AN ASSESSMENT OF LAND DEGRADATION IN THE HEADWATER CATCHMENT OF THE KLEIN ZEEKOEI RIVER, GREAT KAROO, SOUTH AFRICA.

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"We end I think, at what might be called the standard paradox of the twentieth century: our tools are better than we are, and grow better faster than we do. They suffice to crack the atom, to command the tides. But they do not suffice for the oldest task in human history: to live on a piece of land without spoiling it." ***Aldo Leopold (date unknown)***

Abstract

The headwater catchment of the Klein Zeekoei River is situated in the Sneeuberg uplands of the Great Karoo, and is one of the tributaries to the Orange River system. The region comprises a semi-arid area of extensive stock farming and is an important contributor to the South African economy. The Klein Zeekoei River valley has suffered extensive land degradation in the form of sheetwash, rill, and gully erosion and badland development.

This study focussed on the history of land degradation in the upper Klein Zeekoei River catchment, and the relative contributions of inherent soil properties, grazing, cultivation, slope, vegetation, and land management practices to land degradation. The study also assessed the effectiveness of anti-erosion measures that have been implemented since the late 1940's in the upper Klein Zeekoei River Valley. These objectives were achieved by using a combination of the analysis of textural and chemical properties of soils and sediments, the analysis and mapping of aerial photography, an archival investigation, conducting a number of interviews, and from observations made in the field.

The findings indicate that approximately 25% of land in the upper Klein Zeekoei River valley is moderately to severely degraded, and that this figure has remained relatively constant since 1945. This can be attributed partly to the effectiveness of soil erosion measures implemented in the area which have led to limited rehabilitation of some areas. Other areas of degradation have increased in extent since 1945, and many areas of badland erosion are presently actively eroding.

Valley floor incision in the area probably started in the latter part of the 19th century. The most likely trigger for the onset of incision is the disturbance of valley floor vegetation caused by grazing and trampling from animals outspanned along this part of the wagon route to the Kimberley diamond fields to the north. The dispersive and erodible nature of soils and sediments in the Klein Zeekoei River valley, in combination with over-grazing (rather than cultivation) of footslope areas in the first half of the 20th century, is the main cause of the extensive badland erosion in the area.

An understanding of the mechanisms that control soil erosion in headwater catchments such as the upper Klein Zeekoei River are important for two main reasons. Firstly, there is the issue of reduced stock carrying capacities in these areas. Secondly, there is the strategic issue of water quality and water supply due to the downstream siltation of storage dams within the Orange River system, of which the Klein Zeekoei River is a tributary.

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CONTENTS

List of Figures

List of Tables

List of Plates

List of Appendices

Chapter 1

Introduction

1.1 General Introduction and Rationale Behind this Study

The term "land degradation", is defined by Hoffman and Ashwell (in prep, p2) as, "the loss of biological or economic productivity of an area caused primarily by human activities". This definition of land degradation is taken to include not only soil and vegetation cover, but also ground and surface water resources. The United Nations Convention to Combat Desertification (UNCCD, 1994, *cited in* Hoffman and Ashwell, in prep, p2) defines land degradation 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 the soil; and (iii) long term loss of natural vegetation...".

Land degradation is a highly complex problem with many inter-linkages and causes. In South Africa, these causes and inter-linkages are further complicated by previously implemented political and economic systems such as colonialism, apartheid, and migrant labor, which have fundamentally influenced the management of resources and land use practices. It is however important to attempt to unravel these linkages and causes, as there are a number of fundamental reasons why land degradation is of concern. Firstly, there is the issue of food security. Arable land is a finite resource, and degradation of this resource may seriously inhibit South Africa's future ability to feed itself, making the country more reliant on expensive imports. Secondly, there is the issue of the financial cost of land degradation. Hoffman and Ashwell (in prep), state that the estimated cost to South Africa in the 1992/93 financial year, of soil degradation alone was close to R2 billion. This figure does not include the cost of other degradation processes, such as bush encroachment, invasion of alien plants, deforestation or the loss of plant cover. Thirdly, there are important social effects of land degradation. Hoffman and Ashwell (in prep) point out that as land becomes degraded, it becomes increasingly difficult to farm productively. The main consequence of this is migration to urban areas, with the attendant problems of social disruption, unemployment, poverty and crime. Land degradation may ultimately lead to scarcities of fundamental resources such as arable land and potable water, thus increasing competition for these resources, and creating the potential for conflict.

Land degradation has been particularly severe in the Karoo, Hoffman *et al* (1999), found that the grazing land of Karoo uplands of the Eastern Cape (into which the upper Klein Zeekoei River catchment, on which this study focuses, falls) to have one of the highest soil degradation indexes in South Africa. In an earlier study of degradation in the Karoo, Acocks (1988) noted that the Great Karoo has suffered from extensive land degradation, in the form of severe sheet and gully erosion, and the invasion and replacement of grassland by shrub vegetation.

The area of South Africa known as the Karoo covers some 30% of the South African land surface, a significant proportion of the country's interior. The southern most mountains of the Great Escarpment bisect the Karoo from east to west. The geography of the Karoo is described in Holmes (1998), as a dissected landscape of plains and flat-topped hills, dominated by mountain ranges running in a general east-west direction. The Great Karoo and the Little Karoo are separated by the most northern range of the Cape Fold Mountains, the Swartberg mountains. The word "karoo" comes from the Hottentot language, and means "dry", "arid" or "hard soil", a very apt description of this harsh and unpredictable environment. The Karoo is described by Cowling *et al* (1986, piii) as the "most characteristically South African of our extremely diverse terrestrial ecosystems". The Karoo encompasses a high diversity of climates, landforms, soils and vegetation. Rutherford and Westfall (1986) divided the entire Karoo into three regions based on the Summer Aridity Index, percentage winter half-year rainfall, and life form mix. The biomes are: Nama-Karoo Biome, Succulent-Karoo Biome, and the Desert Biome.

Despite the fact that the Karoo is sparsely populated, it makes an important contribution to the South African economy in the form of extensive small stock farming. This occurs in the succulent Karoo, and Nama-Karoo Biomes, where the vegetation is predominantly dwarf open shrubland (Cowling, 1986). Roux *et al* (1981), calculated that of the total gross national income derived from small stock, 36% of the wool, 60% of the mohair and goat meat, and 48% of the mutton income is generated in the Karoo Region. In the central upland areas of the Karoo opportunistic cultivation of potatoes and fodder crops takes place in years of greater than average rainfall. Milton and Dean (1996) refer to this area as "Grassy Karoo Veld" and comment that this region receives more rain than other Karoo regions, with the productive veld being a mixture of Karoo bushes and summer growing grasses.

Contrary to what may be expected from a semi arid area, the Karoo plays an important role in South African water resources. A number of major tributaries of the Orange River are sourced from Great Karoo headwater catchments. Land degradation within these catchments has major impacts on the sediment supply to the Orange river tributaries, which in turn has serious impacts on the siltation rates (and thus useful life span) of the major storage dams in the lower reaches of the Orange River. Hoffman and Ashwell (in prep), state that it has been estimated that South Africa looses 0.35% of its water storage capacity annually through siltation. This is therefore a major area of concern.

This study comprised a detailed investigation of the bio-physical aspects of land degradation within a specifically defined Great Karoo headwater catchment. The Klein Zeekoei River catchment was chosen as a suitable study site, for reasons that are outlined below. The headwater catchment of the Klein Zeekoei River is a relatively typical Karoo catchment, and covers some $20km^2$. In the past, the area was divided between as many as seven land owners, however, a considerable consolidation of land ownership started in the c1940's (H.N. Sheard pers com) and the entire area is presently owned by two farmers. The Klein Zeekoei River valley therefore provides a unique opportunity to study land degradation in a headwater catchment of the Orange River, and to examine the influence of grazing, cultivation, soil type, slope and vegetation on land degradation. Holmes (1998) identified serious land degradation in the Klein Zeekoei River Valley in the form of extensive sheet, rill, and gully erosion. Holmes (1998) comments that the biophysical factors contributing to land degradation are not well understood, and the debate with regard to the relative importance of "natural" as opposed to anthropogenic forcing factors continues. In particular the response of shallow sodic soils to changes in vegetation has not been well documented. This study attempts to address some of these debates more closely.

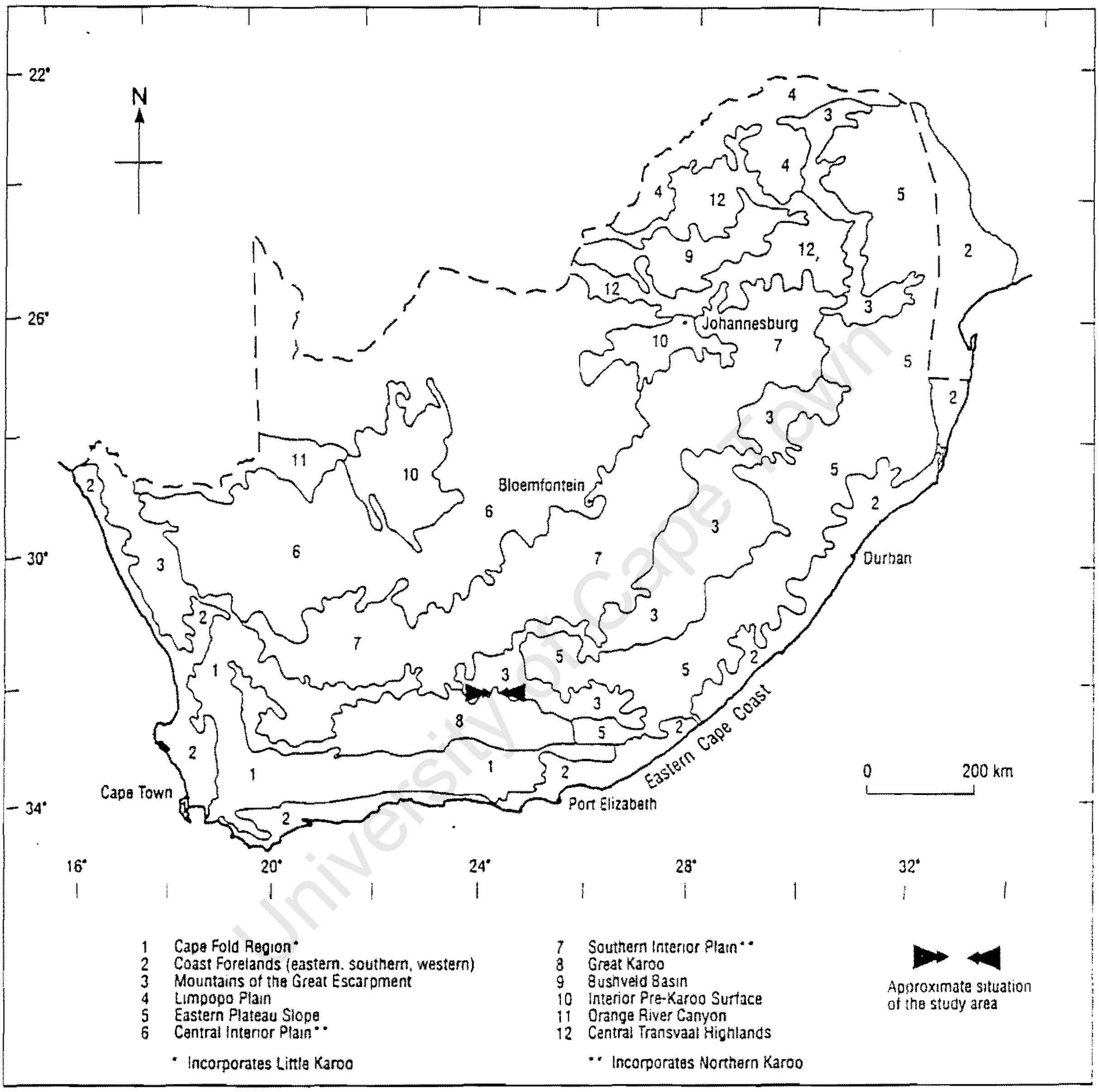

Fig 1.1 Terrain units of South Africa, including the Great Karoo (shaded) and indicating the position of the study area (After Holmes, 1998). Climatically the Karoo covers a significant portion of unit 1, as well as units 6 and 7 west of Bloemfontein.

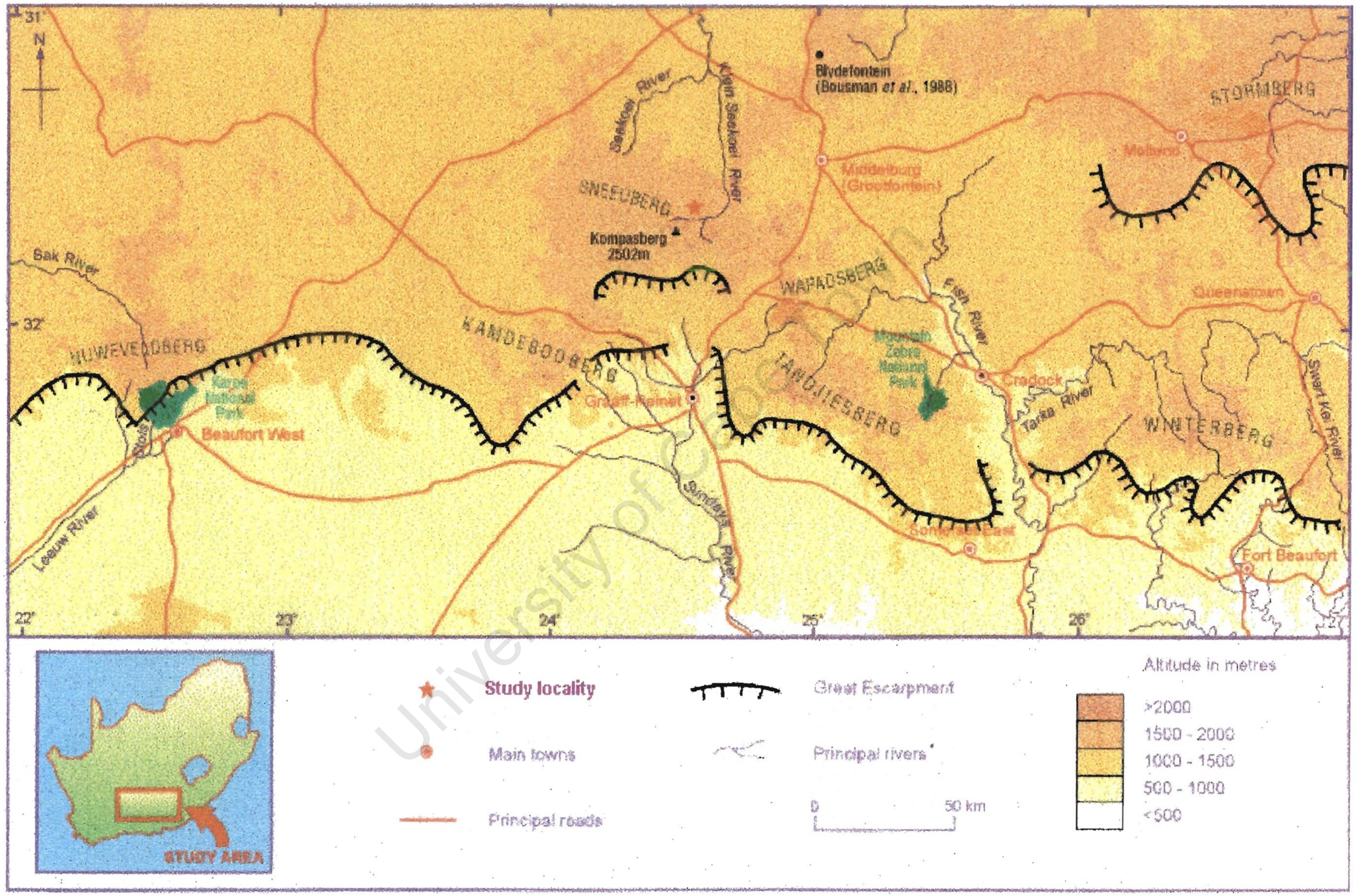

Fig 1.2 The study locality, after Holmes (1998).

1.2 Aim and Specific Objectives

The aim of this study is to assess the extent and nature of land degradation, and the success or otherwise, of rehabilitation in the study area. This will provide information that may be useful in the formulation of catchment management strategies aimed at preventing large-scale downstream sedimentation, thereby contributing to the vital strategic issues of water quality and water supply. This information may also be useful for future policy planning with respect to land management and alternative land use in the Karoo.

In light of this general introduction to the broad motivation and the aim of the study, the following are presented as specific objectives:

1. To determine the present scale and extent, and any changes over time, of degradation in the upper Klein Zeekoei River catchment, by the comparison and mapping of aerial photography

2. To use soil, slope, vegetation and land-use data to develop a deterministic model of land degradation within this catchment.

3. To examine the relative roles of soil, slope, vegetation, and land-use management in determining landscape response within a pre-defined Great Karoo headwater catchment, namely the upper Klein Zeekoei River Catchment.

4. To contribute to the existing inventory of sedimentological data in the study area, in order assess the erodability of these sediments, and to aid in the future interpretation of paleo-environments.

5. To assess the effectiveness of anti-erosion measures in the catchment, by the study of available aerial photography, and from observations made in the field.

6. To attempt to quantify the potential sediment yield for this catchment, by measuring the volume of a gully which has developed over a known period of time. This may serve as an indication of the seriousness of the potential downstream sedimentation effects of degradation in this, and other Karoo catchments.

1.3 Structural Outline

The broad structure of this comprises three parts, according to the follow divisions:

Background and Context

Chapters 1 to 4 familiarize the reader with the topic. The study is area is introduced and the rationale behind the study is given. The aim of the study, as well as the specific objectives, are outlined and the methodologies used to fulfill the objectives are described. The reader is also introduced to the relevant physical and theoretical background to the study.

Observation, analysis and classification

Chapter 5 describes each of the 11 study sites within the Klein Zeekoei River Valley, based on field observations. In **Chapter 6** the results of the laboratory analysis of the soil samples, the statistical analysis of the soil data, and interpretations of the aerial imagery are presented.

Interpretation, Discussion and Conclusions

In **Chapter 7** the results of the laboratory, statistical and aerial imagery analysis are interpreted and synthesized, and the possible implications of the findings are discussed. **Chapter 8** comprises a synthesis of the discussion, some possible future scenarios and a number of conclusions.

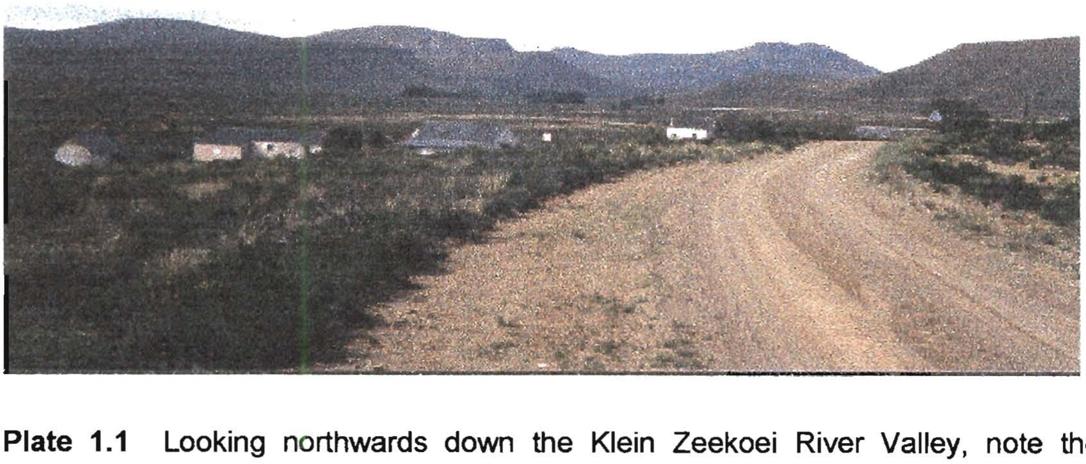

Plate 1.1 Looking northwards down the Klein Zeekoei River Valley, note the Kriegersbaken farm buildings in the left foreground.

Chapter 2

Physical Background

2.1 Introduction

The purpose of this chapter is to introduce the relevant physical background to the study. The physical setting of the study site, geology, geomorphology, soils, climate, vegetation and land use within the study area are discussed. A detailed description of each of the study sites follows in Chapter 5.

2.2 Physical setting

The study area is located to the north of the east-west orientated Sneeuberg mountain range (Fig 1.1 and Fig1.2). The Sneeuberg range is one of the most prominent ranges in the Great Escarpment, with Compassberg, its highest peak, rising to 2502m above sea level (asl). With the exception of the summit of the Cape Drakensberg, this is the highest peak in the Eastern Cape Escarpment. The study area comprises the upper headwater catchment of the Klein Zeekoei River, which is a tributary of the Zeekoei River, which in turn is a tributary of the Orange River.

2.3 Geology, geomorphology and soils

In terms of the overall lithology and stratigraphy, the region of the study area is part of the Beaufort Group in the Karoo Supergroup (Fig 2.1). The beds of the Beaufort Group underlie the greater part of the Karoo region and cover the central Karoo basin. The Beaufort Group has been intruded intensively by dolerites, which influenced both the structure and lithology of the beds (Visser, 1986).

The high lying relief in the study locality comprises Katberg Formation sandstone and mudstones capped by dolerite. Numerous dolerite intrusions occur, with corresponding localised metamorphosis of the adjacent sediments (Holmes 1998). The dolerite intrusions are Jurassic in age, and give rise to uneven topography, because they are more resistant to weathering in the dry climate and show positive landforms. Mesas, hillocks and sharp ridges therefore occur generally (Visser, 1986). The prominent Compasberg peak is a dolerite pluton, while dolerite tors are common in the headwater valley of the Klein Seekoei River. They comprise deeply weathered corestones in a matrix of ferruginous sand (Holmes, 1998).

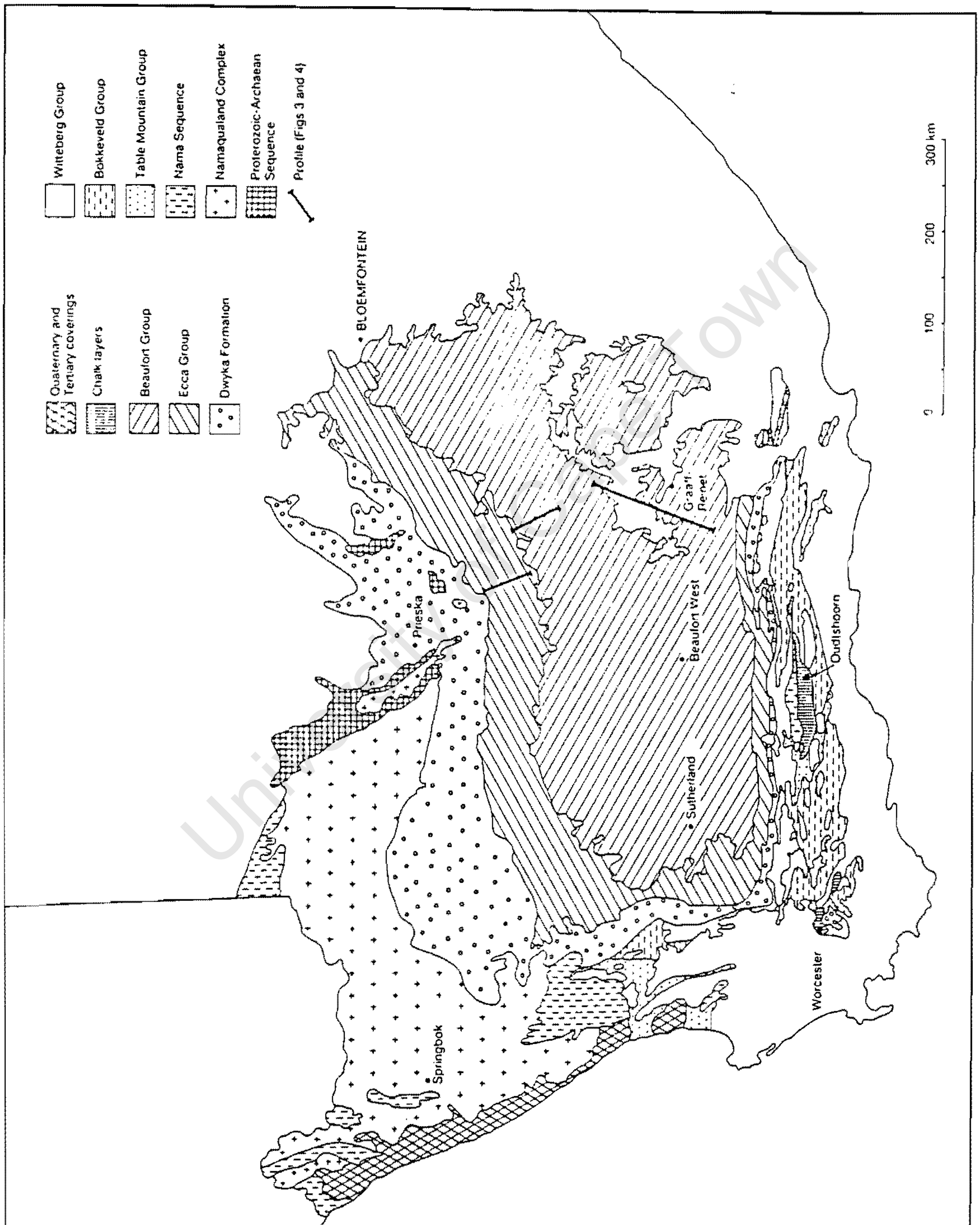

Fig 2.1 Generalised geological map of the Karoo biome (after Cowling *et al* 1986)

Hillslopes display horizontally bedded sandstone and shale. The resistant sandstone bands stand out prominently, resulting in stucturally controlled slopes dominating the landscape (Holmes, 1998). The valley floors comprises less resistant Balfour Formation mudstones, shales, and sandstones covered by a veneer of unconsolidated Quaternary sediment (Holmes, 1998). The underlying geology of the area, is primarily responsible for the dispersive nature of soils and sediments found in the Klein Zeekoei River catchment. A notable feature of these soils is the absence of a modern A horizon. Cowling (1986), asserts that soils derived from the Karoo sequence rocks are generally weakly developed, shallow and alkaline (pH 7,0 to 8,3). This is discussed in Chapter 7.

2.4 Climate

The climate of the Karoo, in common with many other arid and semi-arid regions, is characterised by extremes in temperature, and a high degree of variability in both the amount and timing of rainfall. The Sneeuberg Mountains fall within the eastern region of the Warm Temperate Zone (Sugden, 1989). In terms of latitude, the area falls under the influence of the subtropical high-pressure belt, with its characteristically dry upper air. On account of distance from the sea, the maritimal moderating influence of the ocean is lacking. Height and topography have a great influence on the temperature and rainfall regime (Venter *et al*, 1986). Schulze (1980) sites the average rainfall for the area as 346 mm annually. Rainfall peaks in autumn rather than summer, with a February to March maximum (Sugden, 1989). Convectional thunderstorms are common in summer, while snowfalls, associated with the west east passage of cold fronts, occur in the upper mountainous areas and the valley headwaters during winter.

Rainfall records are available for Compassberg farm (31°42'40"S; 24°33'50"E, altitude 1720m) for 1988 to 1999. They show a higher mean rainfall (544 mm) for this high altitude station, but also show a very high degree of variability, with annual rainfall figures varying between 1545mm and 277mm over this time period. Rainfall records for Verdun, (31°40'05"S; 24°33'00"E, altitude 1660 m) and elsewhere referred to as Aandrus, show a mean of 433 mm a coefficient of variation of 39.4% (Holmes, 1998). Venter *et al* (1986) investigated the possibility of cycles in the rainfall of the Karoo region by examining the five-year running averages of regional rainfall data from the periods 1878 - 1958 and 1921 - 1975. According to Venter *et al* (1986), the rainfall in the Karoo biome is subject to extended periods during which there occur regular decreases and increases in five-year running averages for rainfall. From their analysis Venter *et al* (1986) give the approximate mid points of dry and wet periods as follows:

Wet: 1892, 1909, 1919, 1940, 1957, 1973
Dry: 1904, 1914, 1929, 1947, 1966.

Both diurnal and seasonal temperatures show large fluctuations. A summer maxima of ~30°C and a winter minima of below -10°C is recorded (Schulze, 1980), and Venter *et al* (1986) cites a diurnal temperature range of 25°C as not unusual.

The climate, and specifically the rainfall regime of the study area, is typical of a semi-arid environment, where average annual rainfall is low, with a high coefficient of variability. The area is subject to extended periods of cyclical changes in the five-year running averages of rainfall. This has important implications for the carrying capacity dynamics of the land.

2.5 Vegetation

White (1983) *cited in* Cowling (1986), estimates the richness of Karoo Biome flora at 3 500 species, of which more than 50% are endemic. However, a total of close to 7 000 species for the biome is thought possibly to be more realistic. Structurally the Karoo vegetation can be characterised as dwarf open shrubland Cowling (1986). Readers interested in a more detailed description of Karoo vegetation than provided here, are referred to Cowling and Roux (1987) and Acocks (1988).

The vegetation of the Sneeuberg Range comprises Karroid shrub on the plains and sourveld grass in the mountain reaches (Sugden, 1989). Milton and Dean (1996) classify the area as Grassy Karoo Veld, as this region of the Karoo receives more rain than other Karoo regions, and the productive veld is a mixture of Karoo bushes and summer growing grasses. The Acocks (1988) classification is Karroid *Mermuellera* Mountain Veld in the higher lying areas, and False Upper Karoo in the valleys. The expected vegetation cover (the percentage of soil overshadowed by plants) for the region, is given by Dean and Milton (1996) as 40 - 60 %.

The extensive sheetwash and badland erosion on the footslopes in the study locality has stripped much of the topsoil, resulting in the absence of a modern A horizon in many places. At such places the vegetation has taken root in the B horizon. Holmes

(1998) noted that where extensive sheetwash occurs, *Lycium cinereum*, and *Eriocephalus spinescens* dominate.

Vegetation plays an important role in protecting the dispersive and easily erodible soil in the study area, from erosion. Vegetation cover in its pristine state does not generally exceed 60%, therefore the vegetation cover is very susceptible, and can be dramatically reduced, by grazing pressure.

2.6 Land use

The historical aspects of land use in the Klein Zeekoei River Valley, are largely based on Neville et al (1994) and Sampson (1985a and 1985b) cited by Holmes (1998), unless otherwise stated.

Prior to the second half of the eighteenth century, Bushman hunter-gatherers were the only permanent inhabitants of the Great Karoo. From this time, nomadic European stock farmers (known as *trekboers*) moved into Karoo in search of grazing. The system of loan (as opposed to freehold) farms encouraged this movement (Potgieter, 1974). A *trekboer* farmer would occupy a farm for a year or two, and then sell the improvements to another farmer, and move further into the interior. In this way the central Great Karoo as far as the Sneeuberg Mountains was colonised by Europeans by the end of the eighteenth century. The upper reaches of the Seekoei River formed a strategically important part of the colonial frontier by the end of the eighteenth century. Following the total subjugation of the local Bushman inhabitants, European settlement and the number of farms in the Seekoei River valley increased rapidly during the first two decades of the nineteenth century (Neville *et al*, 1994). The impacts on the physical landscape, the indigenous fauna and flora and the Bushman inhabitants were profound and irreversible. Neville (1996) documents these impacts at length.

Prior to 1892, some twenty five documented accounts of travellers through the Klein Zeekoei river valley exist. Although there are numerous references to the Zeekoei River, as well as "vleis", pools and what is presumably riverine vegetation, it is noteworthy that no specific mention is made of gullies or any channel form which might be interpreted as alluding to valley floor erosion. The wagon track system along the Zeekoei river was reconstructed by Neville *et al* (1994). This became an important route to the interior, after the opening up of the Kimberley diamond fields in the 1870`s. The traffic network was dictated by the availability of water and grazing. Large numbers of stock were outspanned alongside the pools to drink, and Holmes (1998) speculates that this may have served as the trigger to gully erosion in this area, as a result of overgrazing, trampling and soil compaction. Neville *et al* (1994) also concludes that the developing road network was instrumental in causing large scale degradation of the natural vegetation and gully formation.

The present predominant land use throughout the Great Karoo is natural grazing for small stock, such as sheep and to a lesser extent goats. In the wetter eastern margins of the Karoo, cattle are grazed on the Mountain Veld grasses. Limited cultivation occurs in valley floors, usually where perennial water courses make irrigation possible. Fodder crops are grown to supplement natural grazing while cash crops such as potatoes are grown on a very limited scale when local conditions allow. H.N. Sheard (*pers comm.*) estimates that stocking rates in the upper Klein Zeekoei River valley, were approximately three times greater than present, in the early part of the 20th century.

In the early part of the twentieth century the Klein Zeekoei River Valley was divided between as many as seven land owners. A considerable consolidation of land ownership started in the c1940`s (H.N. Sheard *pers comm.*) and the entire area is presently owned by two farmers. The farm "The Valley", owned H.N. Sheard, comprises farms previously known as "The Valley", "Kriegersbaken", "Aandrus", "Good Hope" and "Oppermanskraal". The Farms "Compassberg" and "Lucernvale" are both owned by B. Mc Cabe. A veld management strategy of intensive non-rotational grazing was implemented on the farm "Compassberg" in the late 1980`s and early 1990`s. The strategy aims for ecological rehabilitation in terms of climax vegetation which includes grasses which have been severely impacted as a result of past veld management strategies. Compassberg is not managed at all at present (B. Mc Cabe, *pers. comm.*).

Chapter 3

Theoretical Background

3.1 Introduction

There are many competing definitions of land degradation. Barrow (1991, p1), defines land degradation as "the loss of utility, potential utility, or the change or loss of features or organisms which cannot be replaced". There is a vast body of literature written on various aspects of the land degradation problem, and it is beyond the scope of this research to provide a detailed synthesis of these. As this research focuses on the biophysical aspects of land degradation, this area of the literature is concentrated on. For a detailed synthesis and overview of land degradation literature the reader is referred to texts such as Johnson and Lewis (1995), Barrow, (1991) and Dahlberg (1994).

Soil plays a vital role in biophysical life support systems, and the survival of the human race is ultimately dependant on the condition of the soil. Soil is one of the main resources of the biosphere and has been defined by the International Soil Science Society *cited in* Holy (1980, p1) as follows: "The soil is a limited and irreplaceable resource and the growing degradation and loss of soil means that the expanding population in many parts of the world is pressing this resource to its limits. In its absence the biospheric environments of man will collapse with devastating results for humanity". In view of this quote, it is of particular concern that South African soil loss figures have been conservatively calculated to exceed the rate of soil production by some 30 times (Beckerdahl, 1998). Soil erosion is one of the most serious forms of land degradation and is defined by Blaikie and Brookfield (1987) as the reduction in the capacity of the land to satisfy a particular use, and is associated with the loss of soil productivity. Blaike and Brookfield (1987) define land degradation as a social problem, and maintain that erosion is an environmental process that occurs with or without human interference, but that a social criteria is needed for the process to be described as *degradation*.

3.2 Causes, processes and mechanisms of erosion

The causes, processes and mechanisms of erosion comprise a complex topic, with a vast body of literature, which can only be touched on here. Readers are referred to

Holy (1980), Morgan (1995) and Morgan and Rickson (1995) for a more detailed overview of this topic.

The causes of soil erosion are still poorly understood, however conventional wisdom favors the explanation of erosion as a response to an increase in pressure on the land brought about by population pressure, intensive land use and livestock (Morgan, 1996). Tainton (1988) suggests that there is a close relationship between soil erosion and land use. He maintains that the basic cause of erosion is incorrect land use, such as overgrazing, burning practices and the removal of shrubs for fuel wood, which contribute to the gradual degradation of the land. Boardman (1988, 1990, 1992, 1993) concluded that the main causes of soil erosion on agricultural land in Britain were mismanagement of the land and inappropriate government policies. The cultivation of unsuitable land has been suggested as one of the chief causes of erosion, because the soils are exposed to the sun, wind and rain for a large part of the year, and the combination of bad grazing practices aggravates the erosion resulting in severe degradation (Tainton, 1988).

Erosion is manifested by the deterioration of the soil surface which is affected by exogenous forces such as water, wind and anthropogenic factors. These factors may occur separately or in combination, causing erosion of varying intensities (Holy, 1980).

Soil erosion is a two-phase process consisting of the detachment of individual particles from the soil mass and their transport by erosive agents such as running water and wind. When sufficient energy is no longer available to transport the particles, a third phase, deposition, occurs (Morgan, 1996). The severity of erosion depends upon the quantity of material supplied by detachment and the capacity of eroding agents to transport it.

Because (as is demonstrated shortly) fluvial erosion predominates in the study area, a more detailed outline of the processes involved are presented here. When it rains a portion of the rainfall infiltrates the soil. Infiltration occurs faster on a dry soil than on a moist soil, and on a sandy soil faster than on a clay soil (Rowland 1993). The infiltration capacity is the rate at which a soil can absorb water, and exerts a major control over the generation of surface runoff (Boucher, 1991). Its magnitude depends on soil texture, its moisture content (Luk (1985) observed in field experiments that rainwash differs by four to five times if the full range of antecedent soil moisture content is considered), structure and the slope of the land.

As a storm progresses the soil moisture content increases and the infiltration capacity decreases. When the rainfall intensity exceeds the infiltration capacity, the excess flows away from the site in the form of runoff (Boucher, 1991), unless confined in some way, such as behind a bund or ridge of soil, or in a depression. Soils in arid areas often have low organic matter content, high proportions of fine sand and silt, and a high percentage of calcium carbonate. These factors tend to lead to crusting, and hence decreased infiltration rates compared with soils in more humid areas (Rowland, 1993).

If they have enough energy, raindrops dislodge particles from the soil surface. The particles are then moved downhill by a process known as splash erosion. Splash erosion may occur even before runoff starts. Rain splash is the most important detaching agent, occurring as a result of raindrops striking a bare soil surface (Morgan, 1996; Torri *et al*, 1987). The more intense the rainfall is, the more easily particles are dislodged from the soil surface (Rowland, 1993). Research undertaken by Farres (1987) and Torri *et al* (1987) indicates soil aggregate stability also plays an important role in determining the soils susceptibility to splash erosion. Continuous exposure to heavy rainstorms considerably weakens the soil. Running water and wind are further contributors to the detachment of soil particles (Morgan, 1996). The transporting agents comprise those which act areally and contribute to the removal of a relatively uniform thickness of soil (overland flow and wind) and those which concentrate their action in channels (rills, gullies and rivers) (Morgan, 1996). Once runoff has started, the water exerts a drag on the soil surface and particles are pulled into the flowing water. Normally the runoff forms tiny rivulets, only a few centimeters wide to start with, which gradually become larger as the water progresses down the slope until rill erosion begins to occur (Rowland, 1993). If large percentages of silt and sodium salts are present in the subsoil, tunnel erosion under ground can occur. Eventually the tunnel collapses and a gully appears at the surface.

The importance of vegetative cover cannot be over emphasized. Small plants absorb some of the energy of raindrops and so reduce splash erosion. They also increase the friction of the soil surface, decreasing the velocity of runoff (Rowland, 1993). Their roots help to bind the soil and keep it in place. Soils with little plant cover are low in organic matter and consequently have lower infiltration capacities, which are strongly influenced by organic matter and root growth (Rowland, 1993).

The ambivalent effects of vegetation have been demonstrated in laboratory rainfall simulator tests. De Ploey *et al* (1976) *cited in* Stocking (1994) found that a cover of grass definitely reduced erosion on slopes of under five degrees. Above 8° however, the rate of erosion exceeded the rate on bare soil. The researchers concluded that higher slopes generate turbulent eddies down stream of the grass blades, and that this causes a higher rate of erosion than on bare soil. There obviously exists a complex interaction between vegetation, slope, soil type, and erosion.

Stocking (1994) noted that as a strategy for soil conservation planning, the promotion of vegetation, or a biological approach to soil conservation has much to offer. Vegetation is the factor most easily manipulated by careful management. The problem with this conservation strategy is that it requires continuous, sensitive and knowledgeable management of both soil and crop. The rewards in terms of reduced soil loss are indisputable. The difference in erosion between good cover/high management plots and clean-tilled, fallow plots can be in orders of magnitude of one hundred or more.

Field observations and measurements, as well as lab analysis have shown that slope gradient is one of the major erosion factors (Holy, 1980; Govers, 1991). Its effects on the initiation and course of soil erosion processes may be reduced by other factors, such as soil properties and vegetation cover, but are never fully suppressed. Govers (1985) noted that rill erosion often starts at critical slope angle of 2° to 3°. On gentle slopes, shear velocity and thus erosive power of the flow rises only very slowly with unit discharge. The interdependence of slope gradient and the erosion intensity shows that the intensity of the erosion processes increase with growing tangential stress and the velocity of the surface runoff, which are prevalently the function of slope gradient. The importance of slope gradient for erosion intensity was demonstrated by Bennett (1939 and 1955) in field measurements.

Pilgrim *et al* (1985) however, found that contrary to expectations, slope development rates by overland flow in nine Australian locations, showed no simple or clear relationship with the factors of mean annual rainfall or seasonality, vegetation type, lithology or slope angle. It is therefore clear that the relationships between these factors are extremely complex, and still poorly understood.

3.3 Gully erosion

Due to the high prevalence of gully erosion in the study area, this particular type of erosion is given a more detailed discussion here. As Hoffman *et al* (1999) point out, the terms "gully" and "donga" are synonymous, the latter being the southern African vernacular word for the former. Gullies are relatively permanent steep-sided water courses which experience ephemeral flows during rainstorms (Morgan, 1996). Gullies are actually dynamically similar to small stream channels, except for their ephemeral flow and the direct supply of material from the slopes to the actual channel by collapse and entrapment (Kirkby and Morgan, 1980). Gullies are almost always associated with accelerated erosion and therefore with landscape instability (Morgan, 1996; Bradford and Priest, 1980). Ebisemejiu (1989) classifies gullies as a more severe form of erosion than rill or sheet erosion. Sheet erosion is the more or less uniform removal of soil from an area, caused by the detachment of soil particles by raindrops and the subsequent transport by runoff water. Rills are micro-channels which occupy some transitional position between sheet and gully erosion (Morgan, 1996). Rills are rarely more than a few millimeters wide or deep, although "master rills" may be larger and can eventually become gullies. Gully erosion is described by Van Breda Weaver (1988) as the removal of soil resulting from the excessive concentration of runoff water, which causes the formation of relatively large channels or gullies. Not all gullies develop as a result of surface erosion however, there are three ways in which gullies may form, and these include; surface erosion, piping and linear landslides (Morgan, 1996).

Where homogenous soft rock is subjected to rapid degradation by rainwash, in an arid climate, and the ground is carved into innumerable closely spaced ridges and valleys (gullies) of miniature dimensions, the degraded area is known as a badland (Stamp, 1961). Badland topography is usually associated with nearly horizontal sedimentary beds, but may also develop in decomposed granite, loess or other soft material. Vegetation is usually scant or absent, and the drainage is intricately labyrinthine, with the watercourses usually being dry (Stamp, 1961). The term "badlands" originally applied to a region of badland topography in South Dakota and Nebraska in the United States of America, but is now used to describe similar topography elsewhere in the world. The term is derived from the Indian name, which means bad lands to cross.

Gullies in Hong Kong which formed after the clearance of a natural forest cover, were attributed to subsurface flow (Morgan, 1996). In the South African context, Beckedahl (1988) stresses the importance of soil properties in promoting subsurface flow in pipes. Pipe development is determined, to a large extent, by sediment texture, stratigraphy, and erodibility of the soil. When heavy rainfall provides sufficient flow to flush the soil out of these pipes, the ground surface subsides, exposing the pipe network as gullies. Watt (1999) studied gullying on the farm Boshof in the Swartland (Western Cape, South Africa) observed numerous pipes within a particular gully, ranging in diameter from a few centimeters to over a meter. Watt (1999) was unable to establish whether or not these pipes collapsed to form the gully, or whether the pipes had formed as a result of the gully.

Firth (1991) *cited in* Meister (1998) discovered gullies in sodic soils in Zimbabwe, which were up to eight meters deep and two kilometers long. These gullies were associated with landslip activity and subsurface piping. Stocking (1980) also discovered the development of pipes in sodium rich, fine, sandy soil, which eventually collapsed and led to gully formation.

Compared with stable river channels which have relatively smooth, concave-upwards long profiles, gullies are characterized by a headcut and various knick-points along their course (Morgan, 1996). These rapid changes in slope alternate with sections of very gentle gradient, either straight or slightly convex in long profile. Gullies also have relatively greater depth and smaller width than stable channels, carry greater sediment loads, and display very erratic behavior so that relationships between sediment discharge and runoff are frequently poor. Gully erosion also impinges on water table levels, which in turn impact on both surface and sub-surface hydrology (Morgan, 1996). Botha (1992) has suggested that lowered water tables impinge on pedogenesis.

Watson *et al* (1984) identified two dominant gully forms in Kwazulu Natal. The first of these are ravine gullies, which are linear flat walled channels in soil, colluvium and weathered bedrock. The second are organ pipe gullies, typically dendritic in plan with distinctive fluted walls, normally in colluvium.

Rates of gully erosion are frequently rapid. Dollar and Rowntree (1994) found that a gully in the Mdloti catchment, north of Durban, had eroded more than 50m headward in the last seven years. Rapid expansion of some gullies in the Golden Gate Highlands National Park, was recorded by Brady (1993). The volume of one of these gullies increased by $1348.5m^3$ in the seven years between 1984 and 1991. Holmes (1998) noted that based on evidence from the Stormberg and Sneeuberg, Karoo marginal upland headwater environments display extreme sensitivity with regard to their intrinsic geomorphic thresholds. Holmes (1998) noted that the response to change is manifest not only in a rapid transition from stability to erosion, but also a comparatively rapid return to conditions of relative stability. It is further suggested that from a human perspective, it is far easier on a regional scale to trigger the former response that to initiate the latter.

3.4 What is the trigger mechanism for gully erosion?

In answering this question, the concept of geomorphic thresholds is introduced, and a number of studies are reviewed. The decision to review the Australian studies that follow, arose due to the strong parallels that exist between the sites of these studies and the Klein Zeekoei River valley, in terms of both biophysical environments, and the history of European settlement.

Gullies are perturbations that grow and enlarge by positive feedback until they become inhibited either through spatial competition, excess sediment production or human intervention. Kirkby and Morgan (1980), assert that the initial cause of the perturbation may be random as for example the trampling of vegetation by cattle, the survival of a rill through consecutive seasons, the collapse of a sub-surface hollow or the cutting of a forest for road construction. However, Kirkby and Morgan (1980) also found that certain conditions seem conducive to gully growth and expansion across otherwise un-eroded terrain. The most important of these conditions was found to be very high runoff rates from infrequent storms.

The concept of geomorphic thresholds, as discussed by Schumm (1979), may also be useful to consider when examining the initial cause of gullying. Patton and Schumm (1975) argued that the distribution of gullies, within the semi arid valleys that they studied, is largely controlled by geomorphic thresholds. According to them sediments accumulate on valley floors until a threshold gradient is reached, above which entrenchment occurs. Schumm (1979) distinguishes between intrinsic and extrinsic thresholds. Intrinsic thresholds occur when landforms evolve to a condition of incipient instability following which change or failure occurs. By way of an example Schumm (1979) cites the long-term progressive weathering that reduces the strength of slope materials until eventually there is slope adjustment. Response of a system to an external influence is referred to as an extrinsic threshold. A threshold exists within the system, but will not be exceeded and change will not occur without the influence of an external variable, for example anthropogenic disturbances or climate change. The consideration of extrinsic thresholds may be particularly useful in explaining the onset of erosion in "The Valley". This is discussed in more detail in Chapter 7. The concept of geomorphic thresholds was successfully used by Crouch and Novruzi (1989), when studying the threshold conditions for rill initiation on a vertisol in Gunnedah, New South Wales, Australia.

Schumm and Hadley (1957) studied gullying in eastern Wyoming and northern New Mexico in the USA. They concluded that arroyo (gully) cutting occurred in these areas from c1880, following the introduction of large numbers of cattle into these areas from c1870, as a result of overgrazing.

Prosser (1991) compared past and present episodes of gully erosion at Wangrah Creek, in New South Wales, Australia. Wangrah Creek presently has gullies up to 10m deep, however at the time of European settlement there were no continuous channels, but merely a series of deep pools apparently referred to as "chains of pools". Prosser (1991) concluded that the present gully erosion at Wangrah Creek is the result of major environmental changes caused by European settlement, which had a greater effect on gully erosion than any other environmental change over the last 10 000 years. Gully erosion at Wangrah Creek was concluded to have been initiated by localized disturbances to the valley floor.

Prosser *et al* (1994) studied Holocene valley aggradation and gully erosion in headwater catchments of the southeastern highlands of Australia. They concluded that historical gully erosion was a result of the introduction of European agriculture, and that gully initiation appears to be controlled more by thresholds of incision into valley floor vegetation than by changes in sediment supply.

Prosser and Slade (1994) studied the role of valley floor vegetation on gully formation in southeastern Australia. They used flume experiments on an unincised valley floor to determine the flow resistance and the critical shear stress for scour under natural and degraded vegetation covers. By applying the results to sites of gully formation in southeastern Australia, they were able to demonstrate the crucial role that reduced vegetation cover plays in increasing the susceptibility of valleys to channel incision.

Prosser and Slade (1994) concluded that swampy meadows covered with tussock and sedge are very resistant to incision. They found that a flood of the magnitude of a 100 year recurrence event (Q_{100}), coupled with light grazing would not be capable of initiating incision. They found that swampy meadows covered with tussock and sedge are only susceptible to incision where there is heavy degradation of the vegetation, coupled with increased discharge, or if the surface is laid bare. They demonstrated that rapid gully formation in southeastern Australia across all scales of catchment, during the 19th century, required significant degradation of valley floor vegetation, in addition to increased discharge from historic climatic changes and forest clearing.

In the South African context Holmes and Wesemann (1994) studied the impact of an extreme discharge event (exceeding Q_{100}) on a valley floodplain in the winter rainfall region of the Western Cape. The section of the river under investigation, was characterized by identical soil type, lithological control, and gradient along its entire length. The upper reaches of the river were characterized by natural, mature, pristine, *fynbos* (Mediterranean shrub) vegetation, while the lower reaches of the river had been cleared and replanted with exotic Kikuyu grass, resulting in a reduction in flow resistance. The discharge event left the upper reaches of the river unscathed, however where the vegetation had been replaced by exotic grass, gullying to bedrock at 1.5m depth, over a distance of ~800m occurred within the space of 12 hours.

It must be pointed out that that the concept of trigger mechanisms to erosion is a highly complex topic, and this section is intended only to briefly introduce the reader to the concept. For a more detailed explanation of geomorphic thresholds, the reader is referred to Schumm (1979).

3.5 Consequences of erosion

Once again, the vastness of this topic must be emphasized. The purpose of this section is to introduce the reader to some consequences of erosion that may be relevant to the research. The rapid erosion of soil by wind and water has been a problem ever since land was first cultivated (Rowland, 1993). At a general level, the principal effects of soil degradation are impoverishment of the soil, causing greater susceptibility to droughts and making agricultural production more difficult and expensive; silting of water storage reservoirs, making them uneconomic to operate; silting of harbours, rivers and estuaries; and the modification of land and water based ecosystems (Hoffman et al, 1999). There may also be implications for sustainable land use and food security. Within national boundaries soil and land are finite resources, irreplaceable in the short to medium term. Therefore any reduction in their quantity, or quality, without replacement is not sustainable.

The consequences of erosion occur both on and off-site, and have physical, social and economic components. On-site effects are particularly important on farmland where it leads to a reduction in cultivatable soil depth and a decline in soil fertility as well as decreasing the area of pastoral land. Off-site effects, and costs of erosion may also be significant. Braune and Looser (1989) assessed the costs of sedimentation in reservoirs, sediment deposition on cropland and sediment damage to infrastructure in South Africa. The cost was assessed to be at least R80 million, in 1989 South African rands. The cost of dealing with eutrophication in reservoirs, is not included in this estimate.

Although the differences between soil horizons are not as clearly defined in semi-arid areas as in wetter climates, topsoil is usually more fertile than underlying soil horizons. As finer soil is eroded more easily than coarser material, the concentration of nutrients in the soil washed away is usually greater than in the coarser soil left behind (Rowland, 1993). Erosion therefore usually reduces the soil fertility in the root zone as well as the total store of nutrients in the soil profile.

Off-site problems result from sedimentation downstream or downwind which reduces the capacity of rivers and drainage ditches, enhances the risk of flooding, blocks irrigation canals and shortens the design life of reservoirs. Many South African dams are located in catchments, which are eroding rapidly, and they act as traps or sinks for eroded material. In Kwa-Zulu-Natal, Hazelmere dam has lost more than 25% of its original design capacity since its completion in 1975 (Russow and Garland, 1998. *cited in* Hoffman et al, 1999). Eutrophication often accompanies sedimentation caused by soil erosion. Phosphates from fertilizers, as well as some chemicals from informal settlements and urban areas, are the main culprits (Hoffman *et al*, 1999). Grobler and Silberbauer (1984) noted that South Africa had a number of hypertrophic lakes, and recommended that management of inflows was therefore critical in order for water supply to be maintained.

3.6 Soil erosion in southern Africa, and the Central Great Karoo

Soil erosion has been regarded as an important phenomenon in South Africa since the turn of the century and even before, and its study has been approached from a number of perspectives (Hoffman *et al*, 1999). The southern African subcontinent is vulnerable to soil erosion, with gully erosion being particularly prevalent in the eastern parts (Beckedahl *et al*, 1988). Much of this erosion has occurred in colluvial sediments on unstable hillslopes (Botha, 1992). Of particular concern is the fact that in semi-arid areas of South Africa erosion rates often exceed the rate at which soil is being replaced (Rooseboom, 1981).

The Karoo is a very under-researched area of South Africa (Holmes, 1998). The probable main reason for this is its remoteness from major urban centers and research institutions. Consequently the body of literature on soil erosion in the Karoo is fairly small.

The literature on soil erosion in South Africa goes back some way. Fick`s (1944) book on the veld and water resources of South Africa deals with the causes and consequences of erosion in South Africa and suggests a number of farming practices to limit erosion. Bennet (1945), authored a report advising the South African government on policy and organization with respect to soil erosion control and sound land use. The report concluded that South Africa is severely eroded, and that there was a need for betterment of the erosion situation through a national program of anti-erosion operations. Bennet (1945, p8) commented that; "Under long-standing methods of landuse, far too little attention has been devoted by the average farmer to (a) soil protection against erosion and (b) maintenance of soil productivity through good cropping and grazing practices."

Various studies have been undertaken that attempt to estimate the national soil erosion rate of South Africa. The most frequently quoted of these are based on the sediment yield of the main rivers. Midgely (1952) estimates a figure of 363 million tones per annum, Schwartz and Pullen (1966) estimate a figure of 233 million tones per annum, and Rooseboom (1976) estimates a figure of between 100 and 150 million tones per anum. Annandale (1998) *cited in* Hoffman *et al* (1999) however, suggests that these figures may not be accurate, due to the poor accuracy of mean annual sediment yield assessment techniques. Whatever the accuracy of these figures, they can account only for the total sediment quantity, including river bank and bed material, transported through fluvial systems. Material eroded and re-deposited within catchment boundaries, but not transported by rivers, is excluded. Hoffman *et al* (1999) comments that the differences between sediment yield and soil loss figures could be very high.

Milton *et al* (1994) proposed a conceptual stepwise model of rangeland degradation. In this model five stages of degradation are identified, ranging from pristine rangeland (step 0) to highly degraded (step 4). The first step in the degradation process is identified as being the change in the age structure of plant populations, due to grazing of domestic livestock. The second step involves a decrease in diversity and productivity. The third step involves the reduction of perennial plant cover, and the fourth step involves accelerated soil erosion due to the loss of plant cover, and the salinization of the soil. Milton *et al* (1994) stress the need to recognize and treat degradation early, because management inputs and costs increase for every step of the degradation process. They conclude that unless rangelands are kept in step-one condition during dry years, by the reduction of stock numbers, productivity will be irreparably lost because further degradation involving changes in secondary productivity, fauna and soil, becomes too costly to reverse.

Hoffman *et al* (1999) identified three governmental interventions and societal responses to the acceptance of soil erosion as a problem in South Africa. For the benefit of readers that may not be familiar with South African history, it must be pointed out that the distinction between so called "white" and "black" areas occurs due to the "Apartheid" system of government at the time, which legislated separate areas of land for different racial groups.

The first of these interventions and responses was a surge of scientific measurement and research from the 1940`s onwards. Runoff-plot and catchment experimentation accounts for the bulk of this work. The second of these was the promulgation of legislation aimed at controlling soil loss. The Forest and Veld Conservation Act (Act No.13 of 1941), the Soil Conservation Act (Act No. 76 of 1969), the Conservation of Agricultural Resources Act (Act No. 43 of 1983), and the Environmental Conservation Act of 1989 provided the basis for legal control of soil erosion in, what were under the Apartheid system, regarded as white owned areas. Ross (1963) comments that the original Soil Conservation Act (Act No. 45 of 1946) provided the legislative machinery for dealing far more effectively with the problems of farming rehabilitation and soil conservation than had previously been the case. In black areas legislative provision for soil conservation was under the auspices of the Native Administration Act of 1927, the Bantu Homelands Constitution Act of 1971, legislation formulated by individual homeland governments, and certain proclamations of the State President. The third response was in the form of government or quazi-government initiatives to enhance awareness and actively promote soil conservation. Examples of this include the National Veld trust, the Southern African Regional Commission for Conservation, and Utilization of Soil (SARCCUS), and the establishment of various regional Soil Conservation Committees. Cooper (1996) reviewed South African soil erosion policy between 1910 and 1992, and found that the policies were technocratic, dualistic, and only marginally successful.

Financial support for soil conservation schemes was implemented, and by 1990 the government had spent 303 million rands on soil conservation schemes, mainly in white commercial farming areas (Scotney and McPhee, 1990, *cited in* Hoffman *et al*, 1999). In black areas a policy known as "Betterment Planning" was one of the main interventions intended to control soil erosion. These schemes tended to consist mainly of implementing mechanical and engineering solutions to soil conservation problems. Hoffman *et al* (1999) comments that most authors agree that betterment, as a policy for rural upliftment, and for combating soil erosion has failed.

Stocking and Garland (1995) reviewed a number of policy issues with regard to land degradation and soil conservation in South Africa. They noted that due to the "homeland" system that operated during the apartheid era in South Africa, the country developed two sets of pressures on its resources. This has given rise to two different degrees of severity of the problem of land degradation and two types of environmental change. This system has also led to two sets of conservation policies, and strategies, and two types of reaction to government pronouncements on soil erosion. Stocking and Garland (1995) suggested that the focus of soil conservation policy should be shifted away from large-scale mechanized producers to small-scale marginal and sub-marginal land users, and the scaling up of extension and advice services to a greatly expanded clientele of rural dwellers.

Fick (1944) noted extensive gully erosion in the Karoo and the consequences of exceeding the carrying capacity of the land. He noted that in areas where the grazing was controlled, the grazing remained good and no abnormal erosion took place. In areas where overgrazing had occurred, the grass cover practically disappeared, serious surface erosion took place, and consequently the carrying capacity of the land became drastically reduced.

Garland and Broderick (1992) studied changes in the extent of erosion in the Tugela catchment, between 1944 and 1981, through the comparison of steroscopic air photos. Their research showed that the extent of erosion in the Tugela catchment has decreased over this time period. The reason for this decrease was speculated to be either due to improved conservation techniques, or from medium to long term changes in the variables intrinsic to the erosion system.

Snyman (1999) studied the short term effects of soil water, defoliation and rangeland condition on the productivity of a semi arid rangeland to the west of Bloemfontein, in the Free State. The study evaluated the effects of defoliation and levels of soil water in terms of above ground phytomass and water use efficiency, and concluded that in degraded rangeland, water is used inefficiently, regardless of the quantity of water received. Snyman (1999) also comments that approximately 66% of rangeland in South Africa moderately to seriously degraded and that should this situation be allowed to continue, animal production will not be sustainable in the long run.

The occurrence of extensive sheet, rill and gully erosion in the Upper Klein Zeekoei River catchment was noted by Holmes (1998). Although the study briefly mentions the erosion problems in this area, its main focus is on paleoenvironments.

3.7 Conclusion

This Chapter has introduced the reader to some of the processes and consequences of erosion, the importance of soil conservation, possible trigger mechanisms to erosion, and some of the available literature on soil erosion in South Africa in general and in the Karoo in particular. The discussion in Chapter 7 and Chapter 8 should be considered against the theoretical background presented in this Chapter.

Chapter 4

Research Methodology

4.1 Introduction

This chapter introduces the research methodology used during this research. The methodology was chosen according to its appropriateness in achieving the previously stated research objectives. The methodology is divided into three main sections as follows:

(i) Routine laboratory analysis of soil and sediment samples collected in the field. This includes the physical analysis of samples to determine their textural properties, as well as limited chemical analysis for the purposes of further classification and description of soil and sediment properties.
(ii) The statistical analyses, used for the purposes of data reduction, of the data generated during the laboratory analysis of soil and sediment samples.
(iii) The analysis and mapping of aerial photography, in order to determine the present scale of degradation, any changes in degradation over time, and to assess the effectiveness of anti-erosion measures.

In addition, a brief rationale behind the utilization of the specific laboratory and statistical techniques is provided by way of information.

4.2 Sample collection in the field

In order to classify the material that is presently being eroded in the study area, and to determine which characteristics of this material effect its erosivity, 42 soil and sediment samples were collected during a field trip to the study area in April 1999. The samples were taken from various areas of sheet wash and gullying in uplands, footslopes and in valley bottoms (for a detailed description of the individual study sites, see chapter 5). Field logging, sampling and description of representative soil profiles, including soil type, soil structure, soil micromorphology and soil water properties, was undertaken in order to establish an inventory of the intrinsic field properties of the soils in the study area. The samples were then transported back to the laboratory where they were subjected to various physical and chemical analyses.

4.3 PHYSICAL ANALYSIS

4.3.1 Particle size analysis

Grain size is a fundamental characteristic of soils and sediments, and as such, it is one of the important descriptive properties of a soil or sediment. Leeder (1982), states that particle size distributors of sediments are a function of the parent material from which the sediment derives, the transport to which the material has been subjected, as well as the processes to which it has been subjected subsequent to deposition.

Particle size analysis is the measurement of the proportions of the various sizes of primary sediment particles. This is usually determined either by their capacity to pass through sieves of various mesh sizes, or by their rates of settling in water. These proportions are usually represented by the relative weights of particles within stated size classes (Sheldrick and Wang, 1993).

In order to undertake particle size analysis, a portion of each of the bulk samples was dried in a drying oven at 50° - 60°C for 12 hours, (Dyer, 1979). Once the samples were dried they were subjected to mechanical dispersion. This is because the fine particles may remain as discrete individuals or may become aggregated to form flocs. Upon deposition, the fine particles are brought into close proximity to similar particles and a form of ionic bonding or cohesion results (Dyer, 1979). In order to measure the smallest particle of the sediment (whether they reached the area individually or in aggregates or flocs) the inter-particle cohesion must be eliminated. In order to achieve this 20ml of sodium hexametaphosphate (a dispersant) was added to 50 grams of sediment and the beakers containing the mixture were then placed on a mechanical shaker overnight.

The analysis of silt and clay was done using a soil hydrometer. Sheldrick and Wang (1993) give a detailed methodology for hydrometer determination of the silt and clay size fraction of a soil sample. The soil hydrometer utilizes the relationship between the velocity of fall of spheres in a fluid, the diameter of the sphere, the unit weights of the sphere and the fluid and the viscosity of the fluid as expressed by Soke's Law (Bowles, 1970).

Stokes Law: $V = 2 / 9 * [(Ys - Yw) / ¢] * (D/2)^2$

Where:

v	=	velocity of fall of spheres, cm/sec
Ys	=	unit weight of the sphere, g/cu cm
Yw	=	unit weight of fluid, g/cu cm usually water
¢	=	absolute velocity of the fluid, dyne-sec/sq cm
D	=	diameter of the sphere, cm

The soil hydrometer data was used to calculate percentage values, in phi (∅) units, for silt (4∅ - 8∅), clay (8∅ - 9∅) and fine clay (>9∅) for each of the samples.

Following the hydrometer analysis, the samples were wet sieved through a 63-micron sieve in order to recover the sand fraction. The sand fraction was then dried in a drying oven at 50° to 60°C for 12 hours. The samples were then weighed in order to determine the proportion of sand in each sample.

In order to obtain a random sample of approximately three grams for analysis in a settling column, the samples were processed through a splitter.

These samples were then run through a computerized settling column, the configuration of which is shown in Figure 4.1. The principle behind the operation of the settling column is that sediment settling out of suspension at different velocities correlates directly to the grain size of the particles. This is based on Stokes Law of settling which has been previously described.

4.3.2 Definitions of statistical parameters of sediment grain size distributions

- Mean: average grain size

- Median: that size for which half of the particles (by weight) are coarse and half are fine

- Sorting or Standard Deviation: measures the sorting or uniformity of the particle size distribution

- Skewness: measure of the asymmetry of the distribution. If there is more material in the course tail, the skewness is referred to as being negative, while more material in the fine tail would result in positive skewness.

4.3.3 Munsell Color

A Munsell Soil Color Chart (Munsell, 1994) was used to classify the color of the sediment samples. Munsell color may provide a very broad indication of mineralogy, organic content, or the presence of certain salts.

Munsell notation for color consists of separate notations for hue, value and chroma, which were combined, in that order to form the color designation. Munsell notation is used as a supplement to color names in order to increase the precision of the description.

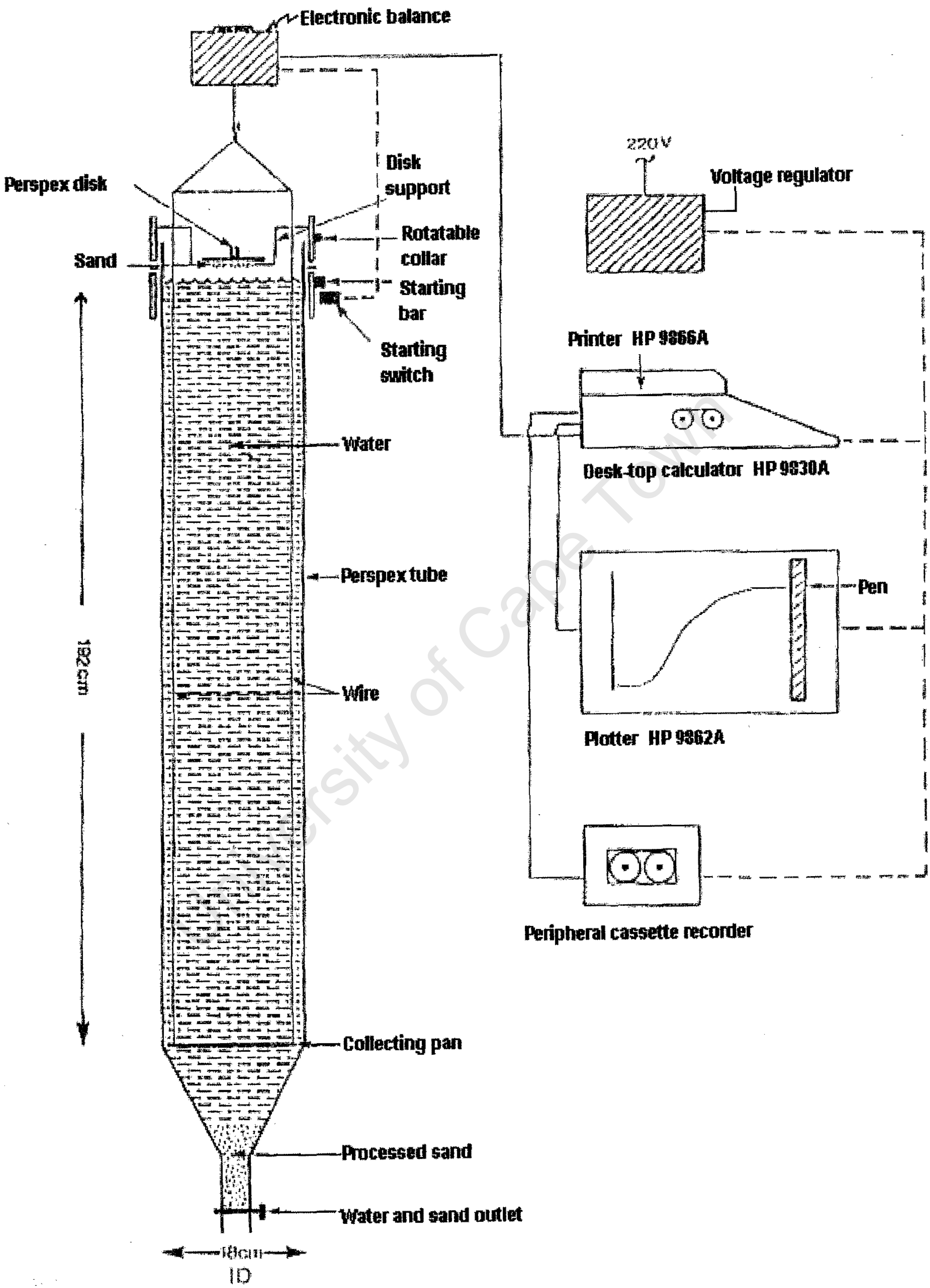

Fig 4.1 Configuration of the settling column (author unknown)

4.4 CHEMICAL ANALYSIS

4.4.1 pH

pH levels measure the activity of ionized H in the sediment water system, the composition of which is variable according to circumstances (McLean, 1982). A sediment water system does not comply with the limitations of a true solution and consequently the pH of a sediment cannot be defined as precisely as that of a solution. Nevertheless, pH is arguably the single most diagnostic chemical measurement made on soil (McBride, 1994; Hendershot *et al*, 1993). Whether a sediment is acidic, neutral, or basic has much to do with the solubility of various compounds, the relative bonding of ions to exchange sites, and the activity of various micro organisms (McLean, 1982). Thomas (1967, *in* Shaw, 1997) noted that three soil pH ranges are particularly informative: a pH < 4 indicates the presence of free acids, generally from the oxidation of sulfides; a pH < 5.5 suggests the likely occurrence of exchangeable Al; and a pH from 7.8 to 8.2 indicates the presence of $CaCO_3$.

The pH of each sample was determined by using a Metohm 691 pH meter. This meter was calibrated before sampling by using two buffer solutions (pH of 7 at 25°C and pH of 4 at 25°C). The measurements for each sample were taken by submerging the pH probe into a supernatant of distilled water and air-dried sediment sample. A ratio of 10g of sediment to 25ml of distilled water was used, as recommended by Avery and Bascomb (1974).

4.4.2 Conductivity

Electrical conductivity values provide a rapid and reasonably accurate estimate of the concentration of ionizable salts in the sediment (Jansen, 1993). The greater the concentration of ionizable salts, the more conductive the sediment and hence the higher the conductivity reading. This method is only approximate due to the relationship between salinity of the sediment and its affects on osmotic pressure (Hesse, 1971). The readings were obtained using a Crison micro cm 2201 conductivity meter. The same supernatant of sediment and distilled water used for the pH readings was used for the conductivity readings.

4.4.3 Calcareous content of the sand fraction

Carbonate accumulates in sediments as a result of pedogenic formation or is inherited from calcareous parent material (Nelson, 1982, *cited in* Shaw 1997). The content of acid-solubles in the sediment, which was equated with carbonate, principally calcium carbonate ($CaCO_3$), was established by measuring the weight loss after acid leaching. The method (Siesser and Rogers, 1970) involved initially treating approximately 10g of each raw sample with 10% HCl to determine which of the samples showed a reaction. Ten grams of the washed sand fraction of the samples which showed a reaction, were then treated with excess 10% HCl on a hot tray until the reaction reached completion. The washed sand fraction was used because of the problems involved in removing the hygroscopic precipitates after the completion of the reaction, which if not removed would have adversely affected the weight of the post treatment sample, resulting in a false reading. The disadvantage of this method is that potentially a percentage of silt sized carbonate may have been lost, and thus the total percentage reflected may be skewed.

4.4.4 Total organic fraction

Organic matter contributes to the physical condition of a sediment by holding moisture and affecting structure. In this, and other studies, the sediment organic matter was taken to include only those organic materials that accompanied sediment particles through a 2mm sieve. In order to determine the approximate percentage of organic material in each sample, the ignition loss method was used. According to Nelson and Sommers (1982) this method tends to give an overestimate of organic content because both organic and inorganic constituents of the sample lose weight during heating. However, the greatest part of the weight loss to inorganic constituents occurs in the temperature range of 450°C to 600°C (Hesse, 1971) and therefore the errors of this method can be considered to be overrated provided that the temperature is kept below 450°C.

All samples were initially oven dried in order to drive off any moisture, and then placed in a furnace and heated to a temperature of 400°C for 12 hours. Samples were weighed before and after firing and the percentage weight loss was calculated.

According to Holmes (1998) the presence of organic material may point to a reducing type environment, which will result in the preservation of such material.

4.5 STATISTICAL METHODS

4.5.1 Introduction

The data obtained from the sedimentological and chemical analysis of the soil samples needed to be reduced to a more manageable form. Multivariate statistical techniques were considered appropriate, as they allow the researcher to work on data sets where a number of variables need to be simultaneously considered. The multivariate statistical techniques that were used to achieve this data reduction are described here. The PCA and cluster analysis were both run using the statistical package, *Statistica* (1998 edition).

4.5.2 Standardization

Standardizing the data matrix converts the original attributes to new unitless attributes. Before performing the statistical analysis, the raw data was first standardized using the *Statistica* standard procedure. The procedure produces a new data, set with a mean of 0 and a standard deviation of 1 for each variable (Holmes, 1998). In this way the scale attributes of the original data set are removed. This implies that no single variable is weighted at the expense of other variables in the data set.

4.5.3 Principal Component Analysis (PCA)

Principal component analysis is a purely inductive or exploratory technique which aims to "describe the variation of the n individuals in p-dimensional space in terms of a set of uncorrelated variables which are linear combinations of the original variables" (Everitt and Dunn, 1983. p.39). The new variables are derived in decreasing order of importance, so that the first principal component accounts for as much as possible of the variation in the original data set. This technique is commonly used when the researcher is searching for some indication of order or pattern in the data. If the first few components account for most of the variation in the original data, then it is argued that they can be used to summarize the data with little loss of information. Thus, a reduction in the dimensionality of the original data is achieved, which may be very useful in simplifying later analysis (Everitt and Dunn, 1983). The variance in each variable accounted for by a principal component is given as the component loading. By examining eigenvalues and component loadings, linear relationships or patterns in the data set may be discovered.

4.5.4 Cluster Analysis

Cluster analysis is the generic name for a variety of mathematical methods that can be used to find out which objects in a set are similar. Although modern clustering techniques began development in biological taxonomy, they are generally applicable to all types of data (Hartigan, 1975). Cluster analysis is also an inductive classifactory technique. The objective of cluster analysis is to separate a set of objects into constituent groups (classes, clumps, clusters) so that the members of any one group differ from one another as little as possible, according to a chosen criterion (Spath, 1980).

Methods of hierarchical cluster analysis follow a prescribed set of steps, the main ones, described by Romesburg (1984), being:

1. Collect a data matrix whose columns stand for the objects to be cluster-analyzed and whose rows are the attributes that describe the objects.
2. Optionally standardize the data matrix.
3. Using the data matrix or the standardized data matrix, compute the values of a resemblance coefficient to measure the similarities among all pairs of objects.
4. Use a clustering method to process the values of the resemblance coefficient, which results in a diagram called a tree, or dendrogram, that shows the hierarchy of similarities among all pairs of objects. From the tree, the clusters can be extrapolated.

Various methods of clustering are available, Single-linkage clustering and Ward`s

Minimum Variance clustering method were used in this study. The single linkage method was chosen due to its usefulness in identifying outlies, while Ward`s method is particularly useful for identifying groups (B. Hewitson, *pers comm.* cited in Holmes 1998). Cluster analysis in this study was performed on both the standardized raw data matrix and on the principal component data (varimax rotated).

4.6 AERIAL PHOTOGRAPHY

4.6.1 Introduction

In order to assist in achieving the stated objectives of determining the present scale of degradation in the study area, assessing the effectiveness of anti erosion measures, and assessing any changes in the scale of degradation in the area over time, an analysis of the available aerial photograph coverage of the area was undertaken. The aerial photographs for the years, 1945, 1959, 1966 and 1980 were obtained from the Chief Director of Surveys and Mapping in Mowbray, Cape Town. The analysis included intensive mapping of individual sites of degradation in 1945 and 1980, as well as producing overall land degradation maps [based on the SARCCUS (1981) system] of the Klein Zeekoei River valley for 1945 and 1980 (Fig 6.16 and Fig 6.17). A composite map of formerly cultivated land was produced using the 1945, 1959 and 1966 aerial photography (Fig 6.15). The purpose of this map was to enable any link between cultivation and land degradation to be investigated.

4.6.2 Analysis

The analysis of the aerial photographs was not without difficulty, and there are a number of limitations to the analysis. The quality of the aerial photographs is variable between years. Tonal differences, and contrast, for example, are variable between aerial photographs taken in different years. In order to facilitate a more accurate analysis of the aerial photography, it was decided that for comparative purposes, the photographs should be standardized to the same scale. However, the differing scales of aerial photographs lead to differing amounts of distortion across an area, when enlarged to a standard scale.

TYPE OF EROSION	CLASS OF EROSION	SYMBOL	DESCRIPTION AND REMARKS
1. EROSION CAUSED BY WATER			
SHEET (SURFACE)	None apparent	S1	No visible signs of erosion on air-photo. Level of management appears to be high.
Uniform removal of surface soil	Slight	S2	Areas of light-tone observed on air-photos. Erosion deduced from poor cover, sediment deposits and plant pedestals.
	Moderate	S3	Eroded areas obvious on air-photos. Plant cover very poor and sediment deposits extensive. Associated with small rills.
	Severe	S4	) Sheet erosion of such severity always associated with rills and gullies. Much or all of the A-horizon has been removed.
	V. Severe	S5	)
RILL	None apparent	R1	As for sheet erosion.
Removal of soil in small channels	Slight	R2	Small, shallow (mainly <0,1 m) rills present but not readily observed on air-photos.
or rivulets, mainly on arable	Moderate	R3	Rills of considerable depth (mainly 0,1 to 0,3 m) and intensity usually observed on air-photos.
land	Severe	R4	An abundance of deep rills (less than 0,5 m) easily observed on air-photos. Subsoil may be exposed.
	V. Severe	R5	Large well defined rills but may be crossed by farm machinery. Associated with gully erosion.
GULLY (DONGA)	None apparent	G1	As for sheet erosion.
Removal of soil in large channels	Slight	G2	Clearly observed on air-photos and usually up to 1 m deep. Cannot be crossed by farm machinery.
or gullies by concentrate runoff	Moderate	G3	Intricate pattern of deep gullies (mainly 1 to 3 m) exposing entire soil profile in places. Many 'islands' of topsoil remain.
from large catchment areas	Severe	G4	Landscape dissected and truncated by large (3 to 5 m deep) gullies. 25 % - 50 % of area unproductive.
	V. Severe	G5	Large and deep (often > 5 m) gullies have totally denuded over 50 % of the area.
LANDSLIDE Soil mass slumps downwards, leaving vertical scarp	Five class ratings also apply to these types of erosion but are seldom used.	L	Usually visible in air-photos. Oversaturation causes soil mass to slide downslope leaving a vertical scarp at the top. Catchment area normally absent.
TERRACETTE Step-like formation on steep slopes		T	Easily observed on air-photos. Usually associated with steep slopes (over 15 %) in high rainfall areas. Aggravated by trampling.
CREEP Gradual viscous movement of the soil mass down slope		C	A natural phenomenon which may be observed in mountaineous areas. Recognition aided by observation of other features. Not readily observed on air-photos.
STREAMBANK Undercutting and slumping in of stream and river banks		B	Occurs on outer curves of stream and rivers where fast-flowing water undercuts the banks. May or may not be seen on air-photos.
2. EROSION CAUSED BY WIND			
WIND	None apparent	W1	Seldom observed in well vegetated and humid areas where clayey soils predominate.
Sandy materials (> 85 % sand) removed by suspension, saltation	Slight	W2	Not readily observed on air-photos. Field checks show evidence of removal and deposition and loamy soils (15-35 % clay and 65-85 % sa) may predominate.
and creep during strong winds	Moderate	W3	Easily observed on air-photos. Sand deposited against obstructions and small dunes are formed. Soils are mostly sandy (< 15 % clay and > 85 % sand)
	Severe	W4	Large parallel sand dunes observed on air-photos. Vegetation is sparse and soils very sandy (< 10 % clay).
	V. Severe	W5	Over 50 % of the area rendered unproductive by so-called 'blow-outs' and deposition of sand.

Note: Moderate (3) to very severe (5) classes often include a combination of two or more types of water erosion.

Table 4.1 Summary of the types and classes of erosion according to the SARCCUS (1981) system. After SARCCUS (1981)

After an initial visual comparison of the available coverage, it was decided that the 1945 photographs provided the most appropriate level of detail. For comparative purposes, aerial photographs from other years were enlarged to the same scale as the 1945 photographs.

The aerial photographs were examined using a stereoscope with a 3x magnification, allowing the photographs to be observed at an effective scale of approximately 1: 6700.

In order to assess the changes in the scale of degradation at specific (individual) sites over time, four degraded areas were selected, each representing a different type of erosional environment. The Lucernvale (LV) and Goodhope (GHS) sites represent areas of badland on footslopes. The site on the Compassberg lands (KBL) represents an area of valley bottom which is presently an area of intense sheetwash erosion, but shows evidence of having been previously cultivated. The Kriegersbaken site is an area of footslope erosion, which is largely re-vegetated, and appears to be presently inactive. The spatial location of these type sites will be indicated in Chapter 5.

The extent of the degraded area at each study site was traced out under a stereoscope, for each available year of coverage, and the area of degradation was then calculated. The change in the extent of degradation was then calculated as a percentage (increase or decrease) of the 1945 scenario. The present extent of degradation of these areas was assessed during the field work stage of the research.

In order to assess the possible link between land degradation and cultivation, and to assess the changes in the nature, extent and intensity of degradation over time, three maps covering the greater part of the headwater catchment of the Klein Zeekoei River were produced. These maps were produced using a stereoscope on 1: 20 000 scale aerial photography using the method previously described for the individual land degradation sites. A map of formerly cultivated land (Fig 6.15) was produced using a composite of the aerial photography from 1945, 1959, 1966 and 1980. Land degradation maps were produced for the years 1945 and 1980 (Fig 6.16 and Fig 6.17). The classification of the type and intensity of erosion in the study area was carried out according to the system of classification developed by the Southern African Regional Commission for the Conservation and Utilization of the Soil (SARCCUS, 1981) was chosen. This was due to the systems simple and effective nature, the ease with which it can be applied to aerial photography, and the fact that is specifically designed for Southern African conditions. The SARCCUS system arose from the need for a standard procedure to assess soil erosion throughout the southern African region. An assessment of soil erosion throughout the region was to serve as a publicity campaign to draw the attention of member countries to the disastrous level of soil erosion in the region (SARCCUS, 1981). The SARCCUS system for soil erosion classification which was used in the production of the overall land degradation maps for 1945 and 1980 is summarized in Table 4.1.

4.7 Archival investigation

In order to assist in the assessment of the effectiveness of anti-erosion measures in the catchment and the rate of gully formation and expansion, detailed records of all government subsidized anti erosion works and fencing, were obtained from the Agricultural Extension Office at Middelburg. These records are meticulously kept and document the date of construction and in some cases the amount of the subsidy given to the farmer for farm improvements such as camp fences, stock watering systems and soil conservation measures. These records are highly detailed and go back as far as the mid 1940`s. In the case of the farm The Valley, the engineers drawings for the four main anti erosion weirs (late 1940`s to early 1950`s) in the upper headwaters of the Klein Zeekoei River are still on record. Photo maps (1:20 000) of each farm, document the approximate location of all government sponsored farm improvements, including fence lines. Knowledge of the fence lines and the dates that fences were erected was used to assess the rates of advance or retreat of gullies.

At the time of visiting the Middelburg Agricultural Extension Office (April 1999), it was in the process of closing down. The danger therefore exists that this wealth of information may become lost. As far as could be ascertained, all records previously kept in Middelburg will now be housed in the Agricultural Extension Office in Cradock.

4.8 Conclusion

This chapter has outlined the methodology for the laboratory processing of the soil/sediment samples collected in the field, and the statistical methods used to organize and interpret this data. The methodology for the interpretation of aerial imagery has also been described. Aspects of the application of these methodologies will be discussed in Chapter 6 and Chapter 7. In the following chapter the reader is introduced to specific study sites from which soil samples were taken, or to which specific mention is made in the interpretation of the aerial imagery.

Chapter 5

Site Descriptions

5.1 Introduction

The choice of particular study sites involves some measure of subjectivity on the part of the researcher, however an attempt was made to choose a representative cross-section of typical erosion sites, in various positions in the landscape. The choice and number of sites was constrained by accessibility and the timeframe of the study. This chapter describes the specific sites referred to in the interpretation of aerial photography, and the sites where soils and sediments were examined in the field, and soil samples were taken. A simplified topographic map showing the position of the study sites is included for the readers information (Fig 5.1). Anotated photographs are used to show the stratigraphy of gully profiles, while a general photograph of each of the other sites is included by way of information. It should be noted that the thickness given for the various gully strata depicted in the photographs, refer to the thickness of the strata at the point where sampling took place, and may in some cases differ slightly from the thickness of the strata at the point where the photograph was taken. Quantitative data on sediment texture and color (Munsell notation) are included in Chapter 6.

5.2 Lucernvale (LV)

The position of this site is approximately 1km west of the Lucernvale farm homestead (Fig 5.1), on a north east facing, concave, foot slope. The site relief (taken to be the altitudinal difference between the highest and lowest point of the site) is approximately 80m with a slope length of approximately 1500m. The main erosional features at this site include extensive badland erosion, with gully systems eroded to the shale bedrock in many places, as well as humps around vegetation and pedestals capped with sandstone blocks, which provide evidence for extensive sheet wash. Field observations show that the maximum depth from the current surface to bedrock is approximately 2.7 meters.

The stone blocks, which occur throughout the area, all comprise sandstone, no shale blocks were observed. The blocks are relatively unweathered and derived from a sandstone outcrop upslope. The maximum long (A) axis length was 40cm and the maximum (B) axis length was 10cm.

5.2.1 Soil sampling sites on Lucernvale:

5.2.1.1 LV1 (Top of slope)

Three distinct horizons occur on top of a weathered shale bedrock. The maximum depth to bedrock is 2.6m. None of the horizons display any soil structure.

- LV1A: This can most closely be equated to a modern A horizon, and consists of a surface veneer of approximately 10cm of grayish gritty sediment.
- LV1B: This is a 1m layer of grayish gritty sediment.
- LV1C: This is a 1.5m layer of reddish gritty sediment.

5.2.1.2 LV2 (Foot of slope)

As is the case for LV1, three distinct horizons occur, none of which display any soil structure. Shale bedrock occurs at a maximum depth of 2.25m.

- LV2A: A 30cm layer of grayish sheetwash (modern A horizon) material.
- LV2B: This layer consists of 55cm of grayish material.
- LV2C: Approximately 1.4m of reddish gritty material.

Plate 5.1 Lucernvale site, showing badlands and pedestals capped with sandstone blocks. Note the scarcity of vegetation in the foreground (dominated by one species) compared to the undegraded slopes in the background.

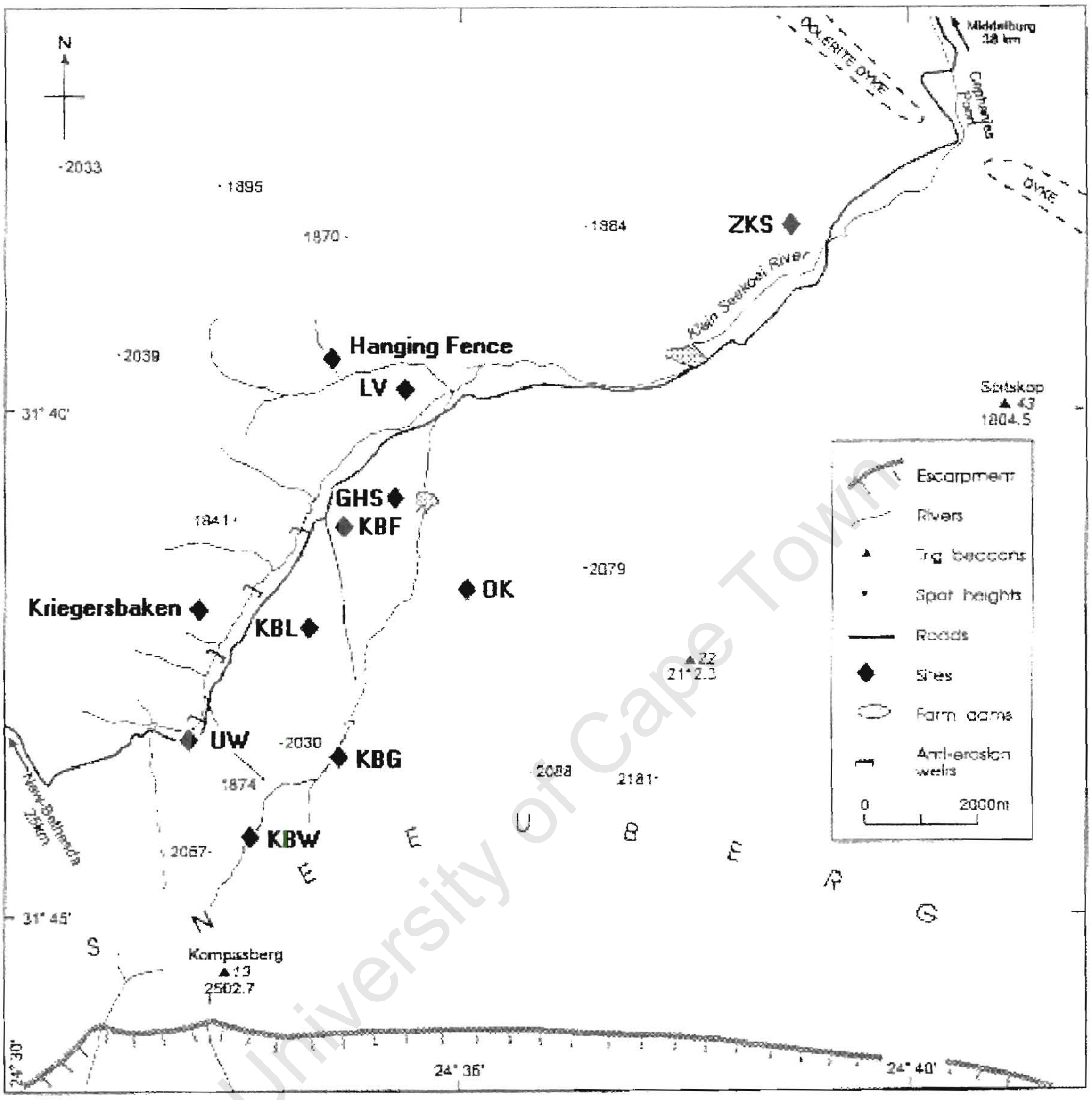

Fig 5.1 Location of study sites in the Klein Zeekoei River Valley (After Holmes, 1998).

5.3 Good Hope Slope (GHS)

This site of badland erosion is located on the east facing, even, foot slope of a hill on the farm Good Hope, approximately 800m south west of the Good Hope homestead (Fig 5.1). The site has a relief of approximately 50m, and a slope length of approximately 400m. The catchment area of this site is very small, but very rocky, therefore facilitating easy runoff generation. A dolerite dyke as well as numerous sandstone bands outcrop upslope of this site.

The main erosional features at this site are active parallel gullies and sheet wash. The gravelly interfluves are stripped of coarser material. The coarser material occurs in the gully floors. The depth to the shale bed rock, increases towards the center of the basin, to a maximum depth of 2.5m. A fan has formed at the foot of the slope, which has partially buried a 1.2m, seven strand fence to a depth of 70cm. There is evidence of crusting on the fan.

There is a progression in the percentage of vegetation cover from the less degraded to the more degraded areas. It was noted that once the grasses are lost, the land is severely degraded. *Lyceum* occurs in the gully floors. A mature Karoo bush was observed which displayed a 15cm soil loss around the base. The pedestals at this site are fewer and smaller than those observed at Lucernvale, and there is less evidence of piping.

Plate 5.2 The GHS site. Note extensive badland erosion in the foreground, and the figures for scale.

5.4 Compassberg Footslope (KBF)

This is an area of badlands (active sheet wash and gullies) on the west facing, concave, foot slope of a hill on the farm Compassberg (Fig 5.1). The site has a relief of approximately 40m and a slope length of approximately 300m. The area is totally denuded of any topsoil, and ground cover is very sparse. Shale bedrock steps underlie the remaining cover material, which is approximately 1.5m deep on the steps. Pedestals, and vegetation growing on well- developed humps were observed.

The fine material in the gully bottoms shows evidence of water movement in the form of ripples and micro-scale channel braiding.

The cover material displays two distinct horizons. The upper horizon (KBF1A) consists of 80cm of slightly darker grayish material, which displays no ped structure. The basal material (KBF1B) consists of 70cm of lighter gray colored material with small angular shale clasts, also showing no soil structure.

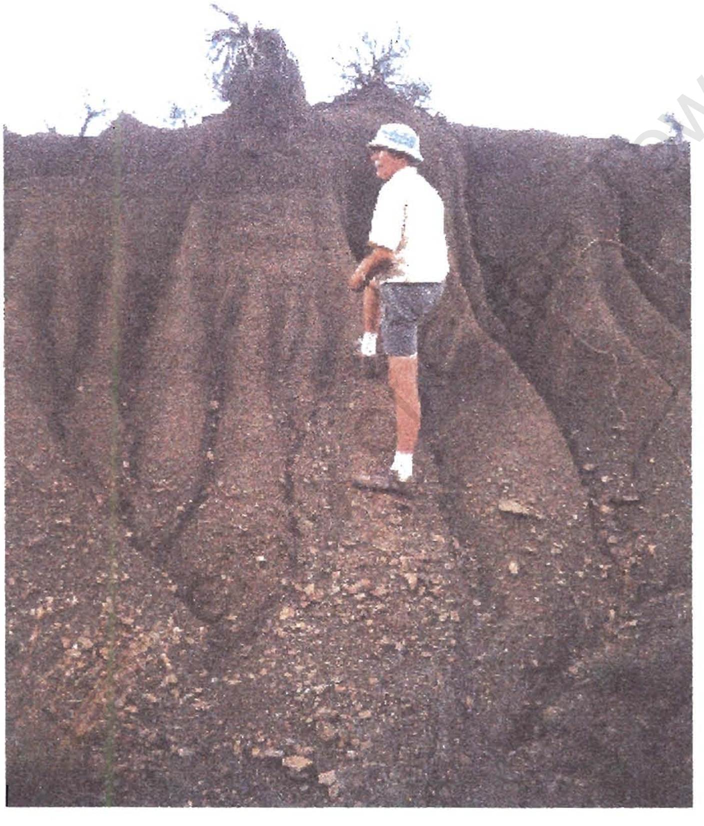

Plate 5.3 Badland erosion at the KBF site. Note that the bushes offer some protection to the soil directly beneath them, leading to pedestal formation.

5.5 Compassberg Lands (KBL)

This site is an area of previously cultivated land approximately 800m north of the Compassberg homestead (Fig 5.1). The site is fairly flat, but does slope gently towards the north (approximately 1.2°). The main erosional features of this site are extensive sheet wash, which has mostly stripped the A horizon. Shallow gullies occur and there is evidence of piping in some areas. Soil samples were taken at two sites, designated KBL1 and KBL2.

- KBL1: These samples were taken 50m west of the farm road leading to the Compassberg homestead. There are two distinct horizons in this area; an A horizon which is mostly stripped, and where it does occur is not more than 10cm deep. The B horizon appears to be desiccated and impermeable.

- KBL2: These samples were taken 250m west of the farm road leading to the Compassberg homestead. Erosion to the shale bedrock has occurred in some gullies at this site. The maximum depth to bedrock is 1m. There appears to be a B and C horizon at this site, denoted by a slight color change, and possible evidence of the B horizon being more resistant. Some piping occurs in this area, and the B horizon forms the roofs of the pipes.

Plate 5.4 The KBL site showing badland development and sheetwash. A soil auger in the left foreground gives an idea of scale. Note the absence of an A horizon, and the hard baked crust which occupies the A horizon position in the profile.

Plate 5.5 The KBL site, showing extensive sheetwash. Note once again, the absence of an A horizon, and the hard baked crust which occupies its position in the profile.

5.6 Compassberg Gully (KBG)

This site is situated approximately 1km south of the Compassberg homestead, and approximately 400m upstream of the main dam above the homestead (Fig 5.1). This site is a deep valley floor gully, with a maximum depth of 5.52m,which occurs at the base of an east facing footslope. Eight distinct stratigraphic units were identified (fig 5.2), all of which contain gritty material which is not well consolidated. The exposed section showed surface cracking, but except for KBG2, showed little ped structure.

5.7 Zeekoei River; Side Gully (ZKS)

The Zeekoei River Side Gully is situated on the eastern boundary of the farm Lucernvale, just to the north of the main dirt road that runs alongside the Klein Zeekoei River (Fig 5.1). The ZKS gully is a tributary of the main valley floor gully of the Klein Zeekoei River and is oriented in a north south direction. The site has a slope length of approximately 400m and a relief of approximately 50m. Seven distinct stratigraphic units were identified in the gully (Fig 5.3), and at the point where soil samples were taken the gully depth was 7m. ZKS, in common with other sites, has been stripped of a modern A horizon, and no ped structure was present. The clasts and gravel lags were poorly sorted and angular. Clastic material was a mixture of sandstone and shale, and showed some evidence of imbrication.

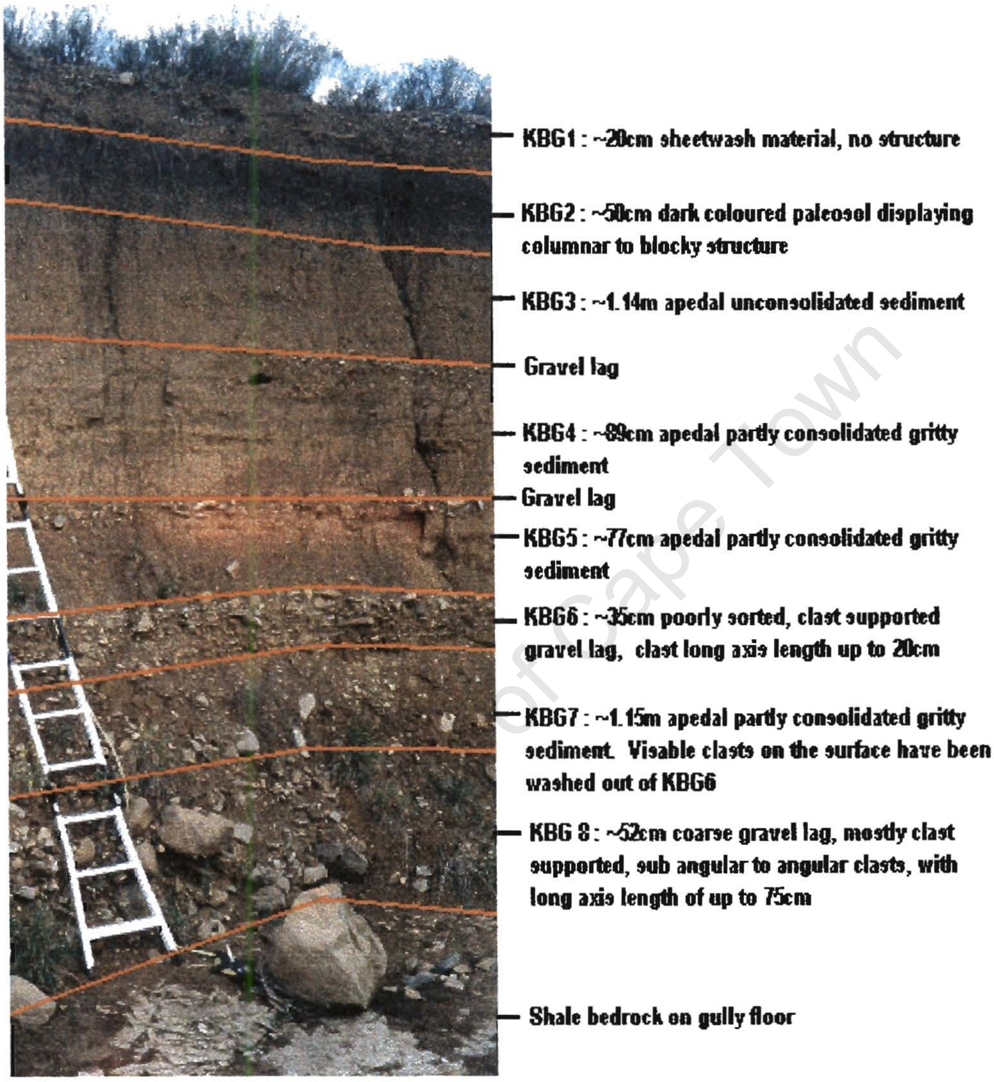

Fig 5.2 The KBG gully profile. The total gully depth is 5.52m.

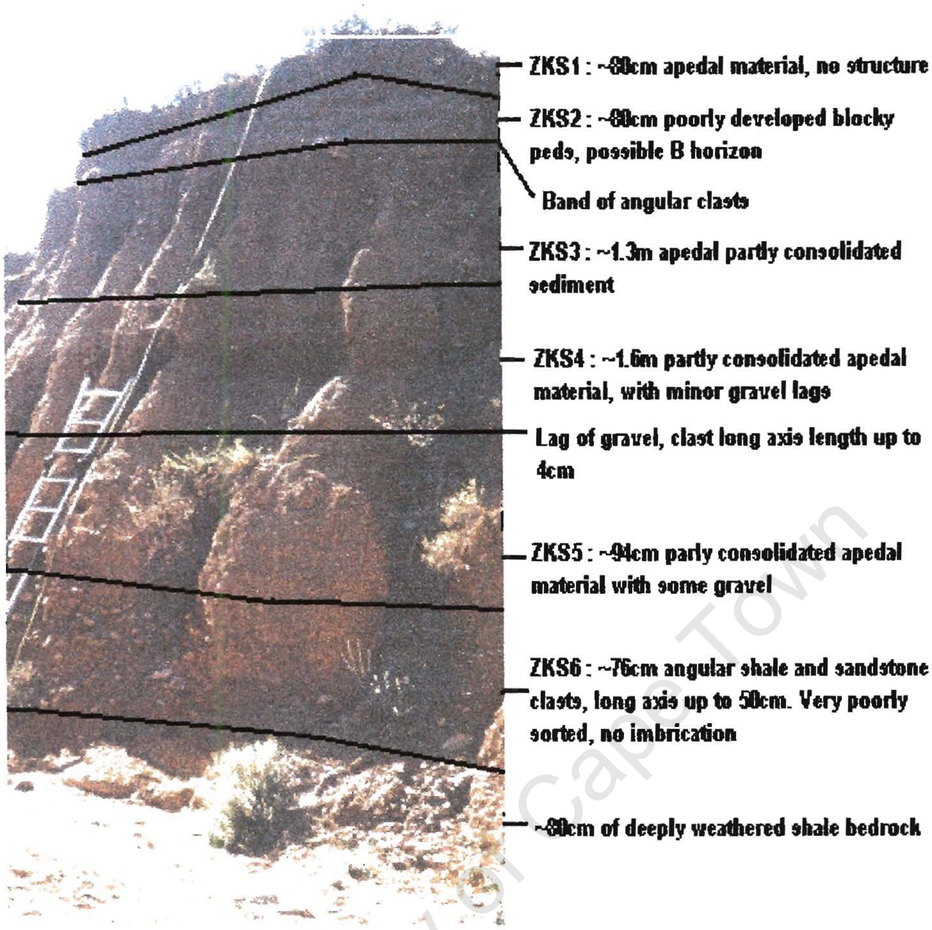

Fig 5.3 The ZKS Gully profile. The total gully depth is 7m.

5.8 Oppermanskraal (OK)

The Oppermanskraal site is situated on the farm Good Hope approximately 1Km north of the Oppermanskraal farmstead (Fig 5.1). This site is part of a valley floor gully running in a west - east direction on a gentle west facing slope and having a total length in excess of 3Km. At the sampled section the gully was 4.1m deep and consisted of five distinct statigraphic units (Fig 5.4). This was the only site that displayed a marked amount of calcification in some of the stratigraphic units (OK3 and OK5). It was noticed that the clast material in OK5 is very weathered, and the doleritic material is exfoliated. The clastic material is composed of approximately 5% dolerite, 20% shale and 75% sandstone, and does show some imbrication. Unit OK5 overlies the shale bedrock which is exposed in the gully floor.

Fig 5.4 Oppermanskraal gully profile. Total gully depth is 4.1m. The holes / burrows are presumably of biogenic origin.

5.9 Compassberg: trekboer wall (KBW)

An old trekboer kraal is situated approximately 4Km south-west of the Compassberg farmstead (Fig 5.1). A valley floor gully has eroded into this upland area, and the gully head is presently situated approximately 10m to the south of the stone wall of the kraal. The gully runs from south to north and at the sample site runs along the foot of a steep east facing slope. The stratigraphy of the gully was divided into three units, as shown in Fig 5.5.

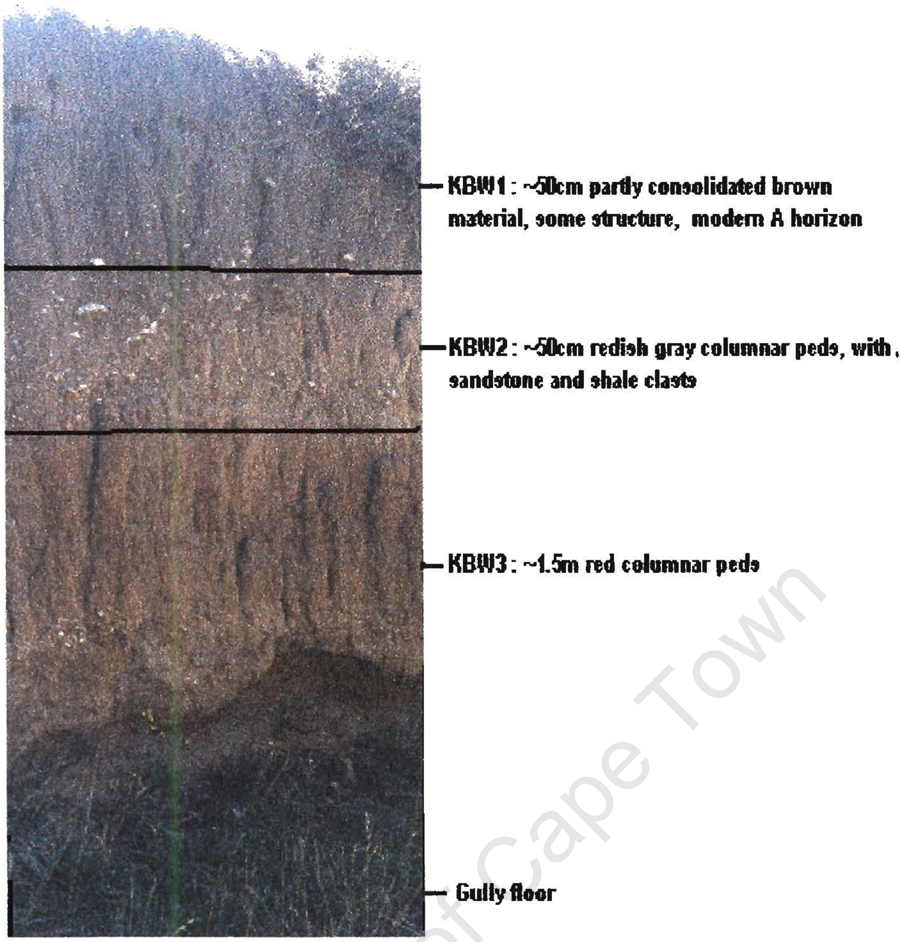

Fig 5.5 KBW gully profile.

5.10 The Uppermost Weir

There are four anti erosion weirs constructed in the main water course that runs through the Klein Zeekoei River Valley (Fig 5.1). Aerial photography and personal communication with the farmer (H.N. Sheard, pers comm) indicate that these weirs filled with sediment within ten years of their construction in the late 1940`s and early 1950`s. Hand coring with a gouge auger was attempted at the uppermost, (most southerly) weir (Plate 5.6). Shale bedrock occurs at a depth of 2.9m. Coring was only possible to a depth of 57cm, where clastic material was struck. No significant stratigraphy was observed in the top 57cm.

5.11 Kriegersbaken

The position of this site is approximately 800m north of the Kriegersbaken farm buildings (Fig 5.1). The site occurs on a north-east facing, concave slope, to the west of the main watercourse the Klein Zeekoei River valley. The site has a relief of approximately 60m and a slope length of approximately 900m. This is a gully system on fairly steep slopes with incision to bedrock. Apart from *Lyceum* growing in some of the peripheral areas the vegetation is generally in good condition, being fairly well grassed. The areas of *Lyceum* seem to have previously been cultivated with spineless cactus. The interfluves are well vegetated, and the area appears to be relatively stable.

Plate 5.6 The uppermost weir in the Klein Zeekoei River Valley.

5.12 Aandrus (Hanging Fence) Gully

This site is situated in the valley that runs due west of the Lucernvale homestead (Fig 5.1). The specific site occurs as a side gully to the main valley floor gully, and enters the main gully approximately 15m to the east of the anti erosion dam which is built across the main gully. The gully occurs on a south west facing slope, with a slope length of approximately 600m and a relief of approximately 60m. A photograph of this site is included in the case study in Chapter 6 (Plate 6.1).

The stratigraphy of the site consists of four distinct units. There is a course basal gravel lag, overlain by reddish gritty material, which is overlain by a greyish colored paleosol, which is in turn overlain by modern sheet-wash material. A hanging fence was observed over the gully, and it is the initial (field) hypothesis that the fence pre dates the gully. Aerial photography analysis will be used to substantiate this hypothesis (Chapter 6).

Chapter 6

Results

6.1 Introduction

In this chapter the results of the sedimentological analysis, the statistical analysis of this data, as well as the results from the interpretation of aerial imagery are presented. The aim of this chapter is to present the results in an objective and unambiguous fashion. The task of interpreting, synthesizing and drawing substantive conclusions from the data is reserved for the discussion in Chapter 7.

6.2 Sediment Samples

The results from the sedimentological analyses are presented according to the sites where they were sampled. Detailed data are presented in the form of tables. Anomalies and noteworthy features are drawn to the readers attention in the text. It should be noted that in the South African system (Soil Classification Working Group, 1991), soils and sediments can be described in terms of "textural classes" although the material is not strictly speaking necessarily soil. A summary table of all data is included in Appendix A. Site descriptions of the sample sites are included in Chapter 5.

6.2.1 Lucernvale (LV)

Grain size analysis of the Lucernvale samples revealed them to be fairly homogenous (Table 6.1). All samples, with the exception of the B horizon at the second sampling location (LV2B), consist of approximately equal proportions of sand and fines (here taken as silt and clay). In all cases, fine sand is the dominant size class of the sand fraction (Table 6.2). All samples contain a significant proportion of silt (> 26%), with varying proportions of clay and fine clay. Sample LV2B contains a significantly higher proportion of fines than any of the other Lucernvale samples. Texturally, all the samples are classified as loam, varying between sandy loam and clay loam.

The sand fraction (Table 6.2) of all samples displays poor sorting, and the graphic statistics show that all display platykurtic curves. The grain size distribution of the sand fraction of the A horizon of both sample locations (LV1A and LV2A) is negatively skewed. Both B horizons (LV1B and LV2B) are symetrical, LV1C is very negatively skewed, and LV2C is positively skewed.

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
LV1A	52.86	32.54	2.73	11.87	sandy loam
LV1B	42.40	31.40	5.11	21.09	loam
LV1C	48.92	26.58	3.90	20.60	loam
LV2A	51.42	31.65	3.98	12.95	loam
LV2B	26.22	40.08	11.21	22.49	clay loam
LV2C	41.26	26.14	5.06	27.54	clay loam

Table 6.1 Lucernvale; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
LV1A	18.86	20.37	60.77	2.23	2.45	1.16	-0.25	0.78
LV1B	29.65	27.89	42.46	1.73	1.69	1.09	0.08	0.82
LV1C	19.27	16.03	64.70	2.25	2.54	1.15	-0.33	0.77
LV2A	22.65	23.91	53.44	2.05	2.14	1.15	-0.12	0.75
LV2B	31.23	23.10	45.67	1.79	1.77	1.13	0.03	0.73
LV2C	44.96	10.03	45.01	1.55	1.39	1.21	0.17	0.69

Table 6.2 Lucernvale; sand fraction classes and statistical parameters.

Sample	pH	Cond. μs	%Organics	Munsell C
LV1A	6.11	86.10	5.44	7.5YR 5/4
LV1B	6.83	108.80	6.16	7.5YR 5/3
LV1C	6.77	789.00	5.08	7.5YR 6/6
LV2A	6.72	56.20	5.41	7.5YR 5/4
LV2B	5.84	377.00	7.39	7.5YR 5/3
LV2C	8.89	346.00	3.75	7.5YR 6/6

Table 6.3 Lucernvale; pH, conductivity, color, and organic content.

The pH range of the Lucernvale samples is fairly large, ranging from 5.84 to 8.89 (Table 6.3). The B horizon of both sample locations (LV1B and LV2B) display fairly neutral pH readings (6.16 and 7.39). Samples LV1A, LV1C and LV2A are all acidic, while LV2C is strongly basic (8.89). The conductivity readings on the Lucernvale samples range from 56.2 μS/cm to 789 μS/cm (Table 6.3). LV1C is the only sample whose conductivity is significantly different (789 μS/cm, that is, more conductive) than the others.

The organic content of the samples is fairly low (all < 7.5%) and shows a high degree of homogeneity (Table 6.3). It is noteworthy that the A horizons in both cases do not display higher organic contents than the other horizons. The soil colors differ only slightly within each profile, with the top two horizons being brown, and the bottom horizon being reddish yellow in both the sample locations (Table 6.3).

6.2.2 Compassberg Lands (KBL)

The grain size analysis of the Compassberg land samples revealed that the sediments at this location are predominantly fine-grained (Table 6.4). The sand fraction of the samples is predominantly fine sand, while silt accounts for the greatest proportion of the fine fraction of the samples. The Folk and Ward statistics of the sand fraction show the samples to all be poorly sorted (Table 6.5). All the distributions display either platykurtic or mesokurtic curves, and all samples are skewed (Table 6.5), with the exception of the B horizon at the second sample location (KBL 2B), which is symetrical. The overall texture of the samples (Table 6.4) varies from loam to clay loam.

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
KBL1A	39.48	39.59	3.81	17.12	loam
KBL1B	25.08	42.32	10.00	22.60	clay loam
KBL2A	34.82	42.18	5.37	17.63	loam
KBL2B	17.24	49.56	10.39	22.18	silty clay loam
KBL2C	27.72	37.68	11.82	22.78	clay loam

Table 6.4 Compassberg lands; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
KBL1A	24.57	19.23	56.20	2.12	2.34	1.19	-0.23	0.67
KBL1B	9.91	13.96	76.13	2.61	2.89	1.00	-0.43	1.04
KBL2A	18.45	23.44	58.11	2.20	25.35	1.12	-0.19	0.74
KBL2B	23.27	27.76	48.97	1.93	1.96	1.08	-0.03	0.82
KBL2C	40.46	29.23	29.91	1.42	1.23	1.06	0.27	0.89

Table 6.5 Compassberg lands; sand fraction classes and statistical parameters.

Chemical analysis of the KBL samples revealed a large range of both pH and conductivity values (Table 6.6). All samples are acidic with the exception of KBL1A which is neutral. The A horizons of both sample locations have a similar conductivity, KBL1B, KBL2B and KBL2C all have high conductivities, with KBL2B and KBL2C being extremely high. The organic content of the samples (Table 6.6) is relatively low. The color of the soil horizons is fairly homogenous, varying between brown and light brown.

Sample	pH	Conductivity µs	%Organics	Munsell C
KBL1A	7.09	153.10	5.62	7.5YR 5/4
KBL1B	6.54	636.00	8.68	7.5YR 5/3
KBL2A	6.38	118.40	5.03	7.5YR 5/3
KBL2B	5.84	5420.00	8.01	7.5YR 6/3
KBL2C	6.10	2230.00	5.74	7.5YR 6/3

Table 6.6 Compassberg lands; pH, conductivity, color, and organic content.

6.2.3 Good Hope Slope (GHS)

The samples analyzed from this site all contain a high proportion of sand (> 37%). The mean grain size of the sand fraction of the GHS samples varies between coarse and medium sand and samples are moderately to poorly sorted (Table 6.7). All samples at this site are classified as loam (Table 6.7), with the exception of the sample taken immediately above bedrock (GHS4), which contains a significantly higher proportion of sand than other samples taken at this site. The GHS samples are symmetrical to positively skewed, with GHS1B and GHS3 being very positively skewed (Table 6.8). The distributions display mesokurtic curves, with the exception of GHS2 which is platykurtic and GHS3 which displays a leptokurtic curve.

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
GHS1A	57.94	21.26	2.59	18.21	sandy clay loam
GHS1B	37.28	32.42	5.76	24.54	clay loam
GHS2	54.30	26.40	19.30	18.60	clay loam
GHS3	44.96	24.44	5.00	25.60	clay loam
GHS4	87.24	10.16	0.00	2.60	Sand

Table 6.7 Good Hope slope; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
GHS1A	44.74	35.30	19.96	1.25	1.11	0.90	0.28	1.05
GHS1B	64.35	23.00	22.65	0.82	0.64	0.96	0.37	1.08
GHS2	31.88	21.56	46.56	1.76	1.86	1.18	-0.08	0.74
GHS3	61.55	25.04	13.41	0.93	0.77	0.85	0.34	1.17
GHS4	28.60	50.00	21.40	1.43	1.42	0.76	0.05	1.05

Table 6.8 Good Hope slope; sand fraction classes and statistical parameters.

Sample	pH	Conductivity μs	%Organics	Munsell C
GHS1A	6.81	1665.00	6.20	7.5YR 5/3
GHS1B	6.97	136.40	7.79	7.5YR 5/2
GHS2	7.21	167.50	6.36	7.5YR 6/6
GHS3	7.44	221.00	8.52	7.5YR 5/3
GHS4	7.71	44.50	5.16	7.5YR 5/3

Table 6.9 Good Hope slope; pH, conductivity color, and organic content.

The chemical analysis of the GHS samples (Table 6.9) revealed that they have neutral to alkaline pH`s. Sample GHS4 is the most alkaline with a pH of 7.71. Sample GHS1A has a significantly higher conductivity than any of the other GHS samples, which have fairly low conductivities. The organic content of samples (Table 6.9) at this site is low, ranging from 5.16% to 8.52%. The color of the samples is fairly homogenous, with all except GHS2 (classified as reddish yellow) being classified as brown (Table 6.9).

6.2.4 Compassberg Gully (KBG)

The grain size analysis of the KBG samples revealed that although the proportion of sand in the samples varies widely (Table 6.10), the samples are all classified as loam of various kinds. All samples are moderately to poorly sorted (Table 6.11). The graphic statistics on the sand fraction of the samples reveals that two of the samples are strongly skewed, KBG4 is strongly negatively skewed and KBG7 is very strongly positively skewed (Table 6.11). The graphic statistics also show that the distributions of the sand fractions display curves varying from being platykurtic to leptokurtic (Table 6.11).

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
KBG1	38.38	33.69	3.33	24.60	Loam
KBG2	25.68	34.37	5.45	34.50	clay loam
KBG3	54.52	23.41	2.03	22.04	sandy clay loam
KBG4	47.98	35.24	0.93	15.85	Loam
KBG5	68.84	19.16	0.00	12.60	sandy loam
KBG6	55.36	19.30	2.94	22.60	sandy clay loam
KBG7	54.32	22.08	3.82	19.78	sandy clay loam
KBG8	63.62	17.44	0.34	18.60	sandy loam

Table 6.10 Compassberg gully; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
KBG1	22.00	20.31	57.69	2.06	2.26	1.14	-0.21	0.81
KBG2	41.73	8.97	49.30	1.85	1.97	1.5	-0.12	0.68
KBG3	40.78	24.72	34.50	1.43	1.28	1.09	0.21	0.80
KBG4	10.28	8.76	79.96	2.64	2.83	0.95	-0.38	1.48
KBG5	25.47	38.38	36.15	1.67	1.76	0.96	-0.08	1.03
KBG6	53.80	25.65	20.55	1.05	0.88	1.03	0.26	0.88
KBG7	68.76	15.39	15.85	0.82	0.50	1.03	0.50	1.15
KBG8	52.41	24.34	23.25	1.10	0.92	1.09	0.26	0.85

Table 6.11 Compassberg gully; sand fraction classes and statistical parameters.

The chemical analysis of the KBG samples (Table 6.12) revealed them to be fairly homogenous in this respect. The pH values vary from being neutral to mildly alkaline with a range from 7.05 to 7.87. The conductivities are all low, with KBG2 having a slightly higher value (175.2μs) than the other samples. The overall organic content of the KBG samples is the highest of all the sample locations, with four of the samples having an organic content of greater than ten percent. Samples KBG5 and KBG7 contain the highest proportion of organic material from all of the sample locations. It is noteworthy that as with other locations, the samples with the greatest proportion of organics are not the surface samples. The color of the samples is predominantly strong brown, with sample KBG2 being the only significant exception, registering a color of dark reddish gray. It is interesting to note that although some samples contain relatively high proportions of organics, this does not seem to have a great influence on their color.

Sample	pH	Conductivity μs	%Organics	Munsell C
KBG1	7.22	88.20	8.36	7.5YR 3/4
KBG2	7.05	175.20	10.02	5YR 4/2
KBG3	7.66	56.60	6.19	7.5YR 4/6
KBG4	7.84	33.10	5.10	7.5YR 5/6
KBG5	7.81	31.30	18.59	7.5YR 5/6
KBG6	7.73	39.40	5.68	7.5YR 5/4
KBG7	7.86	43.70	14.84	7.5YR 5/6
KBG8	7.87	73.20	10.10	7.5YR 5/4

Table 6.12 Compassberg gully; pH, conductivity, color and organic content.

6.2.5 Compassberg footslope (KBF)

The two samples taken from the Compassberg footslope site, are similar in terms of their grain size properties (Table 6.13). The B horizon has more clay than the A horizon, classifying it as a clay, rather than a clay loam. The sand fraction of both samples is moderately sorted, very positively skewed, and displays leptokurtic curves (Table 6.14). The chemical analysis of the two samples (Table 6.15) revealed that the A horizon is mildly acidic, while the B horizon is mildly alkaline. The A horizon has a significantly higher conductivity than does the B horizon. The organic content of both samples is very similar (Table 6.15). The color of the A horizon is classified as light brown, while the B horizon is classified as brown.

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
KBF1A	36.78	28.62	6.83	27.77	clay loam
KBF1B	33.54	24.06	7.64	34.76	clay

Table 6.13 Compassberg footslope; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
KBF1A	64.24	24.55	11.21	0.86	0.77	0.79	0.31	1.40
KBF1B	62.53	22.87	14.60	0.94	0.74	0.88	0.40	1.18

Table 6.14 Compassberg footslope; sand fraction classes and statistical parameters.

Sample	pH	Conductivity μs	%Organics	Munsell C
KBF1A	6.37	1076.00	6.26	7.5YR 5/2
KBF1B	7.80	72.60	5.67	7.5YR 6/3

Table 6.15 Compassberg footslope; pH, cond., color, texture and organics

6.2.6 Zeekoei River; Side Gully (ZKS)

Analysis of the textural properties of the ZKS samples revealed a high degree of homogeneity (Table 6.16). All samples are classified as loam, and vary from being clay loam to sandy clay loam. Sand is the dominant textural class in all samples, however the proportion of sand in the samples decreases down the profile. The sand fraction of all the samples (Table 6.17) is moderately to poorly sorted, and only sample ZKS4 is strongly skewed . The graphic distribution of the sand fractions display curves that vary from platykurtic to mesokurtic.

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
ZKS1	50.52	23.81	4.07	21.60	sandy clay loam
ZKS2	46.12	28.77	2.51	22.60	sandy clay loam
ZKS3	48.18	25.92	2.77	23.13	sandy clay loam
ZKS4	38.18	29.73	4.49	27.60	clay loam
ZKS5	38.14	37.74	1.52	22.60	loam
ZKS6	35.36	31.81	3.23	29.60	clay loam

Table 6.16 Zeekoei side gully; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
ZKS1	28.05	36.88	35.07	1.61	1.61	1.01	0.05	0.97
ZKS2	39.96	29.63	30.41	1.51	1.32	1.16	0.24	0.89
ZKS3	35.57	29.53	34.90	1.57	1.51	1.13	0.09	0.84
ZKS4	59.34	24.45	16.21	1.03	0.82	0.93	0.42	1.29
ZKS5	24.42	23.26	52.32	1.93	2.08	1.12	-0.16	0.81
ZKS6	26.07	24.40	49.53	1.90	1.98	1.16	-0.08	0.81

Table 6.17 Zeekoei side gully; sand fraction classes and statistical parameters.

The chemical properties of the ZKS samples also display a high degree of uniformity (Table 6.18). All samples are alkaline and pH values vary between 7.54 and 8.10. The conductivity of all samples is low, and values vary in a narrow range from 36.4μs/cm to 92.1μs/cm. The organic content of all samples is low (Table 6.18), with all having an organic content of around five percent. The color of all samples is classified as brown, with the exception of the bottom two samples which were classified as strong brown.

Sample	pH	Conductivity μs	%Organics	Munsell C
ZKS1	7.79	92.10	5.53	7.5YR 4/3
ZKS2	7.54	54.70	5.50	7.5YR 4/4
ZKS3	8.10	58.00	6.04	7.5YR 5/4
ZKS4	7.92	47.60	5.80	7.5YR 5/4
ZKS5	7.98	36.40	5.50	7.5YR 5/6
ZKS6	7.75	86.50	7.43	7.5YR 5/6

Table 6.18 Zeekoei side gully; pH, conductivity, color and organic content.

6.2.7 Oppermanskraal (OK)

The horizons of the Oppermanskraal site vary texturally from clay to sandy clay loam (Table 6.19). With the exception of sample OK2, all samples are composed of approximately one half sand and one half fine material. Sample OK2 is different in terms of grain size, to other samples at this site, in that it contains a significantly lower proportion of sand and a significantly higher proportion of fine clay than other samples. The sand fraction of all the Oppermanskraal samples is negatively skewed, the samples are moderately-well to moderately sorted, and the graphic distributions display curves that are mesokurtic to leptokurtic (Table 6.20).

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
OK1	42.92	37.26	1.22	18.60	loam
OK2	27.00	19.40	1.75	51.85	clay
OK3	52.00	23.40	1.06	23.54	sandy clay loam
OK4	44.28	29.75	3.37	22.60	loam
OK5	54.26	17.14	3.07	25.53	sandy clay loam

Table 6.19 Oppermanskraal; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
OK1	2.40	4.79	92.81	2.96	2.96	0.60	-0.08	1.13
OK2	7.91	10.81	81.28	2.63	2.72	0.85	-0.29	1.46
OK3	4.27	10.83	84.90	2.65	2.66	0.69	-0.12	1.34
OK4	4.02	10.05	85.93	2.69	2.69	0.69	-0.10	1.24
OK5	23.18	30.56	46.26	1.78	1.92	0.99	-0.16	0.93

Table 6.20 Oppermanskraal; sand fraction classes and statistical parameters.

Chemical analysis of the Oppermanskraal samples (Table 6.21) also revealed sample OK2 to be significantly different to the other samples. Sample OK2 has the lowest pH and a significantly higher conductivity than the other Oppermanskraal samples. The samples are all alkaline and range from 7.76 to 8.39. All samples have fairly low conductivities with the exception of OK2. Oppermanskraal was the only sample location to contain carbonates. The percentages of $CaCO_3$ are low in all samples, and is shown in Table 6.21. Sample OK2 has a higher organic content than the other Oppermanskraal samples, and as has been noted at other sites the horizon with the highest organic content is not the A horizon. The color variation within the Oppermanskraal samples is from reddish brown to yellowish red, to reddish yellow.

Sample	pH	% CaCO3	Conductivity μs	%Organics	Munsell C
OK1	8.39	3.40	161.40	5.23	5YR 4/3
OK2	7.76	3.98	1680.00	12.29	5YR 4/6
OK3	8.76	4.20	156.80	7.84	5YR 6/6
OK4	8.30	2.29	127.30	6.24	5YR 6/6
OK5	7.98	2.90	141.90	6.69	5YR 5/6

Table 6.21 Oppermanskraal; pH, conductivity, CaCO3, color and organic content.

6.2.8 Compassberg: trekboer wall (KBW)

The KBW samples are relatively homogenous with regard to grain size (Table 6.22). All samples can be texturally classed as either sandy loam or sandy clay loam. The proportion of sand in the samples increases down the profile. The sand fraction of the samples is moderately to poorly sorted, negatively skewed and the distributions display curves that vary from being platykurtic to leptokurtic (Table 6.23). The basal sample (KBW3) displays a somewhat higher conductivity than the other samples at this location. The organic content of the basal sample is marginally higher than the other two samples (Table 6.24). The color of the samples varies from brown in the A horizon, to reddish gray in the B horizon, to dark brown in the C horizon.

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
KBW1	48.78	26.23	2.99	22.00	sandy clay loam
KBW2	53.74	30.28	3.08	12.90	sandy loam
KBW3	61.04	18.36	1.78	18.82	sandy clay loam

Table 6.22 Compassberg trekboer wall; textural classes

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
KBW1	24.09	22.61	53.30	1.93	2.08	1.15	-0.18	0.86
KBW2	14.29	18.31	67.47	2.22	2.39	1.01	-0.27	1.19
KBW3	36.07	18.24	45.69	1.78	1.86	0.96	-0.09	0.96

Table 6.23 Compassberg trekboer wall; sand fraction classes and statistical parameters.

Sample	pH	Conductivity μs	%Organics	Munsell C
KBW1	7.47	54.90	6.06	7.5YR 4/4
KBW2	7.45	65.00	4.20	5YR 5/2
KBW3	6.07	487.00	9.32	7.5YR 3/2

Table 6.24 Compassberg trekboer wall; pH, conduct., color, texture, and organics.

6.2.9 Uppermost Weir (UW)

At this site both samples taken consisted of a high proportion of sand (> 65%) (Table 6.25). The sand fraction of the sample taken from a depth of 57cm was considerably coarser than that of the surface sample. The sand fraction of both samples was positively skewed, with sample UW(57cm) being very positively skewed (Table 6.26). Both samples were moderately to poorly sorted. The graphic distribution of the surface sample displayed a mesokurtic curve, while the sample taken at 57cm displayed a very leptokurtic curve. Both samples displayed a low conductivity, low organic content, and virtually identical color (Table 6.27).

Sample	% Sand	% Silt	% Clay	%FineClay	Texture
UW(S)	75.22	13.18	1.00	10.60	sandy loam
UW(57cm)	65.52	19.28	4.39	10.81	sandy loam

Table 6.25 Upper-most weir; textural classes.

Sample	% coarse	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis
UW(S)	44.54	30.52	24.94	1.30	1.12	1.03	0.26	0.94
UW(57cm)	82.84	8.39	8.77	0.38	0.30	0.84	0.36	1.66

Table 6.26 Upper-most weir; sand fraction classes and statistical parameters.

Sample	pH	Conductivity μs	%Organics	Munsell C
UW(S)	7.27	46.60	5.70	7.5YR 5/4
UW(57cm)	7.57	37.50	2.68	7.5YR 5/4

Table 6.27 Upper-most weir; pH, conduct., color, texture and organics.

6.3 STATISTICAL ANALYSIS

6.3.1 Principal Component Analysis

Principal Component Analysis was undertaken as an initial attempt to search for order in the data set derived from the laboratory analysis of soils and sediments. The analysis was undertaken on the standardized data set comprising 15 variables on 42 cases. Within the matrix, variables were configured as columns, and cases as rows. Each case represents a soil / sediment horizon at a particular sample site. The raw data are displayed in Appendix B. The selection of components for further utilization in, for example cluster analysis, involves a measure of subjective judgement on the part of the researcher. After inspecting the results of this analysis, the first four components were retained, these are shown in Table 6.28. This decision was based on the proportion of the total variance accounted for by these components, as well as the absence of marked loadings on components other than the first four. In total the first four principal components accounted for 72.26% of the variance in the data set.

Eigenvalues (sed_std1.sta)
Extraction: Principal components

	Eigenval	% total Variance	Cumul. Eigenval	Cumul. %
1	4.547572	30.31715	4.547572	30.31715
2	2.946894	19.64596	7.494466	49.96311
3	2.089118	13.92745	9.583584	63.89056
4	1.255335	8.368901	10.83892	72.25946

Table 6.28 Retained Principal Components.

Factor Loadings (Unrotated) (sed_std1.sta)
Extraction: Principal components
(Marked loadings are > .700000)

	Factor 1	Factor 2	Factor 3	Factor 4
%_SAND	-0.56701	-0.58031	-0.50234	-0.14055
%COARSE	**-0.84566**	0.381391	0.198664	0.094383
%_MED	-0.45924	0.187706	-0.53405	-0.19173
%_FINE	**0.904757**	-0.39476	0.053239	-0.00191
MEAN	**0.912611**	-0.36419	-0.05716	-0.03689
MEDIAN	0.425481	0.048364	-0.2675	-0.12419
SORTING	0.177969	0.547574	-0.5066	0.549187
SKEWNESS	**-0.85116**	0.274534	0.243635	-0.00842
KURTOSIS	-0.25308	-0.45304	0.652667	-0.42182
%SILT	0.698764	0.509231	0.082361	-0.11579
%_CLAY	0.166255	**0.728393**	0.138746	-0.13128
FINECLAY	0.195293	0.209253	**0.709515**	0.465151
PH	-0.19914	-0.68005	0.239043	0.400632
CONDUCT_	0.223701	0.509435	0.261362	-0.4635
%_ORG	-0.05994	-0.05035	0.193792	0.266775
Expl.Var	4.547572	2.946894	2.089118	1.255335
Prp.Totl	0.303171	0.19646	0.139275	0.083689

Table 6.29 Component loadings and explained variance from Principal Component Analysis (unrotated). Loadings >.7 marked in bold.

The four principal components were subjected to a non-orthogonal rotation (varimax rotation) in an attempt to establish the clearest pattern of component loadings. The explained variance in terms of the first four factors after varimax rotation (Table 6.30) is similar to the un-rotated analysis (Table 6.29). The varimax rotation did not make a great difference on the loading scores for the first principal component, however varimax rotation does change the loadings on factors 2, 3, and 4, which seems to make them more meaningful. In light of the loading scores (Table 6.29 and Table 6.30), principal component 1 (which accounted for 30.3%of the variance [un-rotated], and 28.1% [rotated]) was interpreted as reflecting the "sand fraction" of the data set. Principal component 2 (which accounted for 19.6% of the variance [un-rotated], and 13.7% [rotated]) was interpreted as reflecting the "overall texture" of samples in the data set. Principal component 3 (which accounted for 13.9% [un-rotated] and 13.6% [rotated]) was interpreted as reflecting the "homogeneity of the sand fraction" of samples in the data set. Principal component 4 (which accounted for 8.4% of the variance [un-rotated] and 16.8% of the variance [rotated]) was interpreted as reflecting the "chemical properties" of the samples in the data set.

Factor Loadings (Varimax raw) (sed_std1.sta)
Extraction: Principal components
(Marked loadings are > .700000)

	Factor 1	Factor 2	Factor 3	Factor 4
%_SAND	0.193282	**-0.74166**	0.135646	-0.56968
%COARSE	**0.950047**	0.072507	0.026723	-0.02043
%_MED	0.406147	-0.58743	-0.23259	0.063081
%_FINE	**-0.96891**	0.182332	0.072166	-0.00405
MEAN	**-0.98042**	0.088146	0.008344	0.032443
MEDIAN	-0.40617	-0.15033	-0.18542	0.219998
SORTING	0.031945	0.085353	**-0.93339**	0.101162
SKEWNESS	**0.910544**	0.024658	0.167724	-0.038
KURTOSIS	0.102215	0.097962	**0.916273**	-0.11661
%SILT	-0.41365	0.299177	-0.23301	0.67296
%_CLAY	0.16199	0.246731	-0.20439	0.682488
FINECLAY	0.035632	**0.893979**	0.034866	0.004465
PH	-0.04473	0.190965	0.26204	**-0.78271**
CONDUCT_	0.015861	0.123594	0.165271	**0.741533**
%_ORG	0.075806	0.265891	-0.00514	-0.19591
Expl.Var	4.217067	2.053529	2.045067	2.523256
Prp.Totl	0.281138	0.136902	0.136338	0.168217

Table 6.30 Component loadings and explained variance from Principal Component Analysis (varimax rotated). Loadings >.7 marked in bold.

6.3.2 Cluster Analysis

Two methods of cluster analysis were performed on the data set. Single linkage clustering has the propensity to identify outliers, while Wards method is useful for identifying groupings. Because groupings and unique cases are of relevance to this study, both methods were used. In order to help obtain the clearest groupings and to identify all the outliers, the clustering methods were applied to both the raw data and the PCA factor scores.

Clustering of the raw data, and the clustering of the PCA factor scores by Wards method, seem to identify six groups (Fig 6.1 and Fig 6.2). For the clustering of the raw data, six groups are obtained by cutting the tree at a linkage distance of between 7 and 10, and for the clustering of the PCA factor scores, six groups are obtained by cutting the tree at a linkage distance of 6. It is interesting to note that in both cases there appears to be a tendency for samples to be clustered by sample location rather than by position in the soil profile. The implications of this will be discussed in Chapter 7.

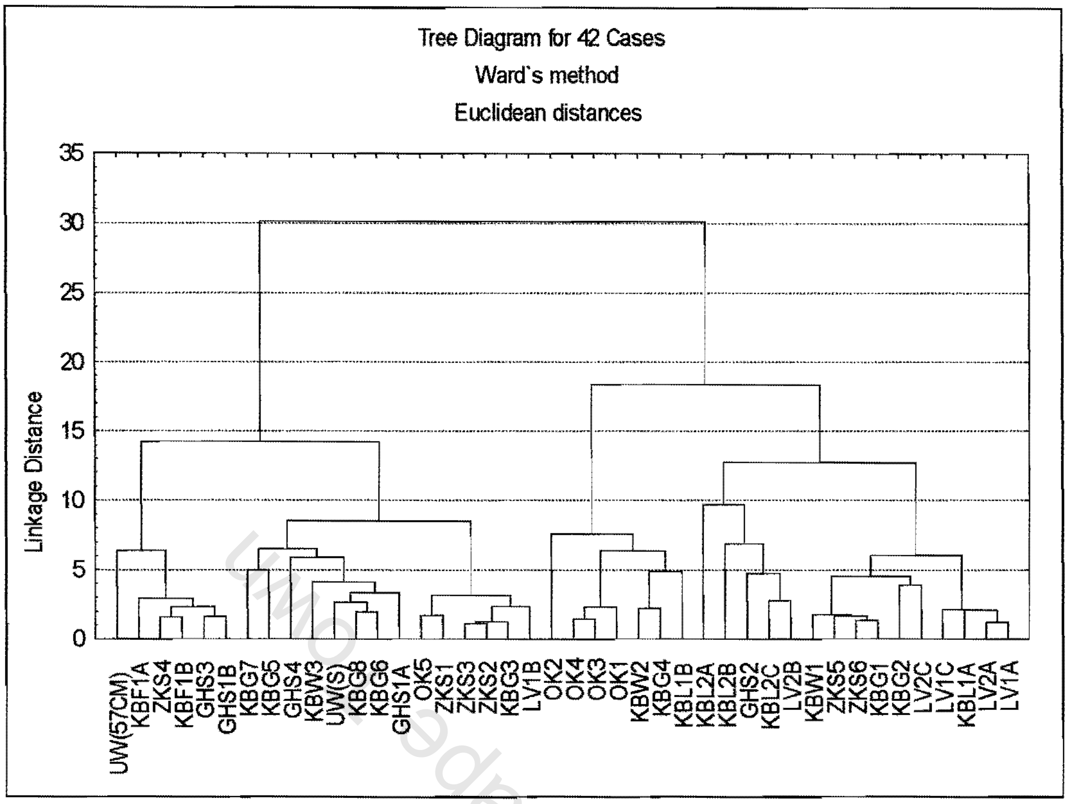

Fig 6.1 Cluster analysis of raw data by Wards method.

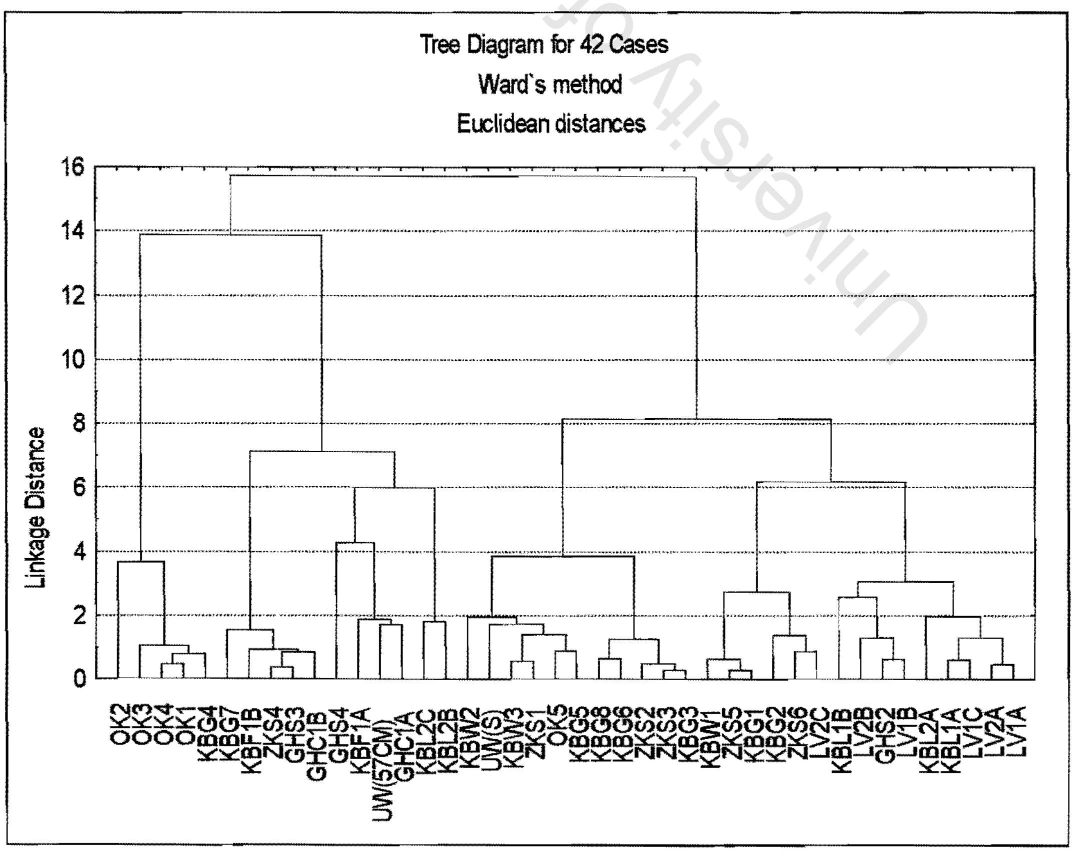

Fig 6.2 Cluster analysis of PCA scores by Wards method.

Single linkage clustering of the data identified two samples as outliers. Single linkage clustering of the raw data identified samples KBL2A and OK2 as clear outliers when cutting the tree at a linkage distance of 5 (Fig 6.3). The single linkage clustering of the PCA factor scores identified sample OK2 as an outlier when cutting the tree at a linkage distance of 2 (Fig 6.4).

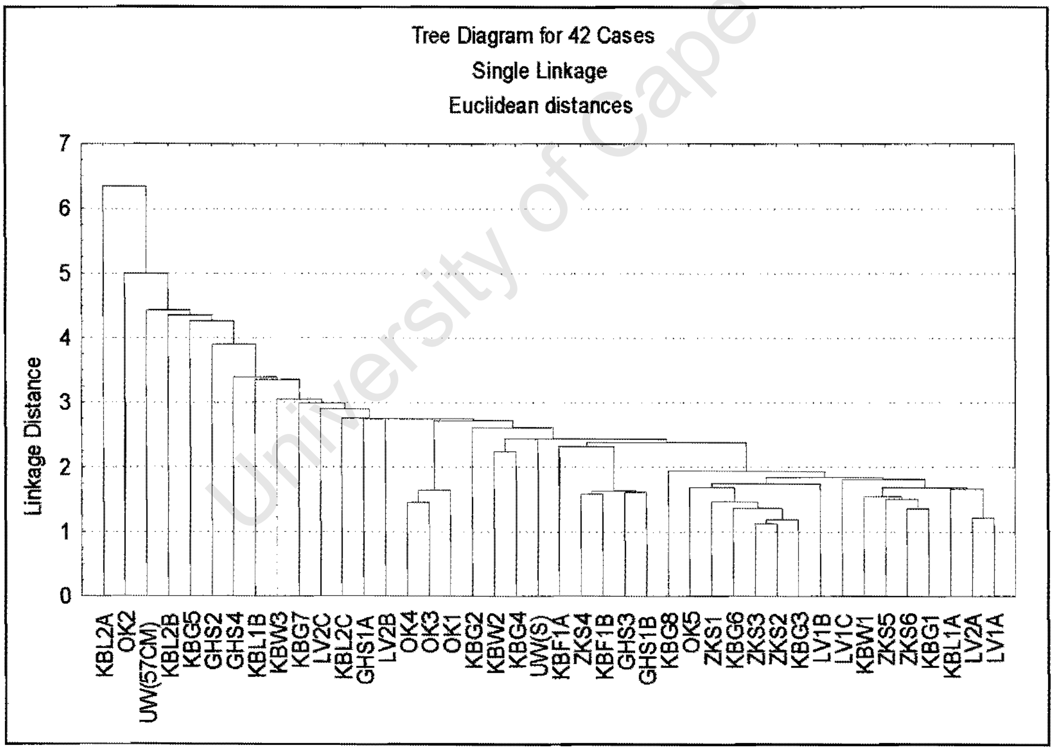

Fig 6.3 Single linkage clustering of raw data.

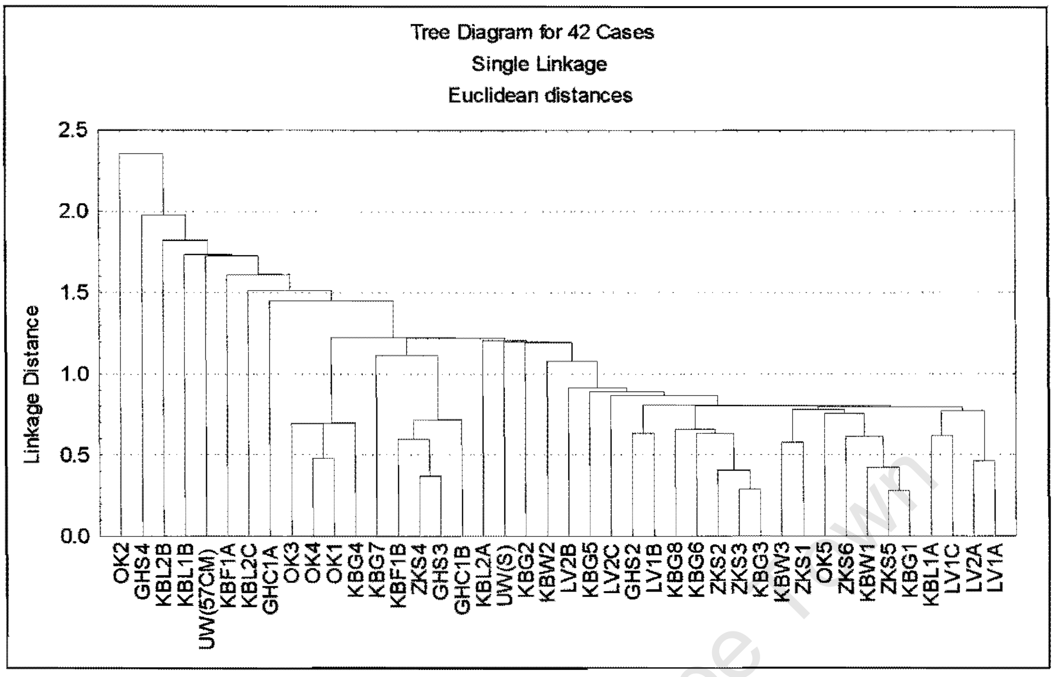

Fig 6.4 Single linkage clustering of PCA factor scores.

Aerial Photography

6.4.1 Introduction

The following section comprises an interpretation of aerial imagery. For a detailed methodology of this section, the reader is referred to Chapter 4. Detailed site descriptions of the individual sites referred to in this section are contained in Chapter 5. The interpretation that follows is constrained by a number of factors, which have previously been discussed in Chapter 4.

6.4.2 Changes in the spatial extent of degradation at individual sites

Analysis of the following areas is based on changes on specific sites of land degradation. The maps / diagrams of the individual sites were produced from 1:20 000 scale aerial photography and are presented in Figs 6.5 to 6.14.

6.4.2.1 Lucernvale

This area of badlands has experienced a 36% decrease in spatial extent from 1945 to 1980. A comparison of the 1945 and the 1980 land degradation maps (Fig 6.16 and Fig 6.17) reveals that the severity of the erosion at this site is largely unchanged over this period. The predominant classification being R4/G3/S4 (SARCCUS, 1981) in both years. An examination of the 1980 aerial photography reveals that an anti erosion wall/bund has been built across the eastern side of the system, to the north of the jeep track (Fig 6.6). Siltation upslope of the bund, as well as some re-vegetation down-slope appears to be the predominant reason for the decrease in the spatial extent of degradation at this site.

6.4.2.2 Good Hope Slope

This area of badland erosion situated on a footslope approximately 800m south of the Good Hope homestead has increased in spatial extent by approximately 10% between 1945 and 1980 (Fig 6.7 and Fig 6.8). A comparison of the 1945 and 1980 land degradation maps (Fig 6.16 Fig 6.17) reveal that the severity of the erosion is largely unchanged over this period.

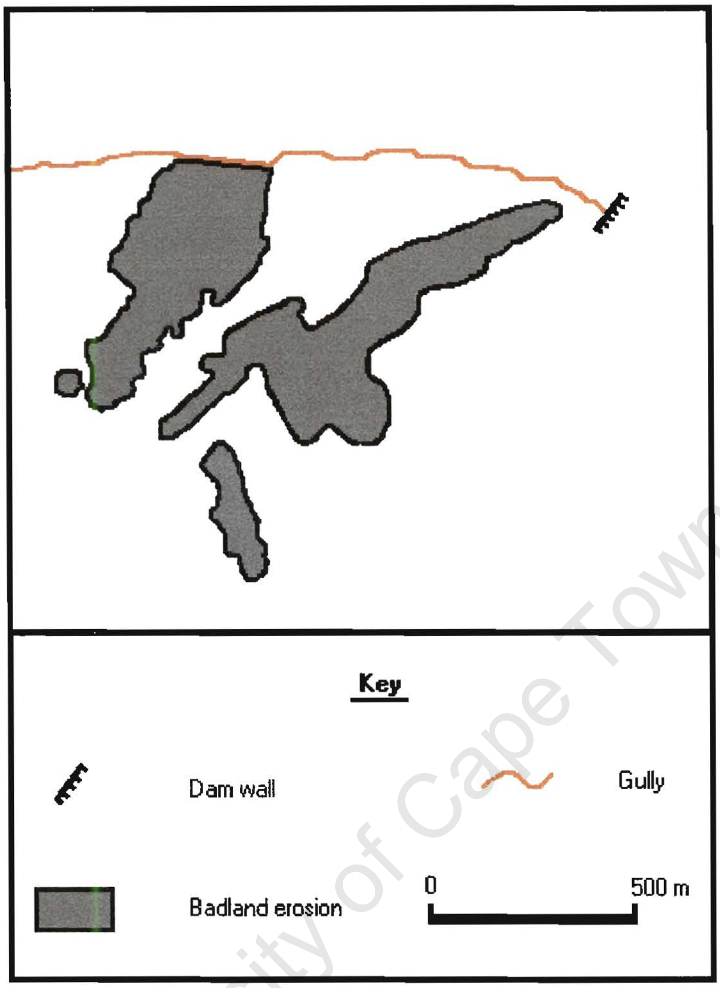

Fig 6.5 Extent of badland erosion at Lucernvale, 1945.

6.4.2.3 Kriegersbaken

This area of gullying and badland erosion approximately 700m north west of the Kriegersbaken farm buildings (Fig 6.9 and Fig 6.10) has decreased in spatial extent by approximately 9% percent between 1945 and 1980. A visual comparison of the 1945 and 1980 aerial photographs indicates that this area was possibly more vegetated than the Lucernevale and Good Hope sites in 1945. Although the 1945 and 1980 land degradation maps (Fig 6.16, Fig 6.17) show that there is no discernable difference in the severity of erosion in the area over this period, field observations indicate that the gullies are presently comparatively well vegetated, and do not appear to be active.

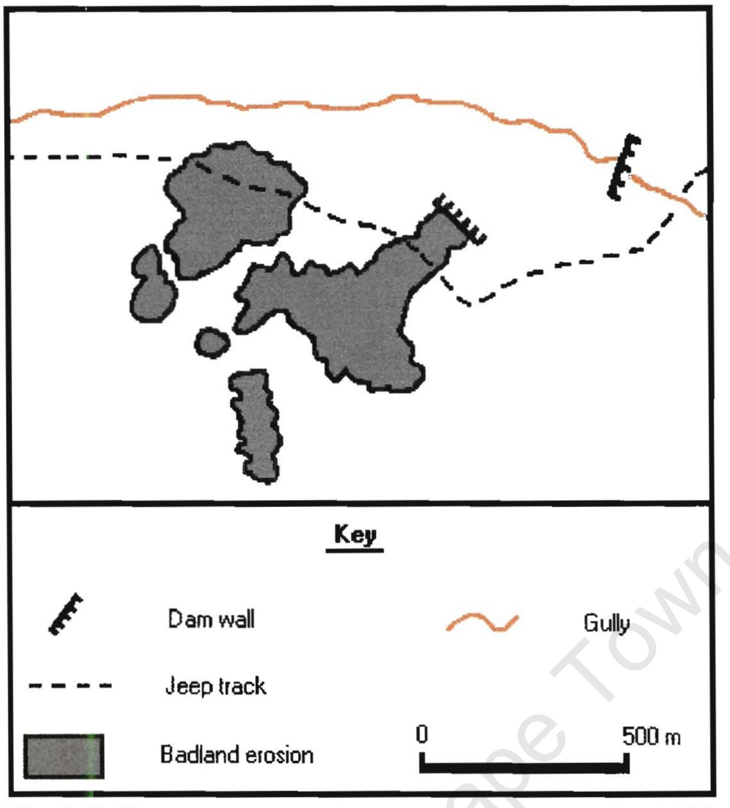

Fig 6.6 Extent of badland erosion at Lucernvale, 1980.

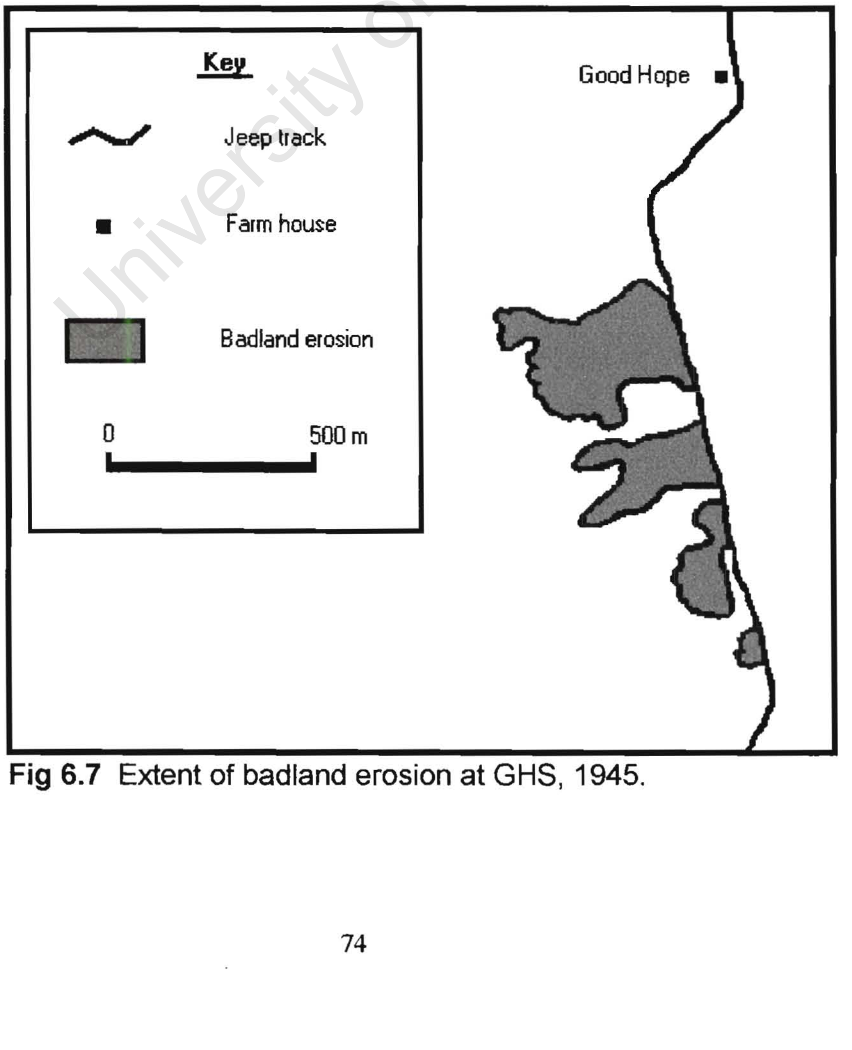

Fig 6.7 Extent of badland erosion at GHS, 1945.

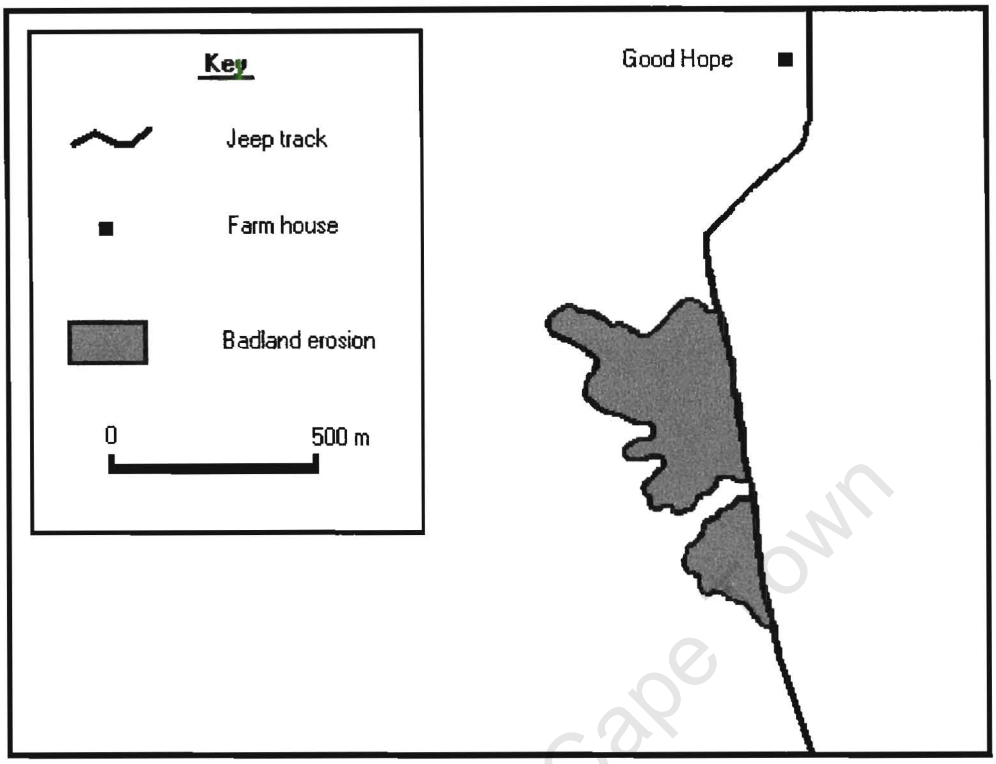

Fig 6.8 Extent of badland erosion at GHS, 1980.

6.4.2.4 Compassberg Lands

This triangular piece of land lies between the main road through the valley of the Klein Zeekoei River, and the road to the Compassberg farmstead. Its southern boundary is marked by the hill that runs in an east-west orientation, to the west of the Compassberg farm stead. In Table 6.31, the proportion of the total land area that is cultivated and the proportion of the land that is moderately to severely degraded at this site is compared for the years 1945, 1959, 1966, and 1980. The spatial extent of cultivated land at this site is shown in Figs 6.11 to 6.14.

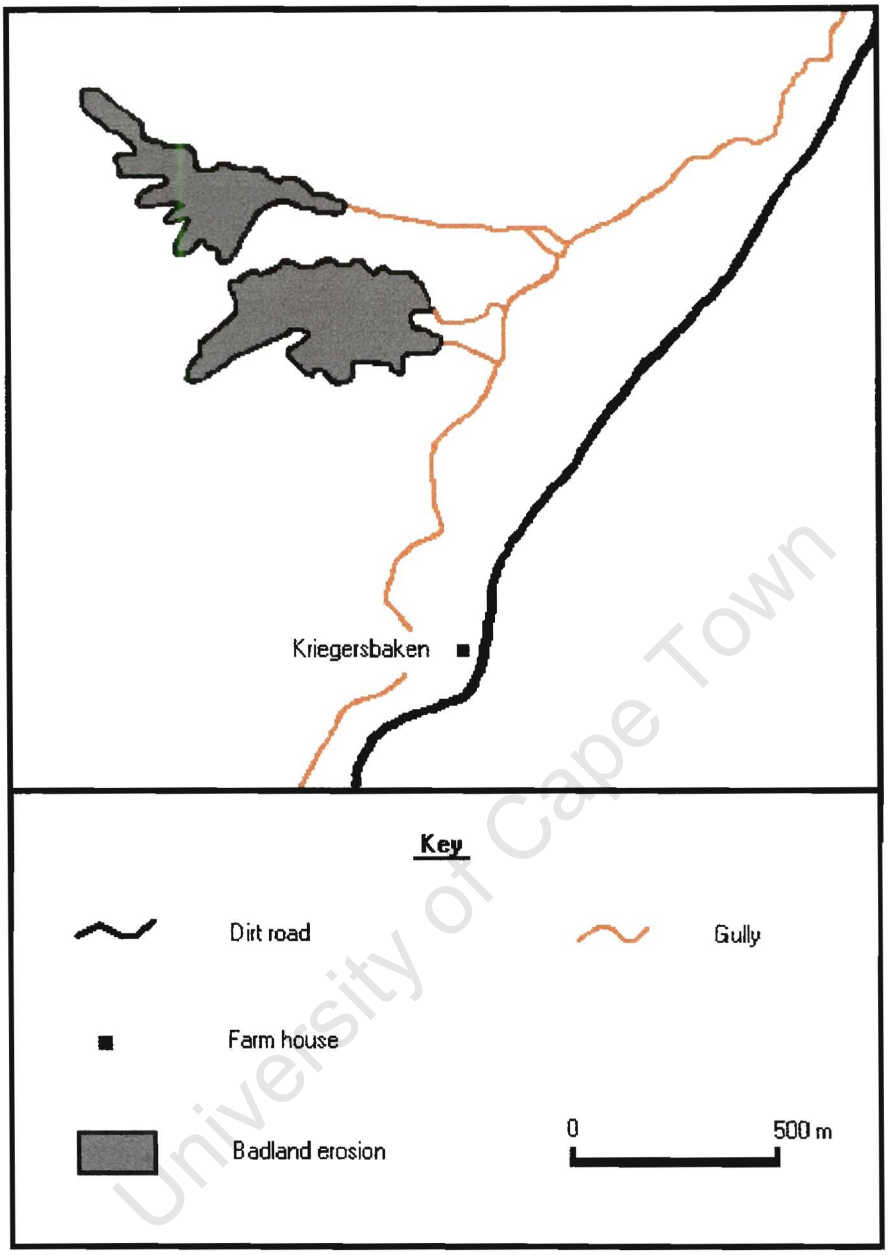

Fig 6.9 Extent of the Kriegersbaken badland, 1945.

During the late 1950`s and 1960`s the Compassberg lands site was fairly extensively cultivated. It is noteworthy that some of this cultivation occurs on land that is previously seen to be degraded by sheetwash and rilling. In studying Table 6.31, there is an apparent inverse relationship between the proportion of land that is cultivated and the proportion of land that is degraded. The main reason for this is that the rills and the evidence of sheetwash are destroyed by the farmers' plough, when a degraded area is cultivated. It should be pointed out that although cultivation of a sheet washed and rilled area hides the immediate evidence of degradation, it is not a solution to the degradation problem as valuable topsoil has already been lost (Morgan, 1981). It is observed that some areas of land that were classified as degraded on the 1945 aerial photography, and subsequently cultivated in the 1950`s and 1960`s, are again classified as degraded in 1980.

Year	% Cultivated	% Degraded
1945	19%	63%
1959	57%	44%
1966	52%	46%
1980	23%	67%

Table 6.31 Relative proportions of cultivated and degraded land at the Compassberg Lands site.

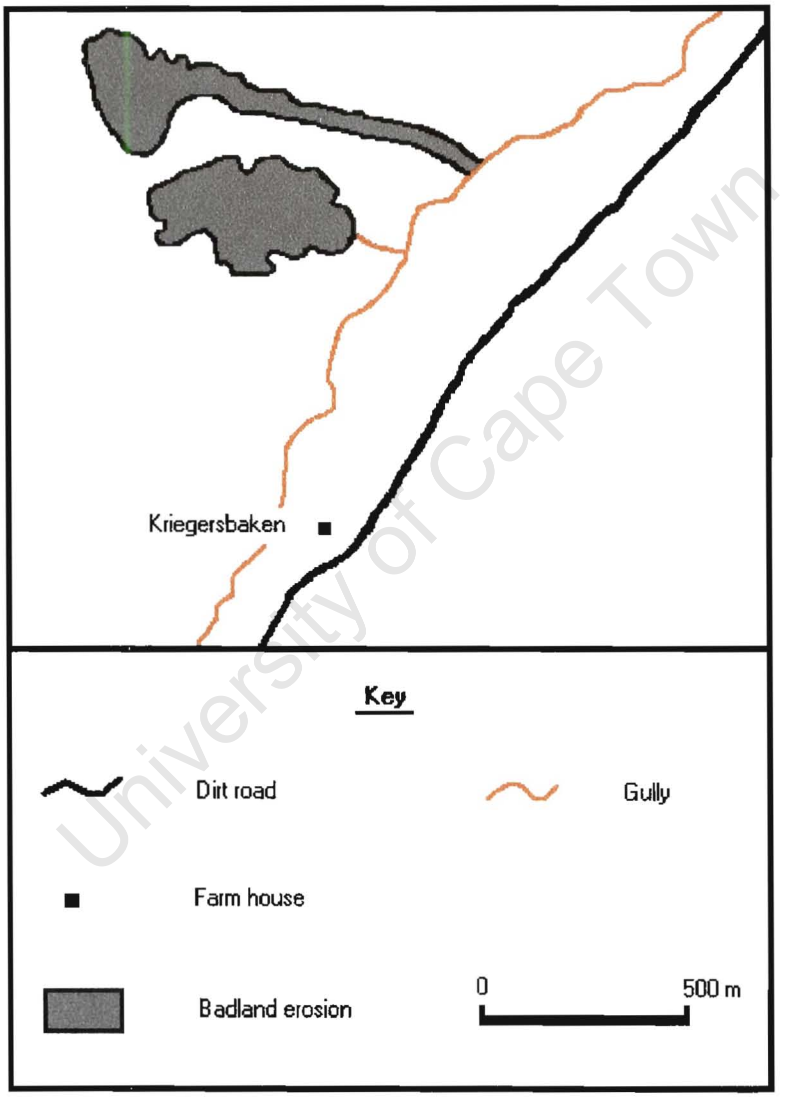

Fig 6.10 Extent of the Kriegersbaken badland, 1980.

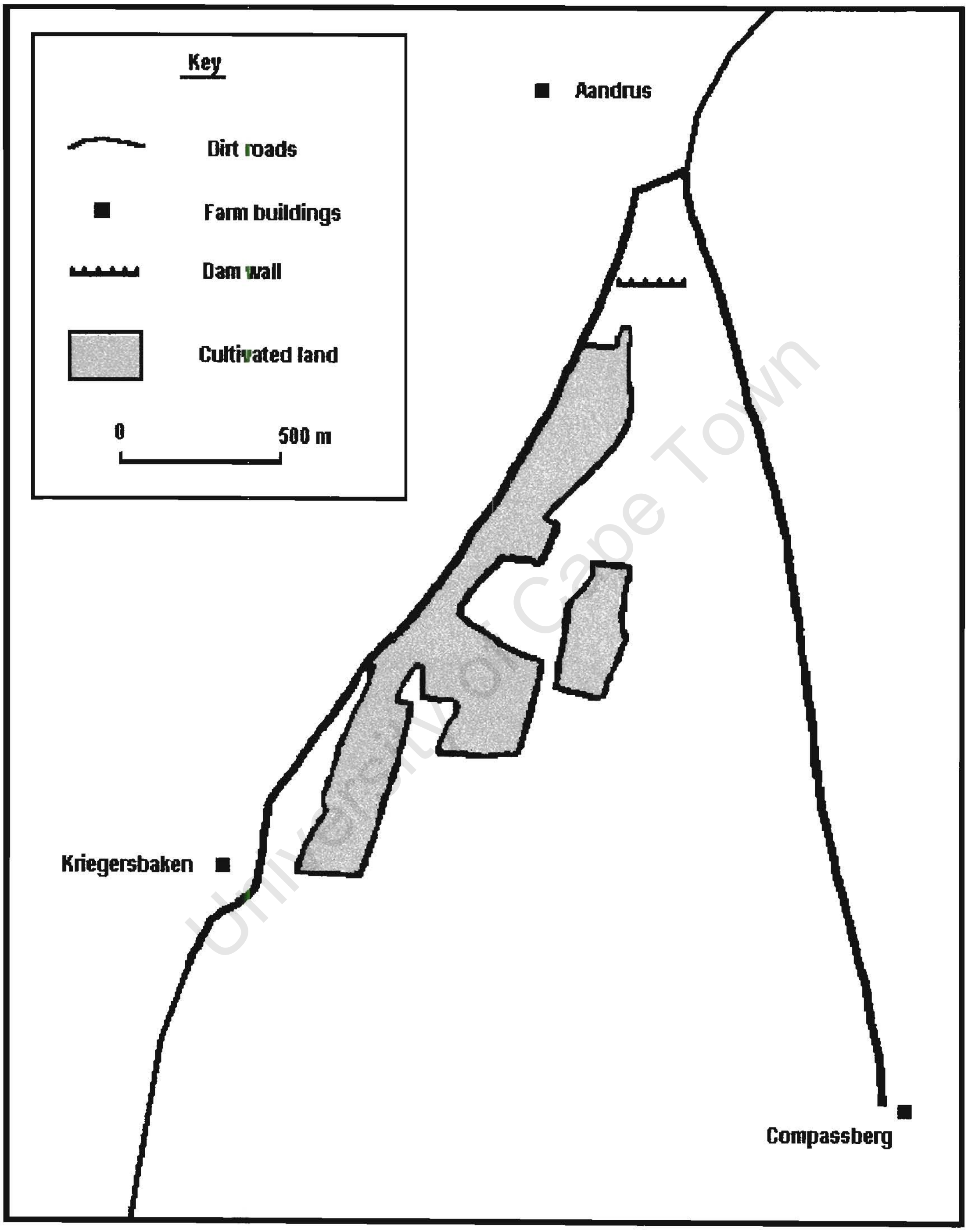

Fig 6.11 Extent of cultivated land at the KBL site, 1945.

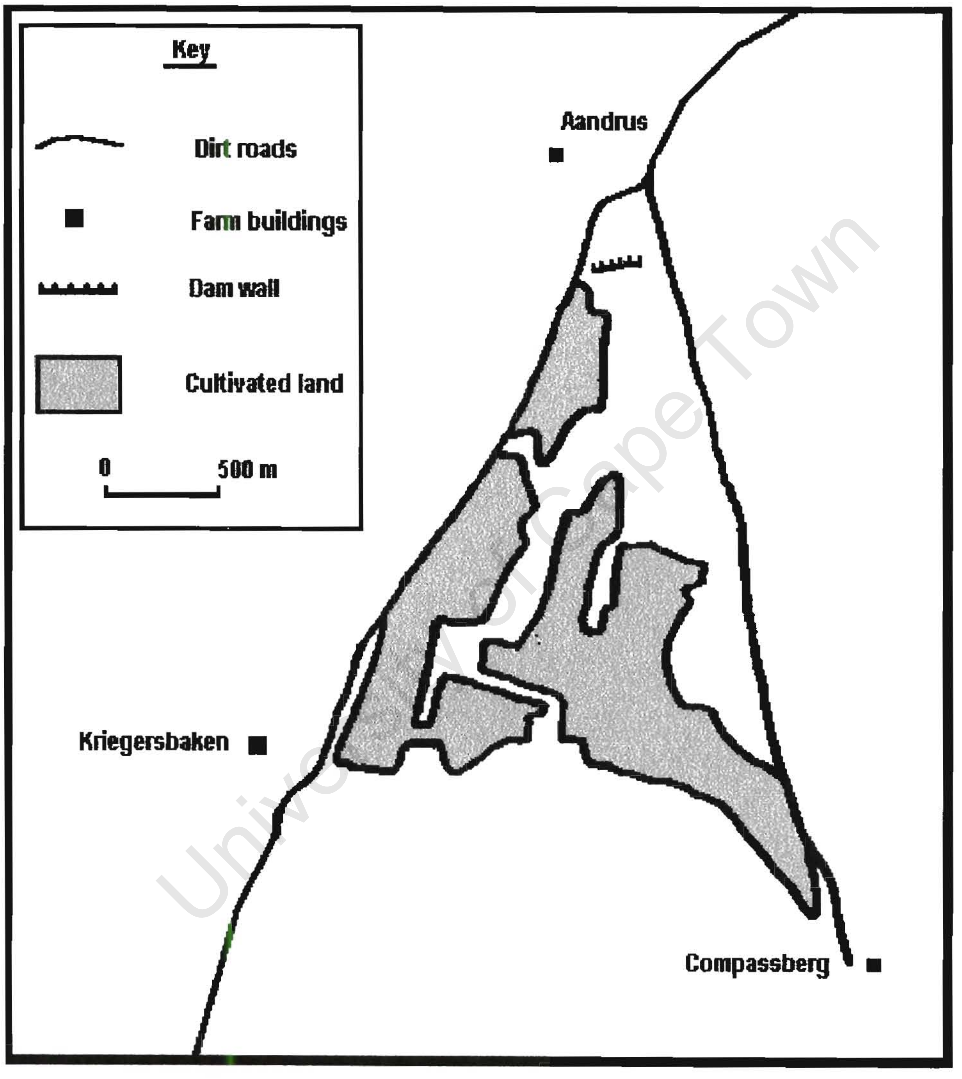

Fig 6.12 Extent of cultivated land at the KBL site, 1959.

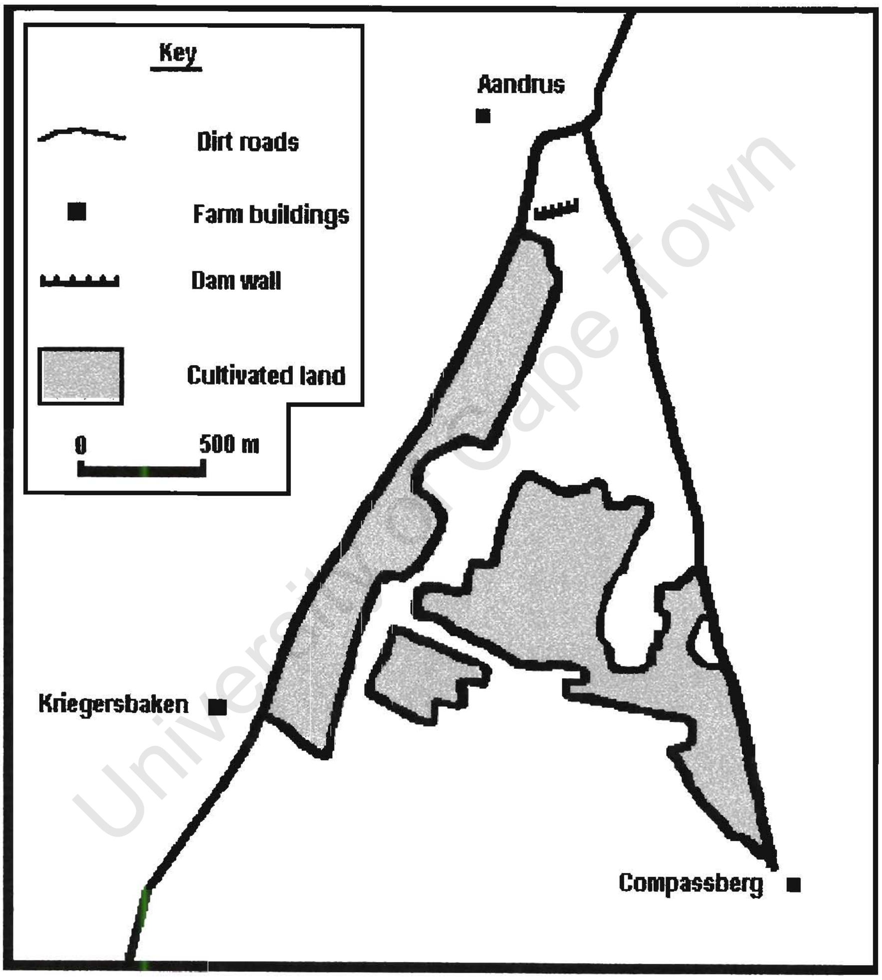

Fig 6.13 Extent of cultivated land at the KBL site, 1966.

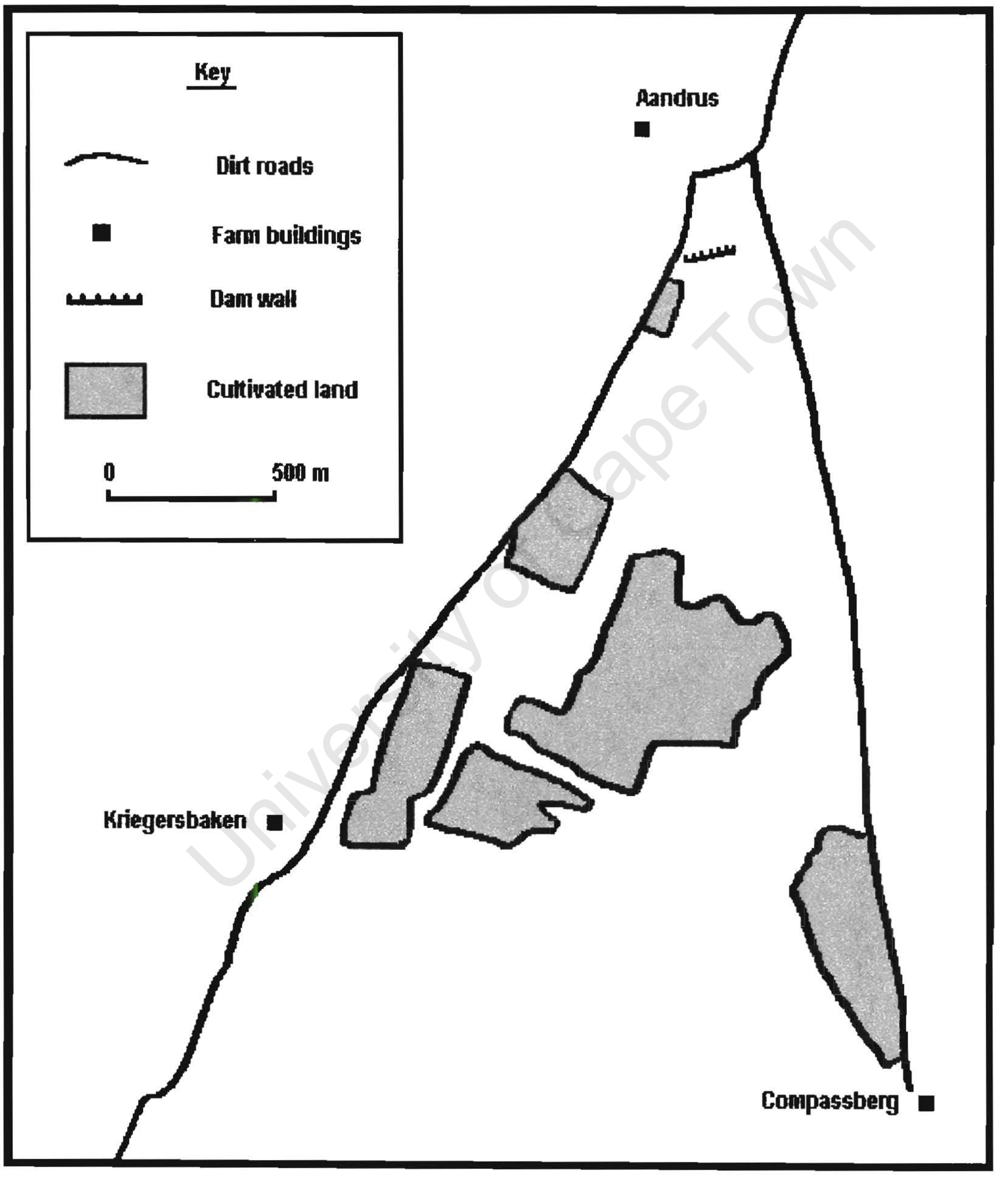

Fig 6.14 Extent of cultivated land at the KBL site, 1980.

6.4.2.5 Case study: erosion rate

During the fieldwork stage of this research, it became apparent that certain gullies in the study area seemed to have formed subsequent to the area being fenced. Since it is known from communications with the farmer (H.N. Sheard, pers comm.) that no fences existed prior to 1937, it was decided that further investigation into the rate at which some of these gullies form, and the volume of material that is eroded would be useful. This investigation is dealt with in the form of the following case study.

The gully chosen for this case study is situated approximately 2 Km to the west of the Lucernvale farmstead. Field observations found that a significant side gully situated at right angles to the main valley floor gully in the area, had a *hanging fence* across it approximately 110m upslope of its confluence with the main gully. This so-called *hanging fence* consists of a seven strand, 1.2m high farm fence, with wooden uprights, which runs roughly parallel to the contours. At the place where the fence crosses the gully, the wooden uprights are left hanging in mid air, marking the level of the land surface prior to erosion taking place (Plate 6.1).

The gully is presently 370 meters long and its depth exceeds 5m in places. At the head of the gully is a 4.6m wide, 4m deep, gorge cut into shale bedrock, with no sign of modem fill on either bank. At the point where the fence crosses the gully, it is presently 15.1m wide and 4.05m deep.

The presence of fence posts along the section of the fence which now hangs in mid-air, led to the field hypothesis that the fence pre dates the gully. H.N. Sheard (*pers comm.*) confirmed that if a fence were to be constructed across an existing gully, it would not be common practice to erect fence posts over that section of fence. Field observations suggest that some attempts to extend the fence down into the gully were made during the initial stages of gully development. The evidence for this is in the form of an extremely long fence post on the western side of the gully, with old wire attached to it, extending down into the gully (Plate 6.1).

A study of the aerial photography over the area revealed that in 1945, although there was evidence of a watercourse in the present day position of the gully, there was no apparent incision. Incision starts to be apparent on the 1966 aerial photography, and by 1980, a well-developed gully can be seen.

Field measurements were taken, in order to calculate the volume of material that has eroded from the gully, since incision occurred. This calculation yields a volume of approximately 11 500m^3 of sediment, which has been lost over a period not longer than 40 years, and from a catchment that is only approximately 1km^2 in area.

Plate 6.1 Hanging fence gully. The gully depth at this point is 4.05m and the width is 15.1m. Note the two extremely long fence posts on the extreme left.

6.4.3 Maps of the upper Klein Zeekoei River valley

The maps are presented in Figures 6.15, 6.16 and 6.17, and were all originally mapped from 1: 20 000 scale aerial photography. This section is comprised of two land degradation maps (1945 and 1980) and a composite map of formerly cultivated land.

6.4.3.1 Composite map of formerly cultivated land

The aim of the composite map of formerly cultivated land (Fig 6.15), is to determine the total proportion of land in the Klein Zeekoei River Valley, that had previously been cultivated, and to assist in elucidating any link between formerly cultivated land, and land degradation. This map is derived from the aerial photography cover of the region in 1945, 1959, and 1966. The 1945 aerial photography was used as a base, to which the areas of cultivation in 1959 and 1966 were added.

It is apparent from the map that only a relatively small proportion of the total land area has been previously cultivated. Cultivation takes place mainly below the 1720m contour (measured from 1:50 000 topographic map) which, as can be seen from the map, has largely confined cultivation to the valley floors of the region, with very little evidence of cultivation on footslopes. Most of the fields are broadly rectangular in shape, and as far as can be ascertained from the aerial photography, contour ploughing seems to have been used.

The total proportion of the land within the mapped area that has previously been, or is presently still under cultivation, is approximately 10.4%. This figure may be slightly inaccurate, due to the fact that field observations found evidence of terraces in the area immediately to the east of the road to the Compassberg farmstead and approximately 2km to its north, which may have been previously cultivated, but no evidence of cultivation of this area could be seen on any of the aerial photography.

It is interesting to note that a proportion of this cultivated land (approximately 22%) is classified as degraded in 1945. This figure is obtained by overlaying the 1945 land degradation map, and the composite map of cultivated land. Some areas of land that are degraded by rilling and sheetwash in 1945 were subsequently cultivated in later years (1959 and 1966 aerial photographs). An example of this is the Compassberg Lands (KBL) site (previous mention of this is made in Sec 6.4.2.4, and will be discussed in more detail in the following chapter). It has also been observed that some cultivated land shows no sign of degradation on any of the aerial photography, including that of 1980.

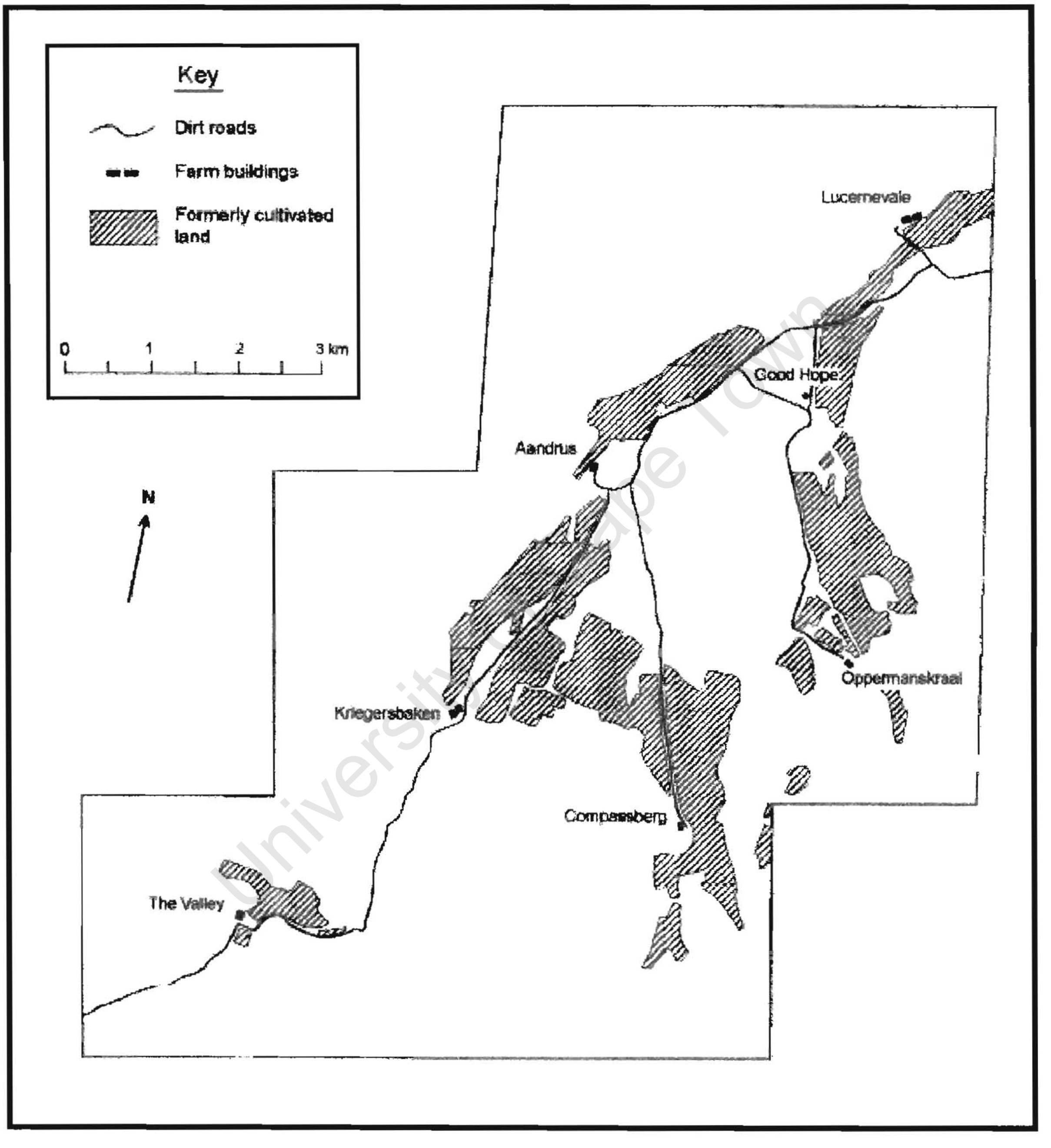

Fig 6.15 Composite map of formerly cultivated land in the Klein Zeekoei River Valley.

6.4.3.2 Land degradation map (1945)

Despite the age of the 1945 aerial photography, its resolution is significantly better than that of the 1980 photographs. This combined with the large scale of the photography allowed a considerable degree of accuracy in the mapping of land degradation for this year. The aim of the map (Fig 6.16) is to classify the type and severity of erosion in the Klein Zeekoei River Valley, in 1945, and to determine the total proportion of land within this area that was degraded at that time. The type and severity of the land degradation is classified according to the SARCCUS (1981) system.

In 1945, approximately 25% of the total mapped area is classified as moderately to severely degraded by either rill, gully or sheet erosion, or a combination of these. The valley floors are incised by gullies differing in intensity from "G3" to "G5" in the SARCCUS (1981) system, and there is evidence of a limited number of anti erosion weirs and dams across these valley floor gullies. It is speculated that these structures were built by the farmer, primarily for water storage purposes, although some may have been to help prevent or curtail erosion. Government subsidized structures, that were built specifically built to combat erosion date from c1949 (Dept. of Agriculture: Middleberg extension office). Areas of badland development appear to be more prevalent on footslopes than any other position in the landscape, and predominantly drain into the valley floor gully system. Large areas of the Compassberg Lands site are classified as sheetwashed and rilled, and as previously pointed out, some of these areas were later cultivated (see map of formerly cultivated land).

6.4.3.3 Land degradation map (1980)

The aim of the 1980 land degradation map (Fig 6.17) is to classify the type and severity of erosion in the Klein Zeekoei River Valley, in 1980, and to determine the total proportion of land within this area that was degraded at that time. This allows for comparisons with the 1945 land degradation map. The type and severity of the land degradation is classified according to the SARCCUS (1981) system. The 1980 aerial photography proved more difficult to map than the 1945 photography, due to its smaller scale and poorer contrast. The smaller scale led to some distortion in the mapped area when it was enlarged to the same scale as the 1945 photography.

In 1980, the proportion of the total mapped area that is moderately to severely degraded, had not changed significantly from the 1945 figure and was still approximately 25%. As with the 1945 map, the valley floors are incised by gullies differing in intensity from "G3" to "G5" in the SARCCUS (1981) system, and areas of badland development are still more prevalent on footslopes than any other position in the landscape.

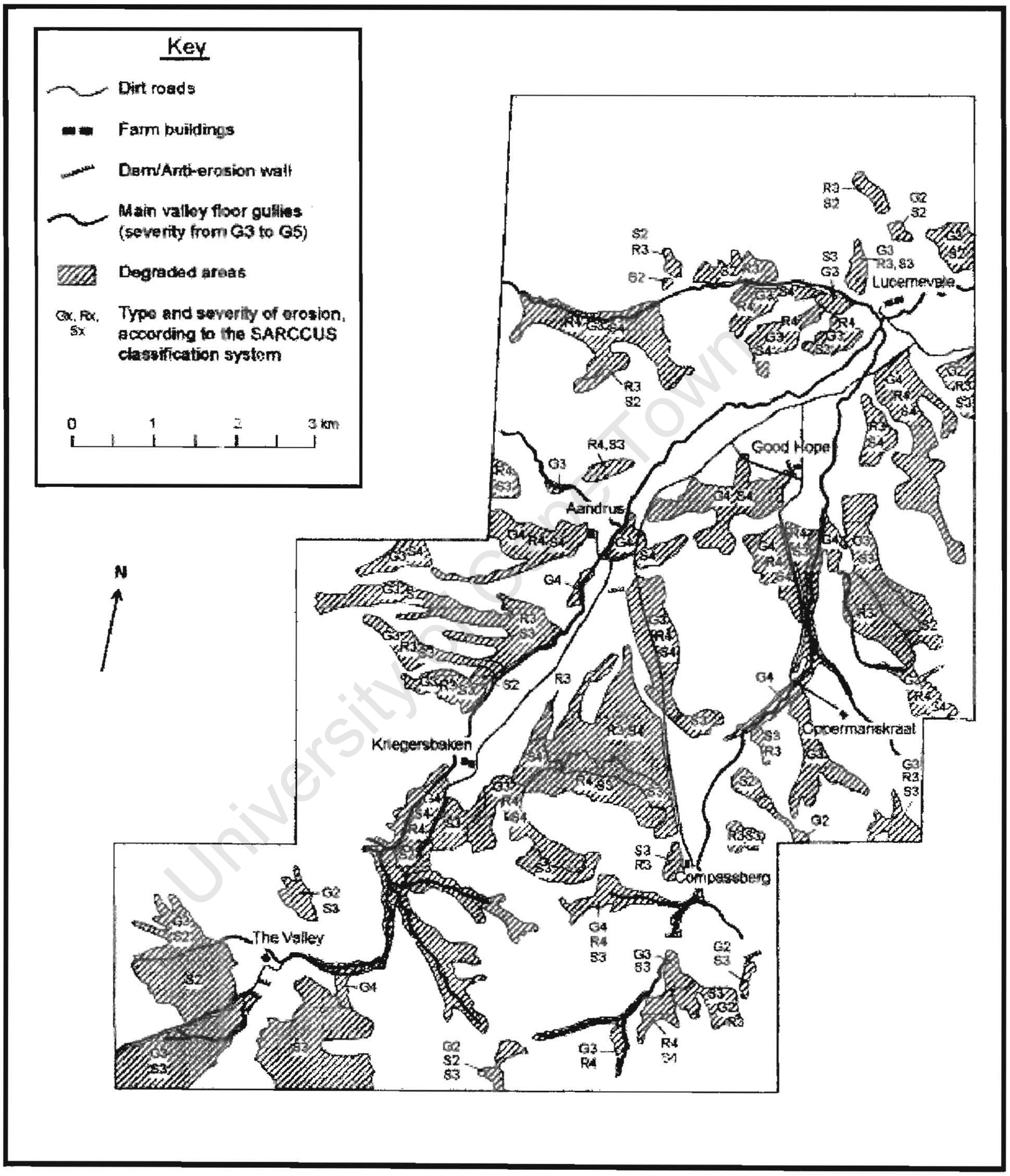

Fig 6.16 Land degradation in the Klein Zeekoei River Valley in 1945.

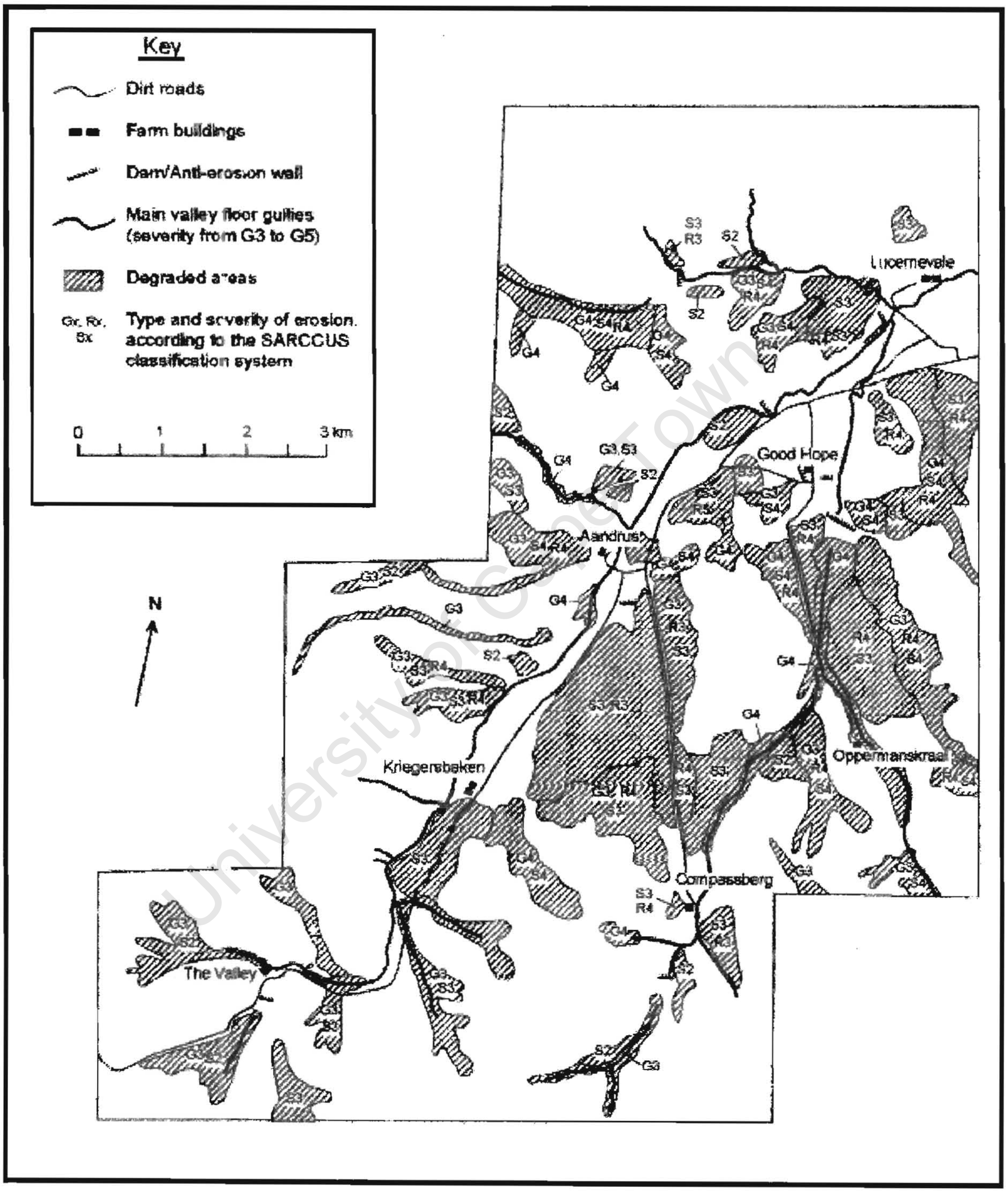

Fig 6.17 Land degradation in the Klein Zeekoei River Valley in 1980.

There are a greater number of anti erosion weirs and dams in the mapped area on the 1980 map. It is known from archival research and personal communication with the farmer, that one of the main reasons for the increase in the number of anti-erosion weirs was government subsidization of these structures, through the Department of Agriculture. Thirteen anti-erosion weirs are shown on the 1980 Land Degradation Map (Fig 6.17), compared to ten on the 1945 map (Fig 6.16). This is however not an entirely accurate reflection of the situation, since, of the four government subsidized anti-erosion weirs built in the late 1940`s and early 1950`s, in the gully in the Klein Zeekoei River, only one is shown on the 1980 Land Degradation Map. The reason for this is the difficulty in pinpointing the positions of weirs 2, 3 and 4 on aerial photographs, due to vegetation in the gully.

It is noted that the road to Oppermanskraal, when compared to the 1945 map, has been re-routed somewhat. An inspection of the aerial photography indicates that the encroachment of a badland area into the former course of the road is the probable reason for the change.

6.4.4 Synthesis

The aim of this section has been to provide a synthesis of the findings from the individual interpretations and analysis presented above. A discussion of the significance of these findings and analyses will follow in chapter 7.

A comparison of the individual sites studied in section 6.4.2 of this chapter reveals that there appears to be no pattern in terms of individual areas of degraded land either increasing or decreasing in spatial extent over the time that the aerial photography is available. It is possible that changes could have occurred between the two dates that were mapped, and that these would not be picked up by comparing and mapping only the 1945 and 1980 aerial photographs. A careful visual examination of the 1959 and 1966 aerial photography, suggest that this is not the case. A comparison of the land degradation maps for 1945 and 1980 reveals that the total proportion of land that is moderately to severely degraded has remained approximately the same over time.

It should be noted that the proportion of land that is cultivated is fairly small compared to the proportion of land that is degraded in both 1945 and 1980. It is also interesting to note that the proportion of cultivated land that is degraded is fairly small (22% in

1945). To express this slightly differently, in 1945, only approximately 9% of the total degraded land was cultivated land. Unfortunately, due to the distortions that occurred in enlarging the 1980 aerial photography to the same scale as that of 1945, a direct overlay of the 1980 land degradation map and the composite map of formerly cultivated land is not possible. However a visual comparison, coupled with observations of the aerial photography indicate that the figure is probably similar in 1980. Therefore, the majority of the degraded land in the upper reaches of the Klein Zeekoei River Valley has not been previously cultivated.

Some areas of degradation on cultivated land appear to be the result of processes happening upslope of the cultivated areas, rather than as a direct result of cultivation its self. For example, on the area of cultivated land that lies to the west of the dirt road between Kriegersbaken and Aandrus, sheetwash and rilling across the cultivated lands appear to be the result of flows from badland areas upslope of the cultivation. This will be discussed in more detail in the following chapter.

Chapter 7

Discussion

7.1 Introduction

In this chapter the results of the laboratory, statistical and aerial imagery analysis are interpreted and synthesized and the possible implications of these findings are discussed. The reader is reminded that this discussion should be considered in light of the theoretical background to the study, presented in Chapter 3.

7.2 The nature of land degradation in the Klein Zeekoei River valley

From the evidence presented in Chapter 6, it is apparent that extensive land degradation has occurred within the upper reaches of the Klein Zeekoei River valley. Approximately 25% of the study area can be classified as moderately to severely degraded (Fig 6.16 and Fig 6.17). There are extensive areas of footslope which have degraded to form badlands. In many areas the valley sides are dissected by gullies, some of which are discontinuous. This could be controlled by slope, or possibly by local sandstone benches, which form local base levels. On Compassberg an area of coalescing alluvial fans was observed as being subject to both deposition and dissection.

On the valley floors the original stream channels have now become incised forming valley floor gullies, with depths of up to eight meters. The absence of an A horizon at the majority of sites bears testimony to the extensive and severe sheetwash erosion that has taken place in the study area. What is referred to descriptively as the A horizon in the majority of soil profiles, is in fact a structureless veneer of sheetwash material. The fact that the original A horizon has been completely denuded and replaced by a veneer of sheetwash material accounts for the fact that the highest proportion of organic material is frequently found elsewhere than in the A horizon of soil profiles in the upper Klein Zeekoei River valley.

The two land degradation maps (Fig 6.16 and Fig 6.17) and the composite map of formerly cultivated land that were presented in Chapter 6 indicate that cultivation is not the main cause of land degradation in the upper Klein Zeekoei River valley. The majority of degraded land occurs in areas that have been used for grazing, and as will be shown presently, footslopes in particular appear to be very vulnerable to badland formation once a particular threshold of minimum vegetation cover is crossed.

Although the total proportion of degraded land has remained approximately the same between 1945 and 1980, (partly due to the soil erosion control and rehabilitation measures that have been implemented in the upper Klein Zeekoei River catchment) field observations in January 2000 showed some areas of badland to be actively eroding during a low magnitude rainfall event. Major channels in and from badland areas carried shallow (<10cm) sediment laden flows, these however failed to reach the major valley floor gully systems.

In the previous chapter it was noted that only a small proportion of the total land area in the upper Klein Zeekoei River catchment has been previously cultivated. This is partly due to slope factors, as only a limited proportion of the total land area is sufficiently flat to be cultivatable. It was also noted that less than a quarter of land that is cultivated, is degraded, and that in some areas the degradation of the cultivated land seems to be the result of processes happening upslope of the cultivation, rather than as a direct result of the cultivation itself. Cultivated land situated on the valley floor downslope of areas of active badlands on footslopes, seems to be particularly vulnerable to sheetwash erosion and rilling. It is suggested that the main cause of this is the increased flows over the cultivated land, as a result of the discharge from the badland areas. The vulnerability of these areas to erosion is compounded by the fact that agriculture is practiced opportunistically in the upper Klein Zeekoei River valley, and therefore the cultivated land has a very low proportion of vegetation cover for most of the year. The majority of the degradation of cultivated land in the Klein Zeekoei River valley occurs at one site, namely KBL (Figs 6.11 - 6.14). This site receives discharges from badlands to its south and east, and although slope has not been accurately measured, the enhanced gradient of this cultivated land is another probable exacerbating factor in the degradation that has occurred there (despite the fact that this site also occurs on a valley floor, it appears to have a greater slope than other cultivated areas).

The sedimentological analysis of samples taken from the Klein Zeekoei River catchment assisted in the determination of the erodability of these soils and sediments. The conductivity of these soils and sediments suggest that they are sodic in nature, and consequently dispersive. Soils and sediments in the upper Klein Zeekoei River catchment are primarily derived from Upper Beaufort Group shales. Field observations support the view that these soils and sediments are highly dispersive, and indicate that they are extremely friable when desiccated. Evidence of crusting in these soils, which decreases infiltration and increases surface runoff, was also noted.

From the evidence presented in Chapter 6, it is apparent that soils and sediments in the upper Klein Zeekoei River catchment are generally of a loamy texture and have low organic contents; texturally they are consequently very erodible (Poesen and Savat, 1981). These inherent soil properties of the area make the catchment very susceptible to erosion if the natural vegetation is disturbed in any way.

The analysis and logging of soil profiles exposed in gullies throughout the study area revealed a broad two-phase pattern of deposition of sediments in the upper Klein Zeekoei River catchment. This sequence consists of reddish colored inorganic sediments, dating from the early Holocene, overlain by an organic sequence of sediments that are generally grayish in color. A detailed paleoenvironmental interpretation is beyond the brief of this dissertation (see 1.2 Aim and Specific Objectives), but this evidence does serve to support the pattern recognized by Bousman *et al* (1988), Sugden (1989) and Holmes (1998).

7.3 Possible triggers to the onset of erosion in the valley

As was previously discussed in Chapter 2, from an ecological and geomorphic perspective, the history of land degradation in the Klein Zeekoei River valley can be traced back to the European incursion into this area in the c1870`s when it became an important route to the interior. The reader is reminded that there is no suggestion of any form of channel or anything that may be interpreted as alluding to valley floor erosion in historical accounts of travelers through the Klein Zeekoei River valley. What then triggered the onset of valley floor gullying?

In Chapter 2, the high variability of climate (particularly rainfall) in the study area was discussed. The role of climatic variation and variability in the region should be considered along with anthropogenic factors when looking for a trigger mechanism for the onset of gully erosion. Tyson (1986) studied the climatic records of southern Africa, and concluded that over the summer rainfall region of South Africa, and over much of the rest of southern Africa, a remarkably regular series of alternating wet and dry spells has occurred over the last eight decades. Tyson (1986) studied the rainfall spectra for a number of stations (including Graaf Rienet, where the rainfall record from 1861 to 1977 was analyzed) and found that most stations had variance peaks at around 18 years. The implication of this is a cyclicity in rainfall of nine wetter than average years, followed by nine dryer than average years. It is possible then that a series of wetter or dryer years, in combination with the anthropogenic pressure may have further contributed to the onset of gullying.

Before speculating on the trigger mechanism for the onset of valley floor incision in the Klein Zeekoei River valley, reference must again be made to the work on valley floor incision done in south-eastern Australia, that was previously reviewed in 3.4. These studies showed that valley floor incision in this region, was controlled more by thresholds of incision into valley floor vegetation, than from changes in sediment or water supply. The disturbances to the valley floor vegetation were suggested to have been caused by the introduction of European agriculture into the area.

In light of this previous work on gully initiation, and in view of the historical aspects of land-use in the Klein Zeekoei River valley (previously discussed in Chapter 2), and the parallels that exist (in terms of biophysical environment and the history of European settlement) between the Klein Zeekoei River valley and the research in south-eastern Australia, the following scenario is suggested as the most likely cause of gully initiation in the upper Klein Zeekoei River valley. Holmes (1998) pointed out that an abundance of land coupled with a shortage of water, provided the incentive to graze an area heavily before moving on to the next available water source. It seems quite likely in this case that the valley floor vegetation became damaged by outspanned animals and that this dramatically reduced the protection offered by the vegetation cover to the valley floor. Water balances in a catchment are highly complex, however damage to the valley floor vegetation may also have led to desiccation of the valley floor, since this vegetation protects the land surface from evaporation. As has been previously mentioned, soils in the upper Klein Zeekoei River catchment become extremely friable when desiccated, and this would certainly have made the valley floor extremely vulnerable to incision during high discharge storm events. It is suggested that incision started at some point during the last two decades of the 19th century due to this disturbance of the valley floor vegetation. If there was simultaneous degradation of footslope areas from grazing, the probability of erosion would have been further increased, due to increased runoff from these areas. However, large-scale sheep farming in the area, that would have degraded the vegetation on the footslopes, only started at the beginning of the 20^{th} century (H.N. Sheard, *pers comm.*).

7.4 A deterministic model of badland formation

The following model of badland formation in the upper Klein Zeekoei River valley, is summarized in Table 7.1, and was developed based on an original observation by J. Boardman (*pers comm.*), and discussions between this author, J. Boardman (*pers comm.*) and P. Holmes (*pers comm.*) and aerial photograph analysis. The model was initially conceived during field observations at the Lucernvale (LV) badlands and then tested at other badland sites, such as Compassberg Foot Slope (KBF), Kriegersbaken and Good Hope Slope (GHS) (see Chapter 5 for detailed site descriptions). A progression from relatively pristine to severely degraded land was recognized at all these sites, however the division into five stages is clearest at Lucernvale. From the observations at the three other sites, it is apparent that the sandstone pedestals that are very characteristic of stage 4 at Lucernvale (the type-site for the model) are less evident at other sites. This is probably due to differing distances to the upslope sandstone outcrops, that provide a source of sandstone blocks, at the various sites. At Kriegersbaken, there is no true stage 4 or stage 5, this is because these stages have been defined as having only approximately 10% vegetation cover, and some re-vegetation of the badland has occurred at this site. At Kriegersbaken, stage 4 and stage 5 badlands now have partially re-vegetated interfluves and gully floors.

The model of badland formation that follows is based on the following conditions and assumptions:

- The model applies to badlands that develop on footslopes in the Upper Klein Zeekoei River Valley that have slopes varying between approximately 3° and 9°.
- The footslopes have not been previously cultivated, but have been used for grazing sheep and to a lesser extent horses. In the past goats were also grazed in these areas, although this is no longer the case (H.N. Sheard, *pers comm.*).

- There is no evidence of transport routes (wheelings) across any of these slopes that may have contributed to badland formation or initiation.
- Erosion takes place in areas comprising a bedrock lithology of Upper Beaufort Group shales.
- Most badland sites have sandstone outcrops upslope of them that provide a source of the sandstone blocks that occur both on pedestals, and in the gully floors.

Based on these conditions and assumptions, a progression of five stages of badland development were identified in the field (from reasonably undisturbed, to severely degraded) and are described below. Note that these observations were made in early April (end of the rainfall season) when vegetation (particularly grass) is at its most abundant.

STAGE 1

Stage 1 describes the state of the footslope in relatively un-degraded condition, before any badland erosion takes place. In this stage the vegetation cover is approximately 40% (made up of roughly half grass and half shrub), stone cover is approximately 50%, leaving approximately 10% bare ground. There are typically two dominant grass species, and four dominant shrub species. In stage 1, there are no visible signs of flow. This is possibly due to the high percentage of stone cover increasing the infiltration rate into the soil, and hence reducing runoff (J. Boardman, *pers comm*). The stone cover occurs as a mixture of small and large stones, and there are no pedestals and no bushes on humps. Stage 1 of this model is shown in plate 7.1 below.

STAGE 2

In stage 2 of the model, the proportion of bare ground increases. This is due to the fact that most of the grass cover has disappeared, and the overall percentage of vegetation cover decreases to approximately 20%, which is dominated by just two species of shrub. There is an increase in the percentage of stony ground. These changes (from stage 1 to stage 2) are presumably brought about by grazing pressure, but once this change has occurred, the land is now extremely vulnerable to erosion from rain fall events, which lead to the progression in degradation to stages 3 to 5. Plate 7.2 shows a typical "stage 2" area.

STAGE 3

In stage 3, the most significant change is that there is evidence of water flow in the form of rills, and humps around vegetation. Due to the loss of unconsolidated material, slopes start to evolve. The vegetation cover is still approximately 20% (90% scrub, 10% grass), however the small stone cover is lost. Wide, flat, partially stripped interfluves develop. Plate 7.3 shows a close up view of an area that is in stage 3 of the badland development model.

Plate 7.1 Stage 1 in the model of badland development. Note that the ground cover offered by vegetation and stones is high, leaving very little bare ground exposed. Note the presence of grass.

STAGE 4

In stage 4 of the badland development model, active gully systems are now present. The vegetation cover drops to less than 10% of the total surface area, and is typically dominated by a single shrub species. There are well developed humps around the shrubs, and numerous pedestals topped with sandstone blocks (Plate 7.4). It was noticed that many of the sandstone blocks have lichens on them, indicating that they may have been in situ for some time. The area is characterized by steeper angle, bare, totally stripped interfluves, and there are frequent signs of water flow such as rills cutting back into interfluves, piping, and bridges joining interfluves.

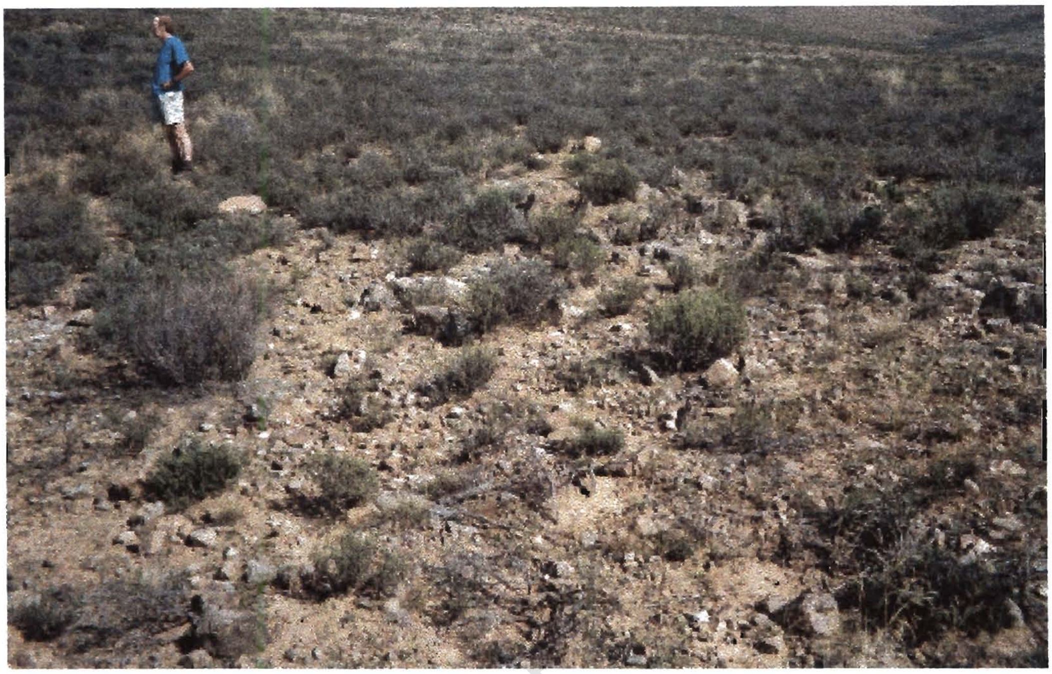

Plate 7.2 Stage 2 in the badland development model. Stage two occurs in the foreground of this photograph. Note the marked increase in bare ground compared to stage 1. Note also the figure for scale, the relative absence of grass and the relatively un-degraded slopes (stage 1) in the background.

STAGE 5

In stage 5, as with stage 4, there are active gully systems, and vegetation cover is less than 10%, with a single dominant shrub species. In stage 5 however, the pedestals have disappeared (eroded away), and the landscape comprises mainly slopes, with sandstone blocks occurring mainly in the gullies, where they have been deposited by a combination of slope and fluvial action. There is evidence of high runoff, and rills are active on very small areas of catchment (An area of 2-3 square meters is able to sustain active rills). There is evidence of grasses growing in a few centimeters of unconsolidated fines within the channels (gully floors). Plate 7.5 shows a view of badland erosion with stage 4 in the foreground (still displaying pedestals) and stage 5 in the background, where the pedestals have been eroded away.

Plate 7.3 Stage 3 in the badland development model. Note the camera case for scale. Also note the reduction in small stone cover, the humps around the vegetation, the single species of shrub, and the rill that the camera case is lying in.

Plate 7.4 Stage 4 and Stage 5 in the badland development model, note the trowel in the foreground for scale. Stage 4 is in the foreground, where pedestals occur on otherwise stripped interfluves. In Stage 5 (in the background), the pedestals have been eroded away.

	Vegetation cover	Vegetation type	Stone cover	% Bare ground	Pedestals	Rills	Interfluves
Stage 1	~ 40%	2 spp. grass 4 spp. shrub	~ 50%	~ 10%	none	none	none
Stage 2	~ 20%	2 spp. shrub	~ 50%	~ 30%	none	none	none
Stage 3	~ 20%	90% shrub 10% grass	small stone cover lost	~ 50%	none	rills present	wide flat and partly stripped
Stage 4	< 10%	1 spp. shrub	< 10%	~ 90%	numerous pedestals topped with sandstone blocks	rills cutting back into interfluves	steeper angle, bare, totally stripped interfluves
Stage 5	<10%	1 spp. shrub	< 10%	> 90%	no pedestals (eroded away)	rills active on very small areas of catchment	as for stage 4

Table 7.1 Summary of the theoretical badland development model.

Plate 7.5 A pedestal typical of the type found in stage 4 of the badland development model. This particular example is approximately 25 cm high. Note the lichen on the sandstone block.

An area of footslope that has degraded to a stage 4 or stage 5 badland, represents severely degraded land that is of very little use to the farmer. This is due to the fact that it supports virtually no vegetation (the single species remaining being a woody unpalatable type), and can therefore not be used for grazing. In addition to this, the bare, sun-baked slopes of the badland are severely crusted and generate higher runoff than pristine areas, which may cause additional erosion from overland flow down slope of the badland area.

The severity of this erosion has long been recognized, and means to combat soil erosion in the Upper Klein Zeekoei River valley have been instigated. In the following section the effectiveness of measures used in the Klein Zeekoei River catchment to combat erosion is assessed.

7.5 Effectiveness of previously implemented soil erosion control measures

The anti-erosion measures implemented in the upper Klein Zeekoei River catchment include the four anti erosion weirs (Fig 5.1), built in the late 1940's and early 1950's across the main water course of the Klein Zeekoei River, a number of small earth bunds, such as the one constructed across the lower part of the Lucernvale badland, a reduction in stocking rates, the fencing off of certain areas, and the system of non-selective grazing that was implemented on Compassberg farm for a period of time.

7.5.1 Bunds and weirs

As was previously mentioned, the four concrete and stone anti-erosion weirs built across the Klein Zeekoei River are known to have filled with sediment within approximately ten years of formation. The rehabilitation effects of these weirs are unfortunately limited to the area up to 250m upstream of the wall, and therefore in the context of the entire Klein Zeekoei River valley, many more of these would be needed to reverse valley floor gullying. The effects of individual structures on the area immediately up-stream of them is quite encouraging. The weirs have created well vegetated vleis above them, Holmes (1998) suggests that this is due to raised saturation levels behind the weirs. As will be discussed in Chapter 8, this type of engineering solution to valley floor gullying is expensive, and it is unlikely that funds will be available to facilitate further rehabilitation of degraded areas by this means.

It is known that some degraded areas (e.g. Lucernevale, see 6.4.2.1) have decreased in area since 1945 due the effect of earth embankments (bunds) in arresting erosion. Field observations indicate that this method of arresting erosion has been effective on other areas of degraded land as well. It is therefore concluded that the proportion of the total mapped area to be classified as degraded in 1980 would be significantly higher in the absence of these measures. H.N. Sheard (*pers comm.*) states that he is using these structures to trap sediment in gullies, and builds new ones further up the gully as they are filled. This method is apparently used in conjunction with encouraging vegetation to grow in the gully floors, thereby reducing flow velocities and trapping additional sediment. These earthen structures are not as resistant to high magnitude rain fall events as the concrete and stone weirs built across the main water course of the Klein Zeekoei River, and aerial photography analysis indicates that these structures do fail on occasion. However, they do appear to play an important role in the rehabilitation and they have the advantage of substantially lower construction costs than concrete weirs, as will be discussed in Chapter 8.

7.5.2 Reduced stocking rates

Another important anti-erosion measure is the reduction of stocking rates in the upper Klein Zeekoei River valley. This seems to have happened in conjunction with the consolidation of land ownership in the area. In the past stocking rates were up to four times greater than present, but numbers have been reduced gradually since the 1960`s (H.N. Sheard, *pers comm.*). It is speculated that in the absence of this reduction in stock numbers, and hence the grazing pressure on the land, that the extent of land degradation that is recorded on the 1980 land degradation map (Fig 6.17) would be far greater.

7.5.3 Non-rotational grazing

The success of the system of non-selective or non-rotational grazing that was implemented on the farm Compassberg during the 1980`s and early 1990`s, which aimed at veld rehabilitation, seems to be questionable. This research has not specifically attempted to quantify any differences in degradation between Compassberg farm and the rest of the study area, however field observations suggest that the state of land degradation is not significantly different on Compassberg farm to the rest of the study area. This policy should not necessarily be dismissed however, as the period over which this system was implemented on Compassberg was relatively short, and at the time of the field work phase of this research, this management strategy had been allowed to lapse for approximately five years. As land in the Upper Klein Zeekoei River catchment degrades very quickly (extensive degradation could occur over a season or two), it is possible that the area was in better condition, prior to this management strategy being abandoned. Unfortunately the lack of regular coverage of the area in aerial photographs, and the fact that no aerial photography is available after 1980 precludes further investigation of the effectiveness of this management strategy in the study area.

7.5.4 Fencing

The fencing off of degraded areas has not been widely implemented in the study area. H.N. Sheard (*pers comm.*) indicated that he has made some attempts to fence off some valley floor gullies, thus separating the gullies from the valley floor, in order to keep stock out. The success of this strategy is unclear, however the Kriegersbaken badland area (Fig 6.9 and Fig 6.10), which has not been grazed for a number of years, shows extensive rehabilitation of the vegetation, with interfluves and gullies now being well vegetated. Keeping stock out of this area and allowing the vegetation to recover seems to have stabilized the badland, and field observations suggest that it is no longer active.

7.6 Conclusion

This chapter has dealt with the nature of land degradation in the upper Klein Zeekoei River valley, and the land-use practices and inherent soil properties that have led to this degradation. The effectiveness or otherwise of human interventions such as weirs and bunds, reduced stocking rates, non rotational grazing, and fencing, to rehabilitate degraded areas and stop further degradation has been discussed. The degradation of valley floor vegetation has been suggested as the trigger for the onset of valley floor gullying in the Upper Klein Zeekoei River valley, and similarly a five-stage model of badland formation has been proposed. These issues will be further discussed and synthesized in Chapter 8, where overall conclusions will be drawn.

Chapter 8

Further discussion and conclusions

8.1 Introduction

In this chapter the history with regard to the subsidization of soil erosion control measures is dealt with, and present government policy is reviewed. In view of the present situation, some future scenarios and possible solutions are discussed. The dissertation is concluded by drawing the readers attention to the salient issues and points that have emerged as a result of this research.

8.2 The present state of Government subsidized anti-erosion measures

In order to gain an insight into the present level of assistance given to farmers, by the government, to combat soil erosion, A. Erasmus, of the Agricultural extension office in Graaf Rienet, P de Bruyn, of the Grootfontein Agricultural college, and H.N. Sheard, a farmer in the upper Klein Zeekoei River catchment, were interviewed.

The picture that immerged from these interviews was that to all intents and purposes, government subsidies of anti-erosion measures no longer exist. A. Erasmus (*pers comm.*) commented that while in the past several million rand was devoted to soil erosion control in his district, the present budget is in the order of R200 000 for the entire Eastern Cape region. The role of the Agricultural Extension offices has therefore been downgraded to being merely an advisory service to farmers, offering technical advice on soil erosion control measures. A. Erasmus and P. de Bruyn (*pers comm*) have both noted a reluctance by farmers to finance anti-erosion measures themselves, and there are concerns that in the absence of subsidies the extent of soil erosion in the Great Karoo may increase.

A visit to the Middelburg Agricultural Extension Office, (co-incidentally on the day before it closed down), revealed the extent of assistance given to farmers in this district in the past. Meticulous and highly detailed records (going back to the late 1940`s) were kept of all government subsidized work carried out on farms in the district. An example of some of these records (from "The Valley") is included in Appendix C. As can be seen from this record, subsidies were available for measures such as fencing, weirs, general soil conservation work, and stock watering systems. The record shows for example that H.N. Sheard applied for a subsidy to build a (anti-erosion) weir on 18/10/1949, and that the estimated total cost of this was 586 pounds. This construction was approved on 13/10/1950. The site was inspected and the work found to have been completed on 6/3/1956, whereupon a subsidy of 419 pounds was approved, which was paid out to the farmer on 5/5/1956. This is in line with the policy at the time in which the government subsidy was in the order of 70% of the total cost of construction (A. Erasmus, *pers comm.*). It is curious that in spite of the highly detailed nature of these records (in addition to the previously mentioned records, 1:20 000 scale maps of each farm were kept, and the position of all subsidized work marked) no formal audit of the effectiveness of these measures in combating soil erosion was undertaken by the Department of Agriculture (P. de Bruyn, *pers comm.*).

As has previously been mentioned, the study area forms part of the catchment of the Orange River system, which is one of South Africa's primary water resources. Soils and sediments that erode from the Klein Zeekoei River catchment are ultimately a pollutant to this water resource, and contribute to the siltation of dams in the Orange river system. It is widely acknowledged that South Africa is a water poor country, and that water availability constitutes a major constraint on further industrial development. In light of this fact, the present Governments policy with regard to the subsidization of soil erosion control measures seems extremely short sighted.

8.3 Soil erosion control in the future?

In view of the fact that government funding and subsidization of anti-erosion works has been reduced to the extent that it is negligible (A. Erasmus and P. de Bruyn, *pers com.*), the responsibility and financing of these measures now falls entirely to the individual farmer. Farmers are therefore in need of efficient, cost effective measures and policies to enable them to prevent further degradation of farmland. As Lal (1981) points out, soil erosion control and preventative techniques are soil and site specific and no single measure can be universally applicable, however, the suggestions that follow are based on observations made in the field.

- Fencing off badland areas in order to ensure that no grazing of these areas occurs, would allow these areas to gradually be revegetated, and thus stabilized. The primary advantage of this would be to prevent the further spread of these areas. As has been previously shown at the Kriegersbaken badlands (Fig 6.9 and Fig 6.10), the re-vegetation of a badland area has the effect of stabilizing that area and trapping sediment, to the point that the area is no longer active. The badland area would be permanently lost as productive land however, since any future grazing would serve to re-activate erosion.

- Field observations indicate that earth bunds constructed across gullies or over areas of badlands have been very effective in trapping sediment and stabilizing areas behind them. There is evidence that in some cases the area downstream of the bund may also be stabilized following its construction. It is speculated that this is due to decreased flow velocities downstream of the bund. An example of this is at the Lucernvale badlands (Fig 6.5 and Fig 6.6) where the area downstream of the bund became re-vegetated following bund construction. Although there is evidence that these structures are occasionally prone to failure (presumably during extreme events) it is felt that these structures may offer a cheaper and effective alternative to the concrete anti erosion weirs of the past. Earth bunds may be constructed with the aid of implements already owned by many farmers, such as a bulldozer or tractor. As was mentioned in the previous chapter, H.N. Sheard (*pers comm.*) feels that the construction of earth bunds is a cost efficient and effective strategy for combating gully erosion, and is implementing it with a reasonable degree of success on his land.

- A further possible measure to reduce the soil erosion problem in the upper Klein Zeekoei River catchment, is to look at alternative land uses which have lower impacts on the natural vegetation than commercial stock farming. In times before large scale commercial stock farming began in the upper Klein Zeekoei River catchment (ie. before the beginning of the 20th century) the indigenous fauna included herds of antelope such as springbok. Although it is beyond the scope of this research to investigate the relative impacts and viability of game farming compared to stock farming, this is a subject worth further investigation, as the possibility exists that game farming may offer a more sustainable land use.

- Another alternative land use that may be worth considering, is the development of the area as a tourist destination, by developing hiking trails in the area, and turning farms into guest farms. This is already happening on a small scale in the upper Klein Zeekoei River valley.

8.4 Conclusions

The readers attention to the following main points which have been demonstrated by this research, these should be considered in light of the stated aim and specific objectives presented in section 1.2:

- The inherent soil and sediment properties of the upper Klein Zeekoei River catchment make the area very susceptible to soil erosion if the natural vegetation is disturbed in any way. These properties include the dispersive nature of soil, its loamy texture, the fact that it becomes extremely friable when desiccated, and its propensity to develop a surface crust. Soils in the upper Klein Zeekoei River catchment are generally poorly developed and exhibit very little structure.

- Extensive land degradation has taken place in the upper Klein Zeekoei River Catchment. The majority of this degradation had occurred by the time of the first aerial photography coverage over the area in 1945. Although the exact date of the onset of land degradation in the Upper Klein Zeekoei River valley can only be speculated, no suggestion of land degradation occurs in the documented accounts of travelers through the Klein Zeekoei River valley, prior to 1892. Damage caused to the valley floor vegetation by outspanned animals has been put forward as the most likely trigger to the onset of valley floor incision in the area. Overgrazing, as a result of high stocking rates in the early part of the 20th century, has been put forward as the probable trigger to badland erosion on footslopes in the upper Klein Zeekoei River catchment. A five stage deterministic model of badland formation has been suggested.

- It is clear that land degradation occurs extremely quickly in this environment, and that poor land management practices can lead to large scale degradation over a period of no more than a few seasons. Conversely, rehabilitation is a lengthy and expensive process. A case study of a valley side gully was used to demonstrate the speed at which these features may appear in the landscape, and the amount of sediment (that will ultimately find its way into the Orange River system) that such a feature can generate. Although evidence exists of successful rehabilitation of small areas, rehabilitation on the same scale as the initial degradation would be both extremely difficult, and prohibitively expensive. Prevention of further land degradation, in terms of both the degradation of presently pristine areas, and the spread of areas already severely degraded, is therefore extremely important.

- The comparison of aerial photography over the upper Klein Zeekoei River catchment between 1945 and 1980, reveals that there is little change in the severity and the overall spatial extent of land degradation in this area over this time period. This is partly attributable to the implementation of anti-erosion control measures in this area from the late 1940`s onwards. These findings are constrained by possible seasonal differences that exist between the photographs. Field observations indicate that significant areas of degraded land (particularly badlands) are presently actively eroding.

- The majority of degraded land in the upper Klein Zeekoei River catchment has not been previously cultivated, and although areas of degraded cultivated land do exist, these account for less than a quarter of the total area of cultivated land. Cultivation is therefore not the main cause of land degradation in the upper Klein Zeekoei River valley.

- The four main anti-erosion control measures implemented in the upper Klein Zeekoei River Valley include the building of weirs and bunds, a reduction in stocking rates, the implementation, for a limited period on Compassberg farm, of a system of non-rotational grazing, and the fencing off of degraded areas. The building of weirs and bunds has been effective on a local scale, with evidence of rehabilitation in the immediate vicinity of the construction. As the development of badland areas seem to be related to the overgrazing of footslopes, the reduction in stocking rates has undoubtedly been instrumental in preventing the present scale of badland degradation from drastically exceeding 1945 levels. The effectiveness of the system of non-rotational grazing seems to be questionable, for reasons that have been previously discussed, and the fencing off of degraded areas has only been implemented on a small scale. Evidence exists however, that it is an effective aid to rehabilitation.

- There is presently a negligible amount of government subsidization of soil erosion control measures, and the responsibility for soil erosion control now rests completely with the individual farmer. The wisdom of this policy is highly questionable for two main reasons. Firstly, farmers are unwilling or unable to finance these measures entirely by themselves. Secondly, in the absence of adequate soil erosion control measures, sediment is polluting one of South Africa's primary water resources, namely the Orange River system, and shortening the designed life-span of its major dams. South Africa is a water poor country, and can ill afford this state of affairs.

This research has focussed on a small headwater catchment of the Orange River system, where a combination of poor land management practices and inherent soil and sediment properties have led to extensive land degradation. Further research into sustainable stocking rates, and land management / grazing strategies, as well as a more in-depth study into the effectiveness of previously implemented anti-erosion measures, and feasible future measures, in this and other similar headwater catchments, is necessary in order for effective catchment management strategies to be formulated and implemented.

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Appendix A

Summary table of soil and sediment data

Sample	% Sand	% course	% med	%fine	Mean	Median	Sorting	Skewness	Kurtosis	% Silt	% Clay	%FineClay	pH	Conduct.	%Organics	Munsell C	Texture
LV1A	52.86	18.86	20.37	60.77	2.23	2.45	1.16	-0.25	0.78	32.54	2.73	11.87	6.11	86.10	5.44	7.5YR 5/4	sandy loam
LV1B	42.40	29.65	27.89	42.46	1.73	1.69	1.09	0.08	0.82	31.40	5.11	21.09	6.83	108.80	6.16	7.5YR 5/3	loam
LV1C	48.92	19.27	16.03	64.70	2.25	2.54	1.15	-0.33	0.77	26.58	3.90	20.60	6.77	789.00	5.08	7.5YR 6/6	loam
LV2A	51.42	22.65	23.91	53.44	2.05	2.14	1.15	-0.12	0.75	31.65	3.98	12.95	6.72	56.20	5.41	7.5YR 5/4	loam
LV2B	26.22	31.23	23.10	45.67	1.79	1.77	1.13	0.03	0.73	40.08	11.21	22.49	5.84	377.00	7.39	7.5YR 5/3	clay loam
LV2C	41.26	44.96	10.03	45.01	1.55	1.39	1.21	0.17	0.69	26.14	5.06	27.54	8.89	346.00	3.75	7.5YR 6/6	clay loam
KBL1A	39.48	24.57	19.23	56.20	2.12	2.34	1.19	-0.23	0.67	39.59	3.81	17.12	7.09	153.10	5.62	7.5YR 5/4	loam
KBL1B	25.08	9.91	13.96	76.13	2.61	2.89	1.00	-0.43	1.04	42.32	10.00	22.60	6.54	636.00	8.68	7.5YR 5/3	clay loam
KBL2A	34.82	18.45	23.44	58.11	2.20	25.35	1.12	-0.19	0.74	42.18	5.37	17.63	6.38	118.40	5.03	7.5YR 5/3	loam
KBL2B	17.24	23.27	27.76	48.97	1.93	1.96	1.08	-0.03	0.82	49.56	10.39	22.18	5.84	5420.00	8.01	7.5YR 6/3	silty clay loam
KBL2C	27.72	40.46	29.23	29.91	1.42	1.23	1.06	0.27	0.89	37.68	11.82	22.78	6.10	2230.00	5.74	7.5YR 6/3	clay loam
GHS1A	57.94	44.74	35.30	19.96	1.25	1.11	0.90	0.28	1.05	21.26	2.59	18.21	6.81	1665.00	6.20	7.5YR 5/3	sandy clay loam
GHS1B	37.28	64.35	23.00	22.65	0.82	0.64	0.96	0.37	1.08	32.42	5.76	24.54	6.97	136.40	7.79	7.5YR 5/2	clay loam
GHS2	54.30	31.88	21.56	46.56	1.76	1.86	1.18	-0.08	0.74	26.40	19.30	18.60	7.21	167.50	6.36	7.5YR 6/6	clay loam
GHS3	44.96	61.55	25.04	13.41	0.93	0.77	0.85	0.34	1.17	24.44	5.00	25.60	7.44	221.00	8.52	7.5YR 5/3	clay loam
GHS4	87.24	28.60	50.00	21.40	1.43	1.42	0.76	0.05	1.05	10.16	0.00	2.60	7.71	44.50	5.16	7.5YR 5/3	sand
KBG1	38.38	22.00	20.31	57.69	2.06	2.26	1.14	-0.21	0.81	33.69	3.33	24.60	7.22	88.20	8.36	7.5YR 3/4	loam
KBG2	25.68	41.73	8.97	49.30	1.85	1.97	1.25	-0.12	0.68	34.37	5.45	34.50	7.05	175.20	10.02	5YR 4/2	clay loam
KBG3	54.52	40.78	24.72	34.50	1.43	1.28	1.09	0.21	0.80	23.41	2.03	22.04	7.66	56.60	6.19	7.5YR 4/6	sandy clay loam
KBG4	47.98	10.28	8.76	79.96	2.64	2.83	0.95	-0.38	1.48	35.24	0.93	15.85	7.84	33.10	5.10	7.5YR 5/6	loam
KBG5	68.84	25.47	38.38	36.15	1.67	1.76	0.96	-0.08	1.03	19.16	0.00	12.60	7.81	31.30	18.59	7.5YR 5/6	sandy loam
KBG6	55.36	53.80	25.65	20.55	1.05	0.88	1.03	0.26	0.88	19.30	2.94	22.60	7.73	39.40	5.68	7.5YR 5/4	sandy clay loam
KBG7	54.32	68.76	15.39	15.85	0.82	0.50	1.03	0.50	1.15	22.08	3.82	19.78	7.86	43.70	14.84	7.5YR 5/6	sandy clay loam
KBG8	63.62	52.41	24.34	23.25	1.10	0.92	1.09	0.26	0.85	17.44	0.34	18.60	7.87	73.20	10.10	7.5YR 5/4	sandy loam
KBF1A	36.78	64.24	24.55	11.21	0.86	0.77	0.79	0.31	1.40	28.62	6.83	27.77	6.37	1076.00	6.26	7.5YR 5/2	clay loam
KBF1B	33.54	62.53	22.87	14.60	0.94	0.74	0.88	0.40	1.18	24.06	7.64	34.76	7.80	72.60	5.67	7.5YR 6/3	clay
ZKS1	50.52	28.05	36.88	35.07	1.61	1.61	1.01	0.05	0.97	23.81	4.07	21.60	7.79	92.10	5.53	7.5YR 4/3	sandy clay loam
ZKS2	46.12	39.96	29.63	30.41	1.51	1.32	1.16	0.24	0.89	28.77	2.51	22.60	7.54	54.70	5.50	7.5YR 4/4	sandy clay loam
ZKS3	48.18	35.57	29.53	34.90	1.57	1.51	1.13	0.09	0.84	25.92	2.77	23.13	8.10	58.00	6.04	7.5YR 5/4	sandy clay loam
ZKS4	38.18	59.34	24.45	16.21	1.03	0.82	0.93	0.42	1.29	29.73	4.49	27.60	7.92	47.60	5.80	7.5YR 5/4	clay loam
ZKS5	38.14	24.42	23.26	52.32	1.93	2.08	1.12	-0.16	0.81	37.74	1.52	22.60	7.98	36.40	5.50	7.5YR 5/6	loam
ZKS6	35.36	26.07	24.40	49.53	1.90	1.98	1.16	-0.08	0.81	31.81	3.23	29.60	7.75	86.50	7.43	7.5YR 5/6	clay loam
OK1	42.92	2.40	4.79	92.81	2.96	2.96	0.60	-0.08	1.13	37.26	1.22	18.60	8.39	161.40	5.23	5YR 4/3	loam
OK2	27.00	7.91	10.81	81.28	2.63	2.72	0.85	-0.29	1.46	19.40	1.75	51.85	7.76	1680.00	12.29	5YR 4/6	clay
OK3	52.00	4.27	10.83	84.90	2.65	2.66	0.69	-0.12	1.34	23.40	1.06	23.54	8.76	156.80	7.84	5YR 6/6	sandy clay loam
OK4	44.28	4.02	10.05	85.93	2.69	2.69	0.69	-0.10	1.24	29.75	3.37	22.60	8.30	127.30	6.24	5YR 6/6	loam
OK5	54.26	23.18	30.56	46.26	1.78	1.92	0.99	-0.16	0.93	17.14	3.07	25.53	7.98	141.90	6.69	5YR 5/6	sandy clay loam
KBW1	48.78	24.09	22.61	53.30	1.93	2.08	1.15	-0.18	0.86	26.23	2.99	22.00	7.47	54.90	6.06	7.5YR 4/4	sandy clay loam
KBW2	53.74	14.29	18.31	67.47	2.22	2.39	1.01	-0.27	1.19	30.28	3.08	12.90	7.45	65.00	4.20	5YR 5/2	sandy loam
KBW3	61.04	36.07	18.24	45.69	1.78	1.86	0.96	-0.09	0.96	18.36	1.78	18.82	6.07	487.00	9.32	7.5YR 3/2	sandy clay loam
UW(S)	75.22	44.54	30.52	24.94	1.30	1.12	1.03	0.26	0.94	13.18	1.00	10.60	7.27	46.60	5.70	7.5YR 5/4	sandy loam
UW(57cm)	65.52	82.84	8.39	8.77	0.38	0.30	0.84	0.36	1.66	19.28	4.39	10.81	7.57	37.50	2.68	7.5YR 5/4	sandy loam

Appendix B

Raw data from statistical analysis of soil and sediment data.

(Including PCA factor scores, and correlation matrix)

Factor Scores (sed_std1.sta)
Rotation: Unrotated
Extraction: Principal components

	Factor 1	Factor 2	Factor 3	Factor 4
1	0.785681	0.01738	-1.4659	-0.36175
2	0.077988	0.509466	-0.53234	0.147884
3	0.920656	-0.04994	-0.75819	0.142046
4	0.462433	0.106516	-1.32113	-0.07679
5	0.66561	1.702533	-0.18402	-0.03711
6	-0.0694	0.163749	0.288101	1.99856
7	0.911324	0.370229	-0.9137	0.567007
8	1.790312	0.439635	0.502235	-0.50762
9	1.629321	0.758099	-1.62744	-0.77625
10	1.285748	2.686215	0.667047	-2.39576
11	0.040453	2.128012	0.35604	-1.22991
12	-1.04771	0.274581	-0.23641	-1.43236
13	-0.93984	0.914449	0.829396	0.047627
14	0.251059	1.09926	-0.67157	0.217267
15	-1.24105	0.303527	0.982426	-0.12275
16	-1.53647	-1.5391	-2.01541	-1.97428
17	0.771552	0.087182	-0.27784	0.931375
18	0.75179	0.955722	0.572536	2.216678
19	-0.59311	-0.05794	-0.47206	0.787429
20	1.191149	-1.55124	0.444265	-0.81296
21	-0.69715	-1.15899	-0.88021	0.33652
22	-1.13	0.040122	-0.20079	0.609244
23	-1.52695	0.072585	0.875007	1.031472
24	-1.21877	-0.33747	-0.50279	1.043618
25	-1.05492	0.953633	1.548345	-1.46966
26	-1.09981	0.62684	1.620449	0.436919
27	-0.41299	-0.19303	-0.53577	0.004302
28	-0.48557	0.318857	-0.44361	0.690272
29	-0.35941	-0.04647	-0.47267	0.961078
30	-1.08585	0.321247	1.229079	0.103786
31	0.590817	-0.10015	-0.36842	0.888576
32	0.454741	0.182031	-0.02828	1.38423
33	1.370919	-1.84571	1.074016	-0.97833
34	1.270026	-0.99536	2.845483	0.745406
35	0.773996	-2.22274	1.171881	-0.41769
36	1.047569	-1.64923	1.108009	-0.68819
37	-0.12577	-0.72006	-0.37738	0.479803
38	0.359678	-0.24867	-0.6317	0.705089
39	0.678208	-0.93829	-0.48769	-0.79319
40	-0.15732	-0.33312	-0.42923	-0.48127
41	-1.32311	-0.59689	-1.30416	-0.40438
42	-1.97582	-0.44746	1.024411	-1.51594

Factor Scores (sed_std1.sta)
Rotation: Varimax raw
Extraction: Principal components

	Factor 1	Factor 2	Factor 3	Factor 4
1	-0.91918	-1.10839	-0.83771	0.349509
2	0.077634	-0.18742	-0.67454	0.273381
3	-0.9414	-0.27462	-0.68712	0.106462
4	-0.55467	-0.90585	-0.907	0.160026
5	0.07786	0.40717	-1.00314	1.482821
6	0.293064	1.3275	-1.08389	-1.04207
7	-0.75409	-0.06694	-1.23556	0.155476
8	-1.39084	0.67315	0.118983	1.22747
9	-1.41889	-1.06666	-1.17694	1.394383
10	-0.10479	0.162598	0.379873	3.856394
11	0.814092	0.107273	-0.04753	2.343715
12	0.933879	-1.16757	0.753255	0.691302
13	1.337052	0.627996	0.214256	0.426244
14	0.151201	-0.07414	-1.10922	0.714766
15	1.365491	0.43219	0.749063	-0.01106
16	0.350201	-3.36847	0.897856	-0.64335
17	-0.6369	0.51483	-0.89985	-0.25907
18	-0.06579	2.060025	-1.54371	-0.29827
19	0.494196	-0.09904	-0.64348	-0.72795
20	-1.70144	-0.15486	1.300787	-0.26934
21	0.049863	-0.93867	-0.09344	-1.35092
22	1.042667	-0.10522	-0.32503	-0.69724
23	1.584231	0.850538	0.145064	-0.95508
24	0.952711	-0.21011	-0.58241	-1.28461
25	1.459429	0.330536	1.57478	1.363978
26	1.493012	1.335509	0.637646	0.000256
27	0.219301	-0.55852	-0.17962	-0.32029
28	0.550983	-0.01481	-0.76232	-0.35466
29	0.29966	0.058198	-0.79165	-0.74735
30	1.280727	0.788093	0.733903	-0.06086
31	-0.56676	0.332051	-0.81316	-0.43783
32	-0.25124	0.891716	-1.00796	-0.53156
33	-1.90983	0.214124	1.903441	-0.28344
34	-1.12172	2.67585	1.595227	-0.54122
35	-1.48112	0.351693	1.903625	-1.07062
36	-1.51552	0.359813	1.71118	-0.40525
37	-0.20549	-0.22685	-0.1646	-0.88665
38	-0.46735	-0.06317	-0.76025	-0.53574
39	-1.11201	-0.84614	0.50088	-0.06293
40	-0.08406	-0.70769	0.202381	-0.05213
41	0.741159	-1.69712	-0.07663	-0.73203
42	1.634676	-0.65863	2.084562	0.015371

Correlations (sed_std1.sta)
Casewise deletion of MD
N=42

	%SAND	%COURSE	%MED	%FINE	MEAN	MEDIAN	SORTING	SKEWNESS	KURTOSIS	%SILT	%CLAY	FINECLAY	PH	CONDUCT	%ORG
%SAND	1	0.147896641	0.377008793	-0.286915096	-0.262914248	-0.171801159	-0.210328257	0.171187383	0.132754817	-0.791105996	-0.491745129	-0.675937727	0.300894378	-0.436583167	-0.003165136
%COURSE	0.147896641	1	0.169496316	-0.913898085	-0.965773354	-0.304855573	0.036015856	0.87608648	0.170885145	-0.336369069	0.134067774	0.032228646	-0.035371646	-0.079881359	0.009902672
%MED	0.377008793	0.169496316	1	-0.549571474	-0.397755735	-0.055084815	0.10739011	0.28305135	-0.270501876	-0.306934743	-0.05126141	-0.325620549	-0.179607128	0.08642858	0.059927983
%FINE	-0.286915096	-0.913898085	-0.549571474	1	0.977374435	0.280713339	-0.077948724	-0.854632702	-0.035639596	0.418771026	-0.09069359	0.108867083	0.098002392	0.030239176	-0.028984356
MEAN	-0.262914248	-0.965773354	-0.397755735	0.977374435	1	0.312497729	-0.042319748	-0.882349379	-0.118179976	0.421969202	-0.099604777	0.063659741	0.034785505	0.061207732	-0.015895113
MEDIAN	-0.171801159	-0.304855573	-0.055084815	0.280713339	0.312497729	1	0.107084895	-0.313138622	-0.179413765	0.330996649	0.026222341	-0.06924816	-0.195823572	-0.039175476	-0.106589973
SORTING	-0.210328257	0.036015856	0.10739011	-0.077948724	-0.042319748	0.107084895	1	-0.172390153	-0.788002205	0.288906227	0.257909774	0.009048519	-0.31912967	-0.012939704	-0.035401943
SKEWNESS	0.171187383	0.87608648	0.28305135	-0.854632702	-0.882349379	-0.313138622	-0.172390153	1	0.197076095	-0.357514644	0.066512055	0.027878058	0.115827559	-0.013292034	0.000112242
KURTOSIS	0.132754817	0.170885145	-0.270501876	-0.035639596	-0.118179976	-0.179413765	-0.788002205	0.197076095	1	-0.281384953	-0.213542886	0.104878035	0.297838011	-0.016238025	0.05406713
%SILT	-0.791105996	-0.336369069	-0.306934743	0.418771026	0.421969202	0.330996649	0.288906227	-0.357514644	-0.281384953	1	0.442569451	0.114033685	-0.431449567	0.36470201	-0.164172955
%CLAY	-0.491745129	0.134067774	-0.05126141	-0.09069359	-0.099604777	0.026222341	0.257909774	0.066512055	-0.213542886	0.442569451	1	0.160871885	-0.465756438	0.353830171	-0.111887515
FINECLAY	-0.675937727	0.032228646	-0.325620549	0.108867083	0.063659741	-0.06924816	0.009048519	0.027878058	0.104878035	0.114033685	0.160871885	1	0.141220642	0.19769808	0.229170722
PH	0.300894378	-0.035371646	-0.179607128	0.098002392	0.034785505	-0.195823572	-0.31912967	0.115827559	0.297838011	-0.431449567	-0.465756438	0.141220642	1	-0.458200034	0.012528329
CONDUCT	-0.436583167	-0.079881359	0.08642858	0.030239176	0.061207732	-0.039175476	-0.012939704	-0.013292034	-0.016238025	0.36470201	0.353830171	0.19769808	-0.458200034	1	0.083533272
%ORG	-0.003165136	0.009902672	0.059927983	-0.028984356	-0.015895113	-0.106589973	-0.035401943	0.000112242	0.05406713	-0.164172955	-0.111887515	0.229170722	0.012528329	0.083533272	1

Appendix C

A sample of some of the records obtained from the Agricultural Extension Office in Middelburg

G.P.-S. 81-30482

(Z 20)

81/30179

(Z20)Blou

LÊER · FILE No.

319/000087/4

LÊER · FILE No.

319/000087/4

ONDERWERP • SUBJECT

HN Sheard
PO Box 205
Middelburg
5900

The Valley

TEL 22418

GRONDBEWARING
LANDBOU

DEPARTEMENT • DEPARTMENT

LÊER · FILE No.

DEEL 2

Dat. van aansoek - subsidie 17/2/1963

Dat. van aansoek - lening(x)

Dat. van diening van plaasplan 14/6/55. (31/1/64)

.....

Nr.	Beskrywing - tipe en doel.	Voor. Versl. Dat.	Voor. Versl. Bedrag	Goed-keur. Dat.	Finale versl. Dat.	Finale versl. Bedrg.	Uit-bet. Dat.
1	Weir	18/10/49	£586-5-0.	13-1-50	6/3/56	£414=11=0	5/5/56
2.	Weir	18/10/49	£253-0-0	13-1=50	6/2/53	£404=2=6.	2/7/53
3	Weir	18/10/49	125-13-4	13-1-50	6/2/53	£243=14=0	2/7/53
4	Dam	18/10/49	63-15-0	13-1-50	12/11/52	£73-7-1	26/3/53
5	Weir						
6.	Reservoir						
x 7	Weir						
x 8.	Weir						
x 9	Diversion Wall						
x 10	Diversion Wall						
x 11	Diversion Wall						
x 12.	Diversion Wall						
13	Reservoir						
x 14	Reservoir						
x 15	Weirs						
x 16	Weir						
x 17	Weir						
x 18	Weir						
x 19	Weir						
20.	Reservoir & 3 troughs						
21	Fence EF.	9/7/54	£420.	30/6/55	26-8-59	£415-13-10	29/9/59
22	Fence JK.	9/7/54	See 21	30/6/55	26-8-59	See 21	29/9/59
23	Fence AG.	9/7/54	See 21	30/6/55	26-8-59	See 21	29/9/59
24	Fence LM.	9/7/54	See 21	30/6/55	26-8-59	See 21	29/9/59
25	Fence GH.	9/7/54	See 21	30/6/55	26-8-59	See 21	29/9/59

NR.	Beskrywing - tipe en doel	Voorl. Verslag Bedrag	Goed-keur-datum	Verval datum	Uitbetaaldatum	BEDRAG
1	Soilconservation work - sub. on Krugersbaekn				56·04·30	£ 419
2	Soilconservation work - sub. on Krugersbaken				53·06·17	£ 409
3	Soilconservation work - sub. on Krugersbaken				do	£ 263
4	Soilconservation work - sub. on Krugersbaken				53·03·16	£ 73
5	Campfence - sub. as EF on Krugersbaken				59·09·17	£ 461
6	Campfence - sub. as JK on Krugersbaken				do	Sien 5
7	Campfence - sub. as AB on Krugersbaken				do	do
8	Campfence - sub. as LM on Krugersbaken				do	do
9	Campfence - sub. as GH on Krugersbaken				do	do
10	Campfence - sub. as ZM on Krugersbaken				do	do
11	Campfence - sub. as no.28 on Krugersbaken				77·09·22	R363
12	Campfence - sub. as no.1 on Aandrus				62·10·31	R396
13	Campfence - sub. as no.2 on Aandrus				do	R384
14	Campfence - sub. as no.3 on Aandrus				do	Sien 12
15	Campfence - sub. as no.4 on Aandrus				do	Sien 12
16	Campfence - sub. as no.5 on Aandrus				do	do
17	Campfence - sub. as no.6 on Aandrus				65·04·08	R1762
18	Campfence - sub. as no.8(a)on Aandrus				62·11·06	R147
19	Campfence - sub. as no.9 on Aandrus				62·10·31	Sien 13
20	Campfence - sub. as no.10(a) on Aandrus				do	Sien 12
21	Campfence - sub. as no.12(a) on Aandrus				do	Sien 13
22	Campfence - sub. as no.24 on Aandrus				65 04·08	R1762
23	Campfence - sub. as no.25 on Aandrus				do	Sien 22
24	Campfence - sub. as no.26 on Aandrus				do	do
25	Campfence -sub. as no. 27 on Aandrus				do	do
26	Campfence - sub. as no.28 on Aandrus				do	do
27	Campfence - sub. as no.29 on Aandrus				do	do
28	Campfence - sub. as no.30 on Aandrus				do	do
29	Campfence - sub. as no.31 on Aandrus				do	do
30	Campfence - sub. as no.32 on Aandrus				do	do
31	Campfence - sub. as no.33 on Aandrus				do	do
32	Campfence -sub. as no.34 on Aandrus				do	do
33	Campfence - sub. as no.35 on Aandrus				do	do
34	Campfence - sub. as no.36 on Aandrus				do	do
35	Campfence - sub. as no.37 on Aandrus				do	do
36	Stockwateringsystem - sub. as no.38 on Aandrus				do	do

DEPARTMENT OF AGRICULTURE

REFERENCE	Head Office:	Region: 234/017807/1
Owner	MR K.I.M. Mc CABE	
Farm Unit	COMPASSBERG	Magisterial District MIDDELBURG
Grazing capacity of veld	14 ha/LSU	Number of stock which may be kept on veld 161

LIST OF SOIL CONSERVATION WORKS AS PER FARM MAP No. 1

Page: 1 of

* If subsidy is required, construction of the proposed soil conservation work may not be commenced with unless written consent thereto has been recieved from the Executive Officer.

* Works under group 1 are proposed soil conse works which may be considered for subsidy.
* Works under group 2 have already been subsi
* Works under group 3 are not subsidized.

Work No. and Group No. 1	2	3	Location as per farm map	Description and purpose of work	Measure
	1		k15: K3 K5	Stockwateringsystem - Res. & Trough Sub as work No. 4 - 58/59	
	2		W23 K27	Campfence sub as word No. 17(a) - 61/62	
	3		K20 K26	Campfence sub as work No. 17(b) - 61/62	
	4		W22 K26	Campfence sub as work No. 17(c) - 61/62	
	5		W23 K26	Campfence sub as work No. 17(d) - 64/65	
	6		K14 K20	Campfence sub as work No. 18 - 54/55	
	7		W12 K13	Campfence sub as work No. 19 - 60/61	
	8		K11 W29	Campfence sub as work No. 20(a) - 64/65	
	9		K15 W29	Campfence sub as work No. 20(b) - 64/65	
	10		W8 K9	Campfence sub as work No. 21 - 54/55	
	11		K3 K29	Campfence sub as work No. 22 - 56/57	
	12		W8 B40	Campfence sub as work No. 24(a) - 58/59	
	13		K9 B40	Campfence sub as work No. 24(b) - 62/63	
	14		K3/K5 K4	Campfence sub as work No. 25 - 58/59	
	15		B30 B42	Campfence sub as work No. 28 - 63/64	
	16		B36 B39	Campfence sub as work No. 30 - 58/59	
	17		B35 B36	Campfence sub as work No. 31 - 58/59	
	18		B32 B35	Campfence sub as work No. 32 - 58/59	
	19		B32 B33	Campfence sub as work No. 33 - 58/59	

	NAME	RANK	OFFICE	DA
COMPILED BY	J.D.BLOM	C.E.TEC.	MIDDELBURG CP	1993.C
CHECKED BY	L. VAN DER WALT	S.A.C.	MIDDELBURG CP	1993.C
APPROVED BY	P.V. DE BRUYN	A.D.TEC.	MIDDELBURG CP	1993.C

Appendix D

List of site abbreviations

The following site abbreviations were used in the field, and in the labeling of samples used in subsequent laboratory analysis. These abbreviations also appear in the text.

Site	Abbreviation
Lucernvale	LV
Good Hope Slope	GHS
Compassberg Footslope	KBF
Compassberg Lands	KBL
Compassberg Gully	KBG
Zeekoei River; Side Gully	ZKS
Oppermanskraal	OK
Compassber; Trekboer Wall	KBW
Uppermost Weir	UW