

In 1850, almost one hundred years since European colonist had settled in the catchment, the owner of the farm De Uytvlugt, Daniel Stefanus Van der Merwe, had a number of erven adjoining the river surveyed with the idea of laying out a town (Burman, 1981). In January the following year the first erven were sold, near the confluence of the Kingna and Keisie river, and the villiage of Montagu was formed (Bulpin, 2001). Originally known as Agter de Cogmans Kloof (Burman, 1981), the town was later renamed after the popular colonial secretary, Sir John Montagu (Bulpin, 2001).

The construction of the Kogmanskloof pass (**Figure 3.9**), completed in 1877, hailed the beginning of a tremendous boom for Montagu, and indeed the Klein Karoo, providing direct access to the trading post of Roodewal (present day Ashton), which was connected to the railway (Bulpi, 2001) and thus opening up trade routes to much of the western Cape Colony (Burman, 1981).

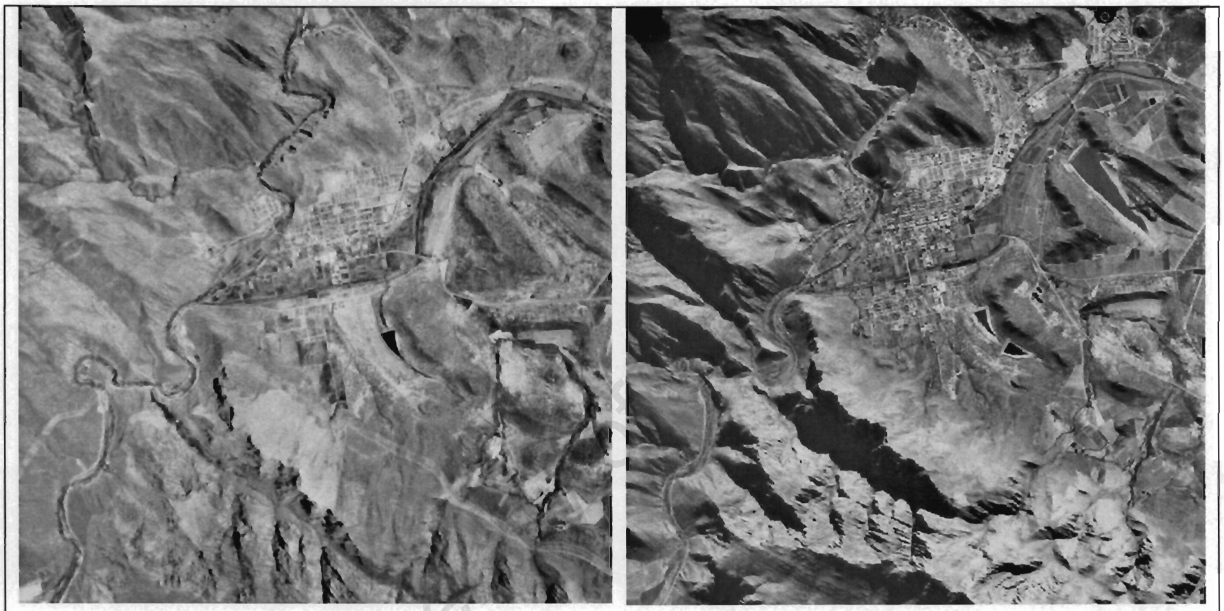
Source: Montagu Tourism

Figure 3.9: Possibly the oldest photograph of the Bains road through the Kogmansloof taken before the building of the English Fort.

With the enhanced transportation and trade options, Montagu began diversifying its commercial activities (Burman, 1981). Trade in ostrich feathers, in particular, was significantly bolstered by this access to new markets, however the start of the First World War (1914 – 1918) brought an end to the lucrative ostrich feather trade and, thus the end of the ostrich boom (Burman, 1981). As a result of the dramatic decline in the ostrich trade, farmers in the Kogmans river catchment began to replant their orchards and vineyards (Burman, 1981).

The fruit and wine industry became the central economy within the catchment and in 1940, the Langeberg Co-operative was formed boosting commercial agricultural production in the catchment (Burman, 1981) through the establishment of a substantial canning factory in Ashton (Bulpin, 2001). The construction of the Poortjieskloof dam on the Kingna river between 1951 and 1953, greatly improved the irrigation of the valley (Burman, 1981) which, in turn, encouraged a wider distribution of farms.

By 1954, the population in the Montagu district had passed 10 000, and for the next 25 years the town continued to expand. **Figure 3.10** shows two aerial photos of Montagu taken in 1960 and 1999 that illustrates the expansion of the town to the north along the R318 and to the south along the south bank of the Kingna River. Smallholdings were sub-divided increasing the density of the centre of town.



Source: CDSM

Source: CDSM

Montagu, 1960

Montagu, 1999

Figure 3.10: Aerial photographs of Montagu illustrating the urban development: 1960-1999.

Today the towns of Ashton, with a population of 14 100, and Montagu, with a population of 9000, can be described as rural towns both of which are surrounded, predominantly, by commercial irrigated farming areas producing mostly stone fruits (apricots and peaches) and wine grapes (DWAF, 2003c). The vineyards and stone fruit orchards are irrigated using river and run-off flow and winter run-off storage from approximately 20 farm dams and two major dams (DWAF, 2000). Economically, both towns rely heavily on irrigated agriculture (DWAF, 2003c). Ashton is host to a wine cellar and two canning factories as well as a fruit packaging facility (DWAF, 2003c). Montagu, in turn, is home to various wine cellars in and around the town, but fruit is processed in

Ashton (DWAF, 2003c). In addition, Montagu is a popular tourist destination, with an established hospitality and tourism industry catering for both local and international tourists visiting the area.

This chapter has described the both the natural and anthropogenic landscape of the Kogmans River catchment and provided a broad geographical context, both physical and human, for this research. With this context and understanding of the Kogmans River catchment, Chapter Four describes and discusses the floods of March 2003 in terms the catchment conditions prior to the heavy rainfall associated with the cut-off low, the formation and the passage of the cut-off low itself and the hydrological response of the catchment and flooding that followed the record rainfall on Sunday the 23rd of March.

Chapter Four

The Montagu Floods: March 2003

Montagu has survived a least ten major floods is its 150 year existence since its establishment in 1850 (**Table 4.1**). The first recorded flood occurred on 8 March 1867, when a severe storm caused the Keisie River to rise rapidly and burst its banks, destroying many vineyards and claiming the lives of at least twelve people (Burman, 1970). That flood was followed just two months later, by another flood that swept through Montagu, causing huge damage to property and completely washing away the road through the Kogmanskloof (Burman, 1970). Fortunately, however, there was no loss of life (Burman, 1970).

Date	**Region/Location of Flood**	**Source**
08 – 03 – 1867	Montagu	Burman, 1970
05 – 1867	Montagu	Burman, 1970
14 – 05 – 1885	Southern Cape	DWAF* (Event ID**: 92)
14 –12 – 1906	Southern Cape	DWAF* (Event ID**: 120)
11 – 10 – 1948	South-Western Districts	DWAF* (Event ID**: 260)
25 – 01 – 1981	Laingsburg	DWAF* (Event ID**: 566)
02 – 02 – 1981	Southern Cape	DWAF* (Event ID**: 568)
22 – 09 – 1983	Southern Cape	DWAF* (Event ID**: 602)
24 – 03 – 2003	Southern Cape	---

* DWAF Flood Atlas – http://edmc1.pwv.gov.za/dwaf/

**'Event ID' is the code used by DWAF to refer to the specific flood event.

Table 4.1: Montagu Flood History: 1867 - 2003

The Great Floods of the 1860s were followed by flood events in 1885, 1906, and 1948. However, the most devastating flood in Montagu's short history was to come seven years later in January 1981.

Sunday 25th of January 1981 will be remembered primarily for the devastating flood that inundated the Karoo town of Laingsburg, some 180km north-east of Monatgu, when the Buffels river broke its banks submerging more than 300 of the 367 houses and business premises in the town under water and mud in a mere seven and a half hours and claiming the lives of more than 100 people (Alexander, 1981). However, the 25th of January of that year will also be remembered by Montagu for the devastating flood that inundated the north-west of the town and caused extensive damage property and the loss of 13 lives.

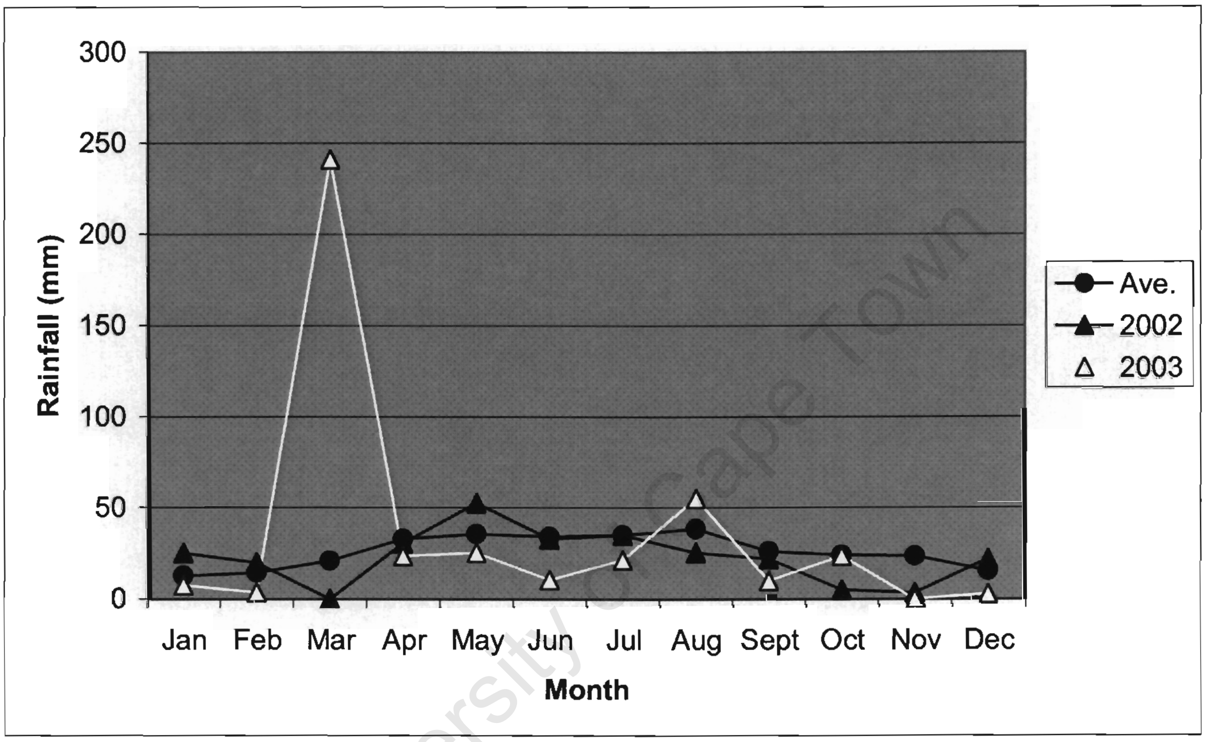
On January 25th, 1981, heavy and continuous rainfall in the west of the catchment caused the Keisie River to swell (Burman, 1981). By late afternoon, the river was high, but the possibility of it breaking its banks seemed remote (Burman, 1981). However, high in the hills above town, the Pietersfontein Dam was slowly reaching capacity (Burman, 1981). The dam had never been full since its construction and soon began to spill (Burman, 1981). Fed by the various seasonal streams flowing down the mountainside, the Keisie River steadily increased in velocity and strength (Burman, 1981). At approximately 6pm, an estimated 8m high wall of water, swept down the valley, inundating the north-west part of the town, taking everybody by surprise (Burman, 1981). Altogether 13 people lost their lives in the floods that day (Burman, 1981). Some of the bodies were recovered as far as 10km downstream, beyond the town of Ashton (Burman, 1981). Suprisingly, very little damage was done to the town itself – only one house and the suspension bridge bore the brunt of flood (Burman, 1981). However, the hot springs and the caravan park were completely destroyed.

In February 1981, Montagu was struck by yet another flood, causing much of the repair work to damage inflicted by the January flood (DWAF, nd). Again, in 1983 flood waters inundated the town as the Kinga and Keisie Rivers overflowed, destroying much of the reconstruction work that had been done after the 1981 floods (DWAF, nd). No major floods occurred in the catchment thereafter until March 2003, when a high magnitude meteorological event caused the Kingna River to reach flood levels.

In order to provide proper context against which to consider the impact of the severe weather that caused flooding and damage in Montagu, and throughout the south Cape region, it is necessary to explore the antecedent conditions within the Kogmans River catchment.

4.1 Antecedent conditions in the Kogmans River Catchment

The Klein Karoo was generally warm and dry prior to the floods in March 2003, particularly in the vicinity of Montagu (Boom, 2003). **Figure 4.1** shows the monthly rainfall totals for Montagu for the year 2002 and 2003 compared with the 120 year long-term monthly averages for the period of 1883 to 2003. The data reveal that, from March 2002 to February 2003, the rainfall totals were approximately equal to or below the long-term averages, with the exception of May and December 2002, which recorded above average totals of 52mm and 22mm respectively. Furthermore, with the exception of March and August, 2003 was in general a dry year for the region.



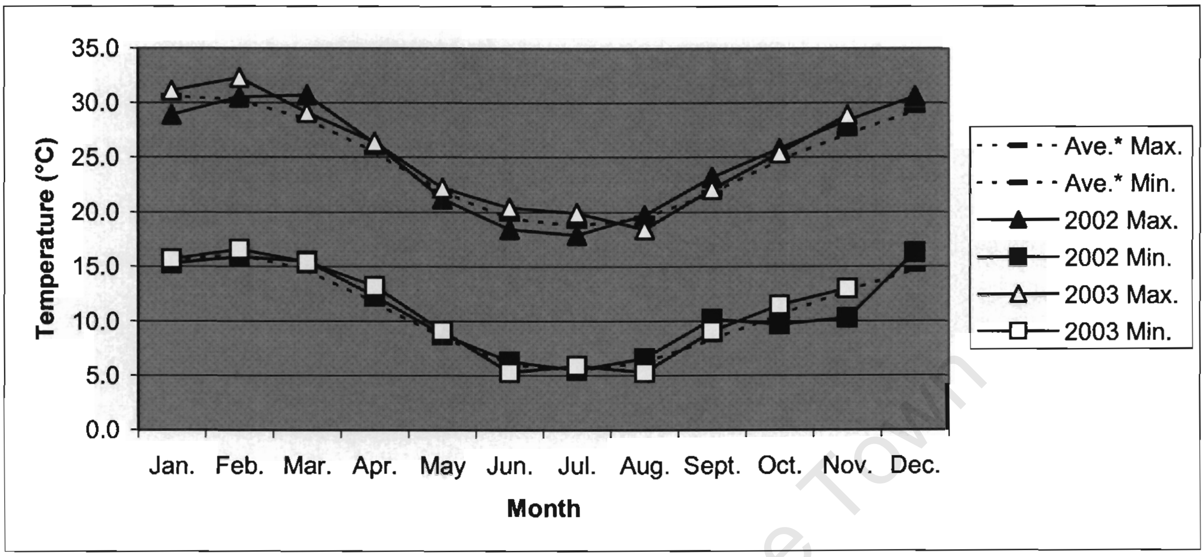
Month	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	TOTAL
Ave.*	12.7	14.5	20.9	33.0	35.5	34.2	35.1	38.5	26.1	24.1	23.6	15.4	**313.6**
2002	25.2	20.0	0.0	30.5	52.5	33.0	35.1	25.5	22.0	5.0	3.5	22.0	**274.3**
2003	7.5	3.6	241.0	23.5	25.5	10.5	21.5	55.0	10.0	23.5	0.0	3.0	**424.6**

* **1883 – 2001**

Source: SAWS

Figure 4.1: Monthly rainfall (mm) for Montagu 2002 –2003.

In addition to the predominantly below average rainfall figures, temperature data for the town of Robertson (**Figure 4.2**), approximately 28.2km east of Montagu (no temperature data are available for Montagu), show that summer temperatures for 2002 and 2003 were consistently above the 33 year average calculated for the period of 1970 to 2003 (excluding 1986 and 1988 due to unreliable or missing data). The monthly maximum averages from February to April 2002, and from August 2002 to the end of 2003 (with the exception of August 2003) show that the temperature was consistently above the long-term average. The minimum monthly averages reflect a similar pattern where temperatures were predominantly above average for 2002 and 2003 (except for October and November 2002 and June, August and December 2003).



Month	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	AVE.
Ave.* Max.	30.6	30.3	28.5	25.5	21.9	19.4	18.7	19.4	21.8	24.8	27.1	29.3	**24.8**
Ave.* Min.	*15.6*	*16.1*	*14.7*	*11.7*	*8.5*	*6.1*	*5.5*	*6.2*	*8.3*	*10.6*	*12.8*	*14.7*	***10.9***
2002 Max.	28.9	30.5	30.7	26.3	21.2	18.4	17.9	19.7	23.2	25.8	28.4	30.6	**25.1**
2002 Min.	*15.3*	*15.9*	*15.5*	*12.3*	*8.8*	*6.3*	*5.5*	*6.6*	*10.2*	*9.7*	*10.3*	*16.3*	***11.1***
2003 Max.	31.1	32.3	29.1	26.4	22.2	20.4	19.9	18.4	22.1	25.4	28.9	28.3	**25.4**
2003 Min.	*15.7*	*16.6*	*15.4*	*13.2*	*9.1*	*5.3*	*5.9*	*5.3*	*9.1*	*11.5*	*13.0*	*14.0*	***11.2***

* **1961-1990**

Source: SAWS

Figure 4.2: Monthly average temperature (°C): Robertson 2002 and 2003.

The persistent heat and dry conditions of the period leading up to March 2003 caused the onset of what is described as one of the worst droughts seen in years in the Klein Karoo (Boom, 2003). A severe meteorological drought is defined by the South African Weather Service (2005) as a period of below average rainfall that constitutes less than 75% of the total long-term average for a particular location. In addition, if the total rainfall for a given period is less than 80% of the long-term average for the same period, crop failure and water shortages can be expected (SAWS, 2005). **Table 4.2** shows the Spring/Summer and Autumn/Winter rainfall totals in relation to the long-term average (1883 –2003) for Montagu from 1998 to 2003. The figures reveal that the Autumn/Winter periods of 1999, 2000 and 2001 experienced severe drought while the same period in 2002 showed a 10.4 reduction in average rainfall. By contrast, the Spring/Summer periods of 1998/1999 and 1999/2000 showed above average rainfall figures. However, 2000/2001 showed a significant 18.4% reduction in rainfall, while the Spring/Summer periods of 2001/2002 and 2002/2003 revealed severe drought conditions in the Kogmans River catchment. Significatly, the six month period prior to the March 2003 floods showed a decrease in rainfall of over 45%.

SPRING/SUMMER

Month Period	Sept	Oct	Nov	Dec	Jan	Feb	6-Month Total (mm)	% of Ave.	Drought Conditions
Ave.* (mm)	26.1	24.1	23.6	15.4	12.7	14.5	116.4		
1998/1999	12.5	0.0	37.0	134.0	0.0	29.0	212.5	182.6	+82.6%
1999/2000	26.0	0.0	3.5	63.5	26.0	0.0	119.0	102.2	+2.2%
2000/2001	9.0	5.5	29.5	33.5	7.0	10.5	95.0	81.6	-18.4%
2001/2002	13.5	9.0	16.5	0.0	25.2	20.0	84.2	72.3	-27.7%
2002/2003	22.0	5.0	3.5	22.0	7.5	3.6	63.6	54.6	-45.4%

AUTUNM/WINTER

Month Period	Mar	Apr	May	Jun	Jul	Aug	6-Month Total (mm)	% of Ave.	Drought Conditions
Ave.* (mm)	20.9	33.0	35.5	34.2	35.1	38.5	197.2		
1999	0.0	30.0	18.0	12.0	0.0	31.0	91.0	46.1	-53.9%
2000	45.0	10.0	0.0	18.5	46.0	5.5	125.0	63.4	-36.6%
2001	0.0	21.8	7.0	14.5	38.5	46.0	127.8	64.8	-35.2%
2002	0.0	30.5	52.5	33.0	35.1	25.5	176.6	89.6	-10.4%

* 1883-2001

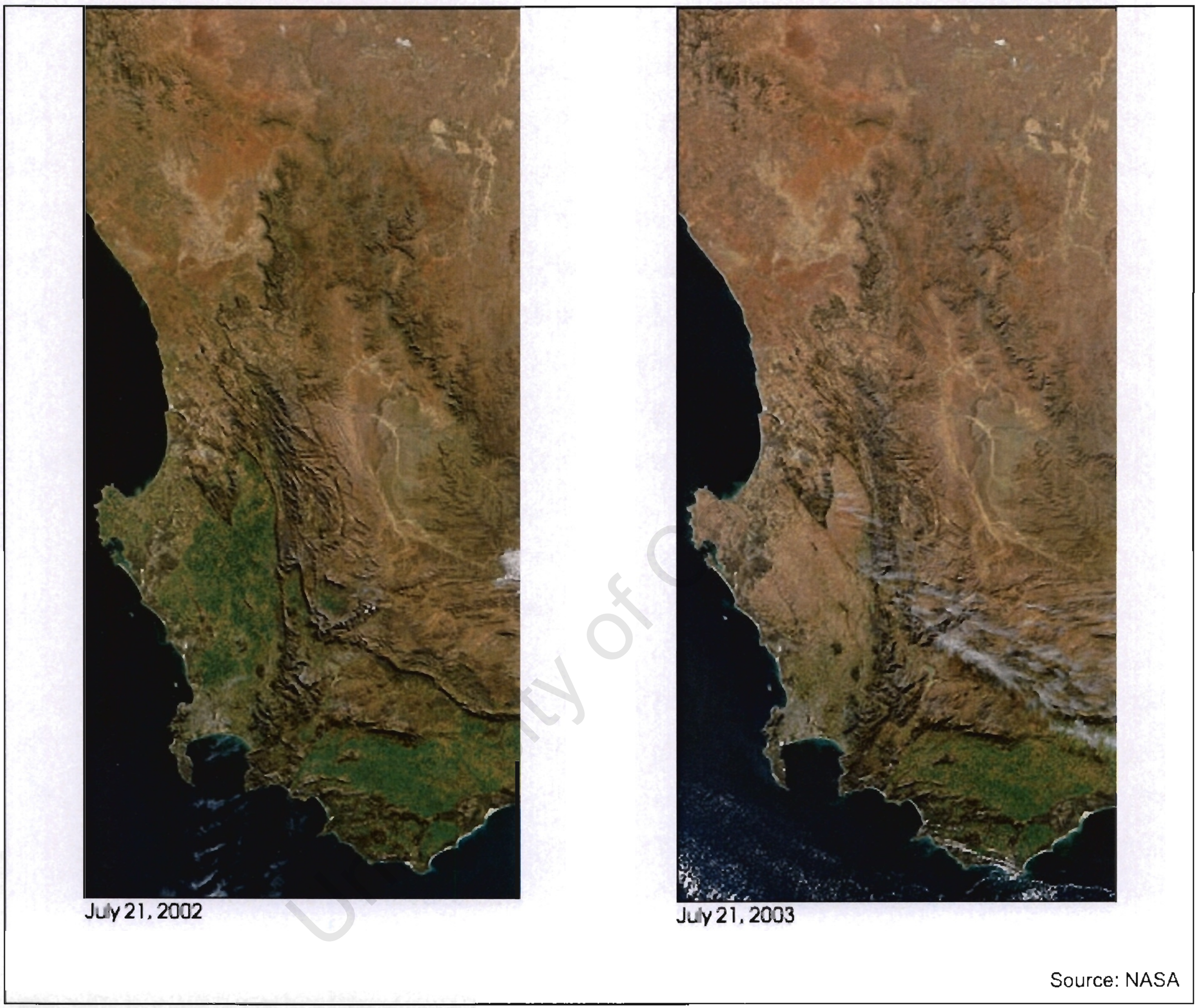
🟥	Severe meteorological drought - less than 75% of normal/average rainfall recorded for the 6-month period.
🟧	Crop and water shortages - less than 80% of normal/average rainfall recorded for the 6-month period.
🟦	No drought but below average - below average rainfall but above 80% of average rainfall for the 6-month period.
■	No drought - average or above average rainfall for the 6-month period.

Data Source: SAWS

Table 4.2: Seasonal Rainfall Figures for Montagu and Implications for Drought:1998 –2003. Drought conditions description after SA Weather Service

On a whole, the vegetation in the Klein Karoo, and indeed throughout the Western Cape region, became withered and its growth was stunted during the 12-month period prior to the March 2003 floods (NASA, 2003).

The Moderate Resolution Imaging Spectroradiometer (MODIS) Rapid Response System provides a pair of images to illustrate the extent and severity of the drought in the South Western Cape (**Figure 4.3**). The two real colour composite images were compiled on July 21, 2002 and July 21, 2003 respectively.



July 21, 2002

July 21, 2003

Source: NASA

Figure 4.3: MODIS images of the south Western Cape: 2002 – 2003.

Comparing the two images, it is apparent that the persistent drought, due to below average rainfall and above average temperature, caused the vegetation health (greenness) to be dramatically reduced in the 2003 image (NASA 2003). This is important in providing a context for the floods in March 2003.

The reduced vegetation greenness infers that there was a reduction in vegetation cover between July 2002 and July 2003. This also means that more soil was laid bare and thus exposed to the direct heat of the sun.

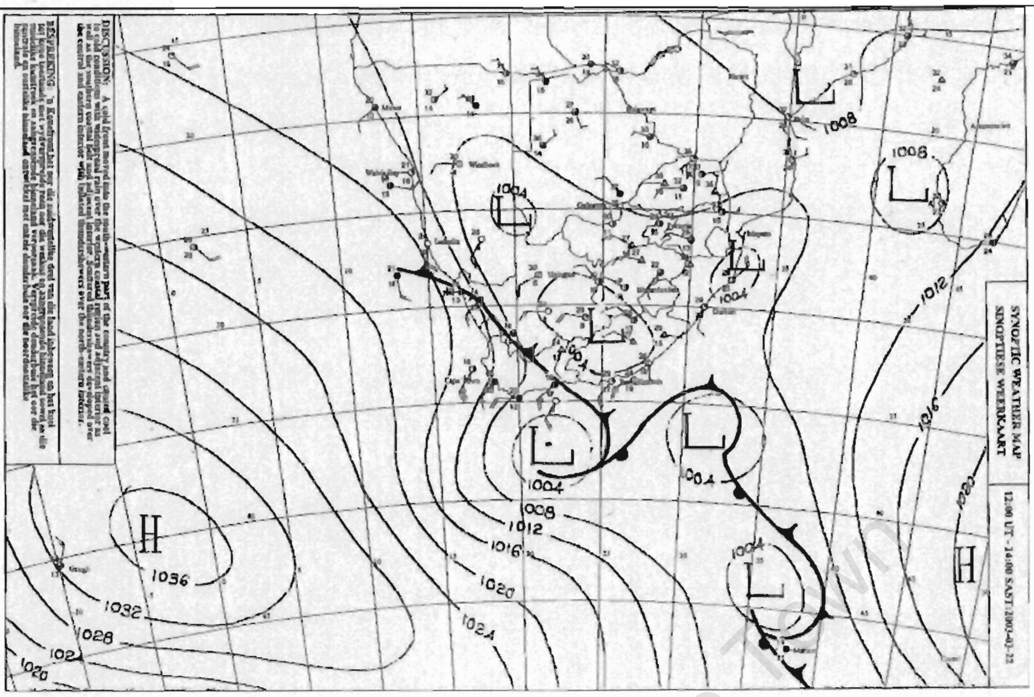
Decreased vegetation cover, and dry, hardened soil are likely to cause a decrease in the volume of precipitation intercepted (by the vegetation) and absorbed into the soil (through infiltration). Thus, in response to an intense rainfall event associated, for example, with a cut-off low, such conditions would help to promote overland flow, and thus intensify the magnitude of a potential flood.

4.2 Meteorology

On Saturday the 22nd of March 2003, a cold front moved into the Western Cape (Scoltz, 2003). During the same period, an extensive low pressure trough had developed in the interior, bringing moist tropical air further south (**Figure 4.4**) (DIMP, 2003). The unusually intense rainfall associated with a cut-off low is usually a result of large areas experiencing strong uplift caused by moist air originating in tropical Africa entering the system (Stander and Moir, 2003). Thus, with the cold front moving in from the south west, fed by the low pressure trough in the interior, the conditions were ripe for the formation of a cut-off low.

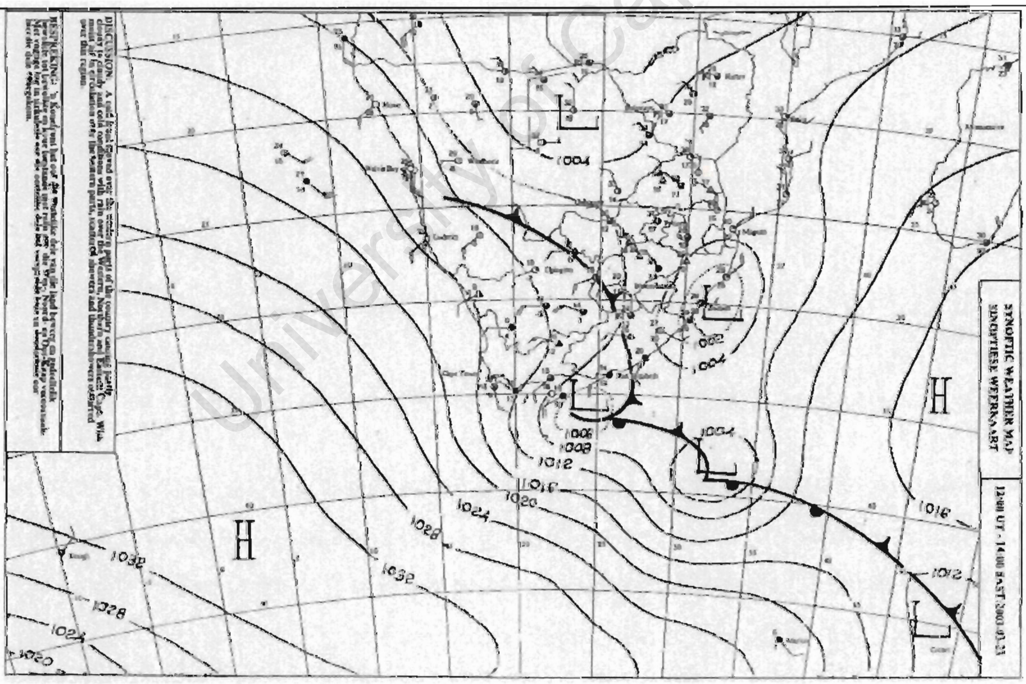
Late on the 22nd, as the front moved over the south coast, the low closed itself, and developed into a cut-off low pressure system (DIMP, 2003). The system intensified on Sunday, March 23rd, and the strong pressure gradient induced instability in the system, causing high wind speeds, low temperatures and record rainfall over much of the south coast and adjacent interior (DIMP, 2003). Montagu recorded a record 178mm of rainfall over a 24-hour period. The total rainfall for March was measured at a record 241mm, only 8.1mm less than the total for the entire previous 12 months (249.1mm measured from February 2002 to February 2003) and about 77% of the long-term annual average rainfall for Montagu (measured at 313.6mm for the period 1883 – 2003).

From the 24th of March, a ridging high pressure began to develop in the South Atlantic, moving in behind the low, gradually pushing the stationary cut-off low over the Indian Ocean by March 26th (DIMP, 2003). The areas most critically impacted by the cut-off low were those where the effect of topographical uplift caused intensive orographic rainfall (DIMP, 2003).



Source: SAWS

March 22, 2003



Source: SAWS

March 23, 2003

Figure 4.4: Movement of the low pressure over South Africa and the formation of a 'cut-off low': 22-23 March 2003.

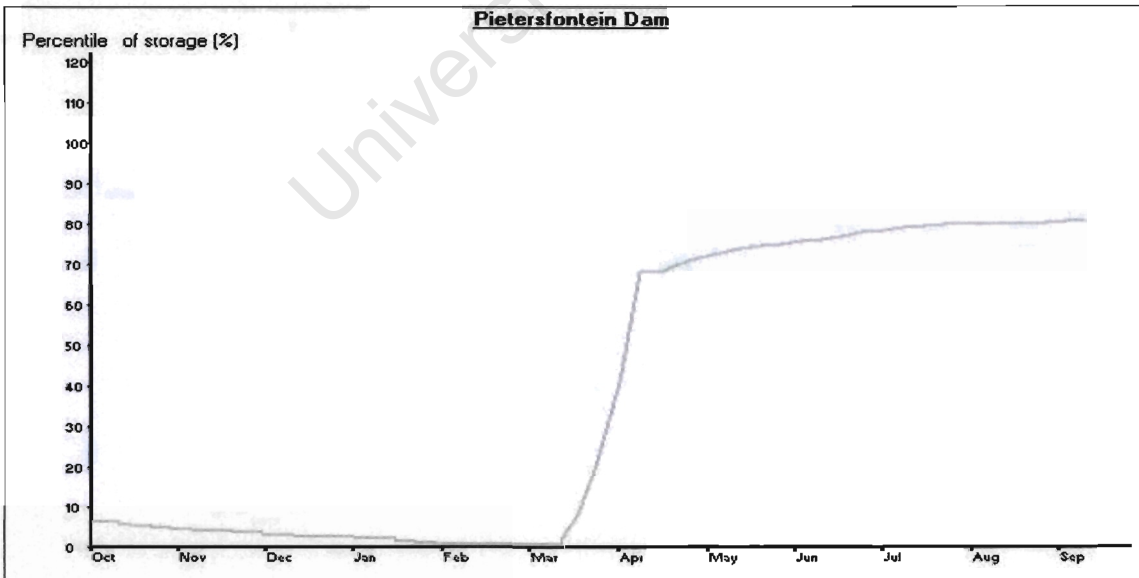
In addition, the steeper slopes experienced more intense runoff as a result of the heavier rainfall (DIMP, 2003). The Monatgu/Ashton area was one of the most vulnerable areas with respect to the combined effect of heavy rainfall and intense mountain runoff (DIMP, 2003).

Cut-off lows account for many of the flood events observed over South Africa (Preston-Whyte and Tyson, 1988). Both the Laingsburg floods (that affected Montagu too) of 1981 and the Natal flood disaster of 1987 are attributed to cut-off low pressure systems (Preston-Whyte and Tyson, 1988). The frequency of cut-off lows that produce heavy rainfall are highest between March and May and September and November (Preston-Whyte and Tyson, 1988).

4.3 Hydrology

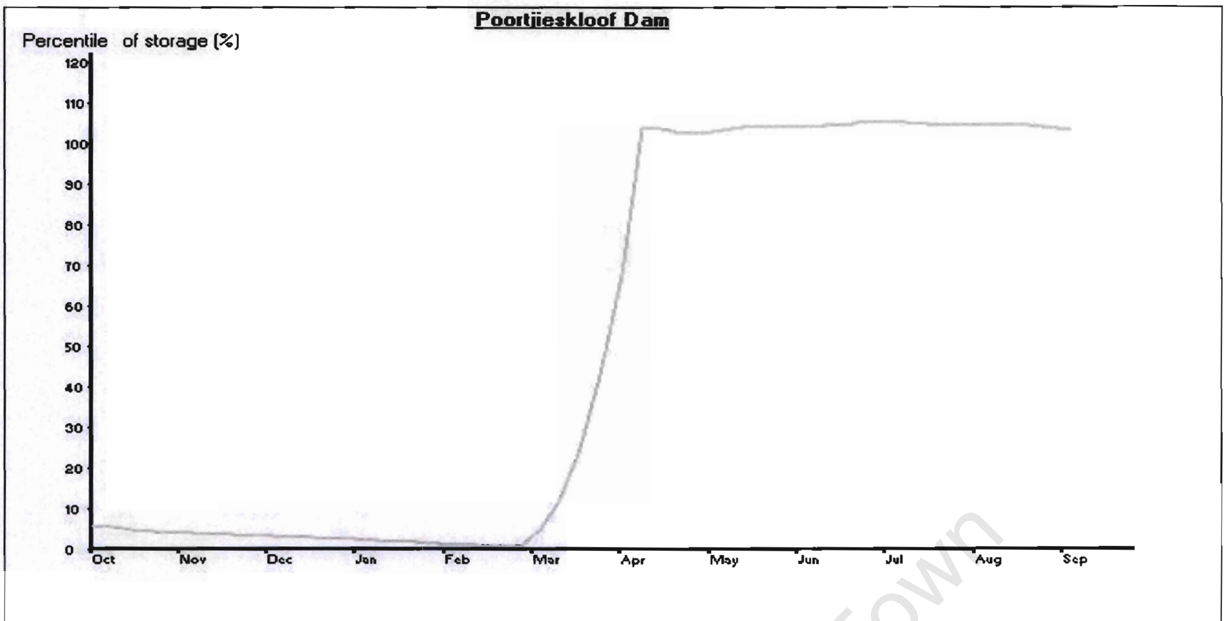
The heavy rainfall that accompanied the cut-off low, as it moved across the south Cape and adjacent interior, resulted in several rivers in the area experiencing record floods, including the Kingna River (DIMP, 2003).

The Kingna River broke its banks at around dawn on Monday, 24th March. The dry antecedent conditions meant that both the Pietersfontein dam (on the Keisie river) and the Poortjieskloof dam (on the Kingna river) were relatively empty prior to the storm hitting the Klein Karoo (**Figure 4.5a & 4.5b**) (DIMP, 2003).



Source: DWAF

Figure 4.5a: Dam storage – Pietersfontein dam: Oct. 2002 – Sept. 2003.



Source: DWAF

Figure 4.5b: Dam storage – Poortjieskloof dam: Oct. 2002 – Sept. 2003.

The intense rainfall caused only the Poortjieskloof dam to spill (**Figure 4.6**) on the evening of the 24th of March (DIMP, 2003). The heaviest rainfall fell on the 23rd and since the dam did not overflow until late the following day, it is reasonable to assume that these dams provided some attenuation to the final flood magnitude experienced downstream at Montagu (DIMP, 2003).

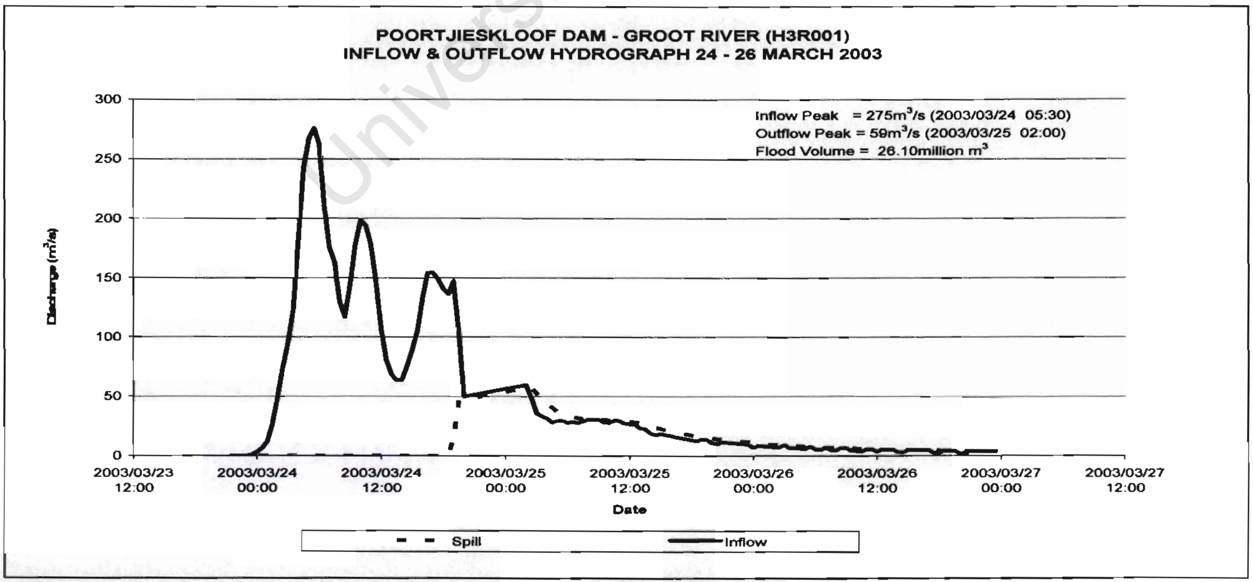


Figure 4.6: Inflow and outflow hydrograph – Poortjeskloof dam: 24-26 March 2003 (DiMP, 2003)

Measurements, taken by the Department of Water Affairs (DWAF) at gauges along the Kingna and Kogmans Rivers, show that the peak discharge was measured at a record 920m³/s on the Kingna River and 1330m³/s on the Kogmans River, just 130m³/s short of the record discharge measured in January 1981. Further calculations showed the flood to have a return period of 20-100 years (DIMP, 2003). **Figures 4.7** and **4.8** show a chronological plot of the floods in the two rivers for the period 1926 to 2003 for the Kingna River and 1954 to 2003 for the Kogmans River. A summary of the flood data for the Kogmans River Catchment is given in **Table 4.3**.

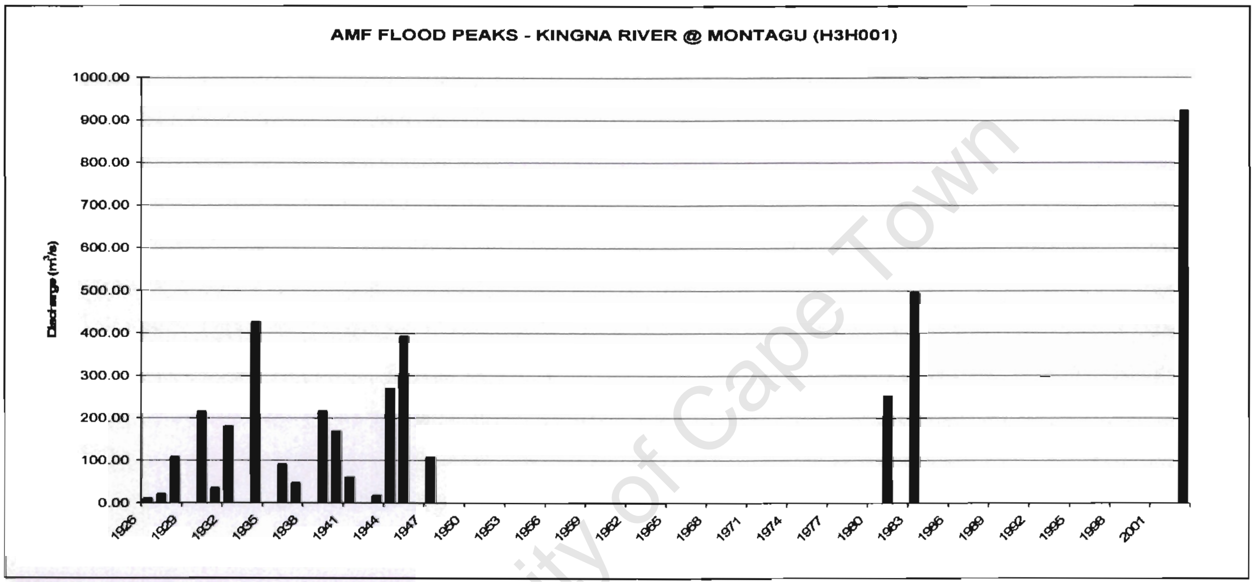


Figure 4.7: Flood peaks for the Kingna River: 1926 – 2003 (DiMP, 2003)

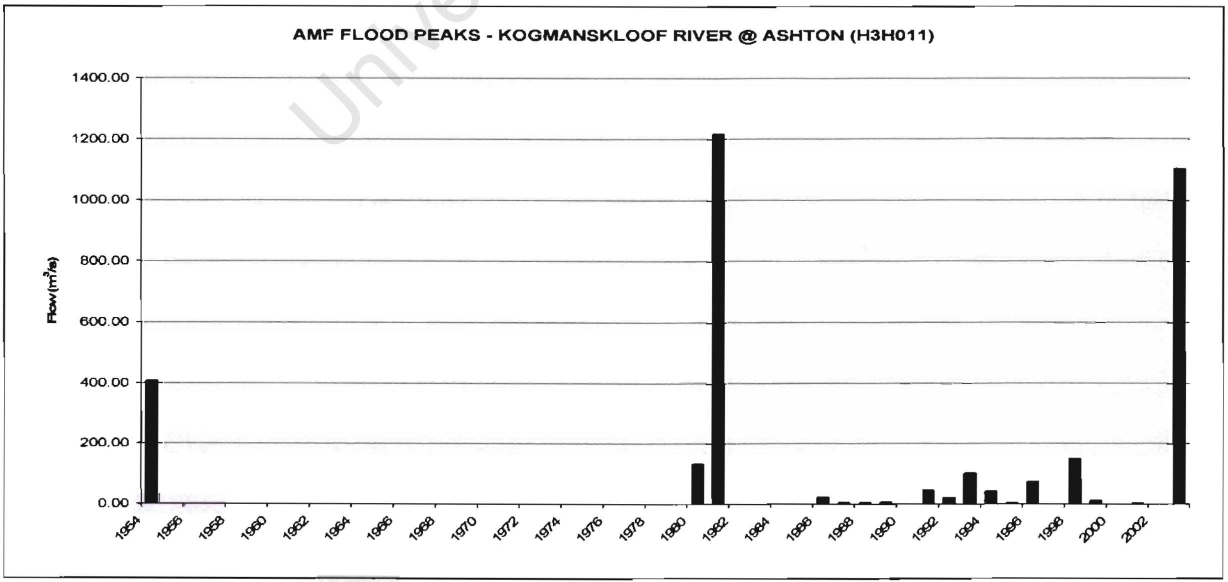


Figure 4.8: Flood peaks for the Kogmans River: 1954 – 2003 (DiMP, 2003)

Gauge Site	River	Place	Catch. Area (km²)	Discharge (m³/s)	Date	Return Period (Years)	Prev. Max. Discharge
H3H005	Keisie	Keisiedoorns	76	36	24/03/03	5	120 ('81)
H3H001	Kingna	Montagu	593	920	24/03/03	50-100	445 ('34)
H3H011	Kogmanskloof	Goudmyn	1201	1100	24/03/03	20-50	1210 ('81)

Table 4.3: Summary of flood data: Kogmans River catchment – 24 March 2003 (DiMP, 2003).

4.4 Impacts, Damage and Cost

Of all the towns and villages impacted by the severe weather that affected the South Cape in late March 2003, Montagu was one of the worst affected by flooding. The strong flow and accompanying debris entrained by the flood waters caused extensive damage to primary infrastructure (roads, bridges, electricity, sanitation) houses, cottages, vineyards, orchards and irrigation systems in the Kogmans river catchment (**Figure 4.9**).

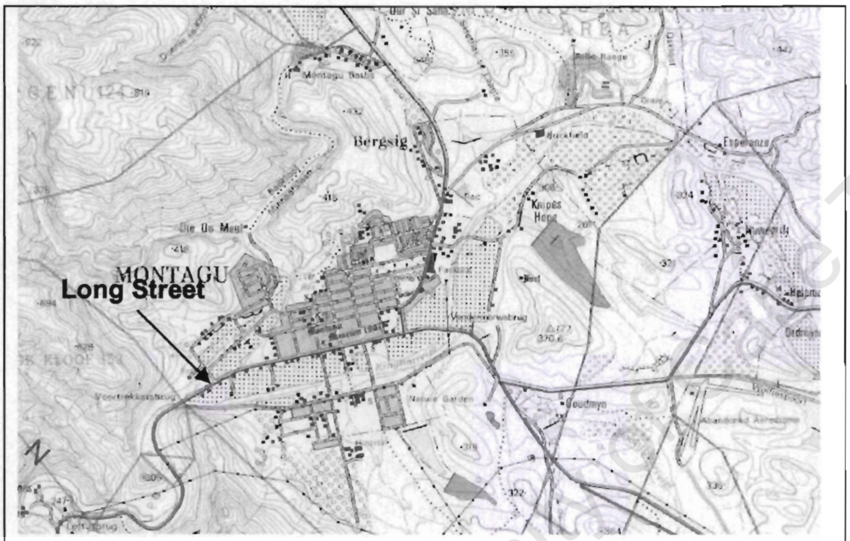
Source: Montagu Museum

Figure 4.9: Debris brought down by the Kingna River on the bridge at the southern entrance to Montagu (Source: Montagu Museum).

The Montagu Mail (April, 2003) reported that several houses and cottages, including some national monuments, were flooded as far as Long Street in Montagu South (**Figure 4.10**). The bridge at the entrance to the town on the Montagu-Aston road (Kogmanskloof) was severely damaged, with the entire onramp on the Ashton side of the bridge being washed away

(Montagu Mail, 2003). The Kogmanskloof road was also severely damaged with entire sections having been washed away.

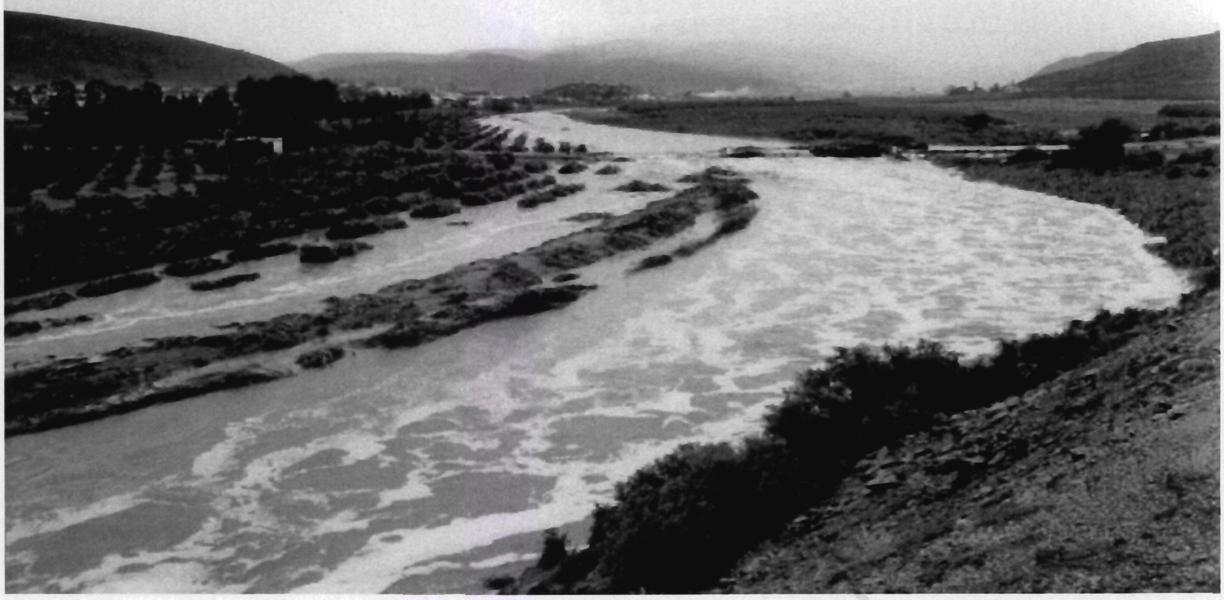
At the eastern end of Lang (Long) Street, access to the R62 to Barrydale was cut off by mud and silt, more than 1m deep that covered the bridge across the Kingna (Montagu Mail, 2003). Two cottages nearby were reported to be roof deep in water (Montagu Mail, 2003). As a result, Montagu was cut off from the outside world, with many people having to airlifted to safety (Thiel and Gosling, 2003).



Source: CDSM

Figure 4.10: Street map of Montagu -1:50 000 Montagu 3320CC.

The rising torrent flooded vineyards and orchards (**Figure 4.11**) along the banks of the Kingna River as it swept towards Monatgu in the early hours of Monday 24th March (Thiel and Gosling, 2003). Irrigation infrastructure, pipelines and drip systems were virtually destroyed by the flood (News 24.com [1], 2003). Once the flood waters retreated hectares of vineyards were under mud, and erosion left the land spoilt (News 24.com [1], 2003).



Source: Montagu Museum

Figure 4.11: Vineyards flooded along the Kingna River.

Power supplies were cut at 9:45am on Monday, and approximately 90% of businesses were reported to have closed down due to the power failure (Thiel, 2003). All electricity, sanitation and water services were interrupted, although most were restored again by Monday evening (News 24.com [2], 2003).

About 500 children had to be emergency evacuated from the Montagu Primary school due to the flooding. After the storm had passed, about 500 people, mainly from Montagu and McGregor, were left homeless and housed in community halls in Montagu (News 24.com [2], 2003). In the months following the extreme weather event, significant increases in child illness were also recorded in health facilities in the areas affected by the cut-off low (DiMP, 2003).

The financial cost of the flooding in the Kogmans River catchment was conservatively estimated at approximately R65 686 013 excluding costs incurred by the Department of Agriculture since the specific cost to the Department of Agriculture in the Montagu Magisterial district not available. The total loss to agriculture in flood and weather affected area of the southern Cape was estimated at R89 521 136. A breakdown loss by sector in the Kogmans River catchment is given in **Table 4.4**.

Sector	**Description**	**Cost (ZAR)**
Provincial Roads	Repair Kogmanskloof road and bridge	59 000 000
Local Municipality	Repair Sewage infrastructure	1 281 015
ESKOM	N/a	220 000
DWAF	Repair Hydrological gauging infrastructure and Poortjieskloof dam	2 550 000
Dept. of Agriculture	Damage to Infrastructure, loss of crops and soil	N/a (R89 521 136 for the whole S. Cape region)
Dept. of Education	Emergency Evacuation, repair damage and clean-up Montagu Pre-Primary Montagu Primary Montagu High	 200 000 1 081 000 320 000
Private Insurance Claims	24 claims in Montagu 7 claims in Ashton	356 000 678 000

Source: DiMP

Table 4.4: Financial cost of the floods in the Kogmans River catchment.

The known processes that influenced the events of late March 2003, climatological, meteorological and hydrological, help frame the questions that remain unanswered, particularly those surrounding the issues of land-cover and land-use change, land degradation and riparian zone management. Chapter Five will present the methodology employed to attempt to answer the questions laid out in the objectives of this study.

Chapter Five

Methodology

In order to determine the magnitude and extent of catchment-wide landscape changes within the Kogmans River catchment, various quantitative and qualitative approaches were used (**Table 5.1**). Aerial photographs and satellite images were used to provide catchment-wide perspectives of land-cover and land-use change and land degradation. Fieldwork within the catchment helped provide a picture of the health and state of the riparian zone along the Kingna and Keisie Rivers. Finally, a hydrological model was used to determine the impact of increased land degradation and urbanisation on the total discharge of the Kogmans river catchment in response to a heavy rainfall event in order to highlight the potential risk posed by changes land-use/land-cover in the catchment.

Objective	**Methodology**
1. Determine and describe the nature and extent of changes within the catchment that may impact on the flood hydrograph.	Time series analysis using aerial photographs; and satellite remote sensing to determine landscape change and disturbance.
2. Describe current management practices with regard to riparian zone management.	Interviews (conducted by DIMP).
3. Determine the influence of the riparian zone on the flooding in the Kogmans River catchment.	Field surveys, observations and literature.
4. Apply a hydrological model to the Kogmans River Catchment to determine the effect of changes in land-use/land-cover on the total discharge of the catchment.	Apply the HEC-Hydrological Modelling System (HMS).

Table 5.1: Objectives and corresponding methodology

5.1 Land-use Change Analysis using Aerial Photography

This preliminary research was undertaken by the author as part of a consolidated report (DiMP, 2003) on the March 2003 floods in the South Cape, Overberg and Klein Karoo regions of the Western Cape. The consolidated report was commissioned and funded by the Department of Social Services and Poverty Alleviation of the Provincial Government of the Western Cape, the Provincial Development Council and the United Nations Food and Agriculture Organisation (FAO) and prepared by Disaster Mitigation for Sustainable Livelihoods Programme (DiMP).

5.1.1 Data and Methodology

Five sets of aerial photographs (1942, 1960, 1972, 1987 and 1999) covering the Kogmans River catchment were supplied by the Chief Directorate of Surveys and Mapping (CDSM). However, only two sets were used were used to determine the nature and extent of land-use and land-cover change in the Kingna River catchment (DiMP, 2003). The 1942 set was incomplete and thus not suitable for comparison with any of the other photo sets. The oldest viable set was taken in December 1960. The most recent set was taken in June 1999. These two photograph sets (**Table 5.2**) were used for the analysis (DiMP, 2003).

	1960		**1999**	
Scale	1: 36 000		1: 50 000	
Job No.	444		1025	
Date	December 1960		07 June 1999	
Flight Strip	2	3	11	12
Photo No.	2526 – 2522	2762 - 2755	2685 - 2682	2694 - 2698

Table 5.2: Aerial photograph sets used for analysis (DiMP, 2003).

A 0.5cm grid was applied manually to both the 1960 and 1999 photograph series (DiMP, 2003). Two broadly defined land-use classes were chosen – urban area (including residential, commercial and industrial land-use) and cultivated land (including small holding and commercial farming) (DiMP, 2003). The extent of each of the land-use classes was then calculated according to the number of cells that defined them (DiMP, 2003). A 50% rule was applied to individual cells when determining the total area occupied by a particular land-use class (DIMP, 2003). For example, if a cell was occupied by less than 50% of a given land-use class the cell was not counted, and if a cell was occupied by more than 50% of a given land-use class the cell was included in the total area calculation for that land-use class (DiMP, 2003).

5.1.2 Problems with using Aerial Photography for the Analysis of Land-use Change

The use of hard-copy aerial photography for the purpose of analysing land-use change has a number of short-comings:

- Image resolution – The coarse resolution of aerial photography makes it difficult to discern discreet land-use classes. For example, degraded land (DiMP, 2003).
- Grey-scale colour – The grey-scale makes it difficult to correctly identify features (DiMP, 2003).
- Distortion – Most aerial photographs are, to varying degrees, distorted. This means that the area and location of a particular feature can be different, in both respects, from one image to another (DiMP, 2003).

- Time and Season of Photograph – The shadow cast by the sun at the time the photograph was taken was different between the two set of images (DiMP, 2003). In addition, the 1960 set was taken in winter, while the 1999 set was taken in summer (DiMP, 2003).
- Coverage – The flight paths used during the acquisition of Aerial photography rarely cover the full extent of the catchment. Areas of particular human interest i.e. urban areas (residential, commercial, industrial) and agricultural etc. are more commonly covered by aerial photographs.

The application of aerial photography left a few key questions unanswered regarding the true nature the land-cover condition and change within the whole catchment as well as the health and state of the riparian zone along the Kingna and Keisie Rivers.

In order to determine the nature of landscape change within the entire catchment, satellite images were used to provide a catchment-wide perspective on land degradation within the Kogmans River catchment.

5.2 Application of Remote Sensing to Determine the Nature and Extent of Land Degradation

With attention shifting towards the prediction of rates of land degradation for planning and mitigation purposes (Harrison *et al.*, 1996), satellite remote sensing has become a invaluable tool for monitoring and understanding patterns of land degradation on the landscape. Since the establishment Landsat Program in the mid-1960s and the launch of its first Earth-observing satellite in July 1972 (USGS, 2003a), satellite remote sensing techniques have become the single most effective method for land-use and land-cover data acquisition (Tanser and Palmer, 1999). Remote sensing offers the advantage of being able to monitor land degradation at both local and regional scale and to do so at relatively frequent time intervals (Harrison *et al.*, 1996).

A joint venture of the United States Geological Survey (USGS) and the National Aeronautics and Space Administration (NASA), the Landsat program was established to develop and launch the first civilian Earth-observing satellite to gather Earth resource data for resource managers and Earth scientists (USGS, 2003a).

Since the launch of the first series of satellites in July 1972, the Landsat Program has launched a total of seven satellites, of which two are still currently operational (**Table 5.3**). As a result of the subsequent satellites launched in the Landsat series, there is a continuous set of Landsat data for much of the Earth from mid-1972 to the present (USGS, 2003a).

Satellite	Launched	Decommissioned
Landsat 1	23/07/1972	06/01/1978
Landsat 2	22/01/1975	25/02/1985
Landsat 3	05/03/1978	31/03/1982
Landsat 4	16/07/1982	30/06/2001
Landsat 5	01/03/1984	Operational
Landsat 6	05/10/1983	Did not achieve orbit
Landsat 7	15/04/1999	Operational

Table 5.3: Satellites launched by the Landsat Program: 1972 to present (USGS, 2003a).

All Landsat satellites have Sun-synchronous orbits, allowing the satellites to maintain a constant orientation between the Earth and the Sun (USGS, 2003a). Landsat 1, 2 and 3 operates in a near-polar orbit at an altitude of 920km and circles the Earth every 103 minutes, completing 14 orbits a day (USGS, 2003a). Landsat 4, 5 and 7 also operates in a near-polar orbit, but at an altitude of 705km and circles the Earth every 99 minutes, completing 14 and 9/16 of an orbit per day (NASA, 2004).

The primary sensor aboard Landsat 1, 2 and 3 is the multispectral scanner (MSS) (USGS, 2003a). The three satellites also carry Return Beam Vidicon (RBV) cameras, however the RBV never achieve the popularity of the MSS (USGS, 2003b). The MSS sensor scans the Earth's surface from west to east in a descending (north to south) orbit over the sunlit side of the Earth (**Figure 5.1**) (USGS, 2003b). The sensor has a radiometric coverage (**Table 5.4**) in four bands – green, red and two near- infrared – with a resolution of approximately 79m (USGS, 2003b). Landsat 3 carries an MSS sensor with a fifth band in the thermal infrared wavelength (USGS, 2003b). Each spectral band has six detectors providing six scan lines on each active scan (USGS, 2003b).

Spectral Bands	Use
Band 4 green	Emphasizes sediment-laden water and delineates areas of shallow water.
Band 5 red	Emphasizes cultural features.
Band 6 near IR	Emphasizes vegetation boundary between land and water, and landforms.
Band 7 near IR	Penetrates atmospheric haze best, emphasizes vegetation, boundary between land and water, and landforms.

Table 5.4: Radiometric coverage of Landsat MSS (USGS, 2003a).

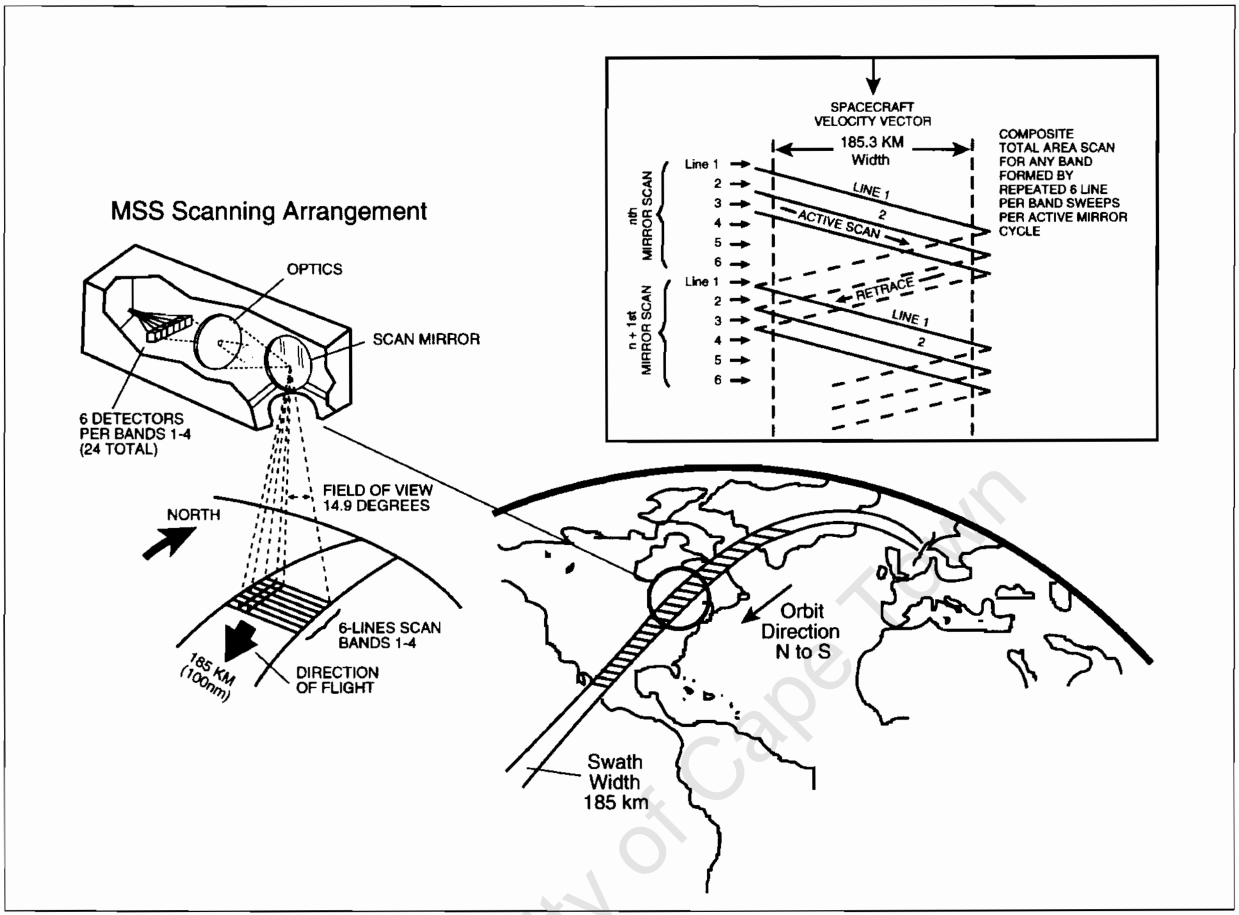


Figure 5.1: Landsat MSS scanning arrangement (USGS, 2003b).

Landsat 4 and 5 carry both carry MSS and Thematic Mapper (TM) sensors, however routine collection MSS data was discontinued in late 1992 (USGS, 2003b). The TM sensor, with its seven spectral bands (**Table 5.5**), provides more radiometric information than the MSS sensor (USGS, 2003c). In addition, Landsat 4 and 5 have a spatial resolution of 30 meters in bands 1 to 5 and band 7, and 120 meters on the ground in band 6 (USGS, 2003c). The visible and mid-infrared spectral bands have sixteen detectors providing sixteen scan lines on each active scan, while the thermal infrared spectral bands have four detectors providing four scan lines on each active scan (USGS, 2003c).

Landsat 7 was launched in April 1999 with an improved TM sensor called the Enhanced Thematic Mapper + (ETM+). The ETM+ sensor has 8 bands – 1 to 7 with the same spectral coverage as the TM sensor and band 8 or the panchromatic band (**Table 5.5**) with a spectral range from visible to near-infrared and 15-m resolution used for "sharpening" of multispectral images (USGS, 2003a). Landsat 7 has a spatial resolution of 30m in bands 1 to 5 and band 7, and an improved 60m on the ground in band 6 (USGS, 2003c).

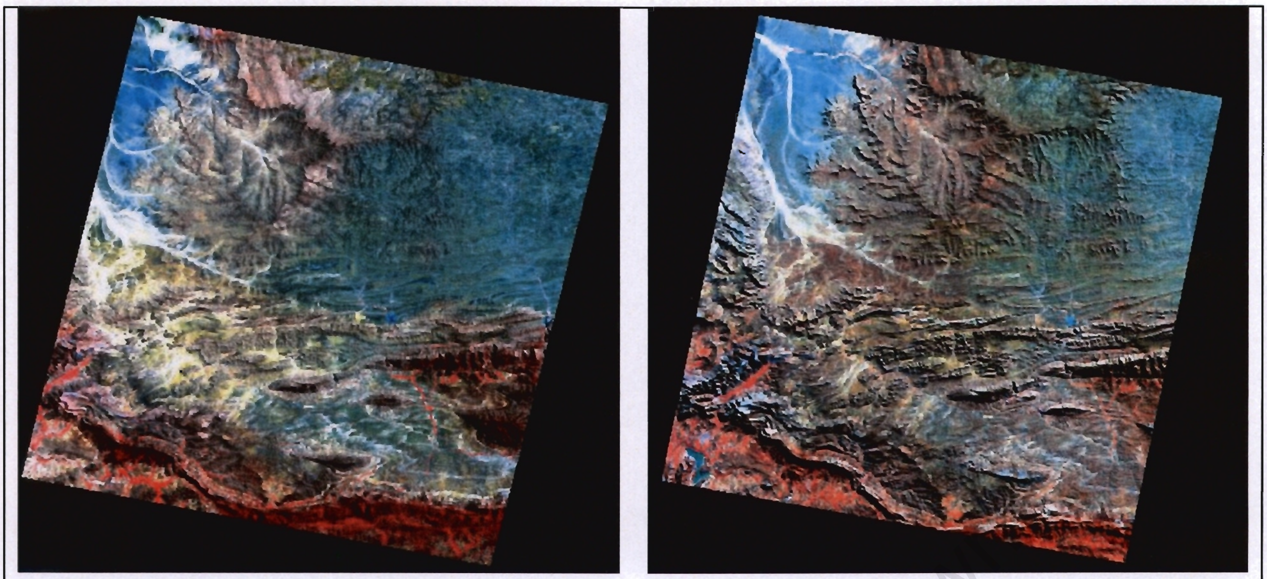
	Spectral Bands	**Use**
1	blue-green	Useful for bathymetric mapping and distinguishing soil from vegetation and deciduous from coniferous vegetation.
2	Green	Emphasizes peak vegetation, which is useful for assessing plant vigor.
3	Red	Discriminates vegetation slopes.
4	Reflected IR	Emphasizes biomass content and shorelines.
5	Reflected IR	Discriminates moisture content of soil and vegetation; penetrates thin clouds.
6	Thermal IR	Useful for thermal mapping and estimated soil moisture.
7	Reflected IR	Useful for mapping hydrothermally altered rocks associated with mineral deposits.
8	Panchromatic	Used for "sharpening" multispectral images

Table 5.5: Radiometric coverage of Landsat TM and ETM+ (USGS, 2003a).

5.2.1 Data

Four Landsat images (1972, 1989, 2000, 2003) (**Figure 5.2**) were acquired, free of charge, from the Global Land Cover Facility (GLCF) based at the University of Maryland in the United States and the Council for Scientific and Industrial Research (CSIR) Satellite Applications Centre (SAC) based at Hartebeeshoek, approximately 70 west of Pretoria, South Africa.

The 1972 MSS image, the 1989 TM image and the 2000 ETM+ image are all GeoCover processed images. GeoCover processed Landsat data is high resolution (MSS images have a pixel size of 57m opposed to the conventional 79m, TM images have a pixel size of 28.5m [Bands 1-5 and 7] and 114m [Band 6] opposed to the conventional 30m [Bands1-5 and 7] and 120m [Band 6] and ETM+ images have a pixel size of 28.5m [Bands 1-5 and 7] and 57m [Band 6] opposed to the conventional 30m [Bands 1-5 and 7] and 60m [Band 6]), orthorectified (corrected for terrain displacement and errors in image geometry) imagery (GLCF, 2003). There are three GeoCover editions that form part of the GLCF GeoCover collection : the 1975 edition, with imagery collected from 1972-1983, the 1990 edition, with imagery collected from 1989-1993, and the 2000 edition, with imagery collected between 1997 and 2000. The GeoCover collection is produced, under contract from NASA, by EarthSat inc., validated for metadata and geolocational accuracy the NASA Stennis Space Center and free to redistribute (GLCF, 2003). The validated product has a pixel accuracy or Root-Mean-Square error (RMSe) of 50m or less for Landsat TM and ETM+ images and 100m for Landsat MSS images (**Table 5.6**) (GLCF, 2003).

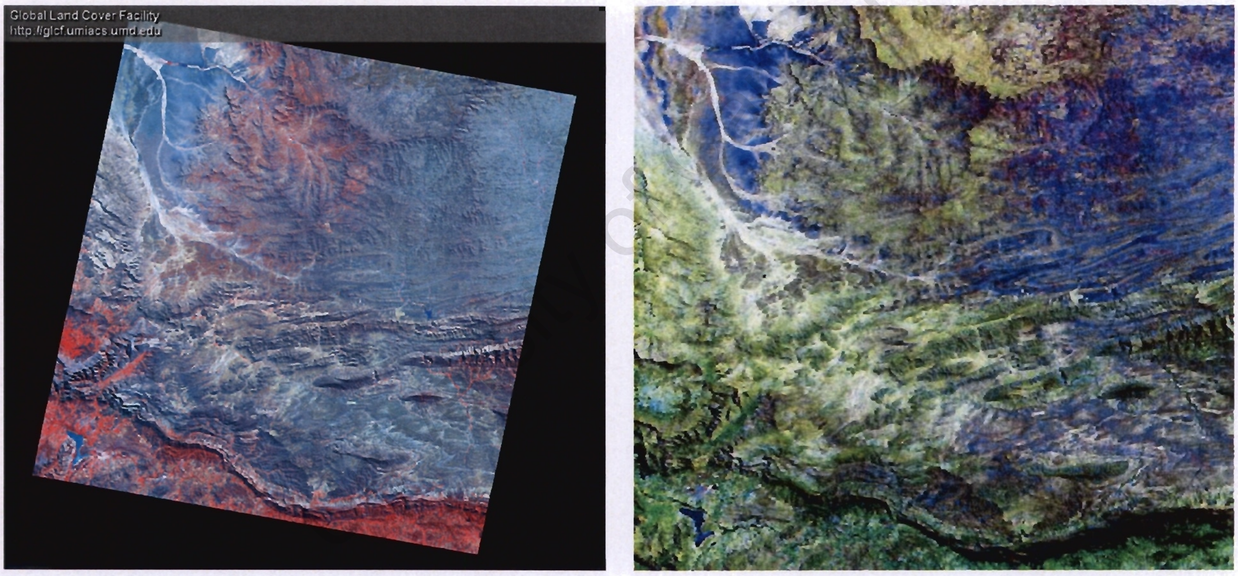


Source: GLCF

1972, Landsat MSS

Source: GLCF

1989, Landsat TM



Source: GLCF

2000, Landsat ETM+

Source: CSIR

2003, Landsat TM

Year	Date	Sensor	Path	No. of Bands	Processed	Format	Source
1972	07 November	MSS	P186R083	4	Yes, Geocover	GeoTiff	GLCF
1989	16 June	TM	P174R083	7	Yes, Geocover	GeoTiff	GLCF
2000	25 August	ETM+	P174R083	7, Pan	Yes, Geocover	GeoTiff	GLCF
2003	30 November	TM	P174R083	7	Yes, Level 1G	Fast	CSIR

Figure 5.2: Satellite images acquired for analysis.

The GeoCover images were supplied in GeoTiff format.

Satellite	**Sensor**	**Pixel Size** (in meters for visible, thermal, pan bands)	**RMSe**
C. 1970	MSS	57, N/A, N/A	100m
C. 1990	TM	28.5, 114, N/A	50m
C. 2000	ETM+	28.5, 57, 14.25	50m

Table 5.6: Landsat GeoCover characteristics (GLCF, 2003).

The 2003 TM image is a Level 1G (L1G) processed image produced by the CSIR. The L1G image is radiometrically and geometrically corrected i.e. orthorectified (USGS, 2004). The correction algorithms model the spacecraft and sensor using data generated by onboard computers during imaging. Sensor, focal plane, and detector alignment information provided by the Image Assessment System (IAS) in the Calibration Parameter File (CPF) is also used to improve the overall geometric fidelity (USGS, 2004). The resulting product is free from distortions related to the sensor (e.g., jitter, view angle effect), satellite (e.g., attitude deviations from nominal), and Earth (e.g., rotation, curvature) (USGS, 2004).

The image was supplied in FAST format and converted to Geotiff format using ERDAS Imagine v.8.6 and ENVI v.3.4 RT.

5.2.2 Remote Sensing and Landscape Disturbance and Change

Remote sensing techniques are often an effective method for detecting excessive landscape disturbances, which may be symptomatic of land degradation and have implications for desertification (Palmer and Tanser, 1999). However, spectrally based degradation assessment techniques are often of limited repeatability and do not operate well in semi arid/arid environments (Tanser and Palmer, 1999). Change detection techniques (e.g. vector change analysis, image differencing, image regression, post classification change analysis, multi temporal compositing and comparison) similarly are not viable without complex correction procedures (e.g. topographic normalization using Cosine method, Minnaert Constant or C-factor correction) (Tanser and Palmer, 1999). Vegetation indices (e.g. Normalised Difference Vegetation Index and Tassled Cap analysis) that attempt to estimate primary productivity cannot be used as reliable indicators of degradation since degradation does not necessarily result in a reduced level of vegetation growth (Tanser and Palmer, 1999).

The spread of a disturbance across a landscape is an important ecological process influenced by spatial heterogeneity (the quality of being diverse ad not comparable in kind) (Tanser and

Palmer, 1999). Any process that leads to an increase in the heterogeneity of soil resources in space and time is likely to lead to degradation in semi-arid regions (Tanser and Palmer, 1999). The remote sensing methodology used to detect land-cover change/degradation in the Kogmans River catchment was influenced by a number of factors. Various analytical options were not possible due to the seasonal variation of the available satellite images. Time series analysis using change detection techniques was not possible for this reason, as well as the requirement for complex correction procedures (i.e. Topographic Normalisaton) that were not possible with the available software (ENVI, ERDAS and Idrisi) and beyond the expertise of the author and academic support. External commercial interests (CSIR, EarthSat inc. and Spatial Dimension) were also consulted, but due to cost or technical capability none were able to assist.

Consequently, an alternative was sought and a remotely sensed diversity index – Moving Standard Deviation Index (MSDI) – developed by Tanser and Palmer (1999) to monitor patterns of degradation was applied.

5.2.2.1 The Moving Standard Deviation Index (MSDI)

The Moving Standard Deviation Index (MSDI) is created by passing a 3 X 3 moving standard deviation across the red band of a Landsat image (Tanser and Palmer, 1999). The filter calculated the standard deviation of the 9 pixels (Tanser and Palmer, 1999). The standard deviation is then placed onto a new map at the same location as the central pixel (Tanser and Palmer, 1999). The window is then moved one pixel to the right and then down one row at the end of the row and then the process is repeated (Tanser and Palmer, 1999). Degraded or disturbed areas (rivers, roads, abandoned cultivated land etc.) are characterized by high MSDI values, while less disturbed area (nature reserves, commercial agriculture etc.) typically exhibit low MSDI values (Tanser and Palmer, 1999).

Tanser and Palmer (1999) applied and tested this methodology across fence lines in the Great Fish River Basin in the Eastern Cape, South Africa (Tanser and Palmer, 1999). Four fence lines were identified in a field survey that separated good condition commercial/conservation rangeland from degraded communal rangeland (Tanser and Palmer, 1999). The fence lines were chosen to reflect a range of elevation, rainfall, substrate and vegetation classes (Tanser and Palmer, 1999). The relationship between the MSDI and Normalised Vegetation Index (NDVI) was investigated using Spearman's rank correlation coefficient (Tanser and Palmer, 1999). As NDVI is related to the condition of the landscape, a significant relationship would strengthen the case for MSDI as a good predictor of landscape condition (Tanser and Palmer, 1999).

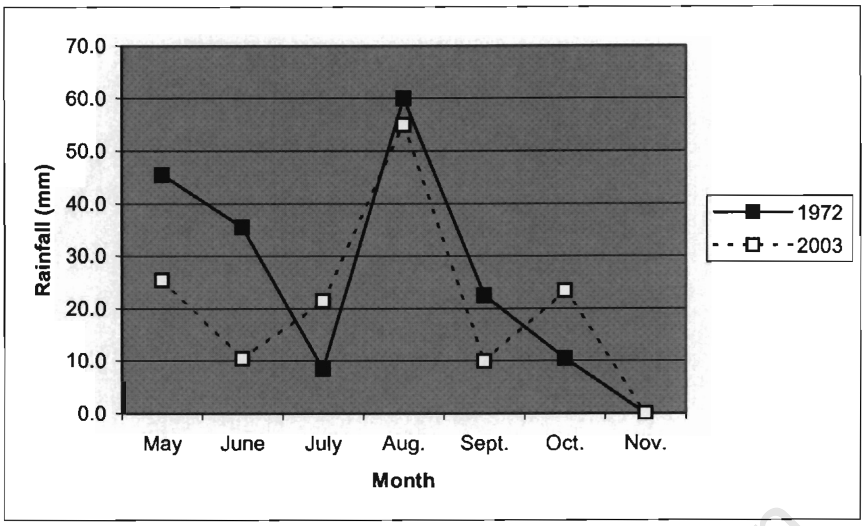
The Spearman rank correlation and test significance correlation between MSDI and NDVI were shown to be highly significant at the 99% confidence level (Tanser and Palmer, 1999). In addition, significant differences in MSDI were detected across all four fence lines, particularly in the most arid part of the study area (Tanser and Palmer, 1999). Thus, the MSDI was shown to be a sensitive indicator of landscape heterogeneity or degradation (Tanser and Palmer, 1999). The primary limitations of the MSDI, noted by Tanser and Palmer (1999), relate to scale and sensitivity of the index. Degradation cannot be estimated in areas less than 8100m² in extent (the size of the filter) (Tanser and Palmer, 1999). The MSDI, is also sensitive to disturbance of any nature e.g. rivers and roads return elevated MSDI values (Tanser and Palmer, 1999).

5.2.2.2 Application of the MSDI

Two near-anniversary images were chosen for the application of the MSDI for comparison – the 1972 Landsat MSS image (acquired on 07 November) and the 2003 Landsat TM image (acquired on 30 November). The red band (MSS Band 5 and TM Band 3) was used to generate an MSDI for 1972 and 2003.

On the advice of Dr. A. Palmer from the Agricultural Research Council (ARC) Range and Forage Institute, the rainfall regime 6 months prior to the acquisition of the images was investigated in order to ensure comparable results. The rainfall values for Montagu for the period of May to October 1972 and 2003 (**Figure 5.3**) show some significant monthly variation with a comparison the 6 month total showing a difference of 36.5mm, making the period of May to October slightly wetter in 1972. However, it should be noted that the additional 36.5mm fell in the first three months of the 6-month period and that the months of August, September and October show almost identical net totals for both 1972 and 2003 – 93mm and 88.5mm respectively. No rainfall was recorded in the November month of either year.

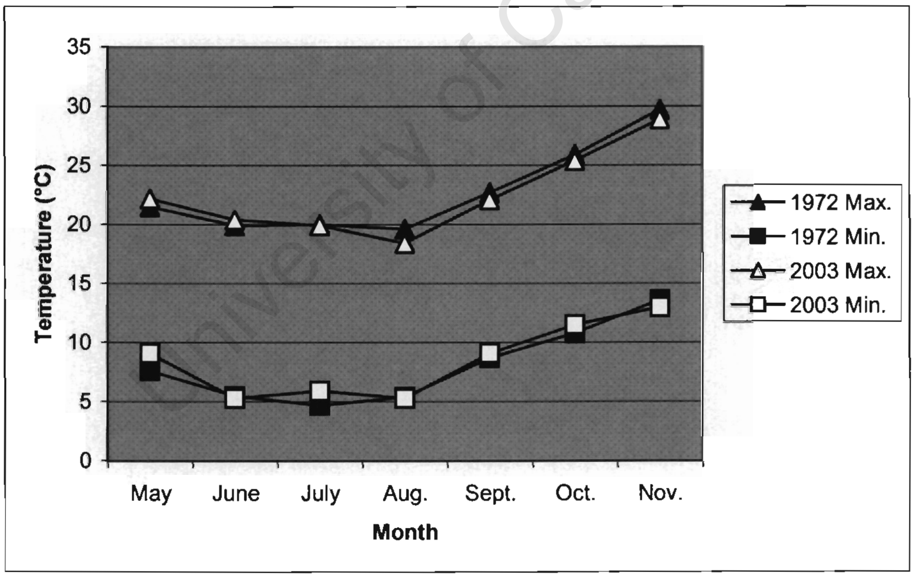
The minimum and maximum temperature data for Robertson (**Figure 5.4**), approximately 28km east of Montagu (no temperature data are available for Montagu), for 1972 and 2003 over same 6-month period show very little significant variance.



Year	May	June	July	Aug.	Sept.	Oct.	Nov.	6-Month Total
1972	45.5	35.5	8.5	60.0	22.5	10.5	0.0	**182.5**
2003	25.5	10.5	21.5	55.0	10.0	23.5	0.0	**146.0**

Source: SAWS

Figure 5.3: Monthly rainfall (mm) for Montagu: May-October 1972 and 2003.



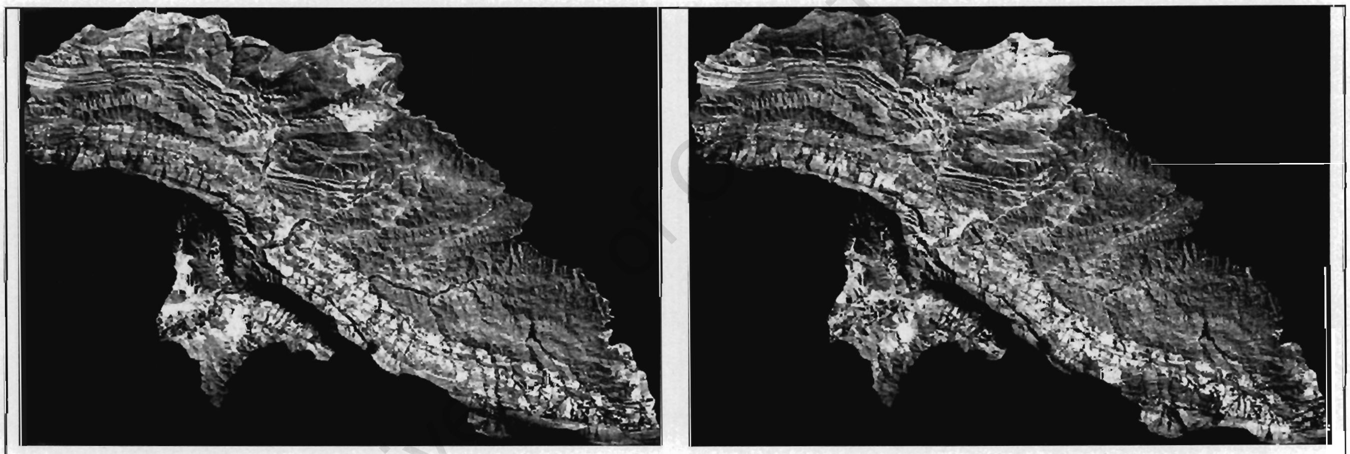
Year	May	June	July	Aug.	Sept.	Oct.	Nov.	6-Month Ave.
1972 Max.	21.5	19.9	20	19.6	22.7	25.9	29.7	**21.6**
1972 Min.	7.6	5.5	4.7	5.4	8.7	10.8	13.6	**7.1**
2003 Max.	22.2	20.4	19.9	18.4	22.1	25.4	28.9	**21.4**
2003 Min.	9.1	5.3	5.9	5.3	9.1	11.5	13.0	**7.7**

Source: SAWS

Figure 5.4: Monthly Average Temperature (°C) for Robertson: May-October 1972 and 2003

Before the red band was extracted from the band sequential (BSQ) Landsat image data for 1972 and 2003, the MSS and TM images were calibrated using the Calibration Utilities in the Basic Tools menu in ENVI v.3.4 RT to convert the digital numbers (DN) to at-sensor reflectance using post-launch gains and biases published in the Earth Observation Satellite (EOSAT) Technical Notes (Markham and Barker, 1986).

Once calibrated, the 1972 and 2003 images were subset to catchment boundary (**Figure 5.5**) (imported as a .shp (shapefile) from the ENPAT database) using ERDAS Imagine v.8.6 and saved as BSQ ERDAS .img files. The .img files were then opened in ENVI v.3.4RT and the red band (MSS Band 5 and TM Band 3) were extracted and saved as ERDAS .lan files to be imported into Idrisi v.32.11.



Source: GLCF

Source: CSIR

1972 Landsat 1 MSS, Band 5

2003 Landsat 5 TM, Band 3

Figure 5.5: Two Landsat images in the red band subset to Kogmans River catchment boundary.

The two subset images were then imported into Idrisi v.32.11 and the MDSI Idrisi Macro (**Appendix 1**), developed by Tanser and Palmer (1999), was applied using the run Macro command on the file menu.

5.3 The Riparian Zone and In-stream Vegetation

In April 2003, the Disaster Mitigation for Sustainable Livelihoods Programme (DiMP) conducted interviews with a number of farmers in the Kogmans River catchment as part of a consolidated report on the cut-off low that swept across the south Cape in March 2003 and caused extensive storm and flood damage to the region.

The interviews highlighted concern about the state and management of the riparian zone and in-stream vegetation prior to the floods. Of particular concern, were the extensive *Phragmites australis* reed stands that dominated the channel of both the Kingna and Keisie Rivers prior to the flood event (**Figure 5.6**). A number of the respondents interviewed observed that the reeds and river debris impeded the natural flow of the rivers and elevated the flood levels of both Kingna and Keisie Rivers (DiMP, 2003).

Source: Field visit, August 2004

Figure 5.6: *Phragmites australis* reed stands in the channel of the Kingna Rivers, Montagu 2004.

Indeed, much of the damage caused by the floods, particularly to the bridges across the Kingna, was as a result of the reeds and accompanying debris that clogged the bridge openings (**Figure 5.7**), increasing the mass pressure of the flood water and entrained sediment.

Source: Montagu Museum

Figure 5.7: Example of the how reeds and debris the clogged the bridge openings during the March 2003 Flood.

The interviews also revealed that a conflict exists between Western Cape Nature Conservation (WCNC), who carry the responsibility for the management and conservation of the riparian and in-stream vegetation, the Department of Water Affairs and Forestry (DWAF), who have jurisdiction over the riverbed, and the local farmers who utilize both the river and its banks (MacGregor, 2003). It seems that various efforts have been made to resolve the impasse and initiate a cooperative management strategy for the rivers in the Kogmans River catchment, however, the considerable differences in opinion regarding, in particular, the management of *Phragmites australis* – conservation as against the elimination of the reeds to protect urban and agricultural land and infrastructure in the event of a flood – have hampered any efforts (DiMP, 2003). In addition, some legal provisions for the management of river systems and an extremely limited budget also served to hinder any real management initiatives.

As consequence of this conflict, some local farmers have taken it upon themselves to manage the strips of river adjacent to their farms (MacGregor, 2003). Various methods including, herbicides, cattle, fire and riverbed dredging have been employed to deal with the extensive *Phragmites australis* reed beds (MacGregor, 2003).

To determine the nature and extent of the reed problem as well the health and functioning of the riparian zone, two field visits were conducted by the author in August and September 2004 (with both the Kingna and the Keisie river functioning very much as they would have pre-March 2003). Various accessible sites along the Kingna and Keisie Rivers were visited and their state described. Mr. Piet van Zyl from Western Cape Nature Conservation (WCNC) (Vrolijkheid Nature Reserve between Robertson and McGregor in the Breede River catchment) assisted with plant identification and the description of general river conditions.

In addition, data on the extent and health of the riparian vegetation in the Kogmans River catchment was extracted from land-use data, mapped as part of the Department of Water Affairs and Forestry's Breede River Basin Study that was concluded in 2003. The land-use map represents land-use practices in catchment in 2000.

5.4 Hydrological Modelling in the Kogmans River Catchment

In order to assess the possible future impact of land-cover and land-use change on the catchment response of the Kogmans River catchment various future land-use changes scenarios were investigated using the Hydrological Engineering Corps Hydrological Modelling System (HEC-HMS) to generate the results (USACE, 2000)

5.4.1 Hydrological Modelling

Hydrology is concerned, essentially, with how much precipitation reaches the Earth's surface, and what happens to it when it gets there (Dodson, 1999). While historical flow, discharge and rainfall data can provide some insight into the rainfall-runoff relationship in a particular catchment, it helps little in predicting the dynamics of this relationship in the future. Hydrological modelling has thus become an invaluable tool for hydrologists, engineers and environmental scientists, allowing them predict the possible affects changes in the landscape composition over time. However, hydrological models rely on accurate and comprehensive data in order to be an effective tool and yield valuable results.

Two models were considered by the author for use in this study – the ACRU Agrohydrological Model, developed by the School of Bioresources Engineering & Environmental Hydrology at the University of Kwazulu-Natal, and the HEC-HMS Hydrological Model, developed by the United States Army Corps of Engineers (USACE).

5.4.1.1 ACRU Agrohydrological Model

The Agricultural Catchments Research Unit (ACRU) Agrohydrological Modelling System is a multi-purpose model which integrates many of the water budgeting and run-off producing elements of the terrestrial component of the hydrological cycle with risk analysis (Schulze *et al*, 1995). The model can be applied in design hydrology studies, crop yield modelling, reservoir yield simulation and irrigation water demand or supply projects, regional water resources assessments, optimum water resource utilisation planning and to resolve conflicting demands on water resources (Schulze *et al*, 1995).

ACRU uses a daily time step and therefore uses daily rainfall input, making optimal use of available data (since rainfall with a finer time step is not available on most occasions) (Schulze *et al*, 1995). However in routines in which sensitive intra-daily information (e.g. rainfall distribution) is required, this is obtained by synthetic disaggregation of daily input within the model (Schulze *et al*, 1995). The ACRU model also revolves around daily multi-layer soil water budgeting and has been developed essentially into a versatile total evaporation model (Schulze *et al*, 1995). It is therefore structured to be highly sensitive to climate and to land cover/use changes on the soil water and run-off regimes (Schulze *et al*, 1995).

Essentially, ACRU is a daily, multi-layer soil water budget model and hence the model simulates the components and processes of the hydrological cycle affecting the soil water budget, including:

i) Canopy interception of rainfall by vegetation, and the net rainfall reaching the ground surface (Schulze *et al*, 1995).
ii) Infiltration and net rainfall into the soil (Schulze *et al*, 1995).
iii) Total evaporation (i.e. transpiration and soil water evaporation) from the various horizons of the soil profile to the root depth (Schulze *et al*, 1995).
iv) Suppression of soil water evaporation by litter or mulch (Schulze *et al*, 1995).
v) The redistribution of soil water in the soil profile (both saturated and unsaturated) (Schulze *et al*, 1995).
vi) Percolation of soil water into the intermediate groundwater zones (Schulze *et al*, 1995).

Additionally, from the soil water budget, the model is capable of outputting simulated elements of streamflow on a daily time step, or as monthly or annual totals of daily values (Schulze *et al*, 1995). These include stormflow and baseflow depth or volume and peak discharge (Schulze *et al*, 1995).

5.4.1.2 Hydrologic Engineering Corp Hydrological Modelling System (HEC - HMS)

The Hydrologic Engineering Corp Hydrological Modelling System (HEC - HMS) was developed by the United States Army Corps of Engineers, and designed to simulate the precipitation - run-off - routing processes of dendritic watershed systems (USACE, 2001). It is designed to be applicable in a wide range of geographic areas and is able to solve problems ranging from large river basin water supply and flood hydrology, to small urban or natural watershed run-off (USACE, 2001).

The model consists of three main components that facilitate the modelling process – the basin model, the meteorologic model and the control specifications. The physical representation of a catchment or river is configured in the basin model (USACE, 2001). A number of hydrological elements are available to build the basin model including, sub-basins, river reaches, junctions, diversions, sinks and sources, all of which can be connected in a dendritic network to simulate runoff processes in a downstream direction (USACE, 2001). Information on infiltration losses, run-off transform and open channel routing can be input into the basin model (USACE, 2001). The analysis of both historical and synthetic meteorological data is performed in the meteorologic model and the time span for a rainfall-runoff simulation is controlled using the control specifications model (USACE, 2001).

In addition, the HEC-HMS provides the following components, for precipitation - run-off - routing simulations (USACE, 2000):

i) Precipitation-specification options that can describe an observed or historical precipitation event, a frequency-based hypothetical precipitation event, or an event that represents the upper limit of precipitation possible at a particular location (USACE, 2000).

ii) Loss models which can estimate the volume of run-off, given the catchment parameters and properties and precipitation data (USACE, 2000).

iii) Direct run-off models that can account for overland flow, storage and energy losses as water runs off a catchment watershed and into stream channels (USACE, 2000).

iv) Hydrological routing models that account for the storage and energy flux as water moves through stream channels (USACE, 2000).

v) Internal models that can represent naturally occurring confluences and bifurcations as well as water control measures, including diversions and storage facilities (USACE, 2000).

In order to determine the relationship between rainfall, run-off, land-use and land-cover change in the Kogmans River catchment, the HEC-HMS model was employed by the author. The choice of model was governed primarily by the fact, that the HEC-HMS model is free, it is Windows-based, and provides a Graphical User Interface (GIU) to guide the modelling process. For the relative novice, these features are invaluable for the clear conceptualisation of the modelling process. ACRU, in contrast, is a DOS-based program that is data intensive and requires training to operate.

5.4.2 Data Available for Modelling in the Kogmans River Catchment

It is important, prior to selecting loss, transform and routing models within the HEC-HMS model, to determine the type, the temporal range and the applicability of available data. **Table 5.7a** and **Table 5.7b** list all the available data for the Kogmans River Catchment that may be useful for modelling rainfall and runoff. Two rainfall events were considered – February 25, 1981 and March 24, 2003. No land-use or land-cover data are available for 1981 and no routing or river channel information is available from the Department of Water Affairs and Forestry (DWAF) for either of the periods. In addition, there are no groundwater flow data for the Kogmans River catchment as well as no evaporation daily data for the area.

Summary of Hydrological Data: February 1981				
Parameter	**No./Code**	**Unit(s)/Format**	**Description**	**Source**
Rainfall	0024/228L0	mm *	Montagu Polisie	ISCW
	0024197 0	mm *	Montagu	SAWS
	H3E001	mm *	Goede Moed	DWAF
River	H3H013	Flow (m³/s) * Volume (m³) *	Left Canal From Dam @ Poortjieskloof	DWAF
	H3H014	Flow (m³/s) * Volume (m³) *	Irrigation Pipeline @ Pietersfontein	DWAF
Dams	H3R001	Storage (%) ** Area (ha) ** Water Level (m) *,** Flow (m³/s) *	Groot River @ Poortjieskloof	DWAF
	H3R002	Storage (%) ** Area (ha) ** Water Level (m) *,** Flow (m³/s) *	Pietersfontein River @ Pietersfontein	DWAF
Soils	————	GIS (Lat./Lon.)	Breede River Basin Study Soils Map	DEAT
	————	GIS (Lat./Lon.)	Soils Map, ENPAT 2000	DEAT
	————	GIS (Lat./Lon.)	South African Landtypes Map	ISCW

* Daily   ** Weekly

Table 5.7a: Summary of data available for hydrological modelling in the Kogmans River Catchment 2003.

Summary of Hydrological Data: March 2003

Parameter	No./Code	Unit(s)/Format	Description	Source
Rainfall	0024/258L0	mm *	Goudmyn	ISCW
	0024197 0	mm *	Montagu	SAWS
River	H3H005	Flow (m^3/s) * Volume (m^3) *	Keisie River @ Keisiesdoorns	DWAF
	H3H011	Flow (m^3/s) * Volume (m^3) *	Kogmanskloof River @ Gold Mine	DWAF
	H3H013	Flow (m^3/s) * Volume (m^3) *	Left Canal From Dam @ Poortjieskloof	DWAF
	H3H015	Flow (m^3/s) * Volume (m^3) *	Pietersfontein River @ Pietersfontein	DWAF
Dams	H3R001	Storage (%) ** Area (ha) ** Water Level (m) *,** Flow (m^3/s) *	Groot River @ Poortjieskloof	DWAF
	H3R002	Storage (%) ** Area (ha) ** Water Level (m) *,** Flow (m^3/s) *	Pietersfontein River @ Pietersfontein	DWAF
Soils	————	GIS (Lat./Lon.)	Breede River Basin Study Soils Map	DEAT
	————	GIS (Lat./Lon.)	Soils, ENPAT 2000	DEAT
	————	GIS (Lat./Lon.)	South African Landtypes Map	ISCW
Land-use	————	GIS (Lat./Lon.)	Breede River Basin Study Land-use Map - 2000	DEAT
	————	GIS (Lat./Lon.)	Land-use, ENPAT 2000	DEAT
Land-cover	————	GIS (Lat./Lon.)	Land-cover, ENPAT 2000	DEAT

* Daily ** Weekly

Table 5.7b: Summary of data available for hydrological modelling in the Kogmans River Catchment 2003.

Based on the available data, as well as the parameters required (and advantages and disadvantages) (**Table 5.8**) for the use of the various loss models in the HEC-HMS model, the United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) - formerly known as the Soil Conservation Service (SCS) - 'Curve Number' (CN) method was chosen by the author to calculate the total excess precipitation generated by a storm event. The NRCS loss model uses rainfall, land-use and antecedent moisture data to generate precipitation excess. These parameters are satisfied by the available data for the March 2003 storm event. The NRCS lag method was employed to calculate the transform model.

Model	Required Parameters	Advantages	Disadvantages
Initial & Constant-Rate **and** **Deficit & Constant-Rate**	- Initial Loss - Constant Rate	- Mature model that has been used successfully in hundreds of studies throughout the US. - Easy to set up and use.	- Model is parsimonious; it includes only a few parameters necessary to explain the variation of runoff volume. - Difficult to apply to ungaged areas due to lack of direct physical relationship of parameters and watershed properties. - Model may be too simple to predict losses within event, even if it does predict total losses well.
NRCS Curve Number	- Rainfall - Soils data - Land-use/Land-cover	- Simple, predictable, and stable method. - Relies on only one parameter, which varies as a function of soil group, land use and treatment, surface condition, and antecedent moisture condition. - Features readily grasped and reasonable well-documented environmental inputs. - Well established method, widely accepted for use in US and abroad.	- Predicted values not in accordance with classical unsaturated flow theory. - Infiltration rate will approach zero during a storm of long duration, rather than constant rate as expected. - Developed with data from small agricultural watersheds in midwestern US, so applicability elsewhere is uncertain. - Rainfall intensity not considered.
Green & Ampt	- Initial loss - Hydraulic conductivity - Wetting front suction - Volume moisture deficit	- Parameters can be estimated for ungaged watersheds from information about soils	- Not widely used. - Less parsimonious than simple empirical models.

Table 5.8: Loss Models available in the HEC-HMS Model (USACE, 2000).

5.4.2.1 .4 The NRCS (SCS) Curve Number Loss Model

The NRCS (SCS) curve number loss model estimates precipitation excess as a function of cumulative rainfall, soil cover, land-use and antecedent moisture using the following equation (USACE, 2000):

$$Q = \frac{(P - I_a)^2}{(P - I_a) - S}$$

Where:

Q = run-off

P = rainfall

S = potential maximum retention after run-off begins

Ia = Initial abstraction

In other words, until the accumulated rainfall (P) exceeds the initial abstraction (Ia) or initial loss, the rainfall excess, and hence the runoff, remains zero (USACE, 2000).

The value for initial abstraction (Ia) was calculated by the USDA to be 0.2, a value based on a number of experiments conducted in small watersheds in the United States (USACE, 2000). However, research, documented Schmidt and Schulze (1987), suggests that a 0.2 is too high for southern African conditions and a conservative value of 0.1 is suggested for use in hydrological studies in southern Africa instead (Schmidt and Schulze, 1987). Initial abstraction (Ia) is calculated using the following equation:

$$I_a = cS$$

Where:

c = coefficient of initial abstraction

S = potential maximum retention after run-off begins

The maximum retention, S, is related to soil and cover conditions of the catchment through the Curve Number (CN) (USACE, 2000). CN has a range of 0 to 100, and S is related to CN by the following equation (USACE, 2000):

$$S = \frac{25400 - 254CN}{CN}$$

Curve Number values range from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates (USACE, 2000). However, the CN value must practically be above 40 (USACE, 2001). The CN values are calculated using soil and land-use/land-cover data and are later adjusted according to the antecedent moisture conditions. Four main hydrological soil groups (HSG) are defined by the method, namely A, B, C, and D. Three intermediate groups were developed for use in southern Africa (Schulze and Arnold, 1979) and are labelled A/B, B/C and C/D. Under the conventional NRCS method, the four main groups are described in **Table 5.9** below.

HSG	Description
A	These soils have low run-off potential and high infiltration rates even when thoroughly wetted. They consist mainly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (> 7.56mm/hr).
B	These soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils typically have a moderate rate of transmission (3.81 - 7.56mm/hr).
C	These soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine texture. These soils have a low water transmission rate (3.81 - 1.27mm/hr).
D	These soils have a high run-off potential. They have low infiltration rates when thoroughly wetted and consist predominantly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a clay pan or clay layer at or near the surface, and shallow soils over nearly impervious material. These soils have a very low rate of water transmission (0 - 1.27mm/hr).

Table 5.9: Primary Hydrological Soil Groups (HSG) (USACE, 2000)

When the hydrological soil group (HSG) of the soils data is known, CN values are then estimated by analysis of the of the land-use/landcover that corresponds with a particular HSG. The HSG and CN values are determined using tables (Table A.1 and Table A.2 in the appendices adapted to southern Africa by Schulze and Arnold, 1979).

For catchments with various soil and land-use/land-cover types a weighted CN is calculated using the following equation (USACE, 2000):

$$CN_{Weighted} = \frac{\sum A_S CN}{\sum A_S}$$

Where:

As = area of each soil subdivision

CN = Curve number of each soil land-use combination

The resultant CN value is then adjusted according to the antecedent moisture conditions within the catchment. This is calculated using the equation:

$$CN_{Adjusted} = \frac{1100}{\frac{1100}{CN} + \frac{\Delta S}{25.4}}$$

where:

ΔS = Soil moisture adjustment factor (mm)

The soil moisture adjustment factor can be determined for a particular climatic zone (**Appendix 2**) and soil and vegetation combination using soil moisture indices (**Appendix 4**) and the nomograph in **Appendix 3**. The indices were developed by Schmidt and Schulze (1987) for southern Africa.

5.4.2.2 .5 NRCS (SCS) Lag Transform Model

Lag is defined as the time from the centre of mass of excess rainfall to the peak rate of run-off and is related to the physical properties of a catchment (Schulze and Arnold, 1979). It can be estimated from historical hydrographs or from specific catchment characteristics such as catchment slope, hydraulic length and flow retardance (Schulze and Arnold, 1979). Lag is defined as:

$$L = \frac{l^{0.8}(S+25.4)^{0.7}}{7069y^{0.5}}$$

Where:
L = lag in hours
l = hydraulic length of the catchment of sub basin in metres
y = average catchment slope in percent
S = potential maximum retention after run-off begins

Hydraulic length can be approximated using the equation:

$$l = 1738A^{0.6}$$

Where:
A = area in km²

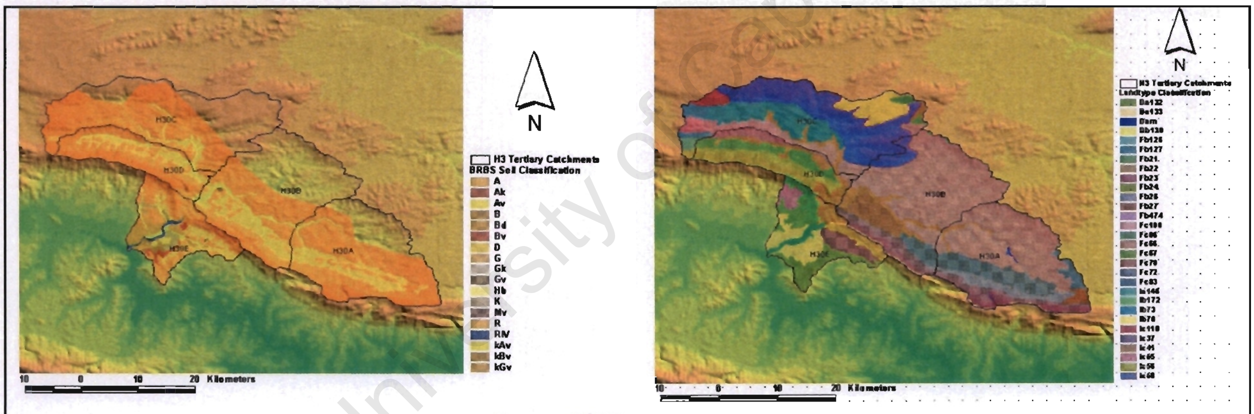
This method for estimating lag was developed to span a broad set of conditions ranging from heavily forested catchments with steep channels, to?or meadows (what?) providing a high retardance to surface run-off to smooth surfaces and long paved parking areas (Schulze and Arnold, 1979).

5.4.3 Determining Catchment Parameters for the HEC-HMS Model

The Kogmans River catchment was divided into five sub-catchments based on the boundaries of the tertiary catchments, and the catchment parameters for each sub-catchment were determined and input into the HEC-HMS model. The following section will describe the methods and analysis used to determine the soil and land-use characteristics as well as the NRCS curve numbers for each sub-catchment. The soil and land-use/land-cover data were analysed and compiled using ArcView 3.1 Geographical Information Systems (GIS) software.

5.4.3.1 Soil and Land-use/Land-cover Characteristics

The soil data for the Kogmans River Catchment was determined using a partial coverage soil map compiled by the Department of Soil Science at the University of Stellenbosch (for the DWAF Breede River Basin Study [BRBS]) (**Figure 5.8**) and the landtypes map compiled by the Institute For Soil, Climate and Water (ISCW) (**Figure 5.8**) to complete the coverage of the study area.



Source: BRBS

Source: ISCW

Figure 5.8: BRBS Soils Map and ISCW Landype Map for the Kogmans River Catchment.

The consolidated soils data were then analysed and converted into Hydrological Soils Groups (HSG) (**Figure 5.9**) using the Soil Classification Working Group's (1991) Taxonomic Soil Classification System for South Africa and the hydrological classifications of soil forms and series found in southern Africa developed by Schulze and Arnold (1979).

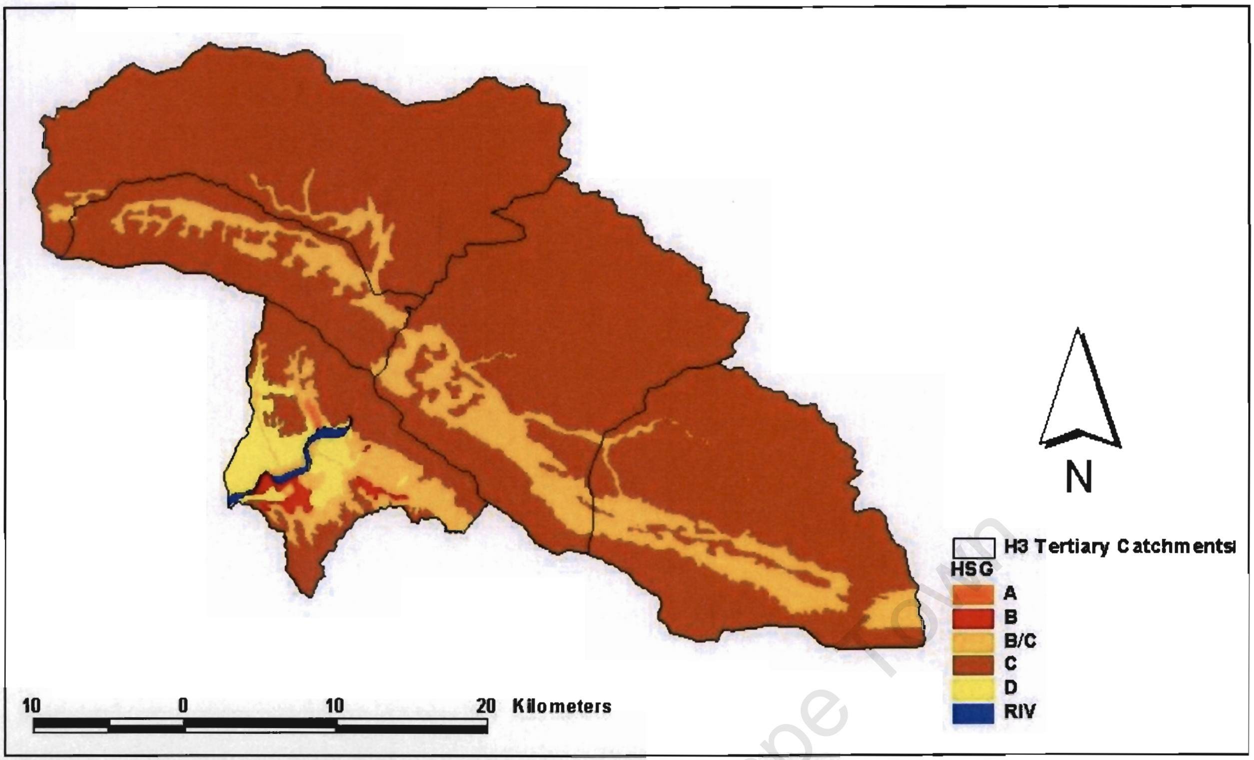


Figure 5.9: Hydrological Soil Group Map for the Kogmans River Catchment.

The land-use/land-cover pattern within the catchment was determined using data from the Breede River Basin Study (BRBS) and the Environmental Potential Atlas 2000 (ENPAT 2000). The land-use map represents land-use in the Kogmans River catchment for the year 2000. The ENPAT 2000 land-cover map was merged with the BRBS land-use map to provide full coverage for the catchment.

5.4.3.2 Generating NRCS (SCS) Curve Numbers for the Kogmans River Catchment

Once the soil and land-use/land-cover was known, the weighted curve numbers (CN) were generated for the five sub-catchments delineated – H30A, B, C, D, and E – using the NRCS method described in section 5.4.1.3 of this chapter. The land-use classes used in the BRBS and ENPAT 2000 GIS data were converted to correspond with the land-use classes ascribed by the NRCS method in order to determine a CN value for a particular Land-use/land-cover and Hydrological Soil Group (HSG) combination. Refer to **Appendix 5** for details of the land-use classes and CN values for the corresponding HSG found within the Kogmans River catchement.

The Langeberg mountains that mark the southern boundary of the Kogmans River catchment are characterised by steep slopes and shallow soils with very little vegetative cover. Consequently, these mountains contribute significant energy and volume to the total run-off generated in the catchment as a result of a rainfall event. It was thus decided (following a field inspection) that the Langeberg mountains be classed as 'disturbed land' to generate a CN value.

Once the weighted CN value was calculated, the result was adjusted according using the soil moisture indices (SMI) developed by Schmidt and Schulze (1987). The soil moisture adjustment factor (SMAF) for each sub-catchment was determined by describing the general soil texture (clay, loam or sandy) and depth (shallow, intermdiate or deep) and the vegetation cover (sparse, intermediate or dense). **Table 5.10** summarises the values generated.

Name	**Climatic Zone**	**SMI**	**SMAF**
H30A	75, 77	2, 4 (3)	-5
H30B	75	2	-7
H30C	75	2	-7
H30D	52	28	-2
H30E	51	3	-5

Table 5.10: Soil Moisture Adjustment Factor (SMAF) generated for the Kogmans River Catchment

5.4.3.3 Land-use/Land-cover Change Scenarios

Using the 2000 land-use/land-cover data as a starting point, two broad land-use/land-cover changes were considered – an increase in urbanisation (Montagu and Ashton) and an increase in degradation.

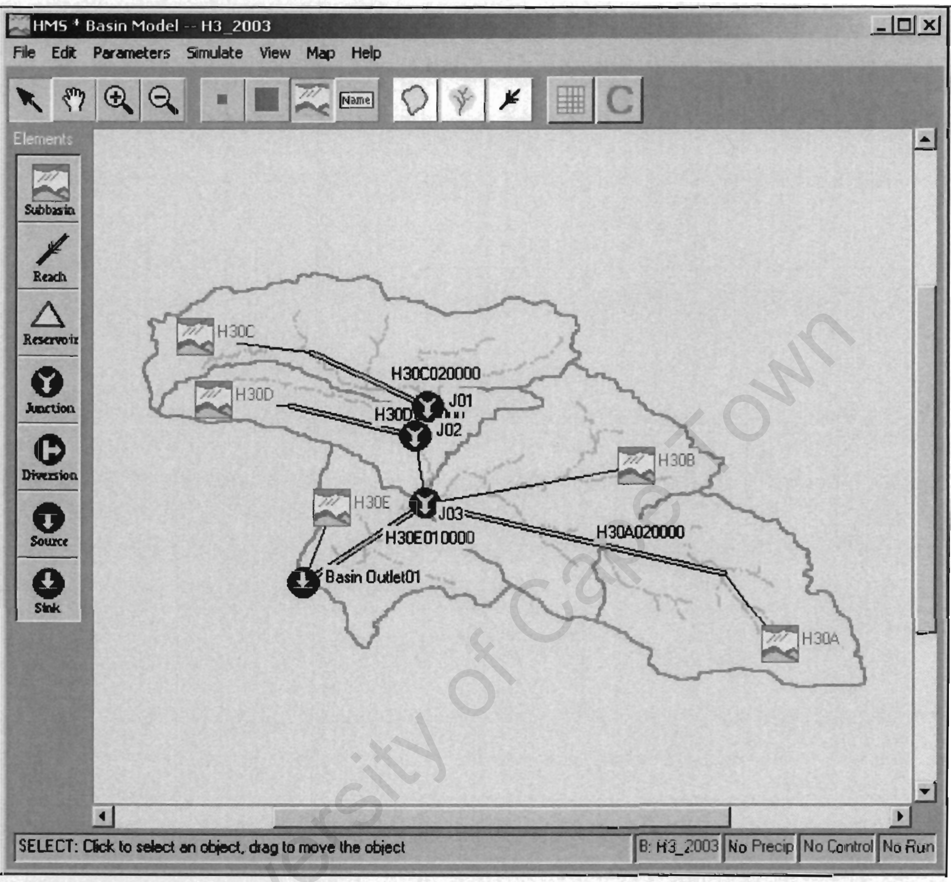
5.4.4 Modelling Land-use/Land-cover Change using HEC-HMS

HEC-HMS consists of three main input components - the basin component model, the meteorological component model and the control specification component. All three components need to be set up before a run or simulation can be performed and discharge values calculated.

5.4.4.1 HEC-HMS Basin Model

The Basin model (**Figure 5.10**) is made up of seven different hydrological elements - sub basin, reach, reservoir, junction, diversion, source and sink (USACE, 2000). These elements are the basic building blocks of the basin model and each represents a physical process such as a sub-catchment, stream reach or confluence (USACE, 2000).

For the purposes of this project and due to the unavailability of certain data only four hydrological elements were used to determine the rainfall run-off relationship in the Kogmans River catchment - the subbasin, reach, junction and sink elements.



SELECT: Click to select an object, drag to move the object

Figure 5.10: HEC-HMS Basin Model.

Six basin models were created to represent a) catchment conditions prior to the March 2003 floods (ie. 1.03% urban, 1.29% degraded), b) increases in urbanisation (3% and 5%) and c) increases in land degradation (3%, 5% and 10%). A network of five subbasin elements, four reach elements, four junction elements and a single sink element was used to create all six Basin models. The input data for each subbasin element was extracted from **Table 5.11** (see **Appendix 6** for full data set). Increases in urbanisation (impervious area) were input directly into the HEC-HMS model, so individual curve numbers did not have to be calculated for 3% and 5% increases in urbanisation. The catchment conditions prior to the March 2003 floods were used as the base conditions for calculating increases in discharge due expanding urbanisation.

Subbasin		**H30A**	**H30B**	**H30C**	**H30D**	**H30E**
Coefficient of Ia		0.1	0.1	0.1	0.1	0.1
Ia (mm)	2000	7.75	14.29	16.93	9.39	8.02
	3% Degraded	7.16	13.68	16.24	8.92	8.02
	5% Degraded	6.75	13.68	15.57	8.42	7.59
	10% Degraded	6.35	12.51	14.92	8.02	6.75
Hydraulic Length (m)		51527.50	54727.67	56076.37	31792.33	35552.56
Lag (hrs)	2000	4.59	6.98	7.56	2.98	3.84
	3% Degraded	4.45	6.80	7.37	2.89	3.84
	5% Degraded	4.32	6.8	7.18	2.81	3.73
	10% Degraded	4.19	6.46	7.00	2.73	3.51
Weighted CN (Adjusted for soil moisture)	2000	77	64	60	73	76
	3% Degraded	78	65	61	74	76
	5% Degraded	79	65	62	75	77
	10% Degraded	80	67	63	76	79

Table 5.11: Summary of calculated subbasin parameters for HEC-HMS.

Daily flow (m^3/s) data for four available stream gauges (H3H005, H3H011, H3H013 and H3H015) was input into the HEC-HMS model. The flow data for March 2003 was used as the observed flow of four river reaches represented in the basin model. Land degradation data for 2000 was extracted from the ENPAT 2000 database.

5.4.4.2 HEC-HMS Meteorologic Model

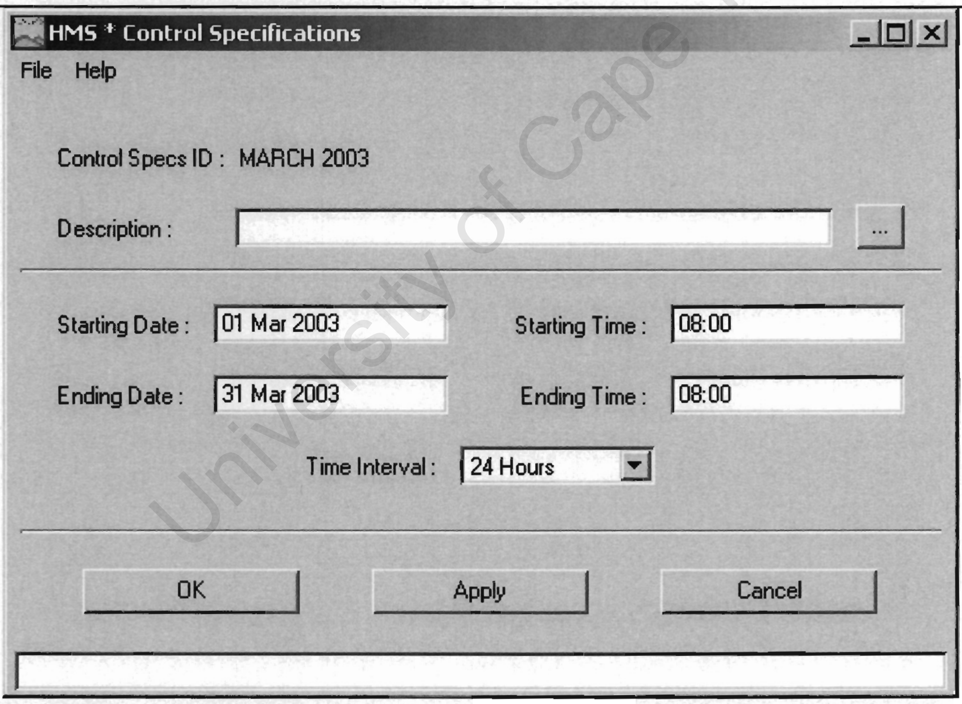
The meteorologic model was established using daily rainfall data for the two available rain gauges in the Kogmans River catchment for March 2003 – Goudmyn (ISCW) and Monatgu (SAWS). The daily rainfall data were entered into the meteorologic model using the so-called User Gauge Weighting method. This requires rainfall data (mm) and mean areal precipitation gauge weightings as well as a temporal gauge weighting for recording gauges. The mean areal precipitation gauge weightings were determined using the Thiessen's Polygon method (USACE, 2000) and the calculations were performed using Arcview 3.1 (**Table 5.12**).

Rain Gauge	**Total Rainfall** (mm)	**Area of Polygon** (%)	**Gauge Weights**	**Weighted precipitation** (mm)
Goudmyn	236.70	53.80	0.54	127.34
Montagu	241.00	46.20	0.46	111.34
Total		100		238.69

Table 5.12: Thiessen's polygon rain gauge weights.

5.4.4.3 HEC-HMS Control Specifications

The control specifications (**Figure 5.11**) set the time parameters within which a run or simulation is computed. The control specifications were set for the month of March 2003 with a daily time interval.



Control Specs ID : MARCH 2003

Description :

Starting Date : 01 Mar 2003

Starting Time : 08:00

Ending Date : 31 Mar 2003

Ending Time : 08:00

Time Interval : 24 Hours

Start date	1 March 2003	End date	08:00
Start time	31 March 2003	End time	08:00
Interval		24 hours	

Table 5.13: HEC – HMS Control Specifications.

This chapter has outlined the methodology used for this study. Chapter Six presents the results and discussion of the analysis of the aerial photography, satellite imagery, the state and composition of the riparian zone and the hydrological modelling component of the study.

Chapter Six

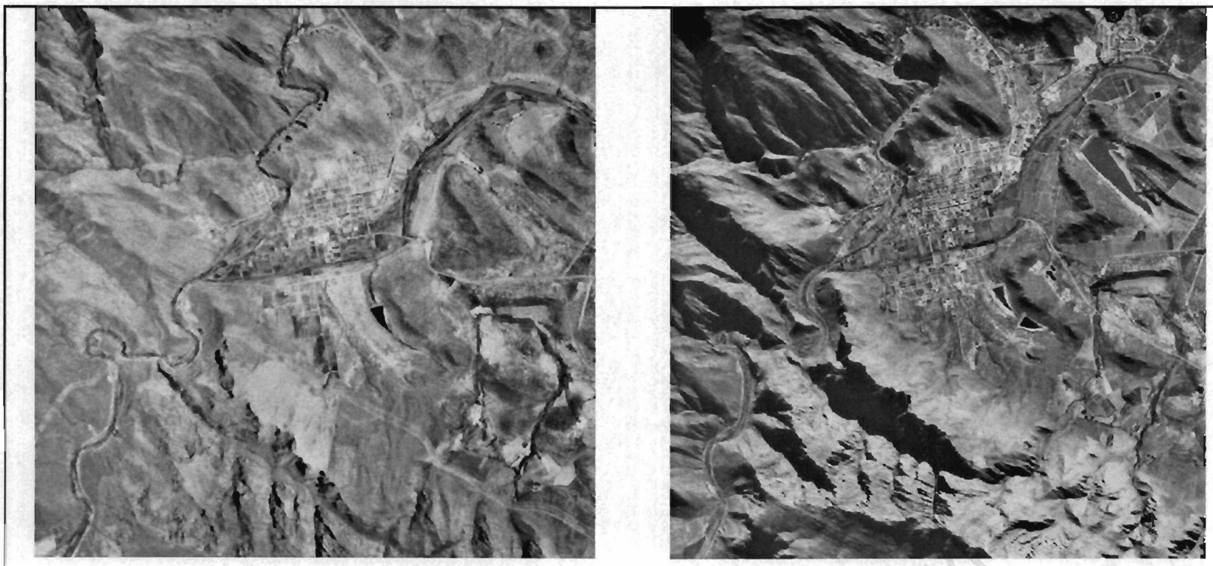
Results and Discussion

6.1 Time Series Analysis using Aerial Photography

The time-series analysis using aerial photographs has revealed that the town of Montagu (which is the major urban area in the catchment and highest at risk of flooding) had increased in area over the period in question by 112.6% (i.e. from 5.76km² in 1960 to 12.25km² in 1999 (DiMP, 2003). In the same 39-year period, land under cultivation has remained relatively stable, decreasing by just 0.74% or 0.85km² from 114.6km² in 1960 to 113.75km² in 1999 (DiMP, 2003).

Although urban areas constitute only a small percentage of the total catchment area, the urban development that has seen Montagu double in size over the 39 year period is indeed significant (**Figure 6.1**) (DiMP, 2003). In particular, as a result of its location at the confluence of the Kingna and Keisie Rivers, the increase in urban area has made the town more vulnerable to flood damage (DiMP, 2003). The town has expanded across both the Kingna and Keisie and with it the network of water, sanitation and electric supply (DiMP, 2003). This has increased the threat to property, which in turn has an effect on insurance, particularly in the aftermath of a disaster (DiMP, 2003). The urban expansion has also required the construction of bridges and roads across both rivers, increasing the potential for serious primary infrastructural damage (DiMP, 2003).

However, from a wider perspective, the analysis has shown that land-use change has been negligible during the past 40 years or so (DiMP, 2003). With the exception of the fact that the town of Monatgu has expanded significantly, no significant wholesale change has occurred elsewhere in the area of the Kogmans River catchment analysed (DiMP, 2003). It is, however, unclear whether there have been any significant changes in land-use practice. Land under orchards and vineyards, for example, will exhibit better drainage, undergo improved weeding management and experience increased irrigation, all of which affect the antecedent soil moisture and runoff.



Source: CDSM

Montagu, 1960

Source: CDSM

Montagu, 1999

Figure 6.1: Aerial photographs of Montagu illustrating the urban development:1960-1999.

The town of Ashton, on the southern side of the Kogmanskloof displays a similar trend of change. The time series analysis revealed that the town itself has increased is size from 4.9km² in 1960 to 8km² in 1999, an increase of approximately 64.6%. Cultivated land, in turn, has increased by approximately 7.1km² or only 8.1%. The urban expansion in Ashton has seen the town develop to the north-east along the R62 and away from the Kogmans River. Ashton is still vulnerable to flooding, however, the town's risk of large-scale destruction as a result of flood waters is far lower than that of Montagu.

6.2 Moving Standard Deviation Index (MSDI)

The Moving Standard Deviation Index (described in section 5.2.2 and 5.2.2.1 of the previous chapter) was applied to two near anniversary red band images - a 1972 Landsat MSS image (acquired on 07 November) and a 2003 Landsat TM image (acquired on 30 November). The resultant images (**Figure 6.2**) were divided into 80 standard deviation classes with the low values representing no or little degradation and the higher values representing significant disturbance.

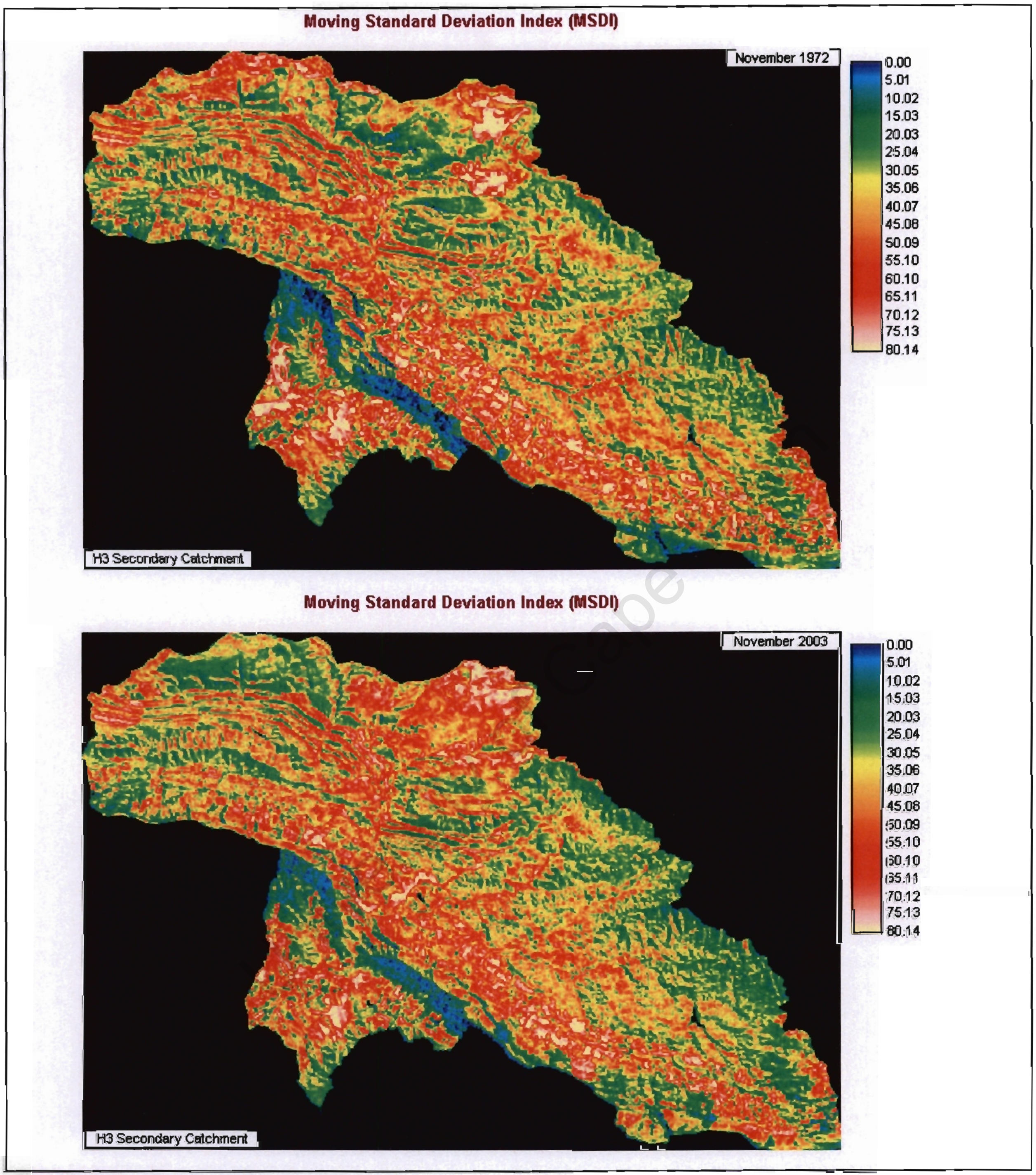
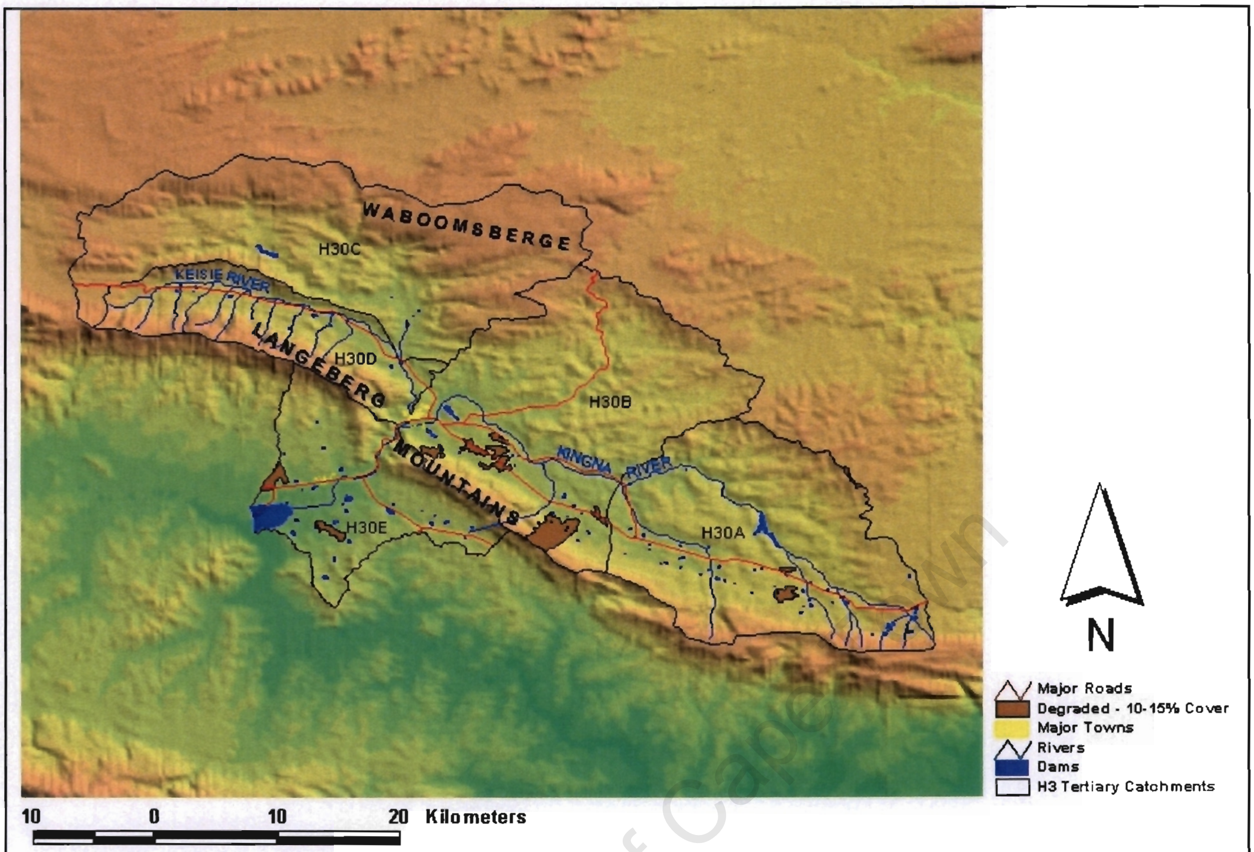
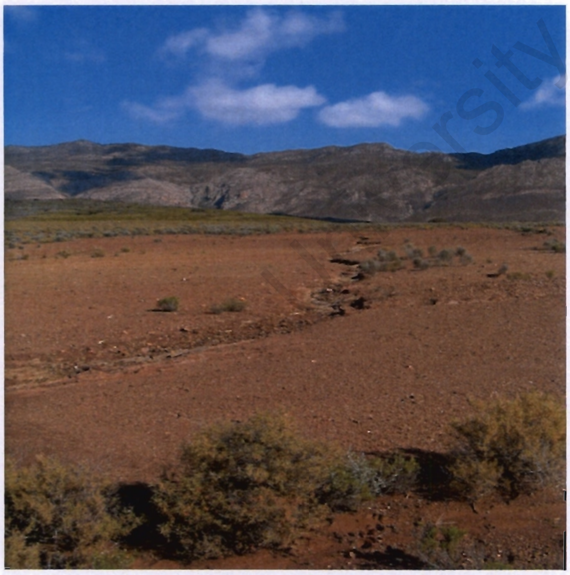


Figure 6.2: MSDI for 1972 and 2003.

Aerial photographs from 1972 were used to verify the 1972 MSDI results, and field visits in late 2004 as well as ENPAT 2000 data were used to verify the 2003 MSDI results (**Figure 6.3**).



Source: ENPAT 2000



Source: Field visit, August 2004

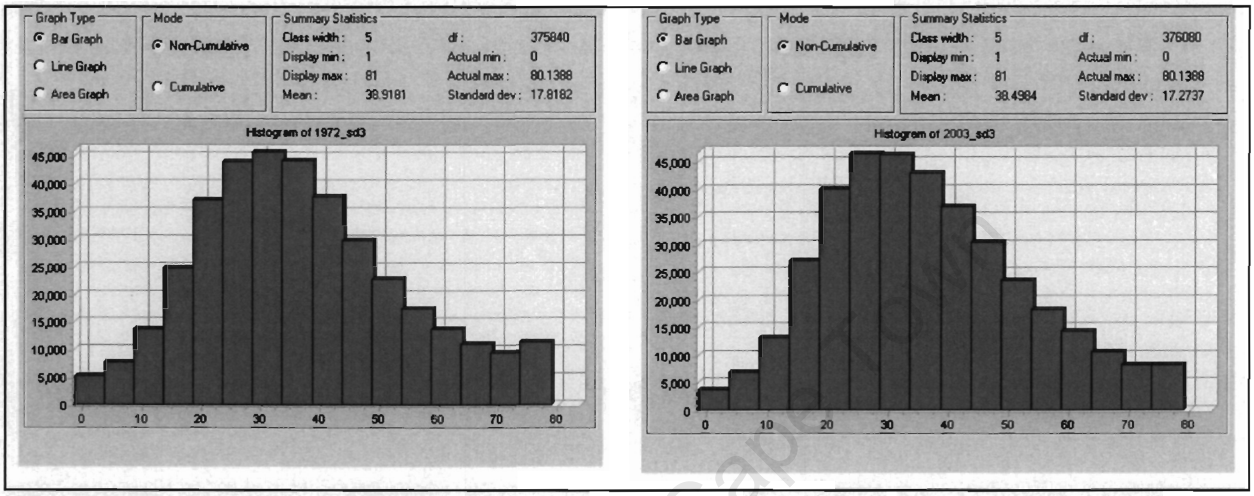
"Badlands" along the R62 just outside Montagu.

Source: Field visit, August 2004

"Badlands" along the R62 just outside Montagu.

Figure 6.4: Data used to verify MSDI results for 2003

The results of the MSDI show that over the 29 year period in question, conditions, in respect to degradation, seem to have improved in the catchment as a whole. Significantly, severe degradation (~standard deviation class 75 – 80) seems to have decreased from over 10000 pixels in 1972 to around 8000 pixels in 2003. **Figure 6.4** shows the histograms of the two images analysed showing the pixel value per standard deviation class with a class size of 5.



Graph Type
● Bar Graph
○ Line Graph
○ Area Graph

Mode
● Non-Cumulative
○ Cumulative

Summary Statistics
Class width : 5
Display min : 1
Display max : 81
Mean : 38.9181
df : 375840
Actual min : 0
Actual max : 80.1388
Standard dev : 17.8182

Graph Type
● Bar Graph
○ Line Graph
○ Area Graph

Mode
● Non-Cumulative
○ Cumulative

Summary Statistics
Class width : 5
Display min : 1
Display max : 81
Mean : 38.4984
df : 376080
Actual min : 0
Actual max : 80.1388
Standard dev : 17.2737

Figure 6.4: Histograms of MSDI Images –1972 and 2003 (the pixel value per standard deviation class).

Referring back to **Figure 6.2**, it is evident that on the northern slopes and foothills of the Langeberg Mountains, conditions remain poor in terms of disturbance and degradation. This can be attributed to the shallow soils and sparse vegetation cover that characterise the steeper, higher altitude slopes and the observed degradation of the lower foothills. Similarly, conditions south of the Kogmanskloof, in the vicinity of Ashton, remain relatively poor. Elsewhere, on the north west boundary of the catchment, conditions have improved, while further east in the Waboomsberge there is evidence of increased disturbance. The area around Montagu also shows increased disturbance, which can be ascribed to the town's expansion during the 29-year period in question.

Although the catchment conditions, in terms of landscape degradation and disturbance (based on the MSDI images), seem to be stable or even reversing, the study area continues to be at risk of degradation in its many forms. Vegetation degradation, in the form of alien plant infestation, is a serious problem in the Kogmans River catchment. And, although the presence of alien vegetation should result in a decrease in runoff, their presence in the riparian zone undermines the stability of the river banks, as woody alien vegetation replaces grasses and other herbaceous vegetation thus causing increased erosion and sedimentation and altering the bank morphology (Rowntree, 1991).

6.3 The Riparian Zone and In-stream Vegetation

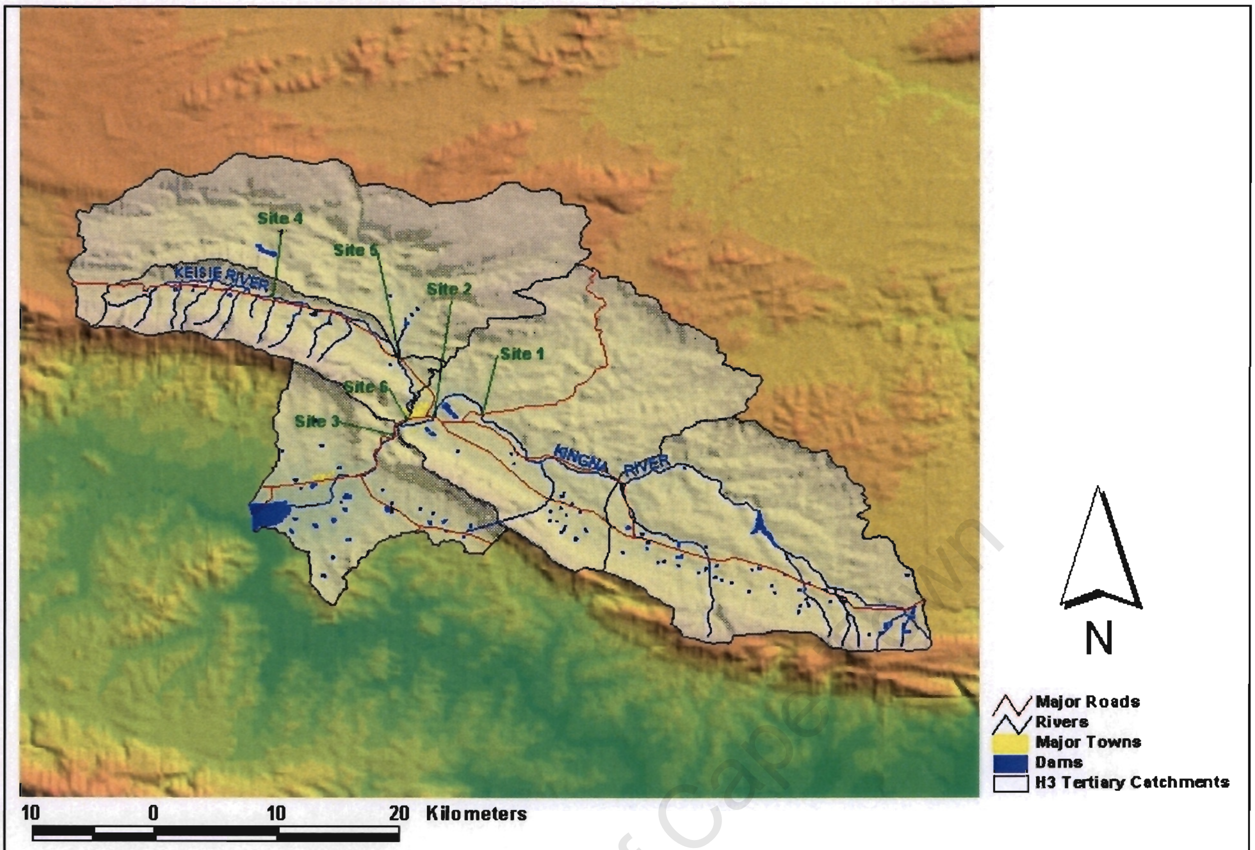
Analysis of the 2000 land-use data mapped by the Breede River Basin Study revealed that of the 178.69km of river bank and 7.15km² (178.69km x 0.04km of potential riparian zone) of riparian zone along the major rivers (Groot, Keisie, Kingna, Kogmans and Pietersfontein) and their main tributaries in the Kogmans River catchment, 3.48km² (48.67%) were occupied by natural riparian plant communities. A total of 2.86 km² (40.14%) was shown to have been invaded by alien plant species and the remaining 0.8 km² (11.19%) of the riparian zone has been replaced by vineyards or stone fruit orchards.

Field work in August and September 2004 helped to determine the composition and health of the riparian zone at various locations along both the Kingna and Keisie Rivers. In addition, the rampant growth of *Phramites australis* was also investigated as it was clear that the dense stands of common reeds played a major role in elevating the flood levels and causing extensive damage to primary infrastructure.

6.3.1 Description of the Riparian Zone Vegetation In-stream Vegetation

Six sites - three along the Kingna River and three along the Keisie River – were visited and described according to their current state and species composition (**Figure 6.7**).

The sites were limited to locations accessible from both the R62 and the R318. All observations were orientated looking downstream. **Table 6.1** provides a summary of the observations made at each site.



Source: BRBS, CDMS & ENPAT 2000

Figure 6.5: Location of sites visited along the Kingna and Keisie Rivers

Observations in the lower reaches of the rivers draining the Kogmans River catchment show that, under natural or undisturbed conditions (Site 3), the riparian zone is made up of predominantly *Acacia karoo* , *Rhus* sp., what is known as '*Karoo num-num*' ., sand olive and wild olive on the outer limit of the zone. *Phragmites australis* dominates the river channel and lower banks at Sites 1-4 and at 6. At Site 5, *Phragmites australis* is less prominant, but still present. Agricultural crops (vineyards and stone fruit orchards) have been cultivated right to the edge of the river banks at Sites 1,2, 4 and 5. Beefwood trees are planted near the banks to create a windbreak (Site2).

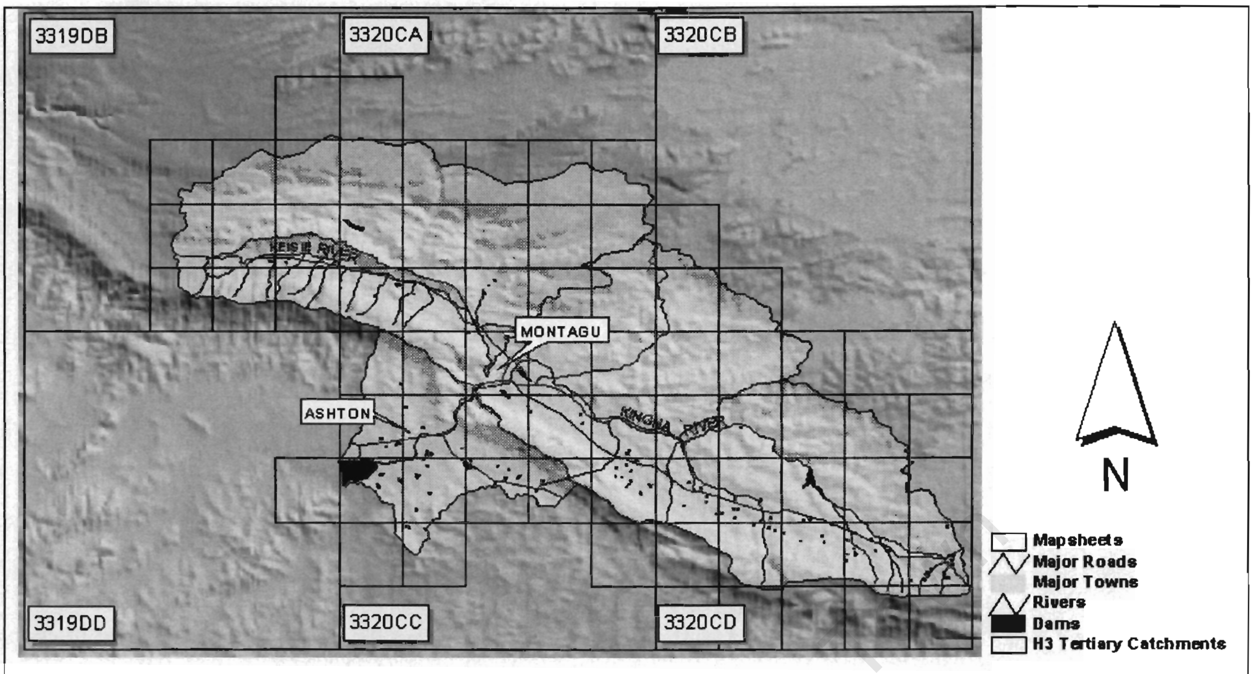
River	Site and Description	Riparian Zone	River Channel
Kingna	Site 1 - low water crossing (off the R62 near Helpmekaar)	- Agriculture: Apricots/Citrus (right bank) & Viticulture (left bank) - *Acacia karoo* (sparse) - Alien sp.: N*icotiana glauca*	- *Phragmites australis* (left bank)
	Site 2 - bridge on R62 (towards Barrydale)	- Agriculture: urban small holdings, vineyards, fruit trees & beefwood trees (windbreak) - *Acacia karoo* (sparse) - *Rhus lancia (sparse)* - Alien sp.: *Acacia cyclops* (left bank)	- *Phragmites australis* (dense stands) - *Typha capensis (sparse)*
	Site 3 - Kogmanskloof (Montagu)	- *Acacia karoo., Rhus* sp., *Karoo num-num* sp., sand olive and wild olive - Alien sp.: *Arundo donax* (sparse – in the process of being cleared)	- *Phragmites australis* (dense in channel; sparse in shade of *Acacia karoo* sp. near the banks)
Keisie	Site 4 - bridge on road to Pietersfontein Dam)	- Agriculture: mixed (vineyards & orchards) - *Acacia karoo* sp. (sparse) - Alien sp.: *Ricinus communis L.*	- *Phragmites australis* (dense stands)
	Site 5 - bridge on R318 after the warmbaths (towards Towsrivier)	- Fallow agricultural land (sparse grass cover)	- *Phragmites australis* (sparse)
	Site 6 – low water crossing at the Ou Meul in Montagu	*Acacia karoo* sp. (sparse)	- *Phragmites australis* (dense stands)

Table 6.1: Observations of Riparian and in-stream vegeation.

Alien plant species were noted at four of the six locations visited (Site 1 - 4). As noted earlier in this section, Alien vegetation infests approximately 40% of the riparian zone along the major rivers in the catchment. The South African Plant Invader Atlas (SAPIA), compiled by Dr. Henderson of the Weeds Division of the Agricultural Research Council (ARC) - Plant Protection Research Institute, provides information on the patterns of occurrence of alien weed and plant species within the Kogmans River catchment by quarter degree squares. The SAPIA data indicate that the watercourses in the Kogmans River catchment are invaded by a variety of alien weed and plant species exhibiting significant abundance in various parts of the catchment. **Table 6.2** lists alien weed and plant species by mapsheet (**Figure 6.8**) occurring in the Kogmans River catchment.

Botanical Name	Common Name	Type	Invades	Map Sheet
Acacia cyclops A.Cunn. ex G.Don	Rooikrans	Invader	Fynbos, forest gaps, dunes, roadsides, watercourses	3320CC
Acacia mearnsii De Wild.	Black Wattle	Invader	Grasslands, forest gaps, roadsides and watercourses	3319DB 3320CC 3320CD
Acacia pycnantha Benth.	Golden Wattle	Weed	Coastal and mountain fynbos, rivers and roadsides.	3319DB
Acacia saligna (Labill) H.L.Wendl.	Port Jackson Willow	Invader	Fynbos, Woodland, coastal dunes, roadsides and watercourses	3319DB 3320CC 3320CD
Arundo donax L.	Giant Reed, Spaanse Riet	Weed	Watercourses (and roadsides)	3320CA 3320CC 3320CD
Eucalyptus camaldulensis Dehnh	Red River Gum	Invader	Perennial, seasonal and intermittent watercourses	3319DB 3320CD
Nicotiana glauca Graham	Wild Tobacco	Weed	Roadsides, road cuttings, wasteland, riverbanks and riverbeds	3320CA 3320CB 3320CC
Populus X canescens (Aiton) Sm.	Grey Poplar	Invader	Riverbanks, vleis and dongas	3319DB
Quercus robur L.	English Oak	-	Forest margins, woodlands, roadsides and river banks in grassland and fynbos	3320CD
Ricinus communis L.	Castor-oil Plant	Invader	Riverbanks, river beds, roadsides and wasteland	3320CA 3320CC 3320CD

Table 6.2: Alien Plant Species by map sheet (Henderson, 2001).



Source: BRBS, CDMS & ENPAT 2000

Figure 6.8: Mapsheets covering the Kogmans River catchment

The significance of the alien infestation of the riparian zone is two-fold. Firstly, as woody alien vegetation begins to establish itself on the banks of a river, it begins to alter the natural vegetation composition that is crucial to bank stablilty (Rowntree, 1991). Natural grasses and other herbaceous plants are low in biomass and have a shallow rooting system, but they provide dense cover and a near-surface root mat that enhances the stability of the banks against scour (Rowntree, 1991). Alien woody species, in contrast, provide poorer ground cover and lack a dense surface root mat (Rowntree, 1991). In addition, many woody alien species including *Acacia mearnsii* and *A. saligna*, found in the Kogmans Catchment, form dense canopies which inhibits undergrowth and leads to poor surface cover which is prone to erosion (Rowntree, 1991). These species also tend to have shallow root systems that are unable to withstand flash floods which enhances the risk of bank collapse (Rowntree, 1991). This is significant since much of the damage caused by the floods in Montagu were as a result of reeds and trees that were uprooted and washed down the river.

Secondly, the presence of alien vegetation decreases the net amount of runoff reaching the stream or river. As noted in Chapter One of this research, alien plant species utilise more water than the indigenous, drought resistant fynbos vegetation. Recent studies by Van Wilgen, Cowling and Burgess in Meadows (1998a) have compared the effects on the hydrological output of two hypothetical mountain fynbos catchments, one with exotic tree removal as a management strategy, the other without (Meadows, 1998a). The results revealed a 30% improvement in run-off in the managed catchment (Meadows, 1998a).

6.3.2 Potential Causes of Dense *Phragmites australis* Reed Stands in the Kogmans River Catchment

It is evident from the floods in March 2003 and the observations made by the author during field visits to the study area, that the extensive and dense stands of *Phragmites australis* in and along the rivers that drain the Kogmans River catchment increase the risk of severe infrastructral damage and significantly elevated water levels during a flood event. The cause of the widespread growth of this perennial macrophtye has both historical and contemporary contexts, attributed to both human interference in and management of the riparian and river environment as well as change in local microclimate.

Historically, the increase in the distribution and density of *P. australis* in the Kogmans River catchment could be ascribed to the eradication of larger mammalian herbivores from the riverine environment with the arrival of the first settlers to the area. Research into the impact of early colonial settlement at Verlorenvlei, on the west coast of South Africa, conducted by Baxter and Meadows (1994) found that the progressive increase in pollen, attributed to the reed *Typha capensis* was caused, in part, by the local extinction of Hippopotami (*Hippopotamus amphibius*). According to Skead (1980), the Breede River basin would have been ideal habitat for hippos, although only sporadic references exist in historical texts to confirm their presence in the area. One can only presume that they were locally eliminated soon after the arrival of European settlers in the area (Skead, 1980). Hippopotami are known to play a vital role in the control and preservation of riparian and wetland vegetation, including the maintenance of open waterways through constant channel disturbance (Baxter and Meadows, 1994).

More recently, however, the establishment of intensively cultivated agricultural lands along the banks of the Kingna and Keisie Rivers has played a significant role in the density of *P. australis* in the river channel. Agricultural water demand, estimated at a theoretical value of 65.8 million m^3/annum (DWAF, 2003e), and the construction of large impoundments and pumping schemes has placed a great burden on the natural flow of rivers within the catchment. As mentioned in Chapter Three, sustained periods of low flow, exacerbated by drought, have been shown to be closely linked to the vigorous growth of *P. australis* reed beds (Haslam, 1970, Ostendorp, 1991; James *et al*, 2002)

A further possible impact of agriculture on the extensive growth of *P. australis* in the Kogmans River catchment can be attributed to the nutrient enrichment of streams and rivers flowing through intensively cultivated lands. According to a water quality assessment conducted by the Department of Water Affairs and Forestry (DWAF) as part of the Breede River Basin Study (BRBS) (2003f), along the Keisie and Kogmans rivers, both river reaches were found to be moderately enriched with nutrients, with some phosphorus and nitogen levels exceeding the upper limit required to generate eutrophic, hypotrophic and mesotrophic conditions.

Finally, as mentioned in the previous section, the presence of alien vegetation along the banks of the river system decreases the amount of net runoff and groundwater supply reaching the stream or river.

6.3.3 Potential Consequences of Dense *Phragmites australis* Reed Stands in the Kogmans River Catchment

Vegetation is a critical component of the river ecosystem influencing the rate, extent and location of erosion and deposition within a river, as well as influencing the velocity and level of flow within a channel. For example, in extensively reeded wetlands and partially reeded rivers, the resistance to flow imposed by reeds determines flood levels and velocities (James *et al*, 2002), which, in turn, influence the rate of deposition of silt (Gordon *et al*, 1997). The deposition of silt encourages the growth of vegetation and thus a complex feedback system is created between vegetation, flow and the processes of deposition and erosion with a river system.

This complex feedback system has important implications during flood events, specifically when the system is out of balance. In particular, the presence of large amounts of aquatic plants or macrophytes is often undesirable, since they retard the water flow encouraging siltation (Thornton *et al*, 1997), and cause waterlogging of adjacent land, increasing the threat of flooding during high flow periods (Gordon *et al.*, 1997).

During the March 2003 floods, the *Phragmites australis* reed beds retarded the velocity of storm flow and flooded acres of agricultural land, destroying crops and infrastructure and removing large amounts of valuable topsoil. Many reed beds were uprooted and washed down the Kingna

River along with large quantities of sediment trapped by the reeds. **Figure 6.9** shows a portion of a the reed bed (along the Kingna River) that remained intact during the floods illustrating the elevated streambed formed as a consequence of reduced boundary shear that induced deposition.

Source: Field visit, August 2004

Figure 6.7: Portion of a reed bed (along the Kingna River) that remained intact during the floods illustrating the elevated streambed indicated by the arrow.

6.4 Hydrological Modelling

A total of seven simulations or runs were performed to determine change in run-off with increases in urbanisation and degradation in the Kogmans River Catchment (**Table 6.3**). Changes in discharge with urbanisation were estimated by increasing the percentage impervious area for the three most urbanised subbasins in the catchment – H30B, D and E – likely to experience further development, whether residential or commercial. Changes in discharge for increases in degradation were estimated by increasing the area of shrubland/fynbos considered to become degraded in the future.

Although the peak discharge value generated for March 2003 in the HEC-HMS model underestimates the actual recorded discharge (from gauge number H3H011) by approximately 16%, the values still reflect significant rates of discharge that would most certainly cause flooding in the catchment in its present condition. This discrepancy is due to the fact that the model can only approximate catchment conditions and storm intensity, duration and spatial context. The Curve Number method is known not reproduce measured runoff from specific events accurately as the Curve Number procedure was developed primarily as a design methodology (Woodward *et al*, ND).

Run	Catchment Condition	Discharge	Peak Discharge	
		Volume (10^3 m³)	m³/sec	% Increase
1	**March 2003**	**181235**	**924.58**	
2	3% Urbanised (impervious)	181890	926.84	0.24
3	5% Urbanised (impervious)	182927	930.37	0.63
4	3% Degraded	184241	936.63	1.30
5	5% Degraded	186760	945.98	2.31
6	10% Degraded	191426	964.61	4.33

Table 6.3: Results generated from HEC-HMS.

The results generated for increases in degradation showed that the condition of the landscape has a greater influence on the rate of discharge than increases in urban area (impervious area). Due to the catchment's steep topography, shallow soils and sparse vegetation, particularly on the slopes of the Langeberg, it is highly likely that much of the storm runoff is generated here. An increase in the proportion of degraded land in the foot slopes of the Langeberg would increase the amount of overland runoff reaching the river systems within the catchment. The establishment of agricultural crops right on the river bank (**Figure 6.10**) further promotes the amount of runoff reaching the rivers in the catchment.

Source: Field visit, April 2003

Figure 6.10: Agricultural land – cultivated and fallow – right of the banks of the Keisie River.

Chapter Seven

Conclusion

Land-cover and land-use change is an important component of environmental change that is studied and monitored globally by various academic, state and non-governmental research institutions, including the United Nations Food and Agriculture Organisation (FAO), Africover Initiative, the NASA Land Cover Land Use Change Program, the Land Use and Land Cover Change Project (LUCC) and many more. Of significant importance, is the role that changes in land-cover and land-use have on the hydrology of an area or catchment. Research into this aspect of land-cover and land-use change is happening both globally (Nagasaka and Nakamura, 1999; Fohrer, *et. al.*,2001; Bronstert, Niehoff and Bürger, 2002) and locally (Schulze, 2000).

In line with studies done elsewhere, the aim of this research was to investigate the extent to which catchment land-use and land cover change influences the severity of floods in the Kogmans River Catchment. In particular, this relationship was explored in the context of urban expansion, land degradation, and changes in the riparian zone. To address the broad aim, a set of objectives were outlined and various quantitative and qualitative methodologies were utilised to investigate these. The results highlighted the complexity of catchment dynamics within the study area as well as the need for further study using better data.

The first objective of the study was to determine and describe the nature and extent of landscape changes within the catchment over time. Land-use and land-cover change (with particular reference to urbanisation and land degradation) within the Kogmans River catchment was investigated using both aerial photography and satellite remote sensing. Analysis of the aerial photography confirms that the town of Montagu has expanded significantly in the last 30 years. Due to its location at the confluence of the Kingna and Keisie Rivers this urban growth, which has seen the town expand across both the Kingna and Keisie Rivers, significantly increases the town's vulnerability during flood events. The issue of land degradation was addressed using the Moving Standard Deviation Index to detect landscape disturbance using two Landsat images from November 1972 and November 2003. The results of the MSDI showed that the overall catchment conditions seem to have improved over the 31-year period, although the catchment remains quite degraded. Land degradation is also not the only form of degradation evident within the catchment. Vegetation degradation, in the form of alien plant infestation, is a serious problem in the Kogmans River catchment.

The next objective was to describe the management, current state and composition of the riparian and riverine vegetation with the Kogmans River catchment. Information from interviews with farmers (conducted by DiMP), field visits and GIS data helped to provide a picture of the current state of the riparian zone and riverine vegetation, its management by both farmers, the State and conservation authorities as well as its significance in during the floods that affected the Kogmans River catchment and much of the south Cape region in March 2003.

The findings showed that much of the riparian zone vegetation was either replaced by agricultural crops or infested with alien vegetation. Furthermore, the prolific growth of the Common Reed *Phragmites australis* was shown to have had a significant role in elevating flood levels during the March 2003 floods and facilitating the destruction of bridges and roads as well as possibly increasing the sediment load of the flood waters.

Finally, a hydrological model was utilised to determine the influence of increasing land degradation and urbanisation on the total discharge of the catchment in response to an extreme rainfall event. Although the results are coarse and delivered values that underestimate the actual discharge, increases in both urbanisation and land degradation were reflected in increases in the total catchment discharge.

7.1 Limitations

Whilst the methodology employed in this study managed to address the broad aim and objectives of this study, there are some limitations. Access to adequate and suitable data proved a major limitation to this study. So too was access to suitable software to analyse the data. Originally, the satellite remote sensing component of this study was to involve time series analysis to isolate specific changes within the catchment. However, a suitable digital terrain model (DTM) was not available to perform a topographic normalisation of the satellite images. In addition, the available software (ENVI 3.4 RT and an evaluation version of ERDAS Imagine 8.6) was unable to perform the adequate topographic correction (i.e. Cosine method, Minnaert Constant or C-factor correction). The satellite data was also not ideal for comparison because the available images were not anniversary images and were captured using different sensor technology.

The hydrological modelling component of this study was also hindered by the lack of available data. No routing, groundwater flow or evaporation data was available for Kogmans River catchment and the weekly reservoir data was not compatible with the daily rainfall and observed flow data. The NRCS (SCS) loss model used to generate discharge values in response to increases in urbanisation and degradation produced coarse results due to the fact that the model has not been extensively tested in larger catchments and is known not reproduce measured runoff from specific events accurately due to the fact that the Curve Number procedure was developed primarily as a design methodology (Woodward *et al*, ND). The NRCS (SCS) loss model is also unable to simulate subsurface flow, which represents a significant proportion of the total runoff in the Western Cape. In addition, the results generated by the hydrological model were unable to link the results of the satellite analysis. With more time and better resources, the modelling could have been conducted in a more distributed fashion in order to generate more specific results for specific areas within the catchment as opposed to the general results generated in this study for the whole catchment. The loss model also requires a certain amount of subjective input from the user, particularly in the designation of land-cover categories which has a significant influence on the Curve Number. A 'spin-up' of the rainfall runoff model for the months (ideally one hydrological year) preceding the event would have lessened the soil moisture's dependence on initial values, however the combination of lack of data, time and expertise meant that this was not possible in the hydrological component of this research.

Finally, there was not quantitative methodology available to analyse changes in the riparian zone and the growth of *Phragmites australis.* High-resolution satellite imagery (e.g. Quickbird imagery at 2.40/2.80m resolution) would have been suitable for a more quantitative approach, however the cost of such imagery was prohibitive. With more time, it would have been useful to assess the channel morphology and roughness, both of which inform the state of the riparian in-stream vegetation.

Generally, the results presented in this research provide a sound basis for further study into the impact of urbanisation and land-use and land-cover change in the Kogmans River catchment.

7.2 Further Considerations

In the context of urban growth and the influence future of climate change, the results of this research warrant further study into the risk of flooding in the Kogman's River catchment. The town of Montagu in the Kogmans River catchment shows a steady annual population growth rate 2% (DWAF, 2003c). As mentioned earlier, this growth combined with the Montagu's location at the confluence of two rivers draining a relatively degraded, high energy catchment, significantly increases the risk of extreme weather events triggering high magnitude floods, increasing the risk of severe damage to infrastructure and property at a massive financial cost, and the potential of loss of life, both directly (e.g. drowning) and indirectly (e.g. health problems as a result of damage to sanitation infrastructure) as a consequence of the flooding.

Climate change is another factor that needs to be considered. According to the Intergovernmental Panel on Climate Change (IPCC), precipitation is projected increase globally, but decrease regionally during the 21st century (IPCC, 2001b). In southern Africa, it is highly likely the total winter rainfall figures will decrease by 5% - 20% (IPCC, 2001b). This will likely cause drought conditions to prevail over much of the region influencing, among other things, the nature and density of surface vegetation cover. This has serious implications when coupled with the fact that extreme weather events, including more intense rainfall events, are projected to occur more frequently as a result of climate change (IPCC, 2001b). Flood magnitude and frequency could increase as a result (IPCC, 2001a) which will have serious consequences for the town of Montagu.

This study helped outline some of the possible causes for the severity of the March 2003 floods. Montagu will always be at risk of flooding due, primarily to its location at the confluence of two rivers in a high energy catchment. There are no definitive answers as to what could have been done to limit the effect of the intense rainfall and subsequent runoff experienced in the area in late March 2003. However, all the issues highlighted warrant further inspection, especially the role of *Phragmites australis* reed beds and what could be done to control them without eliminating them from the rivers completely. Further study into the role of land degradation would be facilitated by better data and the same can be said modelling land-use and land-cover change within the catchment.

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APPENDICES

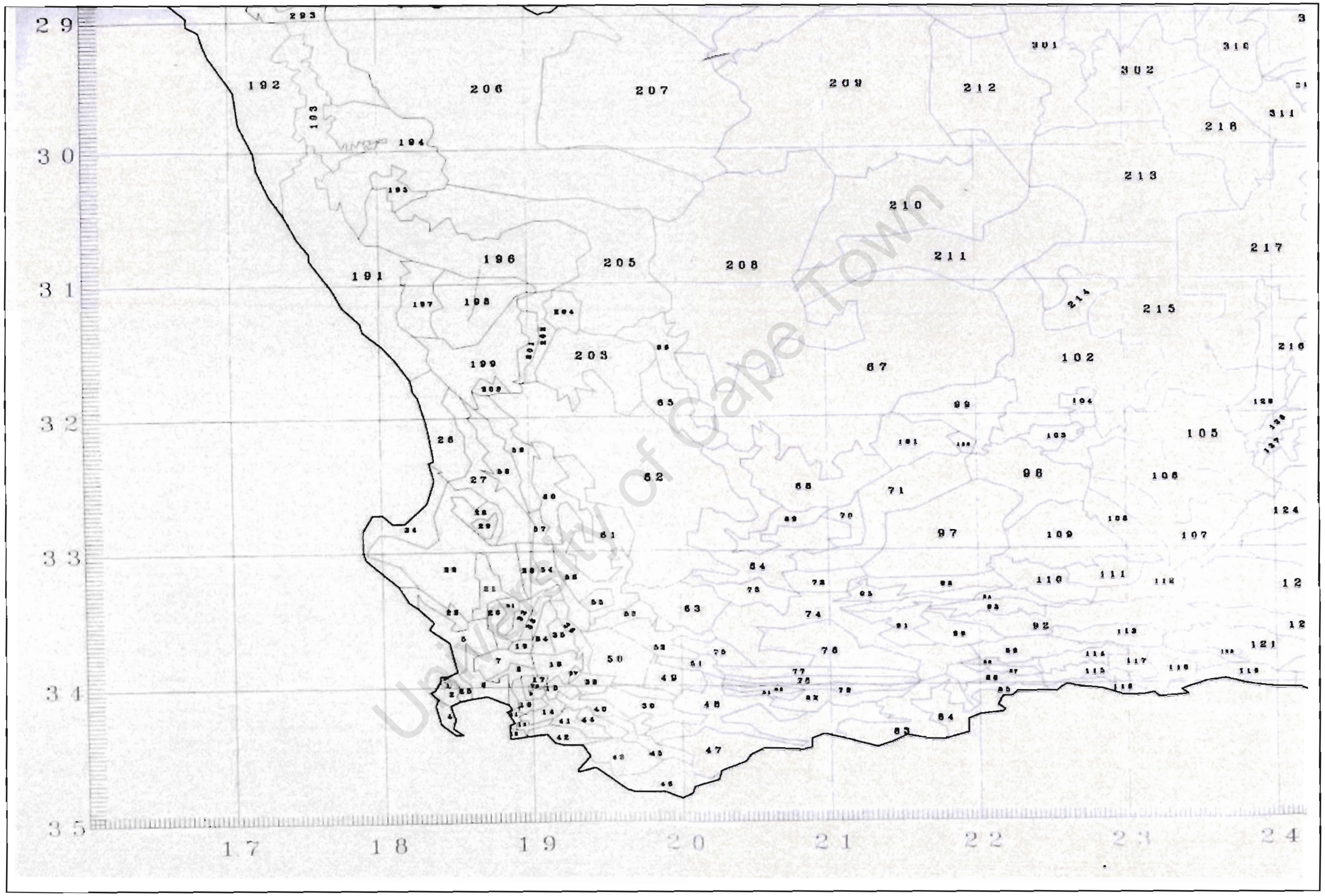
Appendix: 1

MSDI Macro file for Idrisi32 (provided by Dr. A. Palmer from the Agricultural Research Council (ARC) Range and Forage institute via e-mail, 2004).

```
SCALAR X IMAGE_NAME*X2*5*2
FILTER X X2*SX2*1
FILTER X IMAGE_NAME*SX*1
SCALAR X SX*2SX*5*2
SCALAR X 2SX*2SXDN*4*9
OVERLAY X 2*SX2*2SXDN*TOP
SCALAR X TOP*VAR*4*9
SCALAR X VAR*SD3*5*0.5
SCALAR X SD3*SD310*3*10
RECLASS X I*SD310*MTATSD*2*255*255*100000*-9999
CONVERT X MTATSD*MTATSD*I*3*2*2
```

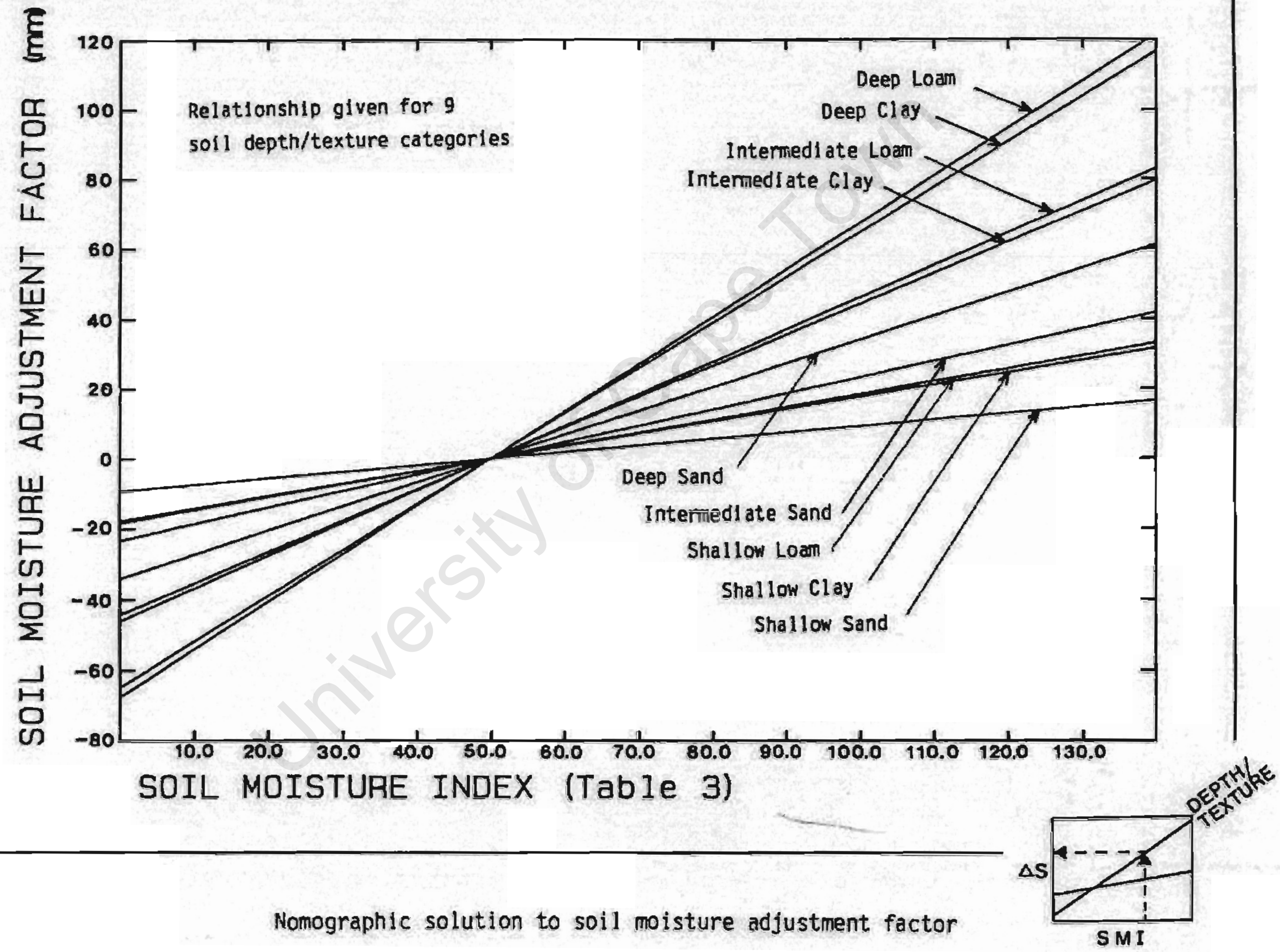
Appendix 2

Climatic zones of the south Cape and interior (Schmidt and Schulze, 1987)



Appendix 3

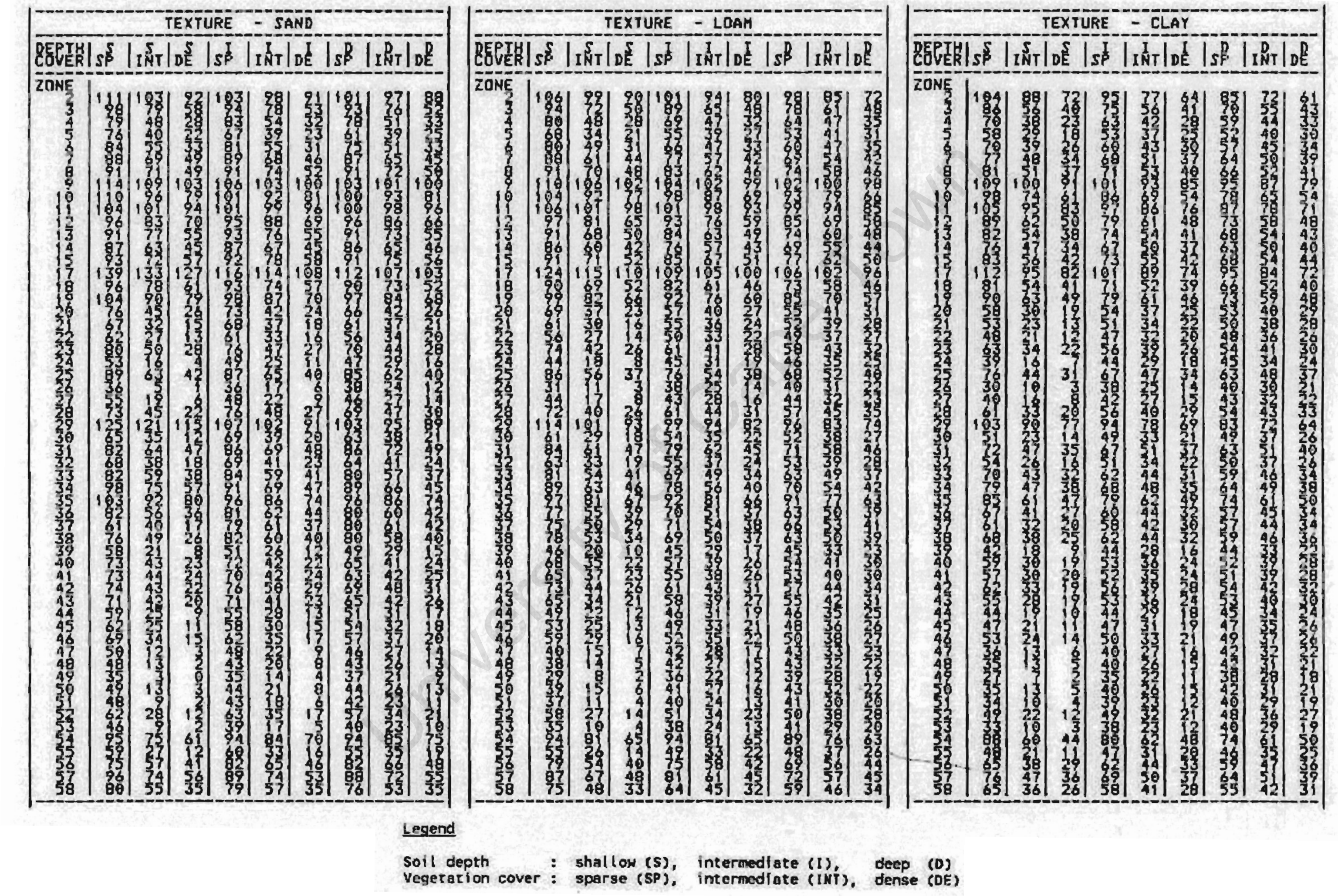
Nomographic Solution to the Soil Moisture Index Factor (Schmidt and Schulze, 1987)



Nomographic solution to soil moisture adjustment factor

Appendix 4

Soil Moisture Indices (Schmidt and Schulze, 1987)



TEXTURE - SAND

DEPTH COVER ZONE	S SP	S INT	S DE	I SP	I INT	I DE	D SP	D INT	D DE
2	111	103	92	103	98	91	101	97	88
3	98	79	58	74	78	53	93	76	52
4	79	48	28	83	54	32	78	51	33
5	76	40	22	67	39	23	61	39	35
6	84	55	33	81	55	31	75	51	33
7	88	69	49	89	68	46	87	65	45
8	91	71	49	91	74	52	91	72	50
9	114	109	103	106	103	100	103	101	100
10	110	96	79	101	92	81	100	93	81
11	104	101	94	101	99	96	100	98	96
12	96	83	70	95	88	69	96	86	66
13	91	77	55	93	76	55	91	73	55
14	87	63	45	87	67	45	86	65	46
15	93	72	57	92	78	58	91	75	56
17	139	133	127	116	114	108	112	107	103
18	96	78	61	93	74	57	90	73	52
19	104	90	79	98	87	70	97	84	68
20	76	45	26	73	42	24	66	42	26
21	67	32	15	68	37	18	61	37	21
22	62	27	13	61	33	16	56	34	20
23	80	50	28	76	37	27	70	44	28
24	53	16	4	47	25	11	47	29	16
25	89	63	42	87	65	40	85	62	40
26	36	5	1	36	17	6	38	24	12
27	55	19	6	48	22	9	46	27	14
28	73	45	22	76	48	27	69	47	30
29	125	121	115	107	102	91	103	95	89
30	65	35	12	69	39	20	63	38	21
31	82	64	47	86	69	48	86	72	49
32	68	38	18	69	41	23	64	41	24
33	82	59	38	84	59	41	80	57	37
34	98	75	57	91	69	47	89	66	45
35	103	92	80	96	86	74	96	86	74
36	82	56	39	81	62	44	80	60	42
37	61	40	17	79	61	37	80	61	42
38	76	49	26	82	60	40	80	58	40
39	58	21	8	51	26	12	49	29	15
40	73	43	23	72	42	22	65	41	24
41	73	44	24	70	42	24	63	42	25
42	74	43	22	76	58	29	69	48	31
43	71	42	20	71	41	23	65	42	26
44	59	25	9	55	28	13	51	31	17
45	62	25	11	58	30	15	54	32	18
46	69	34	15	62	35	17	57	37	20
47	50	12	3	48	22	9	46	27	14
48	48	13	2	43	20	8	43	26	13
49	35	3	0	35	14	4	37	21	9
50	49	13	3	44	21	8	44	26	13
51	48	9	2	43	18	6	42	23	11
52	62	28	12	63	35	17	57	34	21
53	46	9	2	39	17	5	40	23	10
54	95	75	61	94	84	70	94	85	75
55	59	27	12	60	33	16	55	35	19
56	75	57	41	82	65	46	82	66	48
57	96	74	56	89	74	53	88	72	55
58	80	55	35	79	57	35	76	53	35

TEXTURE - LOAM

DEPTH COVER ZONE	S SP	S INT	S DE	I SP	I INT	I DE	D SP	D INT	D DE
2	106	99	90	101	94	80	98	85	72
3	94	72	50	89	65	48	78	61	48
4	80	48	28	69	47	32	64	47	35
5	68	34	21	55	39	27	53	41	31
6	80	49	31	66	47	33	60	47	35
7	88	61	44	77	57	42	67	54	42
8	91	70	48	83	62	46	74	58	46
9	110	106	102	104	102	99	102	100	98
10	104	97	77	98	87	69	93	79	66
11	106	101	98	101	98	93	99	94	85
12	97	81	65	93	76	59	85	69	58
13	91	68	50	84	63	49	74	60	48
14	86	60	42	76	57	43	69	55	44
15	91	71	52	85	67	51	77	62	50
17	124	115	110	109	105	100	106	102	96
18	90	69	52	82	61	46	73	58	46
19	99	82	66	92	76	60	85	70	57
20	69	37	23	57	40	27	55	41	31
21	61	30	16	55	36	24	52	39	28
22	56	27	14	50	33	22	49	37	27
23	74	42	26	61	41	28	58	43	32
24	44	18	8	45	31	17	46	35	25
25	86	56	37	76	54	38	68	52	40
26	31	11	3	38	25	14	40	31	22
27	44	17	8	43	28	16	44	32	23
28	72	40	26	61	44	31	57	45	35
29	114	101	93	99	94	82	96	83	74
30	61	29	18	54	35	22	52	38	27
31	84	61	47	79	62	45	71	58	46
32	63	33	19	55	37	24	53	39	28
33	81	54	41	69	49	34	63	49	37
34	89	63	46	78	56	40	70	54	42
35	97	81	67	92	81	66	91	77	63
36	77	55	39	70	51	37	63	50	39
37	75	50	29	71	54	38	66	53	41
38	78	53	34	69	50	37	63	50	39
39	46	20	10	45	29	17	45	33	23
40	68	35	22	57	39	26	54	41	30
41	65	37	23	55	38	26	53	40	30
42	73	44	26	61	43	31	57	44	34
43	65	34	21	58	39	27	55	42	31
44	49	22	12	46	31	19	46	35	25
45	53	25	13	49	33	21	48	36	26
46	59	29	16	52	35	22	50	38	27
47	40	15	7	42	28	17	43	33	23
48	38	14	5	42	27	15	43	32	22
49	29	8	2	36	22	12	39	28	19
50	39	15	6	41	27	16	43	32	22
51	37	11	4	40	24	13	41	30	20
52	58	27	14	51	34	23	50	38	28
53	35	10	4	38	24	13	41	29	20
54	94	81	65	94	81	65	89	76	63
55	55	26	14	49	33	22	48	37	26
56	79	54	40	75	58	42	69	56	44
57	87	67	48	81	61	45	72	57	45
58	75	48	33	64	45	32	59	46	34

TEXTURE - CLAY

DEPTH COVER ZONE	S SP	S INT	S DE	I SP	I INT	I DE	D SP	D INT	D DE
2	104	88	72	95	77	64	85	72	61
3	86	56	40	75	56	41	70	55	43
4	70	38	23	63	42	28	59	44	33
5	58	29	18	53	37	25	52	40	30
6	70	39	26	60	43	30	57	45	34
7	77	48	34	68	51	37	64	50	39
8	81	51	37	71	53	40	66	52	41
9	109	100	91	101	93	85	95	87	79
10	98	74	61	86	69	54	78	65	54
11	105	95	83	97	86	76	87	78	71
12	89	62	50	79	61	48	73	58	48
13	82	54	38	74	54	41	68	54	43
14	76	47	34	67	50	37	63	50	40
15	83	56	42	73	55	42	68	54	44
17	112	95	82	101	89	74	95	84	72
18	81	54	41	71	52	39	66	52	40
19	90	63	49	79	61	46	73	59	48
20	58	30	19	54	37	25	53	40	29
21	53	23	13	51	34	22	50	38	28
22	48	21	12	47	32	20	48	36	26
23	63	34	22	56	39	26	54	41	30
24	39	16	7	44	29	18	45	34	24
25	76	44	31	67	47	34	63	48	37
26	30	10	3	38	25	14	40	30	21
27	40	16	8	42	27	15	43	32	22
28	61	33	20	56	40	29	54	43	33
29	103	90	77	94	78	69	83	72	64
30	51	23	14	49	33	21	49	37	26
31	72	47	35	67	51	37	63	51	40
32	54	26	16	51	34	22	50	37	26
33	70	43	32	62	44	31	59	46	34
34	79	47	38	68	48	35	64	49	38
35	83	61	47	79	62	49	74	61	50
36	67	41	27	60	44	32	57	45	34
37	61	32	20	58	42	30	57	44	34
38	68	38	25	62	44	32	59	46	36
39	42	18	9	44	28	16	44	33	22
40	59	30	19	53	36	24	52	39	28
41	57	30	20	52	35	24	51	39	28
42	62	33	19	56	39	28	54	42	32
43	55	28	19	53	36	24	53	40	30
44	44	19	10	44	29	18	45	34	24
45	47	21	11	47	31	19	47	35	26
46	53	24	14	50	33	21	49	37	26
47	36	13	6	40	27	16	43	32	22
48	35	13	5	40	26	15	43	31	21
49	27	7	2	35	22	11	38	28	18
50	35	13	5	40	26	13	42	31	21
51	34	10	4	39	23	12	40	29	19
52	49	22	12	49	32	21	48	36	27
53	33	10	3	38	23	12	40	29	19
54	88	60	44	80	62	48	74	61	50
55	48	21	11	47	31	20	46	35	25
56	65	38	29	62	44	33	59	47	36
57	76	47	36	69	50	37	64	51	39
58	65	36	26	58	41	28	55	42	31

Legend

Soil depth : shallow (S), intermediate (I), deep (D)
Vegetation cover : sparse (SP), intermediate (INT), dense (DE)

TEXTURE - SAND

DEPTH COVER ZONE	S SP	S INT	S DE	I SP	I INT	I DE	D SP	D INT	D DE
59	41	6	1	37	14	4	39	20	8
60	96	74	56	89	74	53	88	72	55
61	55	26	7	64	41	19	62	41	22
62	50	12	3	44	18	6	43	23	10
63	41	5	0	37	15	5	38	21	9
64	26	5	0	31	12	3	34	19	7
65	50	12	2	49	20	8	46	24	11
66	29	1	0	31	11	2	34	17	5
67	28	1	0	30	9	1	33	14	3
68	42	4	0	37	13	3	38	19	7
69	44	4	0	38	15	4	39	20	8
70	23	1	0	30	11	2	33	17	5
71	22	0	0	29	6	1	32	12	3
72	44	3	0	38	13	3	39	19	8
73	45	6	0	41	16	5	40	21	10
74	26	1	0	31	11	3	34	17	6
75	24	2	0	31	13	3	34	19	7
76	22	1	0	29	10	2	32	16	5
77	40	4	0	36	13	3	38	20	8
78	76	42	23	78	49	26	77	47	26
79	64	26	11	63	29	12	56	31	15
80	72	38	17	70	39	19	65	38	21
81	65	27	11	61	32	15	56	33	18
82	52	13	4	47	20	7	45	25	12
83	54	20	7	54	27	12	50	30	16
84	49	12	3	46	22	8	45	27	13
85	58	26	11	51	26	12	48	29	16
86	72	43	21	68	43	22	64	42	25
87	82	58	35	86	57	34	83	57	35
88	69	31	15	71	40	18	67	39	20
89	31	2	0	33	12	3	35	18	7
90	28	1	0	32	11	2	34	17	5
91	44	5	0	39	14	3	39	20	8
92	31	1	0	33	11	3	35	16	5
93	47	4	0	44	15	3	42	20	7
94	50	11	1	60	23	6	55	27	10
95	50	18	2	57	25	17	52	30	14
96	28	1	0	31	8	1	33	14	3
97	21	0	0	28	5	0	31	11	2
98	23	1	0	30	9	1	33	15	4
99	24	0	0	30	8	1	32	13	3
100	23	1	0	30	8	1	33	14	3
101	24	1	0	29	8	1	32	14	4
102	38	1	0	33	10	1	35	15	4
103	43	3	0	38	12	2	38	18	6
104	22	0	0	29	7	1	32	12	2
105	39	1	0	33	10	2	35	16	4
106	34	1	0	33	9	1	35	14	4
107	25	1	0	31	9	2	33	15	4
108	27	1	0	30	7	1	33	13	3
109	25	1	0	30	9	1	33	15	4
110	28	1	0	31	10	2	34	16	5
111	22	1	0	29	9	1	32	15	4
112	24	1	0	30	9	1	33	15	4
113	45	7	1	39	15	4	40	20	8
114	62	25	11	59	30	13	54	32	17

TEXTURE - LOAM

DEPTH COVER ZONE	S SP	S INT	S DE	I SP	I INT	I DE	D SP	D INT	D DE
59	32	9	3	37	22	11	39	28	17
60	87	67	48	81	61	45	72	57	45
61	55	28	15	52	35	22	51	39	27
62	37	12	5	40	25	13	42	30	19
63	31	9	2	36	22	11	39	28	18
64	24	6	1	33	20	9	36	26	15
65	41	14	5	41	25	13	42	30	19
66	24	4	0	32	18	7	36	24	12
67	23	3	0	31	15	5	35	22	10
68	30	6	1	35	20	9	38	26	14
69	30	8	2	36	22	11	39	28	18
70	23	4	0	32	16	7	36	24	13
71	22	2	0	31	14	4	34	20	9
72	30	7	1	36	20	10	38	26	16
73	33	9	3	38	23	12	40	29	19
74	24	5	0	32	18	7	36	24	13
75	25	6	1	33	20	9	37	26	15
76	22	4	0	31	18	7	35	24	13
77	29	7	2	36	21	10	38	27	16
78	72	38	23	65	40	25	60	41	28
79	55	21	12	49	30	18	48	34	22
80	61	30	18	55	35	21	53	38	26
81	55	25	13	49	33	20	49	36	25
82	41	14	7	42	26	14	43	31	20
83	48	21	9	45	30	19	46	35	24
84	40	15	6	42	27	15	43	32	22
85	47	21	11	45	30	18	45	34	24
86	63	32	21	56	38	24	53	40	29
87	83	48	32	72	48	32	66	48	34
88	64	29	16	56	33	18	53	35	24
89	26	5	1	34	20	9	37	26	15
90	25	5	0	33	18	7	36	24	13
91	32	7	2	37	21	10	39	27	16
92	26	4	0	33	17	7	36	24	12
93	35	7	1	37	20	9	39	26	15
94	46	12	4	45	24	12	45	30	18
95	49	22	8	45	26	15	45	31	21
96	24	3	0	32	15	5	35	21	10
97	21	1	0	30	12	3	33	18	7
98	23	3	0	31	16	5	35	22	11
99	23	3	0	31	15	4	35	21	9
100	22	3	0	31	15	5	34	21	10
101	22	3	0	31	15	5	35	22	10
102	25	4	0	33	17	6	36	22	11
103	30	5	1	35	19	8	37	25	13
104	22	2	0	31	14	4	34	20	9
105	25	4	0	33	16	6	36	23	11
106	25	4	0	33	16	5	35	22	10
107	24	4	0	32	17	6	35	23	12
108	23	3	0	31	15	4	35	21	10
109	23	3	0	32	16	6	35	22	11
110	25	4	0	32	18	7	35	24	12
111	22	3	0	31	16	6	35	22	11
112	23	3	0	32	16	5	35	22	11
113	34	8	3	37	21	10	39	27	16
114	50	23	11	47	30	18	47	34	23

TEXTURE - CLAY

DEPTH COVER ZONE	S SP	S INT	S DE	I SP	I INT	I DE	D SP	D INT	D DE
59	31	8	3	36	21	10	39	27	16
60	76	47	36	69	50	37	64	51	39
61	47	21	10	47	32	20	48	36	26
62	34	11	5	39	24	12	41	29	19
63	29	8	2	35	21	11	38	27	17
64	24	5	1	32	19	9	36	25	15
65	36	11	4	39	23	12	42	29	18
66	24	4	0	32	17	7	35	23	12
67	22	3	0	31	14	5	34	21	9
68	27	6	1	35	19	8	37	25	14
69	28	7	2	35	21	10	38	27	17
70	23	4	0	32	17	7	35	23	12
71	21	2	0	30	13	4	33	20	8
72	27	6	1	35	19	9	37	25	15
73	29	8	2	36	22	11	39	28	18
74	23	4	0	32	17	7	35	23	13
75	24	6	1	33	19	9	36	25	15
76	22	3	0	31	17	6	34	23	12
77	27	6	1	35	20	9	37	26	15
78	60	27	18	56	33	20	55	37	25
79	45	18	11	46	29	17	46	33	21
80	52	23	15	50	31	19	50	35	24
81	47	21	11	47	31	19	47	35	23
82	36	12	6	41	24	13	42	30	19
83	40	16	8	43	29	17	45	33	23
84	35	13	6	40	26	14	42	31	21
85	43	18	10	44	28	17	45	33	23
86	54	27	18	51	34	22	50	38	27
87	69	35	25	62	40	26	59	43	30
88	49	19	12	49	28	16	49	33	21
89	25	5	1	34	19	8	36	25	14
90	24	4	0	32	17	6	35	23	12
91	29	6	2	36	20	9	38	26	15
92	25	4	0	33	17	6	36	23	12
93	28	5	1	36	19	8	38	25	14
94	35	8	3	39	21	9	41	27	16
95	39	10	4	41	23	12	42	29	17
96	23	3	0	31	14	4	34	20	9
97	21	1	0	29	11	2	32	17	6
98	22	3	0	31	15	5	34	21	10
99	22	3	0	31	14	4	34	20	9
100	22	3	0	30	14	4	34	20	9
101	22	3	0	31	14	5	34	21	10
102	24	3	0	32	15	5	35	21	10
103	26	4	1	33	17	7	36	23	12
104	22	2	0	30	13	3	33	19	8
105	24	3	0	32	15	5	35	22	10
106	24	3	0	32	15	5	35	21	10
107	23	3	0	31	16	6	35	22	11
108	22	2	0	31	14	4	34	20	9
109	23	3	0	31	15	5	34	21	10
110	23	4	0	31	17	6	35	23	12
111	22	3	0	31	15	5	34	22	11
112	22	3	0	31	15	5	34	21	10
113	31	7	2	36	20	9	39	26	15
114	45	19	10	45	29	17	45	33	22

Appendix 5

Land-use classes and CN values for the corresponding HSG found within the Kogmans River catchement (adapted from Schulze and Arnold, 1979).

Land Use	Description	SCS Description	A	B	B/C	C	D
Alien	Invasive alien vegetation	Natural Forest (low run-off potential)	25	55	64	70	77
Built Up : Rural	Small residential areas with usually with agricultural plots in between the residential erven.	Residential: 1000m² (38% impervious)	61	75	80	83	87
Built Up: Urban	Towns	Residential: 500m² (65% impervious)	77	85	88	90	92
Commercial	Cellar /Packing Shed	Industrial districts (65% impervious)	81	88	90	91	93
Cash crop	Vegetables and Irrigated grains	Garden Crops	45	66	72	77	83
Dryland crop	Non-irrigated field crops	Pasture/veld (medium run-off potential)	49	69	75	79	84
Fallow land	Land that has recently been irrigated but currently bare	Fallow	77	86	89	91	94
Forestry	Commercial / Woodlot	Forest/Plantations (medium run-off potential)	41	64	69	74	80
Open space	Open space	Open space 50%-75% cover	49	69	75	79	84
Orchard	Deciduous stone fruit	Orchards	39	53	61	66	71
Pasture	Irrigated fodder crops (Lucerne).	Irrigated pasture	35	48	57	65	70
Riparian	Strips of undeveloped land on either side of rivers.	Natural Forest (medium run-off potential)	36	60	68	73	79
Shrubland / Fynbos	Scrub	Scrub	28	44	53	60	66
Vineyard	Table grapes and wine grapes.	Orchards	39	53	61	66	71
Degraded	Scrub –10-15% cover	Disturbed land					
Dam	Dam/River	Water	100	100	100	100	100

Appendix 6

CN Values for H30A - H30E

H30A

Hydrol.Soil Group	Cover Description	Ha	Km2 (A)	Curve Number (CN)	CN x Area (P)
B/C	Alien	112.81	1.13	64	72.20
	Built Up : Rural	82.55	0.83	80	66.04
	Commercial	1.38	0.01	93	1.28
	Cash crop	10.32	0.10	72	7.43
	Dryland crop	1445.9	14.46	75	1084.43
	Fallow land	242.82	2.43	89	216.11
	Forestry	1.38	0.01	69	0.95
	Open Space	46.09	0.46	75	34.57
	Orchard	666.54	6.67	61	406.59
	Pasture	47.46	0.47	57	27.05
	Degraded (Shrubland/Fynbos)	189.283	1.89	85	160.89
	Riparian	37.14	0.37	68	25.26
	Vineyard	339.12	3.39	82	278.08
C	Alien	157.52	1.58	70	110.26
	Built Up : Rural	29.58	0.30	83	24.55
	Commercial	0.69	0.01	94	0.65
	Cash crop	2.06	0.02	77	1.59
	Dryland crop	739.46	7.39	79	584.17
	Fallow land	55.72	0.56	91	50.71
	Forestry	2.06	0.02	74	1.52
	Open Space	35.77	0.36	79	28.26
	Orchard	73.6	0.74	66	48.58
	Pasture	4.82	0.05	65	3.13
	Riparian	12.38	0.12	73	9.04
	Shrubland / Fynbos	7799.397	77.99	60	4679.64
	Mountains (Langeberg)	16005.32	160.05	88	14084.68
	Vineyard	31.64	0.32	85	26.89
	Dam	227.00	2.27	100	227.00
TOTAL			284.00		22261.54

Initial Loss(Ia)			
S (mm)	75.87	**Weighted CN (P/A)**	**CURVE NUMBER**
c	0.10	78.39	78
Ia (mm)	7.59	**CNf**	
Slope (%)	21.14	76.93	77
Hydraulic Length (m)	51527.50		
Lag (hrs)	4.59	*% Urban*	0.40

CATNUM	AREA_KM	LAT_HI	LAT_LOW	LONG_HI	LONG_LOW	CLIMATIC ZONE
H30A	284.00	33.47.24	33.57.36	20.30.00	20.15.36	75, 77

SMI	SMA FACTOR
2, 4 (3)	-5

Soil: Shallow, sandy with intemediate cover

CN Value for H30B

H30B					
Hydrol.Soil Group	Cover Description	Ha	Km2 (**A**)	Curve Number (**CN**)	CN x Area (**P**)
B/C	Alien	191.86	1.92	64	122.79
	Built Up : Rural	67.93	0.68	80	54.34
	Built Up: Urban	343.21	3.43	88	302.02
	Cash crop	7.15	0.07	72	5.15
	Dryland crop	595.85	5.96	75	446.89
	Fallow land	274.09	2.74	89	243.94
	Open Space	92.95	0.93	75	69.71
	Orchard	572.02	5.72	61	348.93
	Pasture	96.53	0.97	57	55.02
	Degraded (Shrubland/Fynbos)	322.95	3.23	85	274.51
	Riparian	98.91	0.99	68	67.26
	Vineyard	353.94	3.54	82	290.23
C	Alien	190.67	1.91	70	133.47
	Built Up : Rural	44.1	0.44	83	36.60
	Built Up: Urban	26.22	0.26	90	23.60
	Cash crop	2.38	0.02	77	1.83
	Dryland crop	164.46	1.64	79	129.92
	Fallow land	86.99	0.87	91	79.16
	Open Space	60.78	0.61	79	48.02
	Orchard	144.2	1.44	66	95.17
	Pasture	19.07	0.19	65	12.40
	Riparian	3.58	0.04	73	2.61
	Shrubland / Fynbos	24057.76	240.58	60	14434.66
	Shrubland / Fynbos: Degraded	65.54	0.66	88	57.68
	Mountains (Langeberg)	3292.74	32.93	88	2897.61
	Vineyard	110.83	1.11	85	94.21
	Dam	113.21	1.13	100	113.21
TOTAL			*314.00*		*20440.95*

Initial Loss(**Ia**)			
S (mm)	142.88	**Weighted CN (P/A)**	**CURVE NUMBER**
c	0.10	65.10	65
Ia (mm)	14.29	**CNf**	
Slope (%)	20.46	63.96	64
Hydraulic Length (m)	54727.67		
Lag (hrs)	6.98	*% Urban*	1.53

CATNUM	**AREA_KM**	**LAT_HI**	**LAT_LOW**	**LONG_HI**	**LONG_LOW**	**CLIMATIC ZONE**
H30B	314.00	33.40.48	33.53.60	20.22.10	20.06.36	75

SMI	**SMA FACTOR**
2	-7

Soil: Shallow, sandy with intemediate cover

CN Value for H30C

H30C

Hydrol.Soil Group	Cover Description	Ha	Km2 (A)	Curve Number (CN)	CN x Area (P)
B/C	Alien	15.63	0.16	64	10.00
	Built Up : Rural	12.88	0.13	80	10.30
	Dryland crop	119.06	1.19	75	89.30
	Fallow land	21.65	0.22	89	19.27
	Open Space	5.63	0.06	75	4.22
	Orchard	184.00	1.84	61	112.24
	Riparian	43.29	0.43	68	29.44
	Vineyard	158.74	1.59	82	130.17
C	Alien	121.46	1.21	70	85.02
	Built Up : Rural	38.84	0.39	83	32.24
	Cash crop	12.03	0.12	77	9.26
	Dryland crop	577.25	5.77	79	456.03
	Fallow land	43.29	0.43	91	39.39
	Forestry	51.71	0.52	74	38.27
	Open Space	60.82	0.61	79	48.05
	Orchard	155.14	1.55	66	102.39
	Pasture	7.22	0.07	65	4.69
	Riparian	15.63	0.16	73	11.41
	Shrubland / Fynbos	30508.5	305.09	60	18305.10
	Mountains (Langeberg)	411.51	4.12	88	362.13
	Vineyard	91.40	0.91	85	77.69
	Dam	44.50	0.45	100	44.50
TOTAL			*327.00*		*20021.11*

Initial Loss(**Ia**)			
S (mm)	169.33	**Weighted CN (P/A)**	**CURVE NUMBER**
c	0.10	61.23	61
Ia (mm)	16.93	**CNf**	
Slope (%)	22.28	60.08	60
Hydraulic Length (m)	56076.37		
Lag (hrs)	7.56	*% Urban*	0.16

CATNUM	AREA_KM	LAT_HI	LAT_LOW	LONG_HI	LONG_LOW	CLIMATIC ZONE
H30C	327.00	33.36.00	33.45.00	20.15.00	19.52.12	75

SMI	SMA FACTOR
2	-7

Soil: Shallow, sandy with intemediate cover

CN Value for H30D

H30D

Hydrol.Soil Group	Cover Description	Ha	Km2 (A)	Curve Number (CN)	CN x Area (P)
B/C	Alien	31.95	0.32	64	20.45
	Built Up : Rural	63.34	0.63	80	50.67
	Built Up: Urban	50.45	0.50	88	44.40
	Cash crop	0.56	0.01	72	0.40
	Dryland crop	34.19	0.34	75	25.64
	Fallow land	151.35	1.51	89	134.70
	Forestry	3.36	0.03	69	2.32
	Open Space	7.29	0.07	75	5.47
	Orchard	402.47	4.02	61	245.51
	Pasture	4.48	0.04	57	2.55
	Riparian	67.83	0.68	68	46.12
	Vineyard	327.92	3.28	82	268.89
C	Alien	38.12	0.38	70	26.68
	Built Up : Rural	6.16	0.06	83	5.11
	Built Up: Urban	19.06	0.19	90	17.15
	Dryland crop	137.9	1.38	79	108.94
	Fallow land	33.63	0.34	91	30.60
	Open Space	0.56	0.01	79	0.44
	Orchard	57.18	0.57	66	37.74
	Shrubland / Fynbos	6030.76	60.31	60	3618.46
	Mountains (Langeberg)	5136.24	51.36	88	4519.89
	Vineyard	39.24	0.39	85	33.35
	Dam	55.49	0.55	100	55.49
TOTAL			127.00		9301.00

Initial Loss(**Ia**)			
S (mm)	93.95	**Weighted CN (P/A)**	**CURVE NUMBER**
c	0.10	73.24	73
Ia (mm)	9.39	**CNf**	
Slope (%)	29.20	72.62	73
Hydraulic Length (m)	31792.33		
Lag (hrs)	2.98	*% Urban*	1.09

CATNUM	AREA_KM	LAT_HI	LAT_LOW	LONG_HI	LONG_LOW	CLIMATIC ZONE
H30D	127.00	33.40.12	33.47.24	20.08.24	19.52.48	52

SMI	SMA FACTOR
28	-2

Soil: Shallow, sandy with intemediate cover

CN Value for H30E

H30E

Hydrol.Soil Group	Cover Description	Ha	Km2 (**A**)	Curve Number (**CN**)	CN x Area (**P**)
A	Alien	0.75	0.01	25	0.19
	Dryland crop	3.75	0.04	49	1.84
	Pasture	37.52	0.38	35	13.13
B	Alien	18.76	0.19	55	10.32
	Built Up : Rural	3.75	0.04	85	3.19
	Dryland crop	42.03	0.42	69	29.00
	Fallow land	51.78	0.52	86	44.53
	Open Space	4.5	0.05	69	3.11
	Orchard	163.61	1.64	53	86.71
	Pasture	15.76	0.16	48	7.56
	Degraded (Shrubland/Fynbos)	75.99	0.76	82	62.31
	Riparian	1.5	0.02	55	0.83
	Vineyard	66.04	0.66	78	51.51
B/C	Alien	138.84	1.39	64	88.86
	Built Up : Rural	125.33	1.25	88	110.29
	Cash crop	57.79	0.58	72	41.61
	Dryland crop	950.88	9.51	75	713.16
	Fallow land	262.67	2.63	89	233.78
	Forestry	4.5	0.05	69	3.11
	Open Space	33.77	0.34	75	25.33
	Orchard	304.7	3.05	61	185.87
	Pasture	148.6	1.49	57	84.70
	Degraded (Shrubland/Fynbos)	38.275	0.38	85	32.53
	Riparian	12.01	0.12	64	7.69
	Vineyard	173.36	1.73	82	142.16
C	Alien	35.27	0.35	70	24.69
	Built Up : Rural	6	0.06	90	5.40
	Dryland crop	117.08	1.17	79	92.49
	Fallow land	3.75	0.04	91	3.41
	Open Space	22.51	0.23	79	17.78
	Orchard	16.51	0.17	66	10.90
	Pasture	0.75	0.01	65	0.49
	Shrubland / Fynbos	4529.42	45.29	60	2717.65
	Degraded (Shrubland/Fynbos)	0.75	0.01	88	0.66
	Mountains (Langeberg)	4913.94	49.14	88	4324.27
	Vineyard	10.51	0.11	85	8.93
D	Alien	31.52	0.32	77	24.27
	Built Up : Rural	312.96	3.13	92	287.92
	Commercial	6	0.06	95	5.70
	Cash crop	85.56	0.86	83	71.01
	Dryland crop	567.37	5.67	84	476.59
	Fallow land	210.89	2.11	94	198.24

Forestry	3	0.03	80	2.40
Open Space	30.02	0.30	84	25.22
Orchard	352.73	3.53	71	250.44
Pasture	82.55	0.83	70	57.79
Degraded (Shrubland/Fynbos)	184.62	1.85	90	166.16
Riparian	11.26	0.11	77	8.67
Vineyard	468.31	4.68	89	416.80
Dam	560.62	5.61	100	560.62
TOTAL		*153.00*		*11741.79*

Initial Loss(**Ia**)			
S (mm)	80.21	**Weighted CN (P/A)**	**CURVE NUMBER**
c	0.10	76.74	77
Ia (mm)	8.02	**CNf**	
Slope (%)	17.67	75.96	76
Hydraulic Length (m)	35552.56		
Lag (hrs)	3.84	*% Urban*	2.97

CATNUM	**AREA_KM**	**LAT_HI**	**LAT_LOW**	**LONG_HI**	**LONG_LOW**	**CLIMATIC ZONE**
H30E	153.00	33.45.00	33.55.12	20.11.24	20.00.00	51

SMI	**SMA FACTOR**
9	-5

Soil: Shallow, sandy with intemediate cover