SOIL EROSION AND LAND DEGRADATION IN THE SWARTLAND AND SANDVELD, WESTERN CAPE PROVINCE, SOUTH AFRICA: A RE-EVALUATION.

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ABSTRACT

The Swartland and Sandveld are situated in the Western Cape province (political limits) in what is also known as the southwestern Cape region. This area falls within the winter rainfall (or Mediterranean) region of South Africa and has a sharply defined seasonal climate. Vegetation in the region is unique. The soils in the Swartland and Sandveld vary greatly over short distances, making this area vulnerable to varying erosion rates. Landuse in the Swartland and Sandveld is mainly agricultural.

Soil erosion is driven by the force of wind and or water. Sheet flow is what is considered as unconstrained water erosion together with rainsplash, while piping, rill and gully erosion are all forms of constrained water erosion. Erosivity and erodibility are both important factors in determining the vulnerability of an area to soil erosion. By their understanding of the factors involved in the course of degradation, researchers can determine the most effective conservation policies for a region. Of course, the influence of humans on the land should never be under-estimated and should be seen as a potent determinant of the erosion potential.

The use of remote sensing and G.I.S. are essential in the development of erosion maps, and to assess possible changes that over time in the erosional situation in a region. As an analytical and data storage tool, these techniques are very useful, even essential. The total decrease in gully erosion from 1938 to 1989 in the Swartland amounts to 85% compared to the gully erosion in 1938. In the Sandveld wind erosion decreased with 17% from 1928 to 1986.

Soil conservation in South Africa has come a long since the 1930's and much of the experience and the lessons gained in the last six of seven decades have been incorporated in the countries new conservation Act.

It has been concluded that the slowing down of the denudation process in the region, coinciding with effective new conservation strategies, are the

principal reasons for the results obtained in this research project. It must be noted however that without the intervention of the conservation efforts in the Swartland and Sandveld, the remarkable improvement in the water erosion situation (85%) would not have been obtained. The overall improvement (17%) in the Sandveld lags that in the Swartland and even shows a slight deterioration of the wind erosion situation found in 1974. There are therefor grounds for caution, since wind erosion is still very much relevant and not fully contained in the Sandveld. Further research into this situation would indeed be beneficial.

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CHAPTER 1 : INTRODUCTION

Out of the long list of nature's gifts to man, none is perhaps so utterly essential to human life as soil - Bennet (1939).

1.1 MOTIVATION FOR THE STUDY

Soil is a familiar part of our lives; we take it for granted without realising its importance and what its loss implies. The survival of the human race ultimately depends on the soil. It is the medium of all growth, without it there can be no food for the human species dependent on plant life for its existence. One of the most potent environmental problems the world faces today is increasing pressure on available soil resources. This highlights the need to generate awareness of soil erosion potential and to apply preventive conservation measures. Soil is an integral part of the natural environment, it forms the buffer between the land and the atmosphere, absorbing and releasing nutrients and gases to the atmosphere and to the plants dependent on the soil for nutrition. It also absorbs the flow of water between the atmosphere and the ground, and surface waters. Soil consists of loose materials that are made up of organic matter, weathered rock and minerals. In the agricultural context it is a substance that supports the growth of crops and can be tilled (Wild, 1993). Soil should be regarded as a non-renewable resource due to its slow replacement rate (Chappell & Brown, 1993). In the past, new land could be cultivated in response to the demand for more food, but now the situation is changed (Hooke, 1988; Wild, 1993) and remaining soil is increasingly threatened with damage, degradation and even destruction in many parts of the world.

1.2 SOIL EROSION AS A GLOBAL ISSUE

The history of the cultivation of the soil by people goes back to 12000BP, when wheat, barley and other crops were grown in ancient Mesopotamia's (Iraq) northern valleys, a practice followed up to this day (Wild, 1993). The ultimate demise of the old Mesopotamian culture has been laid at the door of soil degradation and erosion, where salinisation and gullies destroyed the upland areas and caused soil loss, which in turn reduced food production (Matthee & Van Schalkwyk, 1990). If this is indeed the case then this could be cited as the first real example of human-induced accelerated erosion affecting an entire watershed (Wild, 1993). Since then, there have been many cases of accelerated soil erosion in the world. From the time when people cut oown forests for building, clearing land by burning it and clearing vegetation for fields, all factors influencing the water regime and runoff in the area, especially on steep slopes, hastened the occurrence of gullies. As Wild (1993) points out: the loss of soil is the most serious form of soil erosion, as effectively the process cannot be reversed, once soil is lost it cannot be quickly restored, then it is up to nature to replace the soil. In the case of acidification, nutrient loss and accumulation of salts, the effects can, to a degree, be reversed. All of these problems emerge from the intense use of soil for food production, often on soils that should ideally have been left alone. Soil erosion is one of the key environmental problems facing the developing world which, if not checked, can lead to famine and hunger (Huntley, 1989).

Having respect for the soil and the conservation thereof has been part of human existence since early times. The remnants of erosion terraces can be seen in countries such as Peru, China and the Philippines, where they are being used even today (Matthee & Van Schalkwyk, 1990; Wild, 1993). In other parts of the world, periods of fallow (rest) were and are observed, showing that farmers are aware of the importance of the fertility and conservation of soil (Wild, 1993). When colonists from Europe settled all over the world, they were presented with a vast expanse of uncultivated land and ample soil, but unfortunately they forgot or simply ignored the soil conservation policies of their countries of origin and, as a consequence, accelerated soil erosion developed in many of the new settlements (Matthee & Van Schalkwyk, 1990).

The worldwide occurrence of soil erosion is illustrated by the following quotation from the World Commission on Environment and Development (1987, p. 125) :

> *By the late 1970's, soil erosion exceeded soil formation on about a third of the US cropland, much of this, on the Midwestern agricultural heartland. In Canada, soil degradation has been costing farmers $1 billion a year. In the (former) USSR, the extension of cultivation to the so-called Virgin Lands was a major plank of agricultural policy, but now*

> *it is believed that much of this land is marginal. In India, soil erosion affects 25 - 30 % of the total land under cultivation. Without conservation measures, the total area of rainfed cropland in developing countries in Asia, Africa and La..n America, will shrink by 544 million hectares over the long term because of soil erosion and degradation.*

In Australia soil erosion is also cause for concern. As stated by Loughran (1989), nearly half of Australia's agricultural and pastoral land is considered to be under threat of erosion. The need to know the spatial extent and variation of soil erosion is stressed by Loughran (1989) as well as the need for simple techniques of measuring the temporal and spatial extent of erosion.

1.3 SOIL EROSION STUDIES IN SOUTH AFRICA

In South Africa, the following situation prevails as described by the Department of Agriculture (1995, p.13):

> *It takes from 30 to 300 years to produce 25mm of soil by natural processes. South Africa is at present losing soil at a rate estimated at more then 30 times higher then the natural rate of soil formation. It is estimated that South Africa loses an average of 300 million tons of arable soil per year. In terms of fertility, plant nutrients lost amount to an estimated 3300 tons of nitrogen, 26400 tons of phosphorus and 363000 tons of potassium per year. If replaced by commercial fertilisers, this loss of valuable plant nutrients would amount to an annual cost of over R1 billion.*

Arbuthnot, (1995) feels that South Africa's resources are in a "critically poor state" (p.1) and that:

> *land degradation is an extremely serious problem that threatens the future of South Africa. Apart from its insidious long term effects, it can severely frustrate the implementation of the Reconstruction and Development Programme with serious socio-economic consequences. Poorly planned land redistribution will seriously aggravate and accelerate the land degradation problem, creating poverty traps that will drain limited resources that must be more effectively used to enhance the quality of life and eradicate the persistent poverty amongst rural communities* (Arbuthnot, 1995, p.1).

Arbuthnot (1995) identifies the key areas of environmental concern as follows

- Agricultural land and production
- Soil fertility

- Acidification of soils
- Loss of biodiversity

Arbuthnot's (1995) concern in these areas is based on the demand for food and the encroaching problem of food production in South Africa due to a loss of land or to the leaching of nutrients from the soil, thereby rendering soils less fertile, a point of view shared by Beckendahl *et al* (1988).

The seriousness of soil erosion in South Africa, as in other developing (and developed) nations can be seen in the effects of soil erosion as indicated by Arbuthnot (1995) and also in other effects indicated by Wild (1993)

- Loss of soil to support the food production, grasslands and forests
- Silting up of dams
- Deposition of erosion causing rivers to change course
- Variable flow of rivers and flooding
- Water pollution (soil nutrients dumped into rivers)
- Air pollution (soil particles reduce the radiation levels reaching the earth and it might affect chemical processes in the air – ozone-destroying gas binding with dust particles, to increase the depletion of ozone)

When the influence of people is taken into account, is clear seen that most of the regions in South Africa are under the threat of soil erosion (Garland, 1982; Moon and Dardis, 1988). The problem in South Africa has wide-ranging ramifications in the social as well as the economic fields as demonstrated by the silting of dams and estuaries, but an alarming feature as mentioned by Garland (1982) is that conservation legislation in South Africa is poorly formulated and easily bypassed.

Soil erosion studies in South Africa are necessary according to Adler (1981) to safeguard soil and allied natural resources, but extensive manpower and money for research, education and state aided schemes are required. Soil erosion is not purely a farmer's problem but must be seen as a major environmental problem affecting everybody. Moon and Dardis (1988) note the relevance of soil erosion studies in South Africa as both extensive and diverse. Hudson (1971), basing his view on a consideration of prevailing climate, states that of the southern Afric a region, up to two thirds, and more are "particularly susceptible" to erosion from wind and water. These potential badlands correspond to erosion areas in South Africa (Moon and Dardis, 1988). Other areas cannot be ignored as potential and actual areas for soil erosion, as Rooseboom (1993) has demonstrated when he compiled the sediment transport map of South Africa on which potential erosion areas are highlighted in his erodibility index map.

Research on soil conservation first started in the USA around 1915, a leadership position it has retained to this day. Studies in South Africa on soil erosion started in the 1930's (Matthee & Van Schalkwyk, 1990), with the work of Talbot, Bennett and others. It can be seen that South African studies lagged behind in time and intensity and it is clear that this is still the case. It is therefore high time for us to address the problem. Here, as in other parts of the world, even though studies have been conducted for many decades, the results of these studies have not brought us any closer to understanding gully erosion. Bocco (1991; p.1) mentions that the sizeable body of soil erosion studies have "confusing and sometimes contradictory results", a view shared by Stocking (1995, p. 253) who notes that:

> *Geomorphology claims an expertise in the study of soil erosion and the development of conservation solutions. Yet what are represented as 'facts' about erosion, especially in developing countries, where the need for conservation is the greatest, is usually helpless and sometimes wrong.*

If it is indeed the case that scientists have let themselves be manipulated (unwittingly) herlading to support false statements, as suggested by Stocking (p.254-255), then the erosion situation may not be as severe as we are sometimes led to believe,

> *(geomorphologists) pander to the sensational, accentuate the bad and distort the negative effects of soil erosion. Little matter is it that much of the eroded material gets re-deposited close to the site and may provide a valuable input for someone else.* (Stocking, 1995, p.255).

Stocking's (1995) point is that we must be more practical with our erosion studies and use models suited to the area. Stocking (1995) highlights the overreaction to the soil erosion question, and concludes that the problem is probably less severe than we have been led to believe. Studies like Rowntree's (1988) on the state of equilibrium that gullies strive for in the Karoo, poses the possibility that gullies could be a natural state of nature.

A new philosophy dealing with the erosion problem is needed in southern Africa, a more interdisciplinary approach, with flexibility and understanding for constraints by other parties involved, like the land-users, economists, developers, engineers and others (Stocking, 1995). In essence, what Stocking (1995) argues for is an objective and scientific approach to soil erosion studies. It is hoped that this study is a meaningful step in that direction.

1.4 SOIL EROSION AND SOIL EROSION STUDIES IN THE SOUTHWESTERN CAPE

Erosion studies in other parts of South Africa have attracted increasing attention from various authors, especially studies on gully erosion in the southeastern Cape province, Lesotho and KwaZulu-Natal, as can be seen in Arbuthnot's (1995) publication on land degradation studies in South Africa. Similar studies in the Mediterranean-climate region of this country are, however, rare and limited to a few, for example the studies of Bennett (1945), Talbot (1947) and Germishuys (1993), and the wind erosion study of Hallward (1988). Moll & Bossi (1984) conducted a study on the remaining natural vegetation in the region. Recently the Department of Agriculture published a report by the Environmental Scientific Association (ESA) Working Group on Land Degradation (Arbuthnot, 1995), in which current research projects on land degradation (physical issues) are listed and briefly described. This is a starting point to publicise current projects so that they can be of use to heralding management, research and planning in the future. In general, however, the region has not attracted much scientific attention on its problem of soil erosion and land degradation.

It is common cause that the action of both wind and water are the dominant causes of soil erosion in South Africa in general, and in the south-western Cape in particular (Meadows, 1998). He mentions that the seasonality of the rainfall and the intensity of agricultural pressure may have produced the impression that soil erosion is rife in the region. In fact, Meadows (1998) is of the opinion that this impression was created due to gloomy interpretations of the situation in the south-western Cape[1] in the 1930`s and 1940`s, chiefly by Bennett (1945), and Talbot (1947).

The extent of soil erosion in the Swartland was estimated by Talbot (1947) as covering an area of more then a 1000 square miles (1600km^2) - 25% of the area of this agriculturally important region is thought to be subject to soil erosion (more particularly water erosion).

More recent studies indicate lower rates of erosion, and even given the steep hills and seasonal rain, the erosion may be less then 100 t km^{-2} (Scott, 1993). Scott`s study was conducted on individual catchments, so it may not be a general regional indication. A similar study was conducted by Germishuysen (1993) on one gully system, where it was found that even though the gully was stable, the soil is susceptible to soil erosion if the top layer is removed. Germishuysen, however, concentrated more on the mechanical conservation mechanisms that can be constructed in the gully system, than on the rates and susceptibility of erosion in the area.

These findings suggest, therefore, that erosion in the region requires reassessment, as it can be seen that there are conflicting opinions on its status. This re-examination should be conducted in an objective way and on a more regional scale, as the recent studies are based on a particular catchment or gully system, while Talbot's (1947) geographical study is dated and requires review.

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1 [1]The term southwestern Cape, as used in this study, refers to the Mediterranean- climate region of the country around Cape Town. The use of the political term, Western Cape, referring to this region would be incorrect, since it incorporates an area that consists out of more then one climatic region. To be more specific, the Sandveld and Swartland, which are natural regions contained within the southwestern Cape, are more cogent to the study area of this study (**Figure 1.1**).

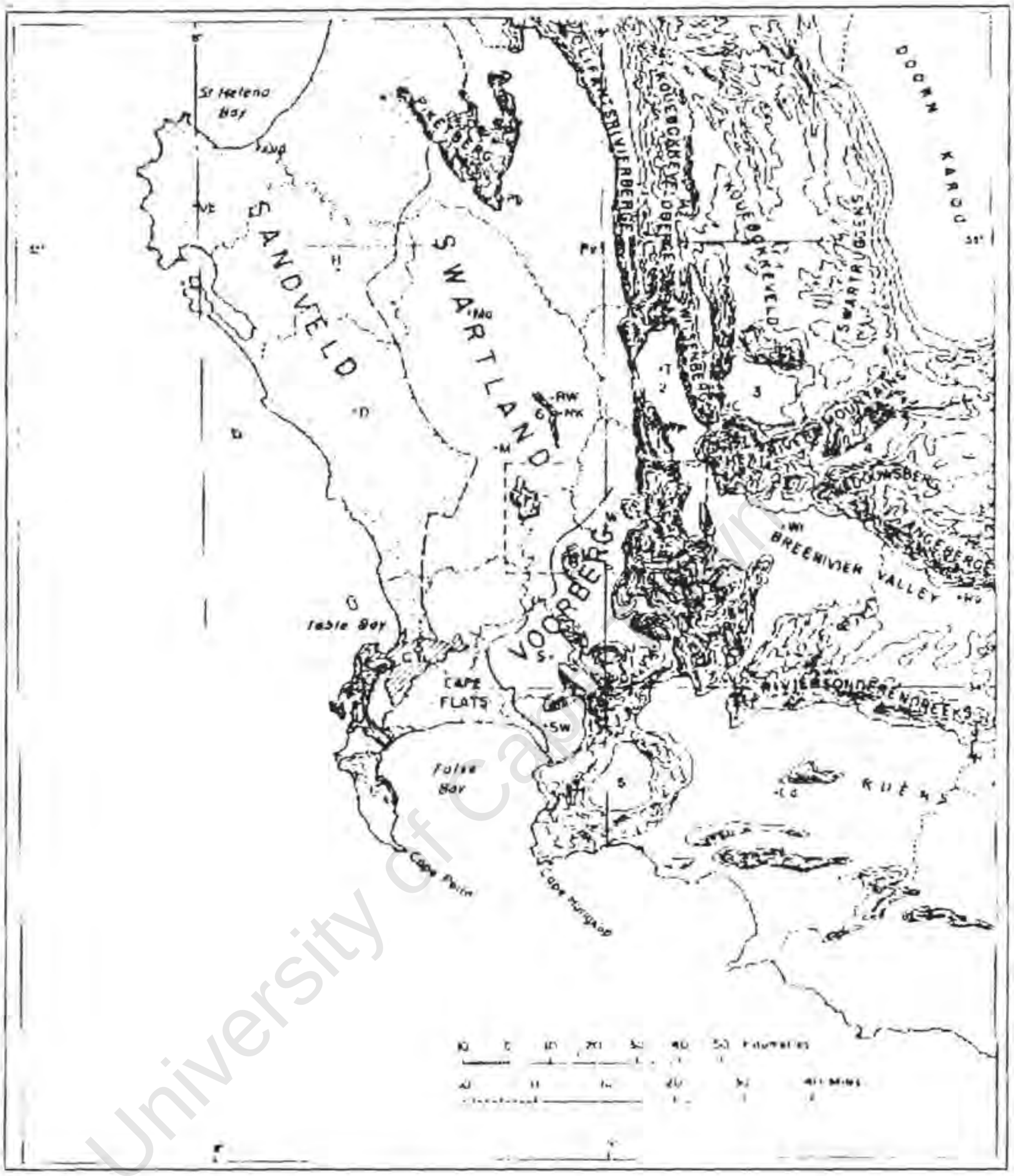


Figure 1. 1 : The south-western Cape region with the Swartland and Sandveld to the north of Cape Town.

Talbot (1947) conducted a comprehensive and thorough study the erosion in the Swartland and Sandveld areas of the south western Cape. He identified areas of extensive drift sands in the western Sandveld area, the occurrence of he attributed to the combined effect of overgrazing, severe fires and a high wind regime. It was estimated that the area covered by this wind erosion was about 6000 hectares in 1938.

The situatior in the Swartland, as depicted in 1938 aerial photographs, was regarded as an understatement of the situation prevailing in 1943 and 1944. When Talbot conducted his field examination, the situation in the Swartland appeared to have worsened, gullies had apparently lengthened and multiplied, and rills had become gullies, thus indicating a deteriorating situation (Talbot, 1947,p.xi). He indicated that in 1944, "no less than 95% of the cropped land in the Swartland have suffered from this form of erosion (sheet erosion) to some extent" (Talbot, 1947, p.xi). **Figure 1.2** illustrates the erosion problem as depicted by Talbot (1947).

The erosion mapping was accomplished by using aerial photographs provided by the War Department and stereo-graphic enlargement to trace all erosion features distinguishable at a scale of 1:36 000. All the gullies and wind erosion in the Swartland and Sandveld was then converted to the final map on 1:10 000 scale by Talbot (1947).

In this study, Talbot (1947) explored the possible reason why the erosion situation had developed and concluded that it was the result of the local increase in the wheat price in 1930. Due to the Wheat Importation Restriction Act, which prohibited the importation of wheat. The area under wheat in the (then) Union of South Africa almost doubled with most expansion in the Free State and in the eastern and south-western districts of the Cape Province. Already in 1919 the government indicated that the area under wheat in the Swartland has almost reached its maximum, and that most arable land was already under the plough (Talbot, 1947). The increase in production was therefore a development that could be ill-afforded. The result was that the farmers started ploughing steeper slopes, rotate and rest their lands less, creating the perfect situation for an erosion problem, as indeed happened. As the area left for grazing decreased due to the increasing wheat lands, the farmers did not decrease their cattle herds to the same effect, thus giving way to overstocking. With the war outbreak in 1939, the production of wheat continued on land in need of rest.

Figure 1.3 (a) and **(b)** and **Figure 1.4** show photographs of the erosion situation in 1945. In his concluding paragraph, Talbot (1947, p.78) states that there was a dire need to examine other methods of farming, ones that would not have such negative effects on the land. He foresaw a future of "declining yield, eroding soils, an inevitable heritage of ruined land, rural poverty, rising food-costs, and widespread malnutrition" (Talbot, 1947, p.78) if the situation prevailing in 1947 in the Swartland remained unchecked.

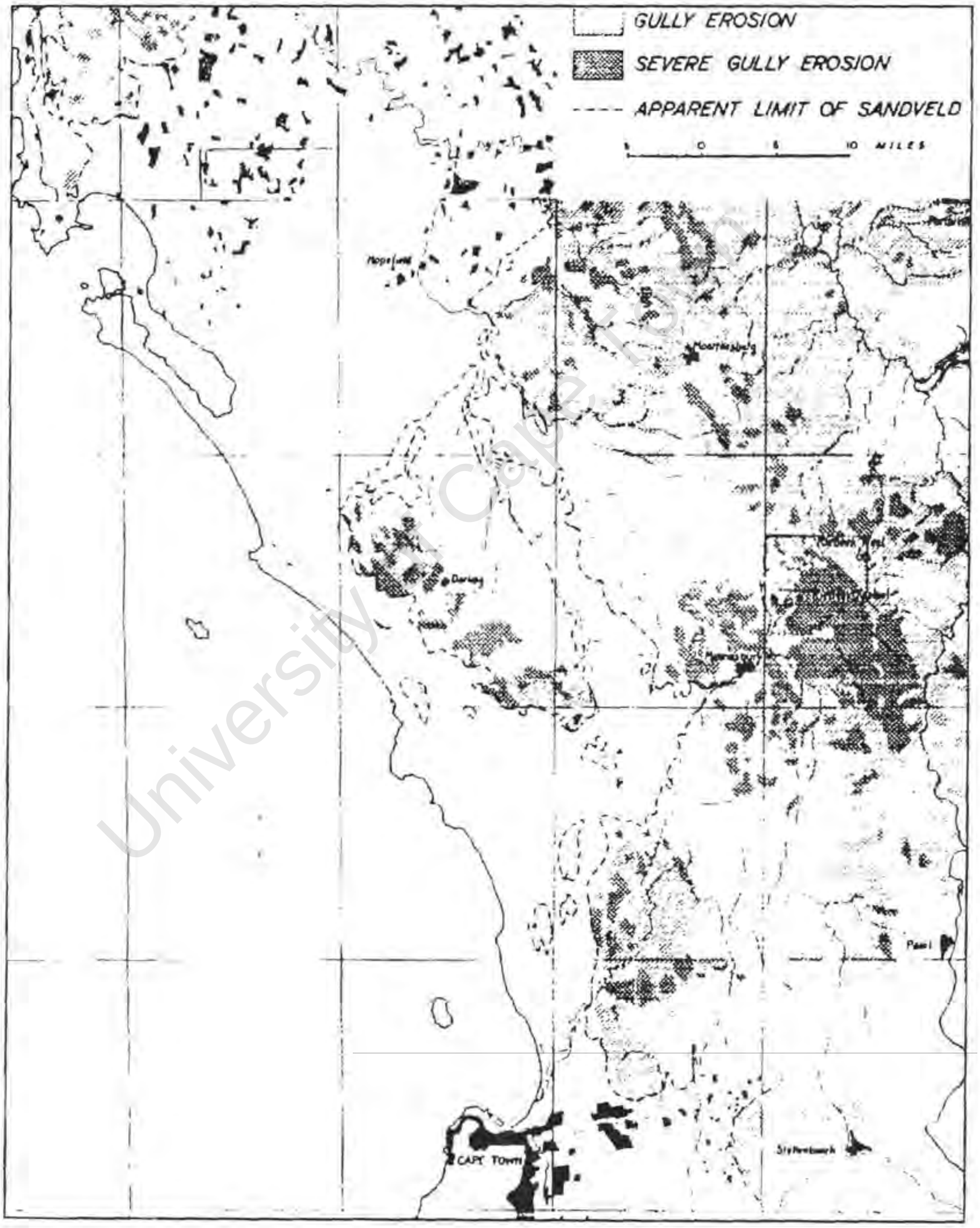


Figure 1.2 : Wind and Gully erosion in the Sandveld and Swartland, as mapped by Talbot (1947).

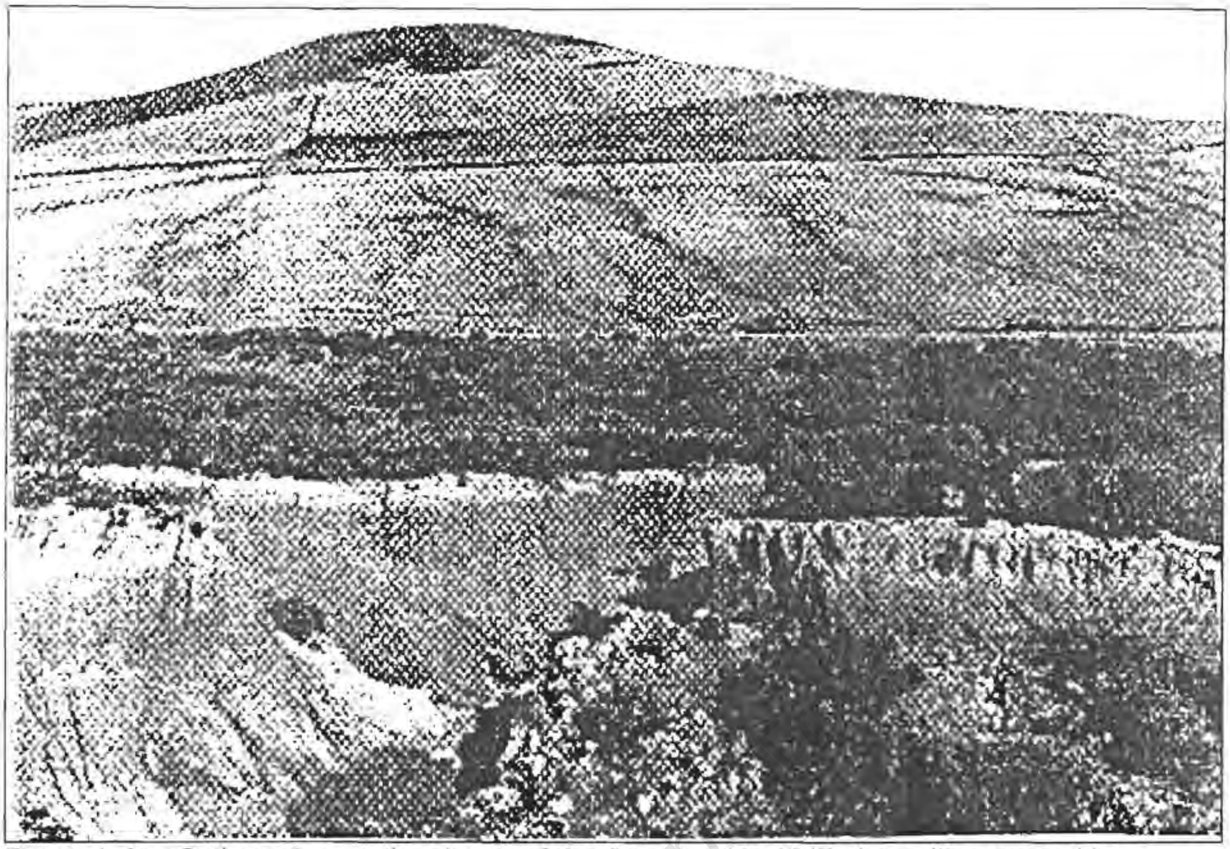


Figure 1. 3a : Soil erosion on the slopes of the Swartland in 1947, the gullies caused by the uncontrolled runoff can clearly be seen (Talbot, 1947)

Figure 1. 3b : Soil erosion on the slopes of the Swartland in 1947, the gullies caused by the uncontrolled runoff can clearly be seen in a fully developed gully (Talbot, 1947)

Figure 1. 4 : An aerial photograph of the Swartland area in 1938, the gullies over the landscape and the general bad shape of the cultivated land can clearly be seen on the photo (Talbot, 1947)

If such was the situation in 1947, it is now an appropriate time for a re-assessment on how soil erosion developed over the last 50 years.

Other than the above-mentioned studies, there is very little information on the soil erosion situation elsewhere in the region. By reviewing the soil and relief characteristics, it can be inferred that the topography would be expected to produce high soil erosion rates in this region, with steep long slopes, relatively high winter rainfall and mountainous topography. The problem that is hypothesised to be occurring, is also a result of the unwise fire regime and wild fires in the area, which increases the resistance of the soil to penetration by water and changes the soil texture, combined with the effect of agriculture on the shallow soils (Rooseboom, 1992 ; Meadows, 1998).

As mentioned by Meadows (1998), for an estimate on soil erosion in the region, we have to rely on the calculated sediment yield values for the south western Cape, which are low compared to the rest of South Africa. The erosion rates vary between 50 - 200 tonnes per square kilometre per annum (Pitman *et al.*, 1982). Although when looking at Rooseboom's (1992) erodibility index map, derived from the sediment yield, it can be seen that the western Cape has areas of both high and low erodibility. He indicates that the catchments are relatively small, resulting in a small total load of sediment. Using sediment yield figures is however, not an adequate reflection of the extent of soil erosion, and in any case few South African rivers have a long and uninterrupted record of sediment yield, as pointed out by Garland & Broderick (1992, p45). The importance of noting changes in erosion in an area is highlighted by their study of the Tugela catchment between 1944-1981.

Studies re-evaluating the erosion situation over an extended period are essential in order to understand natural processes and the impact of human habitation on the landscape. Garland (1982, p4) states that the "mapping and the classification of eroded areas must be regarded as the priority research area, since the regular updating of erosion maps can give a clear indication of the rate of land degradation and the efficiency of soil conservation measures". It therefore appears essential that an examination of the nature and extent of soil erosion in South Africa should be undertaken. This study addresses this need in the south-western Cape, by re-evaluating the erosion trends over the last 50 years in the Swartland area.

1.5 WHY THE SWARTLAND AND SANDVELD?

It was decided to focus on an area representing the situation in the Swartland and Sandveld for the following reasons:

- Talbot (1947) conducted an in-depth study of erosion in the Swartland and Sandveld based on 1938 aerial photographs. After 50 years, it is appropriate to re-evaluate the situation found by Talbot.
- The choice of the Swartland and Sandveld is based upon the information gained from a field trip by a party of expert geomorphologists who visited the area in 1994 as part of the 1994 IGU study group on Erosion and Degradation in Regions of Mediterranean Climate (MED.) conference, which identified an area currently influenced by gully erosion in the same area studied by Talbot (1947).
- The accessibility of the area to the researcher and co-operation of the farmers in the study area greatly facilitated the research in conducting field verification.
- The availability and co-operation of the local conservation officers and the well-established infrastructure at Elsenburg Agricultural Collage to gain further information on the study area.
- The area chosen has aerial photography cover over the period from 1945 onwards.
- This area has experienced a considerable degree of soil erosion (gullies or wind erosion areas) as mapped by Talbot (1947).
- Due to limited time and funds for completion of the research the size of the study areas were limited (55km^2 for the area under threat of water erosion, and 55km^2 for the area under threat of wind erosion) as was the use of satellite imagery.
- The respective areas chosen represented areas of severe erosion in 1945, and change in these areas should represent equal change in less effected areas.
- The area chosen for water erosion represents and area where slopes differ from very steep to relatively level, thus representing a wide range slopes in the region.
- Active gully systems exist in the water erosion area, therefore representing areas of both active and stable gullies.

- The area of wind erosion has remained relatively unchanged (due to the proximity of the air force base) since 1945 in respect to land use. Since Talbot (1947) only measured wind erosion on arable land.
- The wind erosion area is situated to the south of the Sandveld, further encroachment of wind erosion should therefor be detected if occurring.

The location finally decided on to demonstrate the current state of water erosion is situated in the Swartland, at the foot of the Kasteelberg. The area under possible threat from wind erosion is situated in the Sandveld near the Laangebaanweg Air Force base. Aerial photographs of 1944, 1974 and 1986 (wind erosion) and 1989 (water erosion) covered both these areas.

1.6 ADDRESSING THE SOIL EROSION ISSUE IN THE SWARTLAND AND SANDVELD

Although the problem of soil erosion in South Africa was first identified in 1923 by the then Drought Research Commission, official response in the form of soil erosion schemes was only forthcoming in 1930 (Van Schalkwyk, 1990). No evidence has been found to suggest that decision-making is any less tardy then it was in 1930; geomorphologists, who study the soil erosion question, can supply suggestions to aid the local authorities in making the right decision and develop the correct strategies (Hooke, 1988) but we also need a better classification framework to identify factors that promote soil erosion (Dardis & Moon, 1988).

Kirkby & Morgan, (1981) share this view in noting that geomorphologists can help policy makers predict the effects of policies and develop strategies to mitigate adverse effects, because they are able to predict and understand the effect of various land uses via their study of the land surface and the processes operating thereon. It can therefore be seen that the need for further soil erosion studies is always great, both to compliment existing studies (Moon and Dardis, 1988) and to point the way forward.

1.7 AIMS AND OBJECTIVES OF THE STUDY

The general aim of this study is to determine the degree of soil erosion in the Swartland and Sandveld region based on a comparison of the situation as found in Talbot's 1947 study. Furthermore, an attempt is made to establish whether the spatial distribution of contemporary erosion in the representative region has been affected by continued agricultural land use and how it has been influenced by soil conservation practices.

In order to achieve this aim, the following objectives are identified:

- To establish the nature of the soil erosion in the region, i.e. the distribution and characteristic processes involved.
- To establish the possible causes for soil erosion and compare the situation as found in the study area in 1994 to the situation Talbot found in 1947.
- To map the spatial distribution of soil erosion, using aerial photography, as found in the study area over the last 50 years.
- To investigate the effectiveness of remote sensing and GIS; can it be used and to what effect does it contribute to the spatial database ?
- The effect of conservation policies and practice on soil erosion needs to be researched to determine the extent to which they have contributed to the present situation in the study area.

1.8 THE STRUCTURE OF THE STUDY

- **CHAPTER 1: INTRODUCTION**: A general introduction to the incidence and study of soil erosion in the world, South Africa and in the Swartland and Sandveld is presented. The motivation for doing this study, the reasons for specifically choosing the study area, and the question of soil conservation is raised.
- **CHAPTER 2 : THE STUDY AREA** : This entails a description of the area comprising of the Swartland and the Sandveld. Factors such as geology, geomorphology and soil are described, together with the climate, vegetation and the influence of humans upon the present landscape of this winter rainfall area. The reader will have a clear perspective of the conditions found in the study area

at the and of this section, which is followed by a discussion of the concept of soil erosion.

- **<u>CHAPTER 3 : SOIL EROSION CONCEPTS</u>** : In this section, the factors contributing to soil erosion and the differing types of erosion are briefly discussed to give the reader a brief introduction to the soil erosion concepts used. The definition of soil erosion and the difference between geological and accelerated erosion are highlighted, followed briefly by a discussion of erodibility as found in South Africa in general. Water and wind erosion are touched upon with brief discussion on sheet, gully and wind erosion. Human influence, via land use practices, is also mentioned in this section.
- **<u>CHAPTER 4 : METHODOLOGY</u>** : The methodology followed to realise the objectives of the study is described and motivated using references from previous literature. The process of data collection, divided into two stages, and the analysis of the data, are clearly outlined.
- **<u>CHAPTER 5 : RESULTS</u>** : The results obtained following from the methodology employed, as described in chapter 4, are analysed, described and discussed.
- **<u>CHAPTER 6 : CONCLUSION</u>** : The final chapter summarises and briefly concludes the study by making recommendations upon its findings and reflects on the degree to which the objective has been met.

CHAPTER 2: THE SWARTLAND AND SANDVELD

2.1 INTRODUCTION

The study area falls within the south-western Cape, a region climatically and botanically unique enough to be markedly different from other regions of South Africa in respect of natural and cultural environments. The predominantly winter rainfall and proximity to the ocean places it in what could be described as the Mediterranean[2] region of South Africa. The Sandveld and Swartland form part of this greater region to the north of Cape Town. As Talbot (1971) puts it: "Although its limits are ill-defined, its terrain and climate, plant cover and population, past history and present economy all contribute to endow it with a regional individuality that is generally as recognised as that of the Karoo" (Talbot, 1971,p.3). The physical features, regional divisions, magisterial districts, and towns of the south-western Cape can be seen in Figure 1.3.

The areas chosen for the actual study represents of the greater region known as the Swartland (which incorporates the Sandveld, and falls within the south-western Cape Region, **Figure 2.1**). The general geology and geomorphology, soil, climate, vegetation and human influence will be discussed in the rest of this chapter.

2.2 GEOLOGY

The south-western Cape Province has been described by Tankard et al (1982) as the Western Saldanian Tectonic Province. According to SACS (1980) the following geological formations are found in this Province:

- Malmesbury Formation
- Cape Granite Suite
- Klipheuwel Formation
- Cape Supergroup (SACS, 1980)
- Bredasdorp (T-Qb)

Alluvium, sand, calcrete (Q) (Geological Survey, 1984) **(Figure 2.2)**

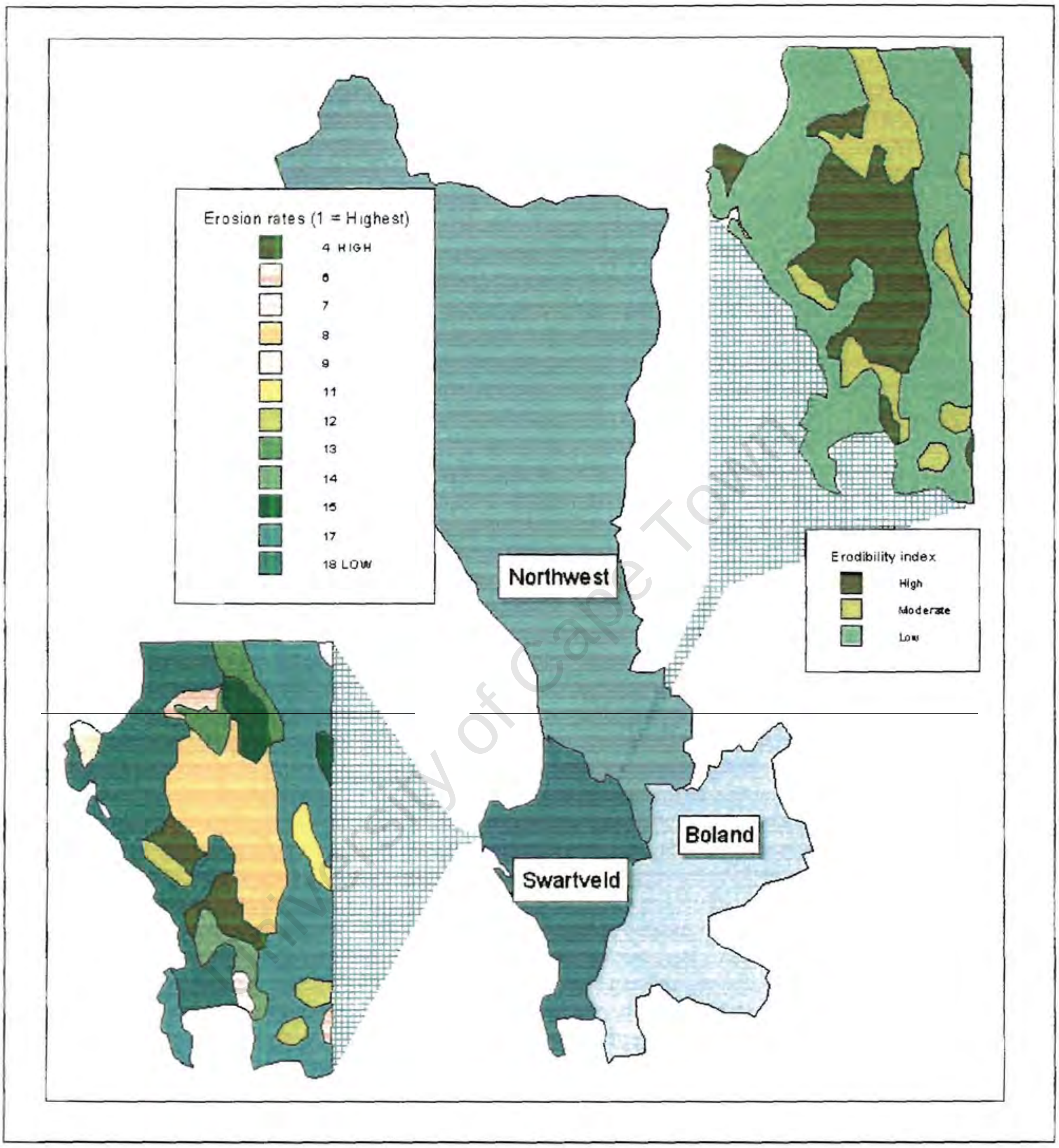


Figure 2.1: The Swartland (as referred to by Elsenburg, but comprising Swartland and Sandveld of Talbot) in context to the south-western Cape region. It can be seen that the study area falls within an area of low to high erosion (After Elsenburg, 1992 and Rooseboom, 1992).

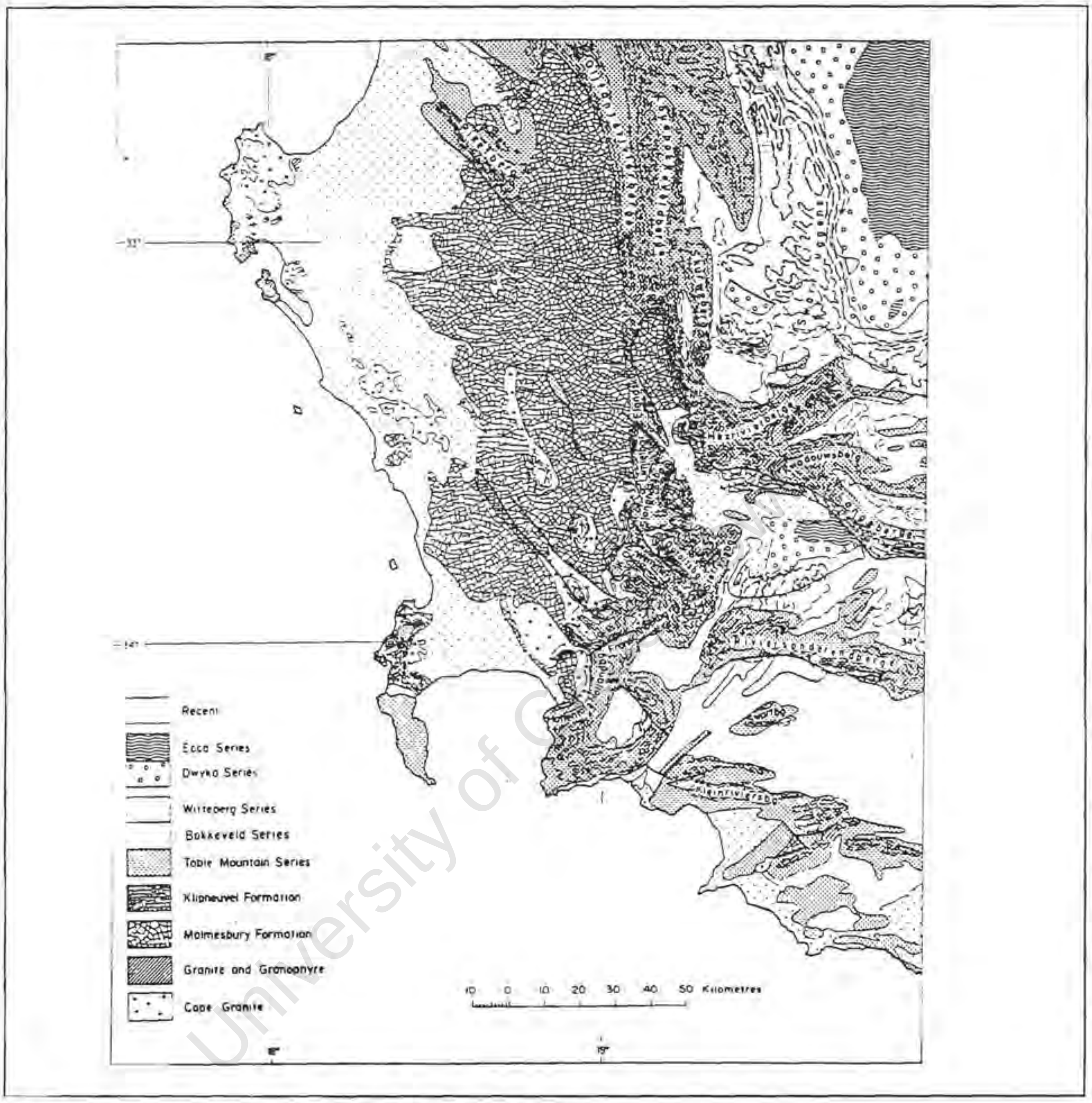


Figure 2.2 The geology of the Cape (Talbot, 1971).

[2] A Mediterranean type climate can be defined as a climate with cool moist winsters and warm dry summers, most (50%-65%) of the rainfall should be winter (Coancher and Sala (1998). They also express the mediterranean climate mathamatically as: $Xm = N - (R+D/2)H$. Where N = no. of days per month, R = no. of days of rain, D = no. of days of mist and dew (reckoned as a half a dry day), H = mean atmospheric humidity of month.

$150 < Xm < 200$ Xerodemiterranean (warm and dry)
$125 < Xm < 150$ Thermomediterranean attenuated long dry season
$100 < Xm < 125$ Thermomediterranean attenuated shorter dry season
$75 < Xm < 100$ Mesomediterranean accentuated - long dry season
$40 < Xm < 75$ Mesomediterranean attenuated - short dry season
$0 < Xm < 40$ Submediterranean - a transitional climate

The study area in the Sandveld and Swartland most probably falls in the thermomediterranean - attenuated class, ie Xm falls between 100 and 125. (After the FAO Xerothermic index).

2.2.1 **Malmesbury Formation**

The Malmesbury geosyncline in the Western Saldanian Province consists of differing low-grade inliers of sedimentary and meta-sedimentary rocks which are combined to form the Malmesbury group in the western Cape Province (SACS, 1980; Tankard, *et al.*, 1982). The origin of the Malmesbury group is overwhelmingly marine. The sediments that were laid down in Precambrian seas, form the bedrock that underlies the brown loamy soil of the Swartland (Talbot, 1971). The importance of the Precambrian rocks associated with granites is in the fact that, when the rocks weather, exchangeable cations are released which are used by plants, such as magnesium, calcium, potassium and sodium (Deacon, *et al*, 1992).

Minor volcanic eruptions occurred during the accumulation of the Tygerberg Formation and the Brandwacht Formation (SACS, 1980). During the folding of the Pan African orogeny the sediments were severely displaced by shearing and faulting along Northwest tending axes (Tankard *et al.*, 1982). This faulting and jointing facilitated the use of rocks in earlier years as building stones (Talbot, 1971). The age of the Malmesbury Group (which forms the oldest rocks in the south-western Cape Province) is estimated at between 600-950 Ma. (Tankard, *et al.*, 1982). The Malmesbury Group can be divided into three separate areas, divided by two zones of dislocation, (a) the south-western domain, (b) the central domain and (c) the north-eastern domain.

2.2.1.1 The south-western domain

In the south-western domain the Tygerberg Formation, situated between the Atlantic Coast and major faulting, is the result of turbidity currents, possibly on a trench plane with some volcanism (Tankard, *et al.*, 1982). Beeson (1975\76; from SACS, 1980) also concluded that the Tygerberg Formation consists of deltoid deposits.

2.2.1.2 The Central domain

The Franschoek Formation and the Malmesbury deformational patterns are similar in that they have both been infolded with the granites. The higher degree of deformation of the Franschoek Formation indicates that it is older than the post-Malmesbury Klipheuwel Formation, although it is lithologically similar (Tankard, *et al.*, 1982).

The Klipheuwel Formation, as a separate formation on its own, not part of the Malmesbury Group, is a molase-type deposit that is attributed to prograding fluvial deposition on a basement of high relief (Tankard, *et al.*, 1982). In places, the formation lies unconformably on granites of the Cape Granite Suite, with an age between 500-630 Ma. The Table Mountain Group further overlies it, discordantly.

2.2.1.3 The North-eastern domain

Hartnardy *et al.* (from Tankard, et al., 1982) supposed a predominantly marine sedimentation with a geosynclinal setting for the Piketberg Formation. The reason for this is that the lithological types and extensive developments of graded bedding are similar to ancient marine fans. Stum (from Tankard, et al., 1982) supports marine-shelf development paired with alluvial environments. In lithology the rocks of the Piketberg Formation closely resemble those of the Franschoek formation (SACS, 1980).

2.2.2 **Saldanian Tectonism**

Two vertical shear belts and fault are identified in the Malmesbury succession, i.e. the Saldanha-Franschoek fault zone in a south-westerly direction, and the Piketberg-Wellington fault zone in a north-easterly direction. These shear belts divide the Saldanian Province into three distinct zones: the south-western and north-eastern zones are similar in structure, but the central zone has a "more complex and less understood structure" (Tankard, *et al.*, 1982).

Folding and faulting are found extensively in the domains. These fault zones have been reactivated repeatedly (component faults are post-Klipheuwel and post-Cape in age) but it is shown that most shearing took place before the deposition of the Cape Supergroup at a time when the Malmesbury rocks were probably at a lower crustal level (Tankard, *et al.*, 1982).

2.2.3 **Syntectonic and post-syntectonic Granitoids**

Schoch *et al.* (from SACS, 1980) found that the Cape Granites are "high-level diapiric" (Franitoid) plutons. These plutons intruded into the Malmesbury sediments, during and following the Saldanian orogeny, exposed as up- faulted/up-folded inliers in the Cape Fold Belt. The Cape Granites can be divided into two groups: the George multiphase batholite in the east and the south-western group (Tankard, *et al.*, 1982).

The south-western group is characterised by elongation in a north-westerly direction in varying degrees of deformation. The late syntectonic emplacement of the Malmesbury country rocks is hereby reflected, a similar fold trend in the Cape Cover, which controls the exposure pattern of basement granites, also causes this apparent alignment (Tankard, *et al.*, 1982). The granite exposed along the length of the Cape Peninsula is only one of some 25 bodies that intrude the pre-Cape rocks. Prominent exposures are the Kuboos mountain in the Richtersveld, and Paarl mountain (SACS, 1980).

2.2.4 **The Cape Supergroup**

Geologically the south-western Cape can be spoken of in terms of the Cape Super Group, since the latter covers most of the south-western Cape Province east of the 19° meridian and extends into the sea around Cape Point, and from Cape Hangklip eastward (Geological Survey, 1984).

The Cape Supergroup has been uniformly deposited over the present south-western Cape province, with a depth of over to 2000m (Tankard, et al, 1982). Structural deformation within these packages varies from gently folding in the west to more intense folding in the south (SACS, 1980), giving rise to the present Cape fold belts. The folding in the south is along East-West tending axes, with over folding and isoclinical folding (SACS, 1980).

The Cape Super Group can be divided into:

a) Table Mountain Group

b) Bokkeveld Group

c) Witteberg Group

2.2.4.1 The Table Mountain Group

The Table Mountain Group lies virtually horizontal in the Cape Peninsula. And is about 440 Ma old. It is younger than the youngest stage of the Cape Granites (SACS, 1980). In depth it is up to 4000m thick and consists of quartz arenites, conglomerates and mudstone on a granite base (Tankard, *et al.*, 1982).

2.2.4.2 The Bokkeveld Group

The Bokkeveld Group represents the most dynamic phase of the development of the Cape basin. Southward flowing rivers deposited large volumes of sediment. The Bokkeveld Group is best known for its diverse suite of invertebrates compassed within the Malvinokaffric faunal province. The stratigraphic framework emphasises the lateral variability in the Bokkeveld Group (Tankard, *et al.*, 1982).

2.2.4.3 The Witteberg Group

The Witteberg Group represents a continuation of Bokkeveld sedimentary patterns in the lower part and encompasses glaciogenic components in the upper parts. Lithofacies are similar to the progradational Bokkeveld facies. The tidal-flat facies consists of extensively bioturbated mudstones and sandstones, with desecration cracks and rill marks reflecting periodic emergence (Tankard, *et al.*, 1982).

The weathering of rock results in the release of nutrients and other elements (magnesium, calcium, and potassium) to the plant life growing in the resulting soil. Topographic features such as mountains also derive from the resistance (or lack thereof) in certain rock types. Deep soil profiles are usually found in valleys, because of the deposition of weathered material, causing fertile soil usually drained by rivers or streams, ideal for agricultural use.

2.3 GEOMORPHOLOGY

Figure 2.3: Geological structure and landform characteristic from the south-western Cape (Talbot, 1971).

In the foreground left, of **Figure 2.3,** quatzitic sandstone outliers, which form part of the Table Mountain Series, lies on an ancient erosion surface that truncates steeply dipped strata of the Malmesbury Formation and the underlying Cape Granites. The Table Mountain Series previously formed a broad anticline where we find the western lowland nowadays. The cape fold belt can be seen in the centre right of the figure, comprising out of relics from the Table Mountain Series, now steeply folded and faulted and dissected. This mountain barrier form a separation between the western lowland and the valley drained by the Bree River. The right foreground illustrates the Badsberg, a faulted quartzite block. The Groenberg, comprising out of a quartzite cap, on the left of the fold mountains, is unconformably overlaying the Malmesbury Formation (Talbot, 1971).

In the present landscape the hills and mountains consisting out of resistant rocks formed islands in earlier geological times, while the rest of the western lowland was under water being eroded by maritime erosion. Today the landscape is smooth, except for the more resistant hills and mountains, and consists out of marine sediments deposited at earlier times. Perdeberg, Dassenberg and Paarlberg are typical examples of the rounded granite domes protruding through the folded Malmesbury Formation. In the present landscape downfaulted outliers of the Klipheuwel Formation and the Table Mountain Series form low hills or prominent ridges, such as the Kasteelberg (centre distance). Outcrops of the Klipheuwel Formation also occur between Kalabaskraal and Klapmuts; in the area between Piketberg - Porterville and Riebeeck Kasteel. It is also found in the Franschoek area, Elandsbaai and Verlorenvlei. The succession lies unconformably on steeply dipping

Malmesbury shale and is unconformably overlain by the basal beds of the Table Mountain Group. Most exposed strata of the Klipheuwel Formation are almost horizontal and undeformed but deformation, tilts, over-folding and well developed cleavage, can be seen around the Heuningberg (SACS, 1989). (SACS, 1980).

Dassen Island and the famous Robben Island emerge offshore respectively as a granite bosse and resistant Malmesbury Formation. Littoral and aeolian deposits can be seen in the sand dunes that extend up north in the Sandveld along the coast. Further inland the Sandveld is found as an ancient sea floor, with rivers draining new shallow valleys (Talbot, 1971).

None of the Malmesbury strata is particularly resistant to erosion and therefore resulted in the gently rounded landforms and gentle slopes characteristic of the Swartland (i.e. Koeberg and Tierberg) (Talbot, 1971).

From the above sections on geology and geomorphology the south-western Cape can be seen as an area with sharply differing landscapes, varying from the fold mountains caused by the folding and shearing, which comprises a big part of the history of the area, to the gently sloping undulating topography of the Swartland to the very sandy landscape of the Sandveld. **Figure 2.4** illustrates the time scale of geological events in the south-western Cape region.

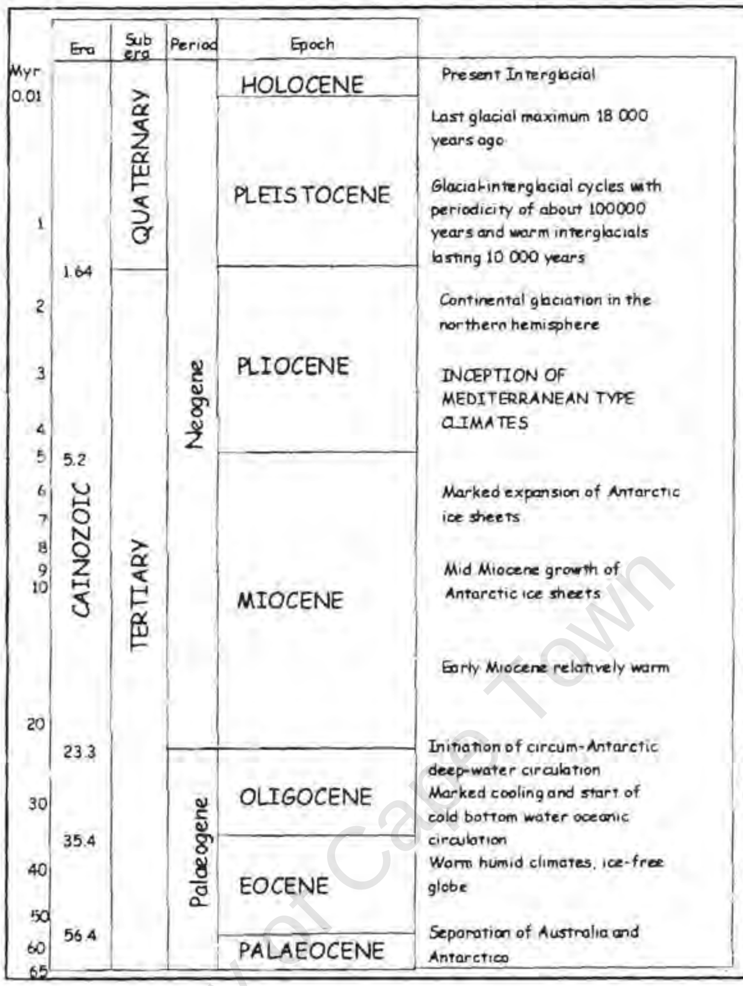


Figure 2.4: Geological time-scales and rock units in the south-western Cape region (after Cowling et al, 1992)

Gully erosion is especially prevalent on steep or long slopes, and the relief of an area cased by the weathering of the underlying parent material has a profound influence on gully erosion. The undulating landscape of the Swartland exposes this landscape to water erosion. In the following section the soil of the south-western Cape will be discussed.

2.4 **SOIL**

The term soil refers to the weathered outer layer of the earth's surface. The study of soils can be conducted by various disciplines and cannot be linked to a specific one as an exclusive field of study (Hillel, 1971). Because of the complex geological and climate differences found in the south-western Cape region, a wide variety of soils occur that differ vastly. Deep, well-drained soils, highly leached soils and shallow calcareous soils are common (Germishuys, 1992, Meadows, 1998). Soils are relatively in-situ, showing a direct relationship to the parent material and terrain. Shallow weakly developed soils (lithosoils) are found on the mountains (of a quarzitic nature), while soils on the coastal platform are more clayey and of residual and duplex nature (**Figure 2.6**). The residual soils are the result of in-situ weathering and duplex soils have sandy topsoil, with more clayey material underneath. On the coastal zone soils are calcareous and non-calcareous and in the valleys it is alluvium. There are some paleosols in the region, which were clearly formed under previous climatic conditions, examples of these are silcretes and red apedal soils developed from ferralitic weathering. The soils on the mountains are prone to podzolization, with associated low nutritional values for plants (Deacon, et al, 1992). Soils from the granite outcrops are deep red soils of a kaolinitic nature, and richer in nutritional value (Meadows, 1998).

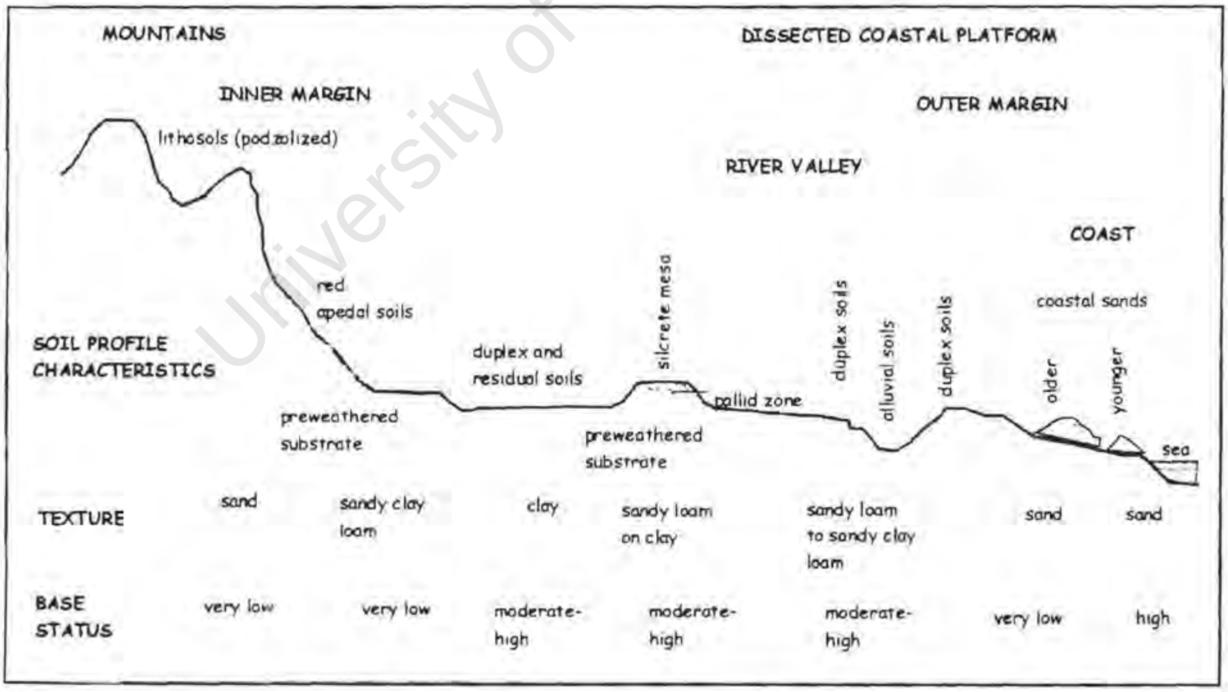


Figure 2.5: Topography and soils of the south-western Cape region biome (after Cowling, 1992).

Figure 2.5 clearly demonstrate the different textures of soil found in the south-western Cape's lowlands to the mountains ranging from sand to clay.

2.4.1 **Soils from the Swartland region (Mixed farming area of Durbanville, Maamreweg, Paardeberg and Riebeek - FARMING AREA 5)**

In the Durbanville, Darling heads and Paardeberg area the soils derive from granites, and are red and yellow in colour, with a well developed internal drainage system. The Riebeekberg comprises Table Mountain Sandstone. The soil around this mountain consists of medium textured sands with varying depths. The sands that overlie the Malmesbury shales found on the lower lying, undulating landscape, form residual soils. The soil found in the area can be roughly divided into 33% deep soil, 33% medium soil and 33% shallow soil. Most of the soil in this region is not high in nutritional values with a low pH value (Elsenburg, 1992).

The soils found in this region are Mispha, Glenrosa, Cartef, Swartland, Sterkspruit, Hutton Clovelly, Kroonstad, Escourt, Pinedene, Bainsvlei, Fernwood, Constantia, Lamotte, Westleigh, Dundee, and Longlands (Elsenburg, 1992).

2.4.2 **Soils from the Sandveld region (Sandveld-agricultural and grazing area-FARMING AREA 1)**

On this slightly undulating to level landscape, the occurrence of wind-blown sand from the coast is common all over the region. Close to the coast the soil consists mainly of young fine to medium textured, calcareous soil, extending to deeper and more acid soils as it extends inland. In areas where the underlying parent material is close to the surface duplex soils occur. The soil found in this region has very low agricultural potential due to its unfavourable physical and chemical composition. The erodibility by wind of these soils is very high, and care should be taken in the cultivation thereof. The principally sandy soil of the Sandveld region has a low water retention potential and low nutrient value for plants.

Soils found in this region are Mispha, Glenrosa, Cartef, Escourt, Kroonstad, Hutton, Clovelly, Fernwoods, Villafontes, Constantia, Lamotte, Dundee and

Westleigh.

The soil texture, nutrient content, moisture retention capability, aeration and aggregate stability are all key factors of the soil. These factors not only determine the agricultural potential, but also the vulnerability of the soil to wind and water erosion. Climate influences the rate of weathering and the formation of soil. In the following section the climate of the south-western Cape region will be discussed.

2.5 **CLIMATE**

The south-western Cape region falls in the Mediterranean climate region of South Africa with mild wet winters and dry sunny summers (Talbot, 1971; Dept. Agric. & Fish., 1991). The Mediterranean-type climate occupies an area of 40000km^2, from the west, Cape Columbine (18^{0}E), and to the south and east to Cape Agulhas (20^{0}E, 35^{0}S). It extends up to Vredendal (32^{0}S) in the north and west.

2.5.1 **Rainfall**

Most rainfall in the south-western Cape region occurs during the period from May to September (70% of annual rainfall for the region),indicating a strong seasonality to the rainfall of the region. The rainfall diminishes from the south towards the north and from the mountains to the valleys. The influence of the topography on the rainfall is prominent, resulting in large differences in the amount of rainfall over small distances. In the Jonkershoek mountains the rainfall can be as high as 2000mm - 3000mm rain per year, while Stellenbosch itself, barely two kilometres, away only receives 300mm - 500mm per year (Dept. Agric.. & Fish. , 1991). The rainfall is mainly cyclonic and orographic, with thunderstorms and hail occurring only occasionally. In winter the mountain tops are regularly covered with snow (Dept. Agric & Fish., 1981). The autumn and spring rains are of supreme importance to the grain farmer. Rain in autumn determines the germination of seeds (early rain will be of benefit while late rain will retard the germination rate and the number of seeds that reach this level). In spring late rain is harmful as this lowers the quality of the grain (Talbot, 1947).

The Sandveld region has relatively low rainfall, compared with the rest of the south-western Cape region. Rainfall varies from 200mm per year (lowest average rainfall) to 400m per year (highest average). This high rainfall average is due to the fact that the area with copious rainfall around Yzerfontein, on the coast, is included in this region, which is much higher than rainfall in the north. The seasonality of the rainfall in this region is very clear, with more than 80% of rainfall occurring from April to September, thus in winter. The sandy soil of this region, with low water retention capability, makes for erratic farming outcomes. Due to low rainfall in the Sandveld it still has a large percentage of natural grazing, but due to the low rainfall very few farms relay on natural grazing. The amount of rainfall increases by about 110mm from north (Redelingshuys) to south (Bloubergstrand) in the Sandveld.

In the Swartland rainfall is closely linked with the height above sea level; as the altitude increases so does the rainfall. Rainfall figures range between 400 to 600mm per year, with 80 percent in winter, from April to September. In the upper regions of the Riebeek mountains, rainfall can be as high as 700mm. From the rainfall figures it is evident that this area is ideal for winter grains (Elsenburg, 1992).

2.5.2 **Temperatures**

Temperatures in the south-western Cape are, with the exception of the Grabouw and Villiersdorp area and the Koue Bokkeveld, high in summer, with an average daily maximum temperature of 30^{0}C. In the drier northern parts 40^{0}C and higher is not uncommon (Dept. Agric. & Fish. 1981). In the winter months, the temperature is mild with an average daily maximum during winter of 15^{0}C. The average minimum is round about 5^{0}C. The coastal areas can be termed frost free, but in the other areas, especially the Koue Bokkeveld, crop damage due to cold and frost is a definite worry (Dept. Agric. & Fish., 1991).

Temperatures in the Sandveld are highest in summer, with mild to cold winters. However, its coastal location ensures that large temperature fluctuations are tempered to a minimum. In the months of January, February and March the highest temperatures often in excess of 30°C are recorded. In the northern part of the

Sandveld chances are 40% in February that temperatures in excess of 34°C will occur. Because most of the crops in the Sandveld are summer varieties heat does not really effect the agriculture of the region. Damage due to frost is also limited due to its limited occurrence. The little frost that does occur is in the north of the region and effects only potato production (Elsenburg, 1992).

The Swartland experiences warm summers with mild winter temperatures. The temperature increases towards the interior. Riebeeck-Wes has almost double the amount of days hotter than 30°C than Durbanville, situated close to the coast. Temperatures lower then -2°C are very rare and damage to grain is therefore limited, except in some cases in the river valleys. (Elsenburg, 1992).

2.5.3 **Wind**

A high-pressure ridge is resident above the south-western Cape region developing from the South Atlantic anticyclone. During the summer it occupies the space near 37^0S with accompanying dry easterly winds causing the South-Easter or Cape Doctor, to be more prevalent during the summer, with winds primarily from the south or south-east. In winter, the winds are predominantly of westerly (and north-westerly) direction with accompanying orographic rainfall, while the high pressure is situated at about 32^0S. Cut off-lows, cold fronts, coastal lows, ridging anticyclones and coastal depressions all add to the variable and unpredictable climate of the region, due to the mid-latitude westerly winds (Preston-Whyte and Tyson, 1988, Dept. Agric.. & Fish., 1991). In February the frequent strong southerly winds cause damage to tobacco and fruit crops, and the scorching effect of wind often damages vines. Winds are highest on the mountains in winter and highest on the coastal plains during the summer (Deacon, et al, 1992).

Most wind velocities greater than 20km per hour (average for the day) in the Sandveld occur from May to September and can inflict wind erosion on unprotected soils. The problem is that strong winds occur in May-June, the period when land is ploughed and seed sown, leaving the soil unprotected. With the wind from the south/south-east in summer after land have been cleared the potential for wind erosion on unprotected and overgrazed land are always great (Elsenburg, 1992). Talbot (1947) mentions the wind erosion occupancy at this time of the year as drifting sands are observed in the cultivated fields and other open areas.

Wind velocities greater than 20km per hour (on average for the day) are less frequent in the Swartland region. Wind in the winter months are the strongest with a five percent chance of strong winds (greater than 20km per hour) to occur. In the winter the winds will carry in moisture from the north-west, whilst in summer dry winds from the south and south-east occur. The cool wind the afternoon in summer attributes to the temperature fluctuations in this region, helping in the production of a good quality grapes (Elsenburg, 1992). **Table 2.1 and 2.2** show the climatic factors for the Sandveld and Swartland respectively.

Table 2.1 Climatic factors for the Sandveld (Farming Area 1)
(from department of agriculture climate Elsenburg, 1992)

Month	Rainfall		Maximun Temp		Min Temp		Days with wind > 20 km/hour
	Highest mm	Lowest mm	Highest C	Lowest C	Highest C	Lowest C	
January	10	0	32	24	17	12	1.5
February	15	5	33	25	17	13	1
March	15	5	30	25	17	12	0.7
April	30	15	27	22	15	11	0
May	60	30	23	19	12	9	1.1
June	75	35	20	18	11	7	1.6
July	75	35	19	17	10	7	1.9
August	70	35	20	16	10	7	1.7
September	35	15	21	18	10	7	1.5
October	25	10	25	20	12	8	0.7
November	15	5	28	21	15	9	1.3
Desember	10	5	30	22	17	11	1.8
Total	435	195					

The seasonality of the climate is clearly visible in the above sections, especially the rainfall that only occur in the winter months. Vegetation is therefore very dependent on the availability of moisture, and must be somewhat drought resistant during the dry hot summers. In the interior the vegetation is dependent on the winds to convey moisture. The natural vegetation of the south-western Cape region will be discussed next.

Table 2.2: Climatic factors for the Swartland (Farming area 5)
(from department of agriculture climate Elsenburg, 1992)

Month	Rainfall		Maximun Temp		Min Temp		Days with wind > 20 km/hour
	Highest mm	Lowest mm	Highest C	Lowest C	Highest C	Lowest C	
January	15	5	30	25	15	12	0.4
February	15	10	31	25	16	12	0
March	20	10	29	25	16	11	0
April	50	30	24	20	14	8	0.3
May	90	60	22	16	12	6	0.8
June	100	75	19	15	10	5	1
July	100	70	19	14	9	4	1.6
August	90	70	19	14	8	4	1
September	50	35	21	15	8	5	0.6
October	40	25	25	18	10	7	0.3
November	25	15	28	22	13	9	0.6
Desember	15	10	29	24	15	11	0.5
Total	610	415					

2.6 VEGETATION

The indigenous vegetation, predominantly hard-leafed evergreen fynbos, is renowned for its extraordinary plant biodiversity, and variety of winter and spring flowering shrubs, including Proteas, *Leucadendrons*, *Ericas* and numerous geophytes and annuals (Talbot, 1971, Cowling, 1992). Fynbos can be defined as:

> "The essential feature of [Cape] fynbos is the presence of restioids... and that other important features are Ericaceae and proteoids, In addition, the following attributes are more or less differential: sedges, particularly leafy sedges; non ericaceous ericoids (with >5% cover; ericoid Asteraceae; stoebois (shrubs with crowded minute leaves in fascicles); leaf spinescenece; Penaeaceae; and Bruniaceae." (After Campbell, as cited by Cowling an Holmes, 1992, p.35).

Botanically it is unique, although reminiscent morphologically of the equally fire-susceptible maquis and garrique, of the climatically similar regions of the Mediterranean. Even though the "Cape Floristic Region" (Cowling and Holmes, 1992, as named by Good (1964), from Meadows, 1998) covers an area greater than the geographical area of the south-western Cape, extending into areas not marked for their winter rainfall, it is still a floristic region found dominantly in areas of Mediterranean climate in South Africa (Meadows, 1998). The Cape Floristic region is recognised as a floral kingdom on its own due to the high number of endemic species (68% of species, 19.5% of genera and six families). It also holds the record for, the highest recorded plant species density, for its size and climate (Cowling *et al*, 1992). Trees, even at the beginning of the colonial era, were confined to the sheltered kloofs in the wetter areas where small numbers of Yellowwoods (*Podocarpus* spp.), Iron woods (*Olea* spp.), Stinkwood (*Ocotea bullata*), Rooi hout (*Olinia cymosa*), Rooi els (*Cunonia capensis*), and associated species, have escaped the recurrent fires to which the highly inflammable shrubs are so susceptible to. Elsewhere in the mountains where the annual rainfall exceeds 750mm, slopes are covered with fynbos and forms a montane macchia association **(Figure 2.6)** (Talbot, 1971, Cowling et al, 1992).

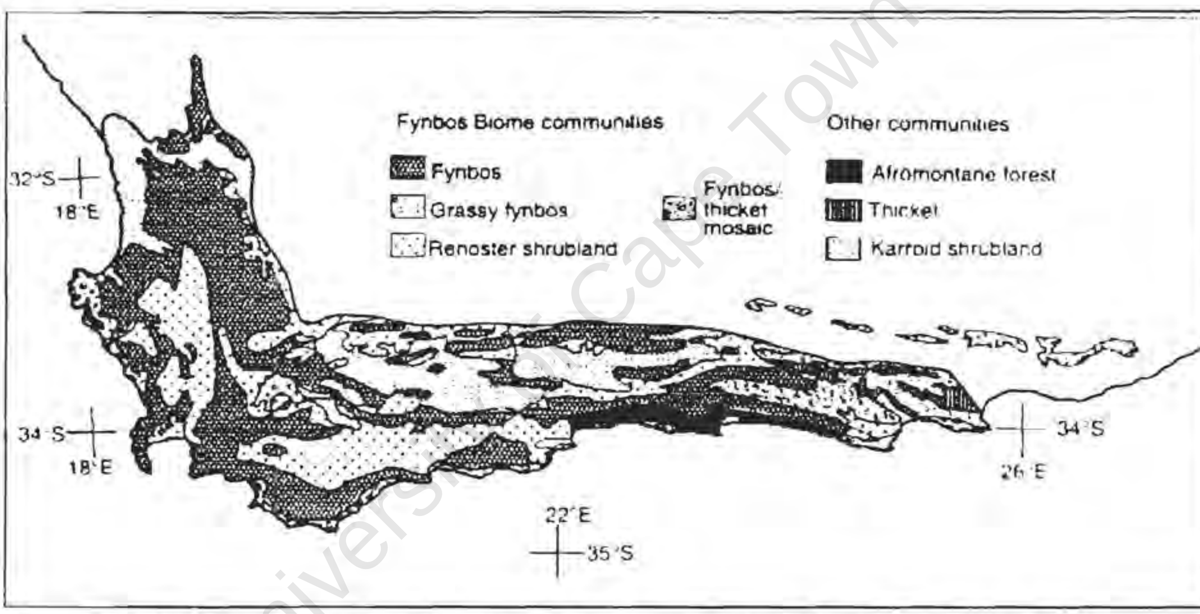


Figure 2.6: Major vegetation communities in the Cape Floristic Region (Cowling, 1992).

Renosterbosveld, a fire-controlled climax stage, was very prevalent in the Swartland before the first settlers arrived. Since then almost the whole Swartland has been converted to farmlands and ploughed, leaving only relic patches of vegetation dominated by renosterbos (*Elytropapps rhinocerotis*), on the slopes that were too steep or too shallow to cultivate (Talbot, 1971, Cowling, 1992). It is from this Renosterbos that the Swartland derived its name, the renosterbos is dark in colour, creating the impression of a black landscape. Although it is the opinion of some (Cowling *et al*, 1992) that Acocks (1953) treated the biome's vegetation very broadly, it is felt that it is relevant to include his observations in this study.

Acocks (1953) identified four main veld types that are common in the south-western Cape Province. These veld types are Strandveld (34), Coastal Renosterbos (46), Coastal Fynbos (47) and Fynbos (69).

The importance of the underlying parent material in determining the vegetation is well illustrated by the varieties of fynbos found on the different underlying parent materials in the region.

2.6.1 **Renosterveld**

Relating more directly to the Sandveld, the Renosterveld occurs on the undulating coastal plain in the west and towards the interior of the Swartland. This plant community is associated with the more nutrient rich shales of the Malmesbury Group (Meadows, 1998). The soils are rich in caly and are taken up for wheat farming so that the remaining relics of the former vegetation are in poor condition and scarce (Acocks, 1953, Meadows, 1998). The rainfall in the area is 300mm - 500mm per annum, falling during the winter (Acocks, 1953). The Renosterveld that replaced scrub where the soil is not cultivated, consists mainly of renosterbos. The Renosterveld that occurs in the West Coast area is an admixture of fynbos and contains less grass compared with the southern parts. The difference is due to winter rainfall. It becomes more semi-succulent where it merges easily with the Strandveld (Acocks, 1953). The renosterveld is closer to the rest of the interior of South Africa than the Cape floristic region phytogeographically (Meadows, 1998). Renoster shrubland can be described as follows: In formation it is low to mid-high, open to mid-dense leptophyllous shrubland, often with an open, grassy understorey. The differentiating features comprise a high cover of leptophylls and elyrtopappoids, and a high total cover. The Floristics are *Elytropappus rhinocerotis, Pteronia* ssp., *Anthospermum aethiopicum, Dodonaea viscosa, Pentaschistis* spp., *Helichrysum* spp., *Ruschia* spp., *and Themeda triandra*. The distribution of the renoster shurubland is on the lower mountains, interior valleys and coastal foreland over the entire fynbos biome. It is usually found on fine textured soils, mostly on the ecotone between the fynbos and succulent shrubland or tall succulent shrubland and very seldom on quartzite (after Campbell, in Cowling, 1992).

Renoster shrubland is associated with the drier interior region of the fynbos biome, the general pH is also higher in these soils than in the soils supporting the fynbos. Renoster shrubland replaces the fynbos often on the more clay-rich (shale and granite derived) soils with rainfall of about 600 mm per year (Cowling et al, 1992). The occurrence of Renoster shrubland in the place of fynbos has been attributed to the disturbing influence of local farmers and settlers, with their practice of annual veld burning (Cowling et al, 1992).

2.6.2 **Strandveld**

Strandveld is found on the calcareous coastal dunes. Strandveld is the vegetation of the lower parts of sandy western coastal plains, receiving 50mm - 300mm of rain per annum, mainly falling in winter. A dense dwarf, semi-succulent scrub, related to the Gouritz River Scrub (34a) and the Strandveld proper (34b), an open semi-succulent scrub of fynbos, form an intermediate between the coastal Fynbos and the Succulent-Karoo, makes up the Strandveld vegetation. Hillocks or "heuweltjies" contains bush clumps of vegetation (Acocks, 1953). These "heuweltjies" are common occurrences in the study area and can be seen on aerial photographs as darker or lighter patches dotted over the landscape, see **Figure 2.7.** The ericoid and proteoid elements are less prominent here, where one finds a transition from fynbos to the communities found in the drier interior of the Karoo (Meadows, 1998).

Farming practices have altered the natural vegetation that occurs in the region. Extensive grasslands have been planted in order to provide grazing for the dairy and meat industry on land unsuitable for crop cultivation (Dept. of Agric.. & Fish., 1981). In the specific study area, most of the natural vegetation has been replaced by croplands and grazing. The original Renosterbos occurred on the gentle slopes of less then five degrees (McDowell, in Meadows, 1998) but is now only found on the high tops of steep hills. According to a study conducted by Van Wilgen (in Meadows, 1998) fires occur more at present then at times before colonisation with indications, consequent upon the global warming trends, that this will intensify in future.

Figure 2.7: The "heuweltjies" found in the Swartland and Sandveld region, clearly visible from this aerial photograph.

2.6.3 **Mountain Fynbos**

Fynbos derives its name from the European Dutch settlers in this region, describing the vegetation, known as *macchia* in Europe. Acocks (1953) states that fynbos is found on sandstone and poor, white sandy soil in winter rainfall regions, with a moisture requirement of 250mm rain per year (Acocks, 1953).

Arid fynbos indicates grazing mismanagement. At this stage the families of Proteaceae, Rutaceae and Ericaceae do not occur at all or are poorly represented (Acocks, 1953). Acocks (1953) feels that there is little place for grasslands in this succession, though there are indicators that more than one kind of grassland is possible, apart from the invading tropical grassveld.

The nutrient-poor soils on the uplands, derived from the Table Mountain Sandstones and in combination with the granitic soils, support the Mountain Fynbos. Shrubs share the leaf-form and physiognomy of the Proteaceae, Restionaceae and Ericaceae, but not necessarily belonging to this group (ericoid, proteoid, restiod). Trees are restricted to large protea types and the Clanwilliam Cedar, confined to the Cederberg (Meadows, 1998). The scarcity of trees can be attributed to the fire regime and the oligotropic soils (Moll et al, 1980). In the acidic soils of the coastal lowland the acid-sand plain fynbos is under threat of urbanisation (Meadows, 1998). The uniform growth form of fynbos seems to be an indicator of nutrient-poor soils in which fynbos is found (Linder et al. 1992).

2.6.4. **Coastal Fynbos**

Coastal Fynbos occurs on the southern and the western coastal beltswhere ploughing has not taken place to the same extent as the coastal Renosterveld (Acocks, 1953). Acocks (1953) was the first scientist to distinguish between the coastal fynbos and the fynbos of the mountains (Cowling et al, 1992). There are, according to Talbot (1971), indicators that the climax vegetation is a grassy, more or less open scrub, at least in the south coast belt and on the Cape Flats. In the west coast belt with its strictly winter rainfall, the climax vegetation could be a bush clump veld in grassy fynbos (Talbot, 1971). The coastal fynbos is structurally similar to the fynbos occurring in the mountains, it has the same families, but it is found in the coastal forelands and limestones (Cowling, et al, 1992) and has a different mixture of species.

There is an intricate relationship between natural factors such as the geology, topography, climate, soil and vegetation, which can be seen in the different soil types suited to different fynbos species. Human influence on the vegetation, such as fynbos with its close relationship with a controlled fire regime, has a marked effect on the vegetation. Another example is the Renosterbos that only occurs on hills too steep to be cultivated. In the following section the human influence on the south-western Cape region will be discussed.

2.7 **HUMAN INFLUENCE IN THE SOUTH WESTERN CAPE REGION**

Humans have occupied the south-western Cape for more than a million years, as the number of occupational sites and stone artefacts testify (Deacon, 1992; Deacon, cited by Meadows, 1998). The so-called Khoisan people, hunter-gatherers from the end of the Pleistocene period, inhabited this region (Deacon, 1992). Two thousand years ago the Khoikhoi arrived (Deacon, 1992). The local inhabitants used the Fynbos plants as a source of food, but patches of these plants only had a sustained yield if regularly burned. The implication of this is that the human influence of fire ecology on the region goes as far back as the beginning of the Late Pleistocene (Deacon, 1992). These Khoikhoi pastoralists had large numbers of sheep and, later, cattle. They followed a more settled lifestyle and co-existed with the "strandloper" at the coast and the San of the mountains (Deacon, 1992). Economic contact with the Bantu-speaking African tribes of the eastern savannahs is assumed (Deacon, 1992; Meadows, 1998). These groups thus inhabited the land when, in 1652, Jan van Riebeeck started the "halfway house" station at Table Bay for the Dutch East India Company, and commenced what would be the first influence of a more marked nature on the sub-continent (Talbot, 1971, Deacon, 1992; Meadows, 1998). The settlement of the south western Cape was established as a victualling station for ships plying the trade routes between India and Holland. By 1679, settlements had moved further inland to places like Stellenbosch, and from here it crept outward in all directions, as farmers started to cultivate the land and use the grazing for their cattle. This process pushed indigenous people inland to more uninhabited areas as their old hunting grounds were gradually taken over by the agricultural settlers, whose number increased as events in Europe unfolded. For example, the Edict of Nantes in 1685 prompted the French Huguenots to flee persecution and come to South Africa, bringing with them their skills and knowledge of agriculture and starting what is the farming community of the south-western Cape today (Talbot, 1971).

As water supplies became permanent and winter grazing well established, the settlement became permanent. The good loamy soils were ideal for agriculture and the natural vegetation made way for the croplands of the farmers. Because of the distance involved in conveying goods to the markets in the Cape, farms further than 65-80 km from Cape Town concentrated on rearing livestock sold for slaughter (Talbot, 1971, Deacon, 1992). Both the Swartland and Sandveld became known for sheep, as the vegetation, like in other Mediterranean climates, is better suited to sheep than cattle. In the beginning, the farms held licences for seasonal grazing which increased to annual grazing and this later developed to the loan farm system. As time passed and heirs settled in the same area the farms were divided into smaller units as the administration improved. By 1813, with new legislation, the Sandveld and Swartland comprised the typical larger farm units, compared with the smaller farms of the Bergriver valley, as can be observed today (Talbot, 1971).

By the late 18th century farms were well developed. Their influence was especially noticeable on the Renoster shrubland. As the size of the individual holdings was smaller than that of the Khoikhoi, the incidence of overgrazing, mismanagement and too-frequent fire resulted in the natural grasslands and thicket being replaced by the anthropologically induced renoster shrubland (Deacon, 1992).

The war between France and England brought the strategic value of the Cape under scrutiny and caused the Cape to be invaded, first by the French and later the British (1781). The British occupation in 1795 drew attention to the excellent wines of the region, which soon began to be exported to Britain. Local architecture was influenced by European visitors and the typical Cape-Dutch style was developed. Building material ranged from local (the Restionaceae used as thatch found on ill-drained ground) to imported (teak from the Dutch colonies in the East) (Talbot, 1971).

The 19th century saw the discovery of precious metals and diamonds in the interior. The only roads to the interior were wagon trails that had been made by farmers to transport consumer goods and farm produce to and from Cape Town. These trails remained dependent for maintenance and improvement on the sporadic efforts of their successors. In later years (1823 onwards) during the British rule of the Cape, the maintenance and building of roads into the interior through mountain passes improved greatly as can be seen by the Bains Kloof Pass built by convicts (1853). It became a scenic byway when the present national road was opened in 1945. This time also saw the first successful dune stabilisation efforts. The Railway was developed first to Wellington then later to Kimberley to serve in the needs of the prospectors, and with the prospectors came the boom of the Swartland and surrounding area in the supply of cattle, horses, wagon, fruits, brandy etc. to the prospectors in the interior (Talbot, 1971).

2.7.1 **Land use in the south-western cape region**

The initial land use in the south-western Cape region became increasingly intensified, receiving a stimulus in the wine-producing areas. The costs of introducing vines that were suitable to the south-western Cape region proved to be too high for many would-be viticulturists who turned to other forms of livelihood as the phylloxera parasite destroyed the native vines (Talbot, 1971). The extension of deciduous food production offered such an alternative. In the same period, on the Cape Flats, German settlers began transforming sheltered hollows between the dunes into productive small vegetable and dairy farms to cater for the growing needs of the emerging metropolis. The attraction of export markets to Britain and Europe was a boost to the agricultural community: orchards replaced vineyards and more vineyards were planted on steeper slopes. The landscape that developed reflected the physical differences in terrain, soil and micro-climate (Talbot, 1971)

The Swartland is a region of extensive farming, a landscape of gently undulating cropland, pasture and fallow, of large fields and large farms. Boundaries are wire fences with the homesteads developing around water points, springs or areas with easy access to ground water. (Talbot, 1971). Wheat was always the staple crop on the loamy soils. The germ period coincide with the first rains in April (autumn) and the subsequent growing period lasts until summer when the grain is ripe and ready for harvesting (Talbot, 1971).

Before mechanisation farmers used oxen and mules to plough. Therefore it made sense that fields were also sown with oats and then, after the harvest, they were left to rest for years and the uncultivated fields were used as grazing. This provided better grazing than the natural veld and so the natural vegetation was slowly but surely replaced; only on patches too shallow, ill-drained, rocky or steep did the natural vegetation survive. In the 19th century intervals between cropping times were considerable, allowing the soil sufficient time to recuperate lost nutrients and thus maintaining the fertility of the soil. Farming methods of the 19th century were therefore still sustainable, but as time passed and the urban population expanded, increased production, so did farming practices change. Land previously unsuitable for cultivation was used, rest periods were shortened and as mechanisation crept in so did the variation in the crop fall away. There was less need for oats and grazing. According to Talbot (1971), the results could be seen on the gullied hillsides and the streams that started to carry more dissolved matter. The soils depleted to such an extent that chemical fertilisers had to be used. Urban population growth was not the only reason for increased land cultivation. The protection offered by import control and rail transportation restrictions in the 1920's provided protection from low-priced imports. The wheat importation restrictions implemented in the 1930's by the government caused domestic prices to be higher than the prices in the free market, these prices in themselves proved to be an incentive for the farmers to expand the cultivation areas (Talbot, 1971).

In 1947 official attempts to control gully erosion began to be made incorporating conservation strategies such as contour farming and rotational cropping. Lupin was introduced on the grain lands. Lupins are ideally suited to the Swartland area, as it grows well in climates of 300-500 mm rain and is tolerant of the slightly acidic soils of the Swartland (Talbot, 1971). The contours, check banks and new field patterns in the Swartland marked the beginning of conservation-minded farms that were set to check erosion (Talbot, 1971).

At present cultivation occupies up to 13% of the south-western Cape land area (Schoeman and Scotney, cited by Meadows, 1998) with an intensification near the metropolitan area of Cape Town (Meadows, 1998). MacDowell (as cited by Meadows, 1998) mentions that the percentage of cultivation may be as high as 75% in the Swartland area. The areas of natural vegetation in this fertile lowland are limited to patches of land where the land is too infertile or steep to be cultivated.

The urban situation at present is in a stage of major growth in the main population centre (Cape Town). The population of Cape Town took 290 years to reach 600 000 inhabitants, as the situation was in 1945, but in the 1970's, a mere 30 years later, it had doubled to 1 200 000. To reach the 3 000 000 mark took only 15 years (Palmer Development Group, cited by Meadows, 1998). This urban expansion took place without planning in most cases and the population, causing very high loss in the natural resources of the south-western Cape, indiscriminately invaded ecologically sensitive areas. A vast area of potential and actual agricultural land is being lost to the urban explosion. The rate of farmland lost to urbanisation was as high as one hectare per day in the 1960's and 1970's, with a doubling of this rate in the 1980's (Gasson, cited by Meadows1998).

The impact on the present day south-western Cape is the consequence of "1 000 000 years of fire-stick farming, 2 000 years of stock raising and 300 years of cultivation. Added to this is the disturbance caused by roads, dams, and urban expansion" (Deacon, 1992, p.268). At present the population of the Western Cape Province (political term) is more then 4 000 000 people with an urbanisation ratio of 90%. The annual population growth of the area is 2.83% (Wesgro, 1994). The settlement started in 1652 has thus steadily been increasing in numbers (an is still increasing) with an accompanying pressure on the natural resources and land available in the south-western Cape region, especially the greater Cape Town area.

The following section will explore the conservation strategies in the Swartland

and Sandveld in more detail.

2.8 SOIL CONSERVATION IN THE SWARTLAND AND SANDVELD

> *The evil has been made widespread, and has been aggravated to negligence, by the failure of those directly concerned to understand fully the nature and the implications of the erosion itself, and by their ignorance of effective conservation methods.* - Talbot (1947,p66)

In the Swartland and Sandveld, around 1945, little had been done to stop erosion. Only small areas show any evidence of soil conservation methods. According to Talbot (1947) few farmers were aware of the erosion problem on their field, they only saw the gully erosion as soil erosion, the sheet wash went past unobserved and they did not pay much attention to the rills. Only a few farmers, around 1945, made ineffective attempts at stopping the erosion, but did not implement correct conservation procedures. They constructed water ditches to drain the excess of the fields, but the ditches were in most cases parallel to the field boundaries, straight lines, not following the contour, too wide and improperly spaced to be effective and in most cases added to the erosion problem by initiating gullies running from them. The use of contour ploughing on the grain farms was conspicuous by its absence around 1945, when Talbot (1947) did his field verification.

Since 1947, much have been done to rectify the situation in the Swartland. Contour walls have been adopted and lupins have been incorporated as a regular rotating crop in the grain-lands (Talbot, 1971). Lucerne, planted in rotation on the wheat-fields not only acted as feed for the cattle, but also increased the fertility of the soil and reduced surface run-off (Bennet, 1945; Talbot, 1971). Although the then Union of South Africa subsidised a few schemes for the prevention of soil erosion and water conservation in 1933 to 1940, the only real achievement was in the area of water conservation. Of the completed works, only 15% were intended for soil erosion control and the rest were for water conservation and watering livestock (Talbot, 1947). Talbot documented the conservation situation in 1946 as: "In extensive field trips in the Swartland the writer (Talbot) has not yet seen a single example of systematic gully control and reclamation by check dams at frequent intervals, although erosion at the heads of the gullies has been arrested on a couple of farms by loose rock fills and ramps." (Talbot, 1947, p.72).

As can be seen in Table 5.1, the conservation officers have since done a great deal of work in the Swartland and Sandveld in terms of conservation. In the Sandveld windbreaks have been erected (**Figure 2.8**) to protect the lands against wind erosion and in the Swartland contours and water ducts have been erected, along with weirs and check dams. In the following sections, the conservation efforts and problems will be discussed.

Figure 2.8: Evidence of the windbreaks erected in the Sandveld, against wind erosion.

2.8.1 **Potential problems with soil conservation in the Swartland and Sandveld**

The Swartland is mainly an agricultural area that has livestock incorporated in some or other way. In the Swartland there is a definite need for grazing-rest-crops, that will act to the advantage of the farming community. There is an opportunity to use rough grains instead of traditional lupines rotation. The stabilisation of the western coastal areas with "**peulgewasse**" must be seriously considered. Planting more nutritional plants can also strengthen the grazing. The grazing - cropland of the Swartland and Sandveld derive supplements from the "leftovers" of the crop after harvesting. The price of the land dictates however that the industry of beef for slaughter can not economically compete with the mutton and dairy industry. The Sandveld, with its cheaper land price, has a substantial amount of natural grazing, which could develop in a more intensively utilised way for the raising of beef. Only about 30-40% of the Sandveld area is under crops. Wool and double purpose sheep are found in these areas. The amount of livestock can be enlarged, depending the resolution of problems with the water and food supply during the dry periods (Dept of Agriculture and Fisheries, 1981).

Factors that cause difficulty, delay and costs in the completion of the erosion prevention works, are as follows:

Farmers do not co-operate on the issue that contours require disregard of farming boundaries, thus forcing the conservation officers to approve drainage on land that are not suited for the actual drainage at that particular point (too steep), this also incur unnecessary costs. Camps on farms are all fenced, therefore many fences have to be displaced, the costs of doing this falls on the farmer , since no subsidy exists for displacement, making the farmers unwilling to co-operate. Existing roads and railway-tracts cause the program to deviate from course, since the costs are to high to redo the section of the road causing problems. The solution to this is that all new road plans must now be evaluated by the Department of conservation before approval. Farmers still want new drainage to end up in the old, mostly wrongly situated and developed, drainage. The costs of rehabilitating an existing gully for the purpose of drainage is very high and therefore farmers are not very keen in this solution. Sheep, rodents and the wrong ploughing methods all contribute to the contour walls being displaced or destroyed (Elsenburg, 1991). The availability of water and costs involved, are problematic in maintaining the windbreaks and strips, as well as the establishment of new strips and wind breaks (Elsenburg, 1991; Personal Communication, Ollie Olivier, 1994).

The state of gully and wind conservation presently found in the Swartland and Sandveld is summarised in **Table 2.3**.

Table 2.3: The state of soil conservation in the Swartland and Sandveld as summarised by Elsenburg (1991).

Description	Area ha
Grazing	391 200
Cultivated lands (not under irrigation)	868 800
Cultivated land (under irrigation)	23 570
Land in need of mechanical erosion control, contours	378 150
Area of land already protected with contours	269 710
Area of land that needs some form of erosion control	120 580
Area of land still in need of water ducts	62 520
Area of land under the influence of wind erosion	178 720
Land that is in no need of any mechanical form of erosion control	67 410

The progress made by Elsenburg on the mechanical erosion measures is substantial in the Swartland area, especially on the grain-fields. The present focus is on biological measures and the successful utilisation of a rotation crop in the Swartland.

Elsenburg still need to protect only a further 108 440 ha on water erosion with contours, Elsenburg further isolated 67 410 ha that is not in need of any erosion control measures (Elsenburg, 1991). Table 5.1 gives an indication of the contour walls and drainage that has been erected in the Swartland since 1972 to 1993. Remarkable improvement resulted from this intervention, the total amount of contour walls that have been subsidised and completed were 79.7 % and drainage were 57.3%, as found in 1991 (Elsenburg, 1991).

There is no doubt about the commitment of the parties involved in soil conservation Swartland and Sandveld to prevent and improve the situation pertaining to erosion in this area compared to 1947.

Other actions involve ongoing research to find a new rotation crop for the Swartland, ongoing *ad hoc* counselling of the farmers in the areas , while a program is being developed where production techniques will be addressed. Further full-time employment of conservation technicians to check and develop a drainage program and inspections of other conservation works are utilised by the conservation department (Dept of Agric. And Fisheries, 1981).

2.8.2 **Future directions**

Who are the responsible parties in improving the situation at hand? The soil conservation policy of the Western Cape falls under the Department of Agriculture which, with the help of the various Agricultural and Conservation Acts, can impose fines on people not complying with regulations. Conservation Extension Officers liase with and educate the local farming communities. Agricultural scientists, with the help of other disciplines, should be able to provide economical solutions to the present situation, which are in line with the ecological stability of the region. According to the Department of Agriculture and Fisheries (1981) the agricultural potential of the Sandveld and Swartland region lies in the production of crops, winter grains, and development of livestock husbandry with the crop production. The focus on developing an economic sound conservation system should be based on getting the maximum with the minimum. Concentrating efforts on depth of soil tillage, type of implements, method of fighting plagues (Dept of Agric and Fisheries, 1981) and above all, a method of ensuring a maintained conservation philosophy.

Regarding the formulation (in 1947), of future conservation policy, Talbot (1947) has the following to say. "Action which should have been taken long ago by farmers themselves - when it would have cost so little and saved so much - must be delayed no longer, irrespective of cost." (Talbot, 1947, p.72). Talbot (1947) advises that before one attempts to formulate a new policy, it is necessary to review the lessons from the past and to summarise the condition and causes of soil erosion as found in the present.

Potential actions to improve the situation presently found in the Swartland and

Sandveld have been isolated by the Department of Agriculture and Fisheries (1981) and Elsenburg (1991). General conservation issues involving both the Swartland and Sandveld will be discussed first before looking at each individual area.

2.8.2.1 General conservation issues in the Swartland and Sandveld

Soil erosion potential classes should be developed, involving new, adapted cultivation techniques for small grains, fruit, vegetables and grazing. This should be done with full involvement of the farmers. It should also incorporate the use of proper drainage works, alternative and additional conservation works and the use of biological techniques to combat the erosion situation at hand in the Swartland and Sandveld. The ongoing education of farmers to ensure the maintenance of existing measures using biological erosion control measures and the correct ploughing methods are essential. The grazing capacity of different veld types must be strictly adhered to. Rest periods for the veld must be incorporated in new improved grazing practice. Existing practice must be re-assessed. The burning of veld must be strictly controlled, as indicated by the local conservation committees and the Act on the conservation of the agricultural resources (act 43, 1983).

2.8.2.2 Conservation issues in the Swartland

Contour walls to cover seven hectares per kilometre and another 17 225 km of contouring are still needed. That would translate to about R18 million in subsidies. Drainage must be increased by 3500 runoffs in order to complement existing and proposed contour walls. This will require R63 million in subsidies. Also needed is the further development of biological measures to facilitate the use of mechanical erosion measures to ensure that the present trend of erosion occurring between the contour walls can be effectively stopped. A renewal programme would also involve reclaiming of all the existing dongas and ditches on farms, especially where they adjoin fences. (Department of agric. And Fish., 1981). The trend whereby contours seem to be eating into these ditches must be stopped before it destroys too much of the landscape.

2.8.2.3 Conservation issues in the Sandveld

Studies should be conducted to find alternative crop to replace small grains in the wind-eroded area of the Sandveld. There should be a program of testing and development of conservation measures to stop wind erosion. The development of a perennial crop to guard against the wind erosion could prove to be useful. More wind breaks and other control measures should be erected to check ongoing wind erosion in the Sandveld.

Talbot (1947) recommended that in light of the study he did in 1945 on the erosion situation in the Swartland and Sandveld, a special committee should have been appointed to compile a comprehensive erosion program for the western lowland of the Cape Province (Talbot, 1947). Even so, the work done by Elsenburg has played a critical point in the strong advances made agains erosion in the Swartland and Sandveld. Elsenburg as an agricultural research institution is the ideal place to develop erosion control measures as suggested by Talbot (1947). Educational programmes highlighting each farmer's individual role and the education of "new" farmers are invaluable.

2.8.3 **Conclusion**

The reasons why conservation control is not always effective, or less effective than anticipated are ample. Cooke & Doornkamp (1990) isolated a few causes. Often conservation techniques do not work because technical application fails through inadequate or misapplied research. Techniques quite often do not fit into local agricultural and pastoral practices and therefore are not applied by the farmers. Existing land tenure hampers conservation control. Government-sponsored conservation is not acceptable to the land users and there are fundamental institutional weaknesses in the enforcement of conservation (Cooke & Doornkamp, 1990).

The success of conservation must firstly begin with the education of the all the people in the country, from primary school through to university and other educational institutions, to the private sector. Awareness of the soil as a valuable national asset at an early age will breed a greater appreciation of the land. Decision-makers with an educational background where respect for natural resources was an integral part will only benefit the conservation ideals.

The most important point made by Roberts (1993) on the implementation of conservation strategies is that the research on the subject is good enough to solve more then 80% of South Africa's land degradation problems, but that the implementation of this research is not effective. Cooper (1998) did a PhD thesis on the conservation acts and strategies in South Africa. Such a study is a step in the right direction and will be beneficial in developing new conservation laws for South Africa.

The third level at which there should be control is that the Soil Conservation Act must be applied more stringently. Fines for mismanagement should be increased. Funding for education, research, development and implementation of soil erosion control measures, unaffordable to farmers as individuals, should be increased as it is in the national that there should be adequate soil conservation works and appropriate measures developed and implemented.

The result of the research into the conservation situation in the Swartland and Sandveld clearly illustrates that with the help of the correct conservation policy and the involvement of only a portion of the farming community effective conservation measures can cause an improvement in the landscape.

CHAPTER 3: SOIL EROSION CONCEPTS

3.1 INTRODUCTION

Soil erosion can be viewed from different perspectives: Firstly, it can be seen in the context of the geological time scale as a part of the normal denudation process. A narrower perspective would see it as an instantaneous process with climatic and vegetation controls. The third perspective is to see it as a dynamic process operating at different scales through time and space (Kirkby &Morgan, 1990). Soil erosion is a geomorphologic process that continuously influences and changes the environment in which we work and live. It is also a natural and inevitable geological process that causes denudation of the land over time by wind and water (Talbot, 1971; Kirkby & Morgan, 1980; Whittow, 1984; Strahler & Strahler, 1989). Soil erosion removes the valuable top layer of the soil that contains the vast majority of nutrients needed for sustainable plant growth (Kirkby & Morgan, 1980; Lal *et al.*, 1989). Natural (geological) erosion is essential for the maintenance of the fertility of the soil, it is through natural erosion that the essential nutrients for the soil are released to the root zone of plants and therefore the sustenance for the plants (Selby, 1990). For erosion to occur, a force greater than the shear strength of the land surface must be exerted onto the land surface (Whittow, 1984).

Within this study, soil erosion will be viewed as the accelerated removal of the top layer of soil from the surface, by either aeolian action or the working of running water and rainsplash. It is part of the natural processes at work in the environment with periods of more intensive erosion caused by changing human influence, climate and vegetative conditions. The rate of erosion by water is dependent upon many factors such as soil characteristics, climate, topography, and soil cover. If the effects of each of these can be quantified, the rate of soil erosion can be predicted.

Bocco (1991) developed a conceptual model of erosion as follows:

Erosion = (erosivity, erodibility).

As seen from Bocco (1991), many other methods for quantification of the soil erosion process have been proposed and applied with varying degrees of success. One such approach is called the Universal Soil Loss Equation (USLE). The USLE was developed empirically in the late 1950's at the Soil Loss Data Center of the U.S. Department of Agriculture, Agricultural Research Service at Purdue University by Wischmeier and Smith. The USLE was a modification of earlier equations, which were found to be too localized for general use. In the early 1990's, modifications were made to the original USLE and the Revised Universal Soil Loss Equation (RUSLE) was developed (Smoot & Smith, 1998). The USLE will be discussed briefly. The USLE utilises the following parameters to take into account rain erosiveness, soil erodibility, slope length and steepness as well as the erosion control practices applied to the land:

$$\mathbf{A = (R, K, L, S, C, P)}.$$

Where **A** = average annual soil loss per unit, **R** = rainfall erosivity factor, **K** = erodibility of soil factor, **L** = slope length factor and **S** = slope steepness factor , **C** = cover management factor and **P** = conservation practice factor. By substituting these factors with values, an erosion rate (soil loss) in tons per acre per year can be obtained (Wischmeier & Smith, 1965).

Early research on soil loss indicated that when all factors other than rainfall were held constant, the soil loss was directly proportional to the total kinetic energy of the storm event times its maximum 30-minute intensity. This factor, the Rainfall/Runoff Factor (R), has been called the Erosion Index (EI) factor (Wischmeier & Smith, 1965; Smoot & Smith, 1998).

The Soil Erodibility Factor (K) is an experimentally determined quantitative factor. It is an empirical measure of soil erodibility as affected by intrinsic soil properties. The K factor is influenced by the detachability of the soil, infiltration and runoff, and the transportability of the sediment eroded from the soil. Normal K values can be determined, once the soil type has been identified from county soil maps. Estimates of the value are based on the composition (textural classification) of the soil mixture. This requires knowledge of the percent of the soil of each sand, silt and clay. The main soil properties affecting K are soil texture, including the amount of fine sand in addition to the usual sand, silt, and clay percentage used to describe soil texture, organic matter, structure, and permeability of the soil profile. In general terms, clay soils have a low K value because theses soils are resistant to detachment. Sandy soils have low K values because these soils have high infiltration rates and reduced runoff, and sediment eroded from these soils is not easily transported. Silt loam soils have moderate to high K values because soil particles are moderate to easily detached, infiltration is moderate to low producing moderate to high runoff, and the sediment is moderate to easily transported. Silt soils have the highest K values because these soils readily crust producing high runoff rates and amounts. Also, soil particles are easily detached from these soils, and the resulting sediment is easily transported (Wischmeier & Smith, 1965; Smoot & Smith. 1998). In South Africa the K factor reduces as one progress deeper into the soil profile (Smithen, Undated) as soil becomes more resistant with depth. Platford (1982) measured the K-factor by re-calculating the soil loss under artificial rainfall in Natal and found relatively good correspondence to the USLE predictions.

The slope length (L) and the slope steepness (S) are both major contributors to erosion potential, with steep and/or long slopes being most susceptible to soil loss. Rill erosion is primarily caused by surface runoff and increases in a downslope direction because runoff increases in a downslope direction. Interrill erosion is caused primarily by raindrop impact and is uniform along a slope. Therefore, the L factor is greater for those conditions where rill erosion tends to be greater than interrill erosion. Slope shape is a variation of slope steepness along the slope. Slope steepness and position along the slope interact to greatly affect erosion. Soil loss is greatest for convex slopes that are steep near the end of the slope length where runoff rate is greatest and least for concave slopes where the steep section is at upper end of the slope where runoff rate is least. The LS factor is a measure of sediment production. Deposition can occur on concave slopes where transport capacity of the runoff is reduced as the slope flattens. This deposition and its effect on sediment yield from the slope is considered in the supporting practices P factor (Wischmeier & Smith, 1965; Smoot & Smith, 1998).

The Cover and Management Factor (C) is the ratio of the soil loss using certain cover or cropping conditions compared to the corresponding soil loss assuming bare soils. The C factor for the effects of cover-management, along with the P factor, is one of the most important factors in USLE because it represents the effect of land use on erosion. It is the single factor most easily changed and is the factor most often considered in developing a conservation plan. For example, the C factor describes the effects of differences between vegetation communities, tillage systems, and addition of mulches. The C factor is influenced by canopy (cover above but not in contact with the soil surface), ground cover (cover directly in contact with the soil surface), surface roughness, time since last mechanical disturbance, amount of live and dead roots in the soil, and organic material that has been incorporated into the soil. These variable change through the year as plants grow and senesce, the soil is disturbed, material is added to the soil surface, and plant material is removed. The C factor is an average annual value for soil loss ratio, weighted according to the variation of rainfall erosivity over the year (Wischmeier & Smith, 1965; Smoot & Smith, 1998).

The Erosion Control Practice Factor (P) enables accounting for such land or crop management practices as contouring, terracing and strip-cropping or for general land use designations The supporting practice P factor describes the effects of practices such as contouring, strip cropping, concave slopes, terraces, sediment basins, grass hedges, silt fences, straw bales, and subsurface drainage. These practices are applied to support the basic cultural practices used to control erosion, such as vegetation, management system, and mulch additions that are represented by the C factor. Supporting practices typically affect erosion by redirecting runoff around the slope so that it has less erosivity or slowing down the runoff to cause deposition such as concave slopes or barriers like vegetative strips and terraces. The major factors considered in estimating a P factor value include runoff rate as a function of location, soil, and management practice; erosivity and transport capacity of the runoff as affected by slope steepness and hydraulic roughness of the surface; and sediment size and density (Wishmeier & Smith, 1965; Smoot & Smith, 1998).

As Stocking & Elwell (1976) point out, the only factors that can credulously be influenced and comprehensively controlled by people are the last two factors, viz.: agricultural practice and direct conservation intervention. It is clearly these two factors that have the greatest influence, when manipulated by people, on erosion, as is demonstrated by this study. Bocco's (1991) model does not consider the human influence, thereby leaving out an important factor in the soil erosion equation of today. The human influence and the use of the soil by man Moeyersons (1990) plays an integral part in the cycle of erosion.

In the erosion equation, erodibility (erodibility of soil as a factor to the landscape) and erosivity (erosivity of the eroding agent) have its place in determining the amount of erosion on the landscape.

3.2 FACTORS INFLUENCING SOIL EROSION

3.2.1 Erosivity

Rainfall is a major factor in determining the erosivity of a region. It is primarily through rainsplash that soil is detached from the ground and ready to be transported, either by wind or water. The effects on the detachment of soil particles by short bursts of rain and long showers of low intensity are not clear in terms of soil loss (Morgan, 1995). Bocco (1991) maintains it is not the catastrophic, infrequent events that cause the greatest harm, but the low magnitude frequent events, which has a constant influence on the soil, but effects of storms are highly variable from environment to environment. No generalisation can be made regarding the intensity of rainfall and the erosivity. Many intrinsic factors (soil type, texture) play a role in this equation from region to region (Morgan, 1995). Morgan (1995, p27) expresses the erosivity of a rainstorm as "a function of its intensity and duration, and of the mass, diameter and velocity of the raindrops".

Wind erosivity is seen as the relationship between the velocity and the duration of the wind as ascertained by Skidmore and Woodruff (1968) (Morgan, 1995).

3.2.2 **Erodibility**

Erodibility can be defined as the potential for the land to be "eaten" away by erosion. Erodibility relates to the resistance of soil to detachment and transport. It depends on the aggregate stability, the texture of soil particles and related chemical and organic characteristics and strength of the soil (Cooke & Doornkamp, 1990). The topography of the land has a certain influence but it is mainly determined with the properties of soil (Morgan, 1995). "Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical content" (Morgan, 1995, p.29). Particle size is a main determinant in the erodibility of soil; smaller soil particle sizes (silts) are more easily transported since they do not need high energy to be displaced (Morgan, 1995). The moisture content of soil is a further determining factor in erodibiliy, but it varies from wind erosion to water erosion. Soils with a higher water content less erodible via wind erosion, but is more susceptible to water erosion, other factors (particle size, texture, organic and chemical composition, freezing and thawing, aggregate stability) determining erodibility are more or less the same for water and wind erosion (Morgan, 1995).

According to Strakov's weathering model, South Africa falls into an area of "slightly altered rock", the general soil profile is therefore shallow and not deeply weathered (Strahler & Strahler, 1989). Rooseboom *et al* (1992) developed a sediment yield map of South Africa. This map was compiled by dividing South Africa into zones of equal theoretical sediment yield potential and subsequent calibration in terms of recorded yield values (Rooseboom, 1992). It is evident that the south-western Cape falls intc differing categories of erodibility. According to the revised sediment yield map, the south-western Cape falls into the category of low and medium erodibility with extensive patches of high erodibility. The area of high erodibility coincides with the Swartland region of the south-western Cape, which is also an area of extensive gully erosion (Talbot, 1947).

Erodibility varies from environment to environment in its geological rate as well as the influence of the climate and other factors (neo-tectonic activity, human influence) on the erosion rate, determining the scale of the impact on the soil. In arid regions, erosion is particularly variable (Thornes, 1985). Bosaza (1951) believed that erodibility by water was dependent upon the organic soil content as well as the balance between kaolite, illitite and montmorillonite. He put forward the theory (which was later proven corect by Stern (1991) (Garland, 1995)) that ferricrete and lime crusting will actually reduce the erodibility of an area.

South African run-off figures have accumulated over the last 50 years, but due to the sparse distribution of these reading it is difficult to find accurate detailed rainfall data for all the regions in South Africa. It is perhaps due to this that the amount of studies, which links erosion to rainfall, are so few. Smithen (1981) created a rainfall erosivity index to for South Africa. Internationally South Africa falls within the lower ranges of rainfall erosivity with the highest mean annual erosivity at > 500 units / yr. The higher regions of erosion on his map was mostley on areas covered by Karoo sediments and not over the higher geological resistive areas (Garland, 1995).

3.2.3 **Vegetation**

The role of vegetation, or the lack thereof, in promoting soil erosion is evident and many studies have been made on the deployment of vegetation as a preventative technique (Morgan & Rickson, 1988; Rowntree, 1988). Morgan & Rickson (1988) suggest the planting of vegetation as a protective cover crop in a crop rotating system during fallow periods. But vegetation is not always beneficial for soil erosion. The size of the leaves and the height of the canopy have been found to be a determining factor in the promotion or prevention of erosion by ways of rain splash (Noble & Morgan, 1983; Thornes, 1985; Morgan & Rickson, 1988;

Morgan, 1995). If the canopy is at 7m above the ground, 90% of the velocity of the raindrops is retained, thus making the drops equally erosive, as well as the added factor of the leave acting as a trap in consolidating raindrops (Morgan, 1995) thus creating bigger drops to fall to the ground, which in turn causes more erosion. Rowntree (1988) found that a ground cover of at least 20%-30% is critical in preventing sheet erosion, with a cover of 70% being the most effective (Morgan, 1995). Elwell (1981) also found that the percentage increase in ground cover has an exponential relationship with soil loss. The speed at which runoff occurs is reduced by the amount of vegetation cover (roughness), thus limiting the erosive power and energy of sheetflow (Morgan, 1995).

A good vegetation cover (adding roughness) reduces the velocity of wind. With crops it was found that wind speeds near the ground were reduced, but that the additional movement of the canopy increased the speed higher up, thus increasing the drag factor (Morgan, 1995)

3.2.4 **Slope gradient and length**

Slope gradient and length proved to be a consideration at the occurrence of soil erosion, especially the formation of gullies. As Teixeira de Oliveira (1990) puts it: short and steep slopes tend to increase the effect of concentrated overland flow in channels while long and gentle slopes tend to determine the further evolution of gullies by enhancing subsurface flow and tunnelling excavation. Sheet erosion proceeds most rapidly in areas of high rainfall intensity, on steep slopes (Cooke & Doornkamp, 1990) and on the lower sections of long slopes (Talbot, 1947). Teixeira de Oliveira (1990) attributes the formation of gullies at the bottom of the slopes to seepage where gullies tend to become wider downstream, with increasing slope length.

3.2.5 **Human Influence**

The problem of erosion occurs when the demand for land exceeds the supply that it can give. In most primitive societies accelerated erosion is assumed to have been negligible, because humans practised agriculture that suited the land and the conditions thereof. The erosion problem started when competition for land started, when people began to compete for better grazing and agricultural land. The demand for food increased and the land had to supply this demand. With this increase in demand, however, the land also began to display accelerated erosion. The impact of modern day equipment on soil has aggravated erosion. Heavy farming equipment causes compacting of soil helping the formation of hardpans which results in increased sheetflow over these hardened surfaces, the beginning of a vicious circle.

Ploughing, or otherwise tilling the soil, exposes fresh surfaces to the sun and the open air, and results in rapid aeration. This accelerates the rate of oxidation of soil organic material and its decomposition into carbon dioxide, water, mineral salts, etc. Thus the 'capital' of nutrients and topsoil, built up by the field over centuries may be lost in a few seasons. As the humus content of the soil diminishes, soil aggregates break down and the granular structure of the soil changes to the so-called single grain structure. This has a negative effect on the tilth and also lessens the resistance of all soils to erosion (Talbot, 1947; Kirkby & Morgan, 1980).

As the granular structure of the soil disappears, clay, clay- loam, and loams become more difficult to plough and are easily puddled into hard lumps if worked when too wet, because the soils become vulnerable to mechanical forces involved in normal farming operations (Lal *et al*, 1989). The permeability becomes less and the proportion of rainfall lost to run-off increases, poor aeration causes a decline in biomass production (Lal, *et al.*, 1989). At the same time the loose soil grains created by the disintegration of granules facilitates increased run-off by sweeping away large quantities of fine soil particles. In turn, sheet erosion results in the loss of topsoil in increasing quantities as the soil structure deteriorates (Talbot, 1971; Kirkby & Morgan, 1980). The vulnerability of the soil to water is a fundamental cause of the erosion of water on the soil (Jaiyeoba & Ologe 1990).

The colonisation of the New World and the ensuing overstocking of cattle led to overgrazing, which further depleted the vegetative layer needed to protect the soil against wind and water. This added to the accelerated erosion problem of today and the existence of badlands and "dust bowls" (Stocking and Elwell, 1976). Overgrazing due the absence of rotation camps, and the concentration of livestock around fountains for water, contributes to the problem, stripping the land of the vegetation cover necessary for protection against erosion.

Soil erosion can be divided into two categories: one is natural (geological erosion) and the other is induced by man (accelerated erosion). Accelerated soil erosion will be discussed in more detail in the following section.

3.3 ACCELERATED SOIL EROSION

Moon & Dardis (1988) note that water and wind are the main geomorphic agents of natural soil erosion, and human interference acts as a catalyst inducing accelerated rates of erosion. Accelerated soil erosion can be defined as "The removal of soil at a greater rate than its replacement by natural agencies" (Whittow, 1984. p.496). Accelerated soil erosion takes place when natural conditions are modified by human actions, thus creating a rate of erosion that is faster than the rate of soil formation (Cooke & Doornkamp, 1990). In effect soil is removed, by wind or water, at rates which are not acceptable (Higgitt, 1991). "Acceptable" rates of erosion are commonly fixed at between 2510 and 12550 kg per hectare per year (Cooke & Doornkamp, 1990), but here again these rates are highly variable from environment to environment. Under natural conditions the erosion rate is usually slow (although some areas have a naturally high erosion rate), thus forming and maintaining soil with distinct horizons (Strahler & Strahler, 1989), and enabling plant communities to maintain themselves in a state of equilibrium. The erosion that takes place is without the interference of man. Soil scientists refer to this state of equilibrium as the geologic norm (Moon & Dardis, 1988; Strahler & Strahler, 1989; Cooke & Doornkamp, 1990).

The threat of accelerated erosion on the soil resource has not passed unnoticed by mankind (SARCCUS, 1981). Most studies of accelerated erosion have been conducted especially on badlands, which, according to Palacio-Prieto & Selem (1990), form "natural laboratories". Soil conservation is therefore necessary to help reduce the accelerated soil erosion rates to the rates of natural soil formation (Kirkby & Morgan, 1980; Cooke & Doornkamp, 1990). The idea of the past influencing the future in terms of soil erosion during antiquity, has been explored by researchers as a means of understanding the human influence on natural and accelerated erosion (Bruhchner & Hoffman, 1992).

3.4 SOIL EROSION PROCESSES

3.4.1 Water erosion

Areas in the world threatened by water erosion can be seen in **Figure 3.1.** Water erosion occurs because of various factors such as rainfall, surface flow, subsurface flow, and in coastal areas, seawater (Moon & Dardis, 1988). Rainfall can be perceived as the most important instigator of soil erosion, because it is from rainfall that the other factors evolve. Erosive rainfall occurs when the intensity exceeds 25mm/hr (Rowntree, 1991). Rainfall is responsible for the initial breakdown of the soil structure (Moon & Dardis, 1988), but other sources indicate that it is also responsible for the initial transportation of the soil particles and the compacting of the soils, thus reducing the infiltration capability of the soil by ways of rain-splash (Morgan, 1986). Severe soil erosion is typified by the presence of gullies, where total sediment loss took place, as a result of hydraulic action (Kirkby & Morgan, 1980). As the granules are broken down, fine particles are released, and increasing amounts of topsoil is available to wind or water erosion (Talbot, 1947), especially where there are appreciable amounts of silt sized particles in the soil composition (Kirkby & Morgan, 1980).

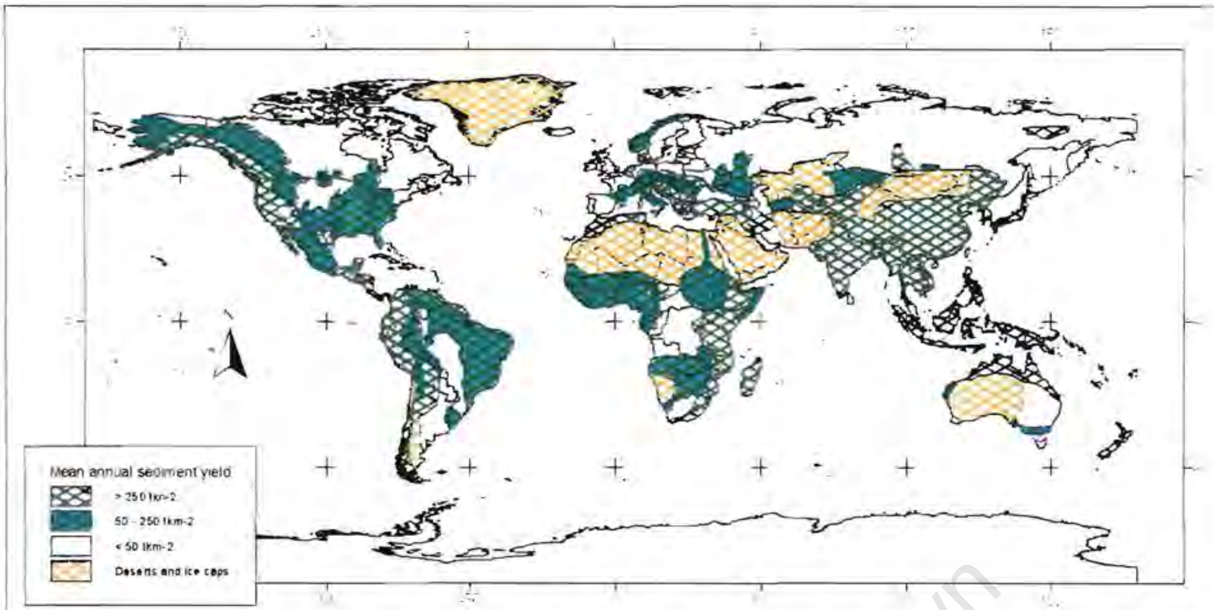


Figure 3.1: Areas in the world that are susceptible to water erosion as can be seen from the sediment yield from the catchments (Morgan, 1995)

3.4.1.1 Rainsplash and subsurface flow

Morgan (1995) considers rainsplash as the most important factor in the detachment process of erosion. Running water and wind follows suit and also act as the main transportation agents, with rainsplash taking the back seat. The action of the raindrop striking the ground has two effects, one of compaction and one of dispersion, compacting the soil and sending jets of water over a larger area as it strikes the ground or water surface (Morgan, 1995). Soils like "silt loams, loams, fine sands and sandy loams are the most detachable" (Morgan, 1995, p.11).

Subsurface flow or throughflow is the movement of water laterally downslope, through the soil in concentrated flows. The concentrated flow of water through the soil gives way to erosion to occur in the form of sub-terrain tunnels, that are known as "pipes" and is an instigator in the formation (by weakening the sub-surface) and widening of gullies (Morgan, 1995).

3.4.1.2 Sheetflow

Surface flow can be classified into confined and unconfined erosion.

Confined erosion results in rills and gullies forming because of an accumulation of sheetflow or channel flow. Unconfined erosion results from sheetflow, sheetwash and sheet flooding (Moon & Dardis, 1988). Subsurface flow is another form of confined erosion and results in the formation of soil pipes (Moon & Dardis, 1988).

Sheetflow is referred to as "The least conspicuous and most insidious type of erosion" (Talbot, 1947,p.16), although throughflow and piping are even less obvious and more important in some environments. The bulk of sediment transport is caused by surface flow, depending on the erosive power of surface flow and the amount of vegetation cover. Surface flow also carries away material loosened by other agents (e.g. rainsplash, ploughing) (Moon & Dardis, 1988).

From research studies into the power of sheetflow it became evident that the main factor determining the amount of erosion on the land surface was the amount of vegetation covering the given surface. On well vegetated slopes, the amount of soil loss due to sheetflow was much lower than on slopes with sparse to no vegetation (Morgan, 1995).

The saturation capacity of soils also determines whether it will be susceptible to sheetflow erosion or not (Talbot, 1947; Dardis & Moon, 1988). Infiltration rates are influenced by the "rate of supply" to the soil and the "soil structure, texture, mineral composition, vegetation cover, biotic activity, moisture content and surface conditions" (Moon & Dardis, 1988). It therefore becomes evident that sheetflow erosion is the first step to severe erosion, culminating in the formation of gullies (Moon & Dardis, 1988).

3.4.1.2 Rill and gully erosion

Rill erosion is the first definite step towards the formation of gullies. Rills can be defined as a temporary phenomenon that can be destroyed by cultivation (ploughing) and cross grading (Moon & Dardis, 1988, Morgan, 1995). Rills are thought to be the result of high erosivity conditions (Palacio-Prieto & Selem, 1990).

Where rills develop into drainage networks and are deepened, gullies develop (Moon & Dardis, 1988; Cooke & Doornkamp, 1990).

Rills are believed to be created downslope once sheetflow becomes channelled. Three to 3.5 cm/s is seen as the critical shear velocity for sediment transportation of non-cohesive soils in the initiation of rills (Morgan, 1995). Once rills are crated they cut up-slope due to the velocity of the flow, height and angle of the headwall slope and the cohesiveness of the soil. The down-cutting of rills is connected to the shear stress of the flow versus the intrinsic strength of the soil. The power of rill erosion can relate to most of the material eroded from the hillside, due to the fact that rills are non-selective in the particle size that they can carry (Morgan, 1995).

Gullies are larger and more permanent features than rills (Moon & Dardis, 1988; Cooke & Doornkamp, 1990). They are steep sided and carry vast volumes of water during rainstorms (Morgan, 1995). Bocco (1991) has mentioned the "arbitrary minimum depth" of gullies to be 0.5 m. Footpaths and cattle tracks usually deteriorate into gullies, because they are devoid of vegetation and they act as the concentration point of sheetwash (Moon & Dardis, 1988). Morgan (1995, p.19) says gully erosion is "...almost always associated with accelerated erosion and therefore landscape instability".

Gullies are narrower then they are deep as would be expected from normal streams; the sediment load is also high. Characteristics of gullies are headcuts and "nickpoints" in the course, as well as the varying slope gradient from gentle to severe (Morgan, 1995). The development of gullies were once believed to be due to rills that enlarged, but new studies on arroyos revealed a much more complex formation (Morgan, 1995). The development of gullies, according to Leopold, *et al*, (1964) in Morgan (1995, p19) can be summarised as follows:

- Small depressions or nick form on a hillside due to a localised loss vegetation cover (overgrazing / fire).

- Several of these depressions, enlarged by water collecting in them, unite to from a channel.
- Superficial flow occurs over near vertical scarps, created by headward cutting of the depressions.
- Although some erosion occurs from the scarp, most erosion is associated with scouring at the base of the scarp, deepening the channel, which undermines the head wall and results in the eventual retreat of the scarp upslope due to collapse.
- Further erosion of the gully sides by bank erosion and the collapse of the sidewalls occur.

Subsurface flow (as mentioned earlier) can be another causal factor in the development and enlargement of gullies. As these subsurface pipes are exposed to the surface, due to sheetflow or collapse, they can later develop into gullies. The third method for gully development would be when a landslide has left huge scars down the side of a slope to be further eroded during heavy rainfall activity (Morgan, 1995)

3.4.2 **Wind erosion**

Wind erosion, unlike water erosion, occurs independently of relief, affecting hillslopes and flat lands alike, transporting soil material uphill or downhill, without regard for gravity. Areas where there is low rainfall in combination with high temperatures are particularly vulnerable to wind erosion because dry soil lacks cohesion and is therefore easily removed by the wind (Moon & Dardis, 1988; Cooke & Doornkamp, 1990). The velocity of the air movement can be considered as the primary factor to wind erosion (Morgan, 1995). The other principal factors influencing wind erosion are the physical characteristics of the soil, the degree of exposure to the wind, and the duration and velocity of strong winds (Talbot, 1947; Moon & Dardis, 1988). The velocity of the wind is usually lowest near to the ground due to the roughness induced by uneven surfaces such as stones and vegetation. Above a certain height above the aerodynamic surface, a plane of zero wind velocity is found (Z_0). Above Z_0 wind speeds increase exponentially with height (Morgan, 1995).

The amount of shear velocity needed to detach a soil particle through wind erosion is more than that needed for water erosion, due to the difference in the density of the transporting agent, and the massiveness of the grain of sand. The critical shear velocity varies with the particle size, increasing and decreasing with the particle size. Suspension, surface creep and saltation describe the three stages of particle movement by wind. Suspension is the movement of fine particles, commonly less than 0.2mm, at altitude and over distance. Surface creep is when the particles are blown long the surface in a rolling motion. Saltation is when the particle moves via a series of leaps and jumps, bounding along the surface (Morgan, 1995). Where the soil surface is protected by vegetation or rocks, or has become hardened via other means, the velocity needed to dislodge a particle will need to be much higher. "The most erodible particles are 0.10 to 0.15 mm in size, particles between 0.05 and 0.5 mm are generally selectively removed by wind." (Morgan, 1995 p.25). Soil consisting of 60% of particles are aggregates larger then 1mm are almost entirely resistant to wind erosion (Morgan, 1995).

Deflation is a cardinal process associated with wind erosion, and causes the landscape to be lowered and the topsoil to be removed (Moon & Dardis, 1988). Lack of protective vegetative cover enhances the severity of the wind erosion (Moon & Dardis. 1988). The south-western Cape, especially near the coast, where the low, relatively level, and almost treeless landscape offers few obstacles to the wind, is prone to wind erosion (Talbot, 1947).

The action of wind erosion is the same as that of sheet erosion in that it removes the nutritious topsoil layer first (Talbot, 1971). The effect of this loss can sometimes go unnoticed because farmers in the region are using more and more fertilisers (Hallward, 1988). The heavier particles underneath skip and roll along the surface, and collect in hollows and against vegetation. The lighter particles, on the other hand, can be carried away for kilometres (Talbot, 1947). Wind erosion can be seen as an almost "undetected" problem as it does not always leave obvious scars such as those left by gully erosion, it is therefore easy to miss the signs of wind erosion (Hallward, 1988). The problems of wind erosion were first marked in the 1930's as an international discussion point, when the "dust bowl" effect was observed in the United States (Hallward, 1988). Wind erosion has since been proven to be a problem in many countries around the world especially in the drier areas of the world, where the barren soils are at risk. In a country like Burkina Faso when the Harmmatan blows from January to February, it causes "dust pollution" for kilometres, picking up the valuable top soils, barren after the harvests (Personal observation, 1997). Areas under threat of severe erosion have been defined as those which receive less then 250-300mm rain a year with prevailing winds in one direction and the vegetation cover is insufficient as can be seen in **Figure 3.2** (Hudson, 1971, Chepil, 1957). This is, however, not the only land under threat of wind erosion, areas like river banks and along coast lines are prone to wind erosion because of the exposure factor, barren land on agricultural fields, irrespective of the climate, are also at risk to wind erosion (Zachar, 1982, Bennett, 1939).

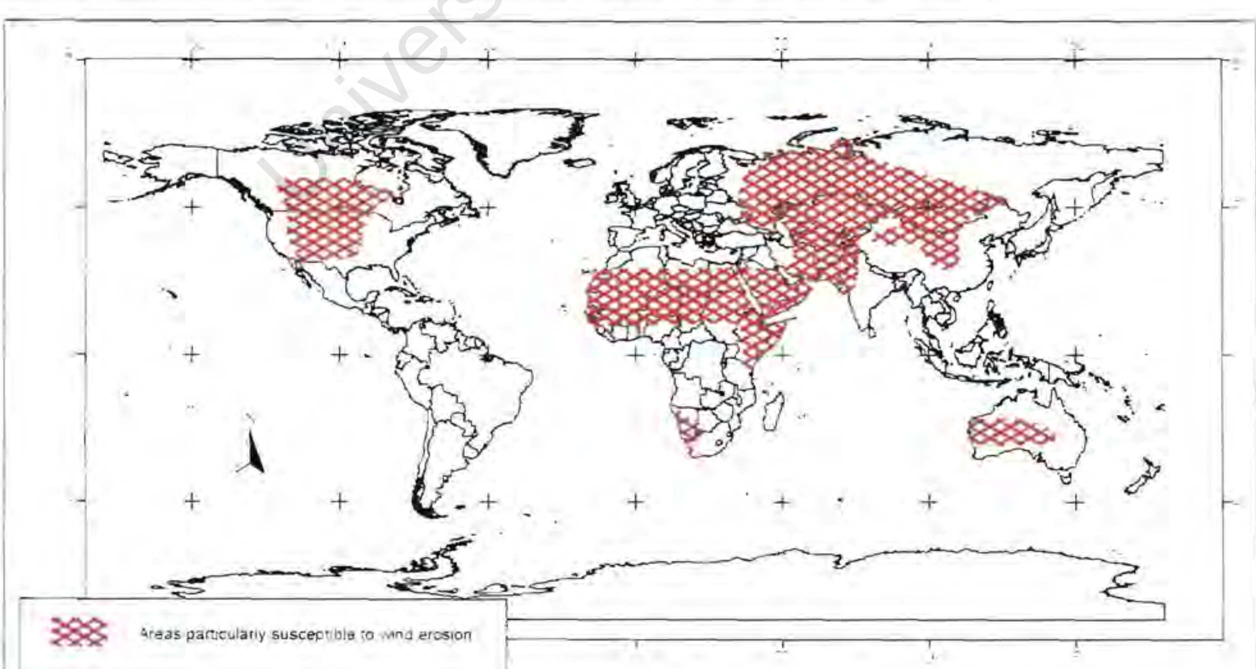


Figure 3.2: Areas in the world sucptable to severe soil erosion by wind (after, Hallward, 1988)

3.5 Soil Erosion in the Swartland and Sandveld

Factors that contributed to soil erosion in the Swartland and Sandveld (as discussed in Chapter 2) were disregarded in the 1930's as long as apparently profitable crops were produced (Talbot, 1947). The consequent disregard of the hazards of cultivating long slopes and steep slopes and a neglect of any effective precautions that could be taken to minimise erosion, caused erosion to take place at an accelerated rate (Talbot, 1947). In the 1930's there were a general failure to employ appropriate tillage methods on sloping lands (Talbot, 1947), the general practice was to plough up and down slopes by means of livestock (Germishuys, 1992) which caused severe sheet erosion, that could have been avoided had the farming taken place on the contour (Bennett, 1939).

The long slopes characteristic of the Swartland area make it vulnerable to gully erosion. Most of the slopes in the Swartland area are between 3° to 15°, with some crops even cultivated on a 15° slope, which, with the duplex soils found in the area creates the ideal situation for gully erosion. Due to the nature of the Swartland soils, the top layer is resistant to erosion, but as soon as it is eroded or disturbed (by overgrazing or ploughing, etc.) the bottom part crumbles easily, especially in the presence of water and causes large erosion gullies (Germishuys, Personal communication, 1994). Steep slopes in the Boland area, where new slopes are being cleared for vineyards, are also vulnerable to severe water erosion and care is therefore needed in the preparation of these slopes for cultivation. The Swartland soils derived from the Malmesbury Series, is a good example of an area where sheet erosion as well as piping can be found (Talbot, 1947). The pervious, well-drained soils of the Sandveld are practically immune to sheet erosion (Talbot, 1947), but wind erosion is found on large areas of the Sandveld, with its sandy soils.

The first corn cultivates that were used in the Swartland and Sandveld took long to grow and therefore the land was exposed to the elements for a long period before there was any cover on the lands (Germishuys, 1992). The further practice of burning the veld in order to obtain early grazing after the first rains (Germishuys, 1992) also caused the amount of surface run-off to increase, due to the lack of vegetation and the increased water repellence of soils, caused by fire (Graaf, et. al, 1993) thus resulting in more erosion.

In 1938 there was also a general failure of engineers to make proper provision for the disposal of drainage water from roads and highways (Talbot, 1947). The run-off caused erosion gullies to develop next to roads. These gullies then encroached further into the surrounding natural veld and the adjacent farm lands and resulted in unsightly scars on the landscape, and diminished arable lands.

Wind erosion in the Sandveld area effects 178 720 hectares (Elsenburg. 1991). According to Elsenburg (1991) and Germishuys (1992) wind erosion in the Sandveld can be divided into three different categories.

- Natural wind erosion with coastal drift sand and coastal dunes from the False Bay coast up to Elands Bay covers an area of approximately 1 800 hectares.
- Wind erosion on farmlands, covers approximately 155 000 hectares.
- Wind erosion on natural grazing, covers approximately 60 000 hectares (Elsenburg, 1991; Germishuys, 1992).

3.6 CONCLUSION

Soil erosion in the form of water erosion and wind erosion has been with us from the earliest of times. By understanding and studying the processes and factors involved in the soil erosion equation we can come to a better understanding of the fundamentals affecting soil erosion and thereby limit the harmful influence of human activity on the environment. There are few aspects in geography that encompass so many disciplines as the study of soil erosion and its affiliated soil conservation (Stocking & Elwell, 1976; Higgitt, 1992). Soil conservation and erosion research should be used to help in the development of sustainable agriculture (Higgitt, 1992), through sustainable soil management. Soil conservation strategies will benefit from the understanding of soil erosion processes and factors, by implementing the fundamentals in soil conservation practices, such as preventing overgrazing or covering bare soil to prevent wind and water erosion.

CHAPTER 4: METHODOLOGY

4.1 INTRODUCTION

In defining a methodology for this study many factors had to be taken into consideration (see section 1.1 and 1.5). The study areas were selected from the major erosion areas as defined by Talbot's (1947) study of soil erosion in the Swartland and Sandveld (**Figure 4.1**). The area exhibiting gully erosion is located in the Kasteelberg/Riebeeck-Wes/Riebeeckasteel area. Contributing to its selection was the fact that a system of major gullies was known to exist, as seen on a field trip from the 1994 MED conference, on the Farm Boshof (**Figure 4.2a, b**).

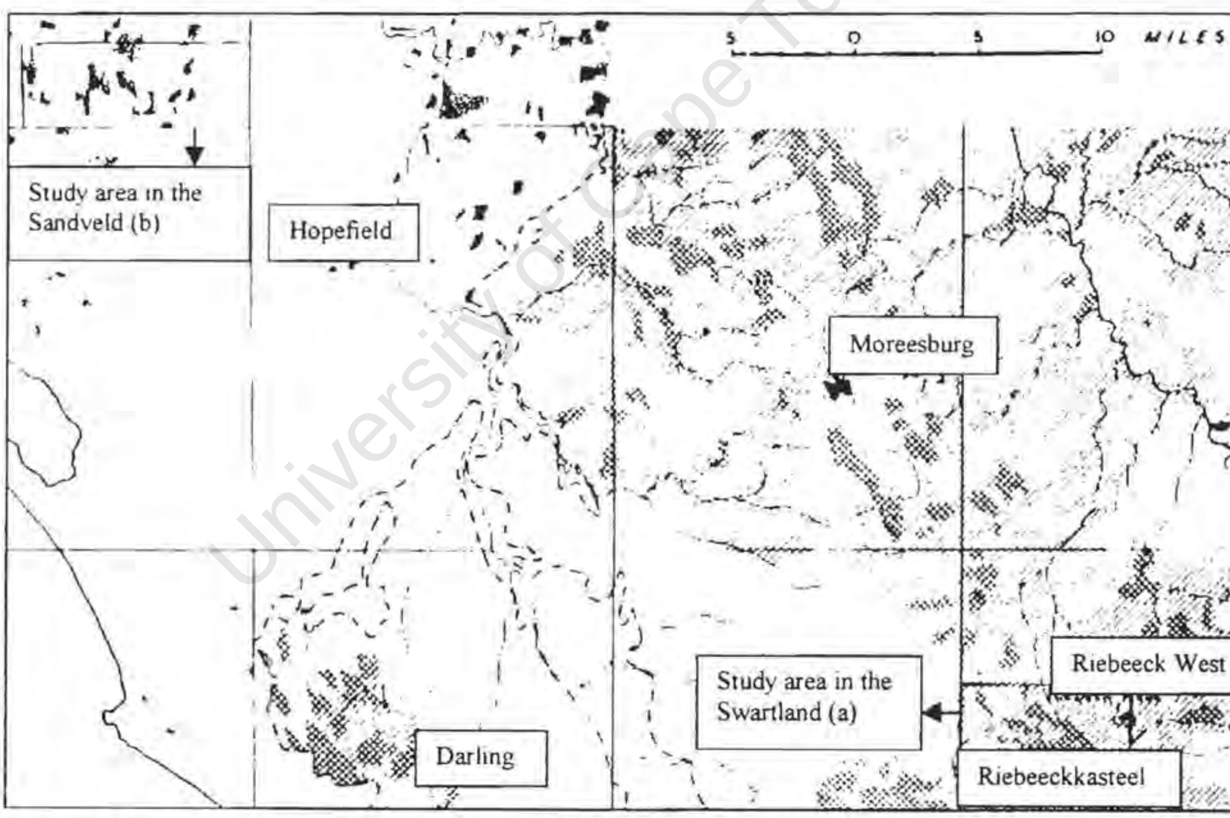


Figure 4.1): The study area of water erosion, depicting the gullies as mapped by Talbot (1947) (a) and the area chosen for the wind erosion mapping as mapped by Talbot in (1947) (b)

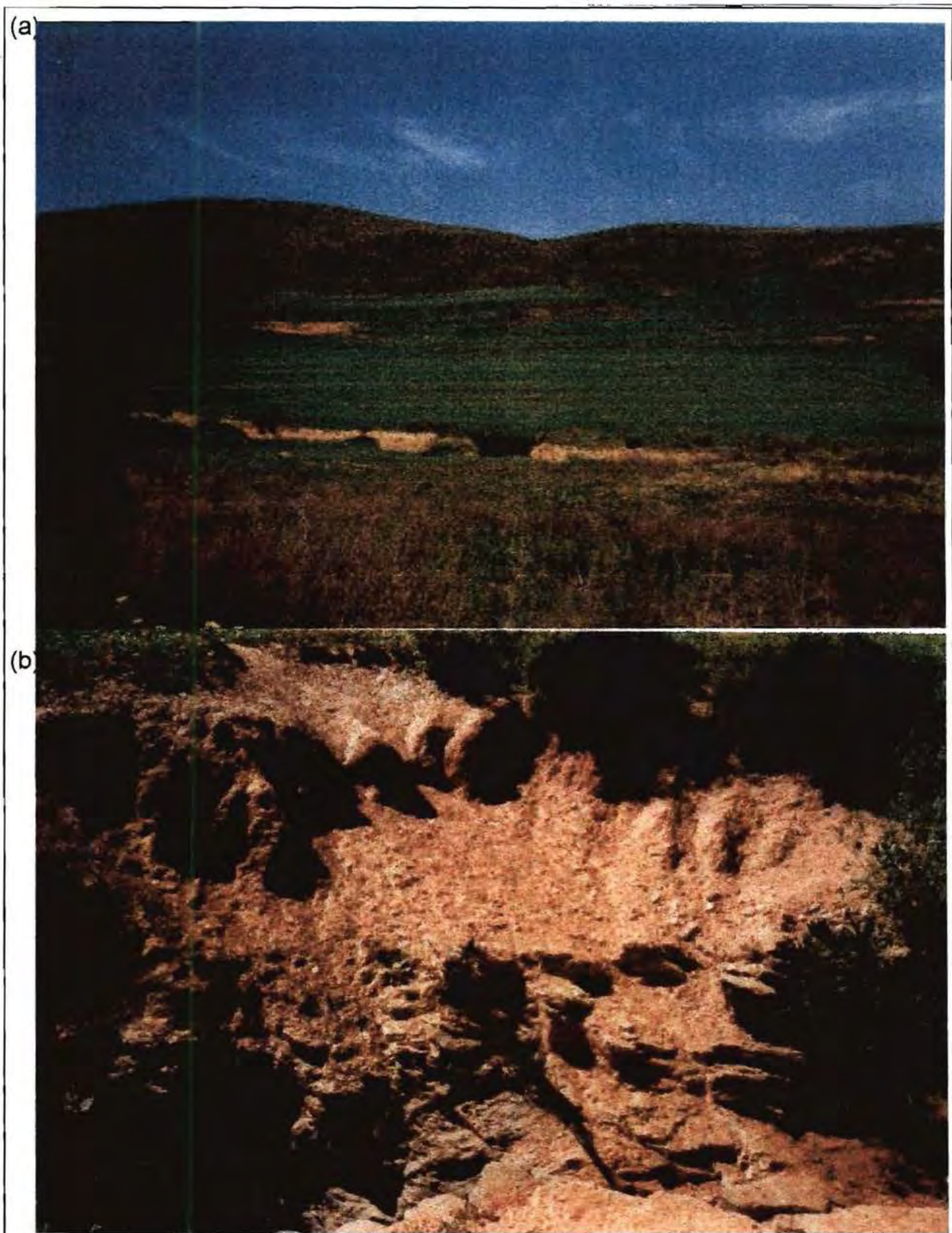


Figure 4.2: Photos taken from the area visited during the MED conference in 1994, the huge existing gully in the foreground can clearly be seen from a distance (a) on closer inspection it is seen that the erosion is down to the bedrock, some plants can be seen (b)

The second study area is situated near Velddrift, close to the Langebaan Air Force base in what is known as the Sandveld district. This area has a high incidence of wind erosion as mapped by Talbot (1947).

A criteria (as listed in section 1.5) in selecting these areas was the availability of aerial photography at acceptable scales (between 1:10 000 - 1:50 000) over the period from 1944 - 1993 chosen for this study (**Table 4.1**).

Table 4.1 : Summary of aerial photographs used in the study

YEAR	SCALE	SEASON	EROSION
1938	1:36 000	Summer (FEB/MAR)	WATER WIND
1974	1:10 000 (ortho-photos based upon 1:30000 air photos)	Summer (NOVEMBER)	WATER WIND
1986	1:50 000		WIND
1989	1:50 000	Spring (AUGUST)	WATER

The general aim of this study, as listed in Chapter one, is to compare the erosion in the Swartland and Sandveld found today with the situation in 1945. In order to achieve this aim various objectives had to be achieved. In order to realise these objectives, as specified in section 1.2, the methodology followed by the researcher can be summarised as:

a) A study of the *general situation* in the study areas pertaining to soil erosion; this was accomplished by interviewing the relevant conservation officer and other parties familiar with the erosion situation in the Swartland and Sandveld. (Ollie Olivier was contacted as the relevant conservation officer, Hennis Germishuys, from Elsenburg Agricultural Centre has a wide knowledge of the area and conducted a study of soil erosion in the Swartland and Sandveld).

b) *Aerial photo interpretation and mapping* of water and wind erosion found in the Swartland and Sandveld area over the last 50 years. In order to accomplish this, aerial photographs were examined from 1938, 1974 and 1986 (wind erosion)/1989 (water erosion). This followed through to the fulfilment of the next aim.

c) The use of *remote sensing and GIS* in analysing and reporting trends over a period of time as a way to locate erosion or to highlight the erosion threat to an area.

d) *Study conservation policies* as a preventative measure against erosion, this was concluded by researching the conservation policies in the statutes and the development of these statutes to effectively address the erosion question.

4.2. AERIAL PHOTOGRAPHY, GIS AND REMOTE SENSING

The interpretation of aerial photographs, remote sensing and GIS has become popular in the interpretation and modelling of land degradation studies (Higgitt, 1993). Brunnthaler (1969) feels that after the introduction of air survey methods, it was soon realised that air photos as a medium for storing spatial data was by far the best available and that information could be easily transferred to vector maps. The use of aerial photography in erosion mapping is, however, not new. Talbot (1947) performed a groundbreaking study of soil erosion in South Africa by mapping all the erosion gullies and areas of wind erosion in the Swartland and Sandveld using aerial photographs and later ground-truthing the results. He used the photos provided by the Defence Force and topographical maps from the (then) new Trigonometrical Survey. The photo's dated from the period January to March 1938. When he conducted the field observation in 1944 he found that erosion, as seen in 1938, was an underestimation of the situation. Results from photographic analysis of the erosion maps were superimposed on relief, thus creating a map of erosion in relation to the relief of the area. The maps produced are detailed and simplified maps of every gully and erosion area in the Swartland and Sandveld in 1938-1945 (Talbot, 1947).

Similar methods of study have been applied in various countries and continents throughout the world, and were found to be satisfactory in interpreting and assessing erosion risks (Thwaites, 1986; Loughran, 1989; Garland & Broderick, 1992; Higgitt, 1993). Olsen (1984) mentioned how soil survey and land use can be mapped with the use of remote sensing techniques. The data are further refined on computer, where various grids are overlain and interpretations made (Olsen, 1984). Garland & Broderick (1992) made use of aerial photos for an interpretation on the soil erosion in the Tugela region of Kwa-Zulu/Natal over the period 1944 - 1981. In their study they mentioned that sample populations have been used to represent an area, but that nowhere are there clear guidelines for the size of this sample area (Garland & Broderick, 1992).

Thwaites (1986) used 1:10000 orthophoto maps to identify and classify areas of erosion. Symbols depicting the erosion in the area were overlain so that the erosion in the area could become clear in a simplified manner (BRAR-Project (Bethlehem Runoff Augmentation Research)) (Thwaites, 1986). Using symbols to depict various erosion occurrences explains at first glance exactly where erosion occurs. No subjective interpretation of the image is needed by each person looking at the map, all second parties will see the map as the researcher has interpreted it. By using orthophotos, detail may be very precisely transferred to transparent overlays with little chance of error, since the orthophotos, which are corrected for radial distortions, represent the topographic maps and the aerial photographs accurately.

The use of aerial photographs as a preliminary study to indicate the presence of soil erosion is very effective and was used as such by Thwaites (1986). However, Thwaites (1986) emphasises the importance of following up the results obtained from the aerial photos in the field. Whitlow (1992; 1994) carried out an erosion survey in Zimbabwe in the 1980's. The erosion was recorded using 1:25000 aerial photographs and magnification. By dividing each area up into grid squares of 1 by 1 km, the erosion in each of these squares was logged and then overlain onto detailed maps of the area. In a study done in Spain by Garg & Harrison (1992) two sets of aerial photos were overlain over a DEM (Digital Elevation Model) to obtain an analysis of the distributed land changes in relation to terrain. The result of their study was an erosion risk map, developing from gully density, slope and landuse (Garg & Harrison, 1992). From the above it can be seen that the use of sequential aerial photographs is an acceptable method for the interpretation and logging of erosion trends, but certain factors need to be taken into account. The interval between the capture of succesive images needs to be long enough to be able to capture the development of the changing gully structure. The scale of the photographs must be large enough to allow accurate measurement and reasonable stereo threshold (Bocco, 1991).

Photographs flown during the time when there are young crops on the lands or when the fields have been ploughed after the harvest, are usually the best to see all the erosion forms (Bergsma, 1975). Care must be taken in the occurrence of any seasonal differences in photographs that are compared with each other. Photographs must be of the same season, or as close as possible to each other in seasonal time, the reason being that the reflection from the photograph will differ, depending on vegetation cover; areas that are barren in summer will be covered by vegetation in winter.

Loss of detail due to inappropriate scale can never be overcome (Garland & Broderick, 1992). The scale used in the final mapping is dependent on the smallest scale of the photographs available. When executing the mapping and working with different scales it must always be taken into account that the loss of scale cannot be overcome, therefore the interpreter must discount all those features on the larger scales that will be lost due to the smaller scale of the one set. The scale limit must be set to the smallest scale photographs. The threshold as indicated by Watson (1990) is set at $2mm^2$ for 1:50 000 scale, translating to 0.5 ha on the ground. Therefore on each photograph of differing scale this adjustment has to be made for an area of 0.5ha on the ground, in order to compensate for the difference in scale (Watson, 1990). For this study it was decided that all features on the 1:50 000 scale smaller than 1mm, translating to features smaller than 50m in the real world, would be the limit in length for the larger (1:10000; 1:30000) photographic scales. No feature translating to a length shorter than 50m on the ground was mapped on the rest of the aerial photographs. The best scales for mapping geomorphologic features from 1:30000 / 1:15 000; 1:50 000 can be marginal in picking up all the features (Janicott, 1969). But Klimaszewski (1988) disagrees with Janicott (1969), the best scale would be from 1:50 000 and larger. Such maps must be compiled with the use of aerial photography and aerial photography interpretation (Klimaszewski, 1988). Even though the reliability of the results is subject to the experience of the interpreter, season, scale, quality and density of vegetation, the results can still be very revealing (Garland & Broderick, 1992). By using the stereoscope, most erosion features can be identified, and it can be stated that this method is reliable and cost effective in making relevant and accurate maps and evaluations of the soil erosion found in the study area (Thwaites, 1986). Goudie (1990) feels that the use of aerial photography and stereoscopes must be in the hands of an experienced operator, the use of these tools to obtain post- and prediction findings will obtain more accurate findings. The limitation of time-period of photography and area covered by photography can be a severe handicap to researchers (Goudie, 1990) especially in lesser developed and poorer countries, where the air photo coverage is less reliable and of poorer quality. Allison (1993) notes the importance of using photogrammetry when stating:

> *Being able to obtain quantitative data from oblique photographs is a welcome development in itself, opening up a new potential in the analysis of archival photography, but the technique can also be applied to sequences of photographs to monitor changes in slope form and movement derive morphological and morphogenetic indices and compute displacement vectors and strain tensors.* (Allison, 1993, p.182).

Aerial photographs are generally preferred above topographic maps, especially when landforms can clearly be seen upon them (Cooke & Doornkamp, 1990). The mapping of gully advancement and other geomorphologic features to provide quantitative information on the changes over time relies on aerial photographs (Lane *et al*, 1993). It is, however, important to note that it is the surface form of the process that is being mapped and not the process itself. For example, it is the gullies that are being mapped not the gully formation (Cooke & Doornkamp, 1990). Gullies are the first sign of advanced water erosion, so that mapping the extent of the problem should always be the first step in obtaining the best and most cost effective control measures (Cook & Doornkamp, 1990). Not only geographers, but geologists, prospectors, foresters, town-planners, agronomists and engineers find aerial photography useful in the pursuit of their disciplines (Janicot, 1969). Loughran (1989) mentions a case where highly accurate topographical maps were constructed from aerial photographs, in which changes were mapped by comparing different photos. The added advantage is that the photogrammetic records are permanent (Loughran, 1989). The mapping of dongas by using stereoscopes is highly effective since the stereo-vision enables a distinction to be drawn between dongas and rills due to the depth of the dongas compared to the rills (Bergsma, 1975, Thwaites, 1986). Thwaites (1986) remarks that one can distinguish between an active gully by the lighter tones of the un-vegetated eroded bank. One might also find the base of the donga darker where some vegetation has settled in its drainage course. Lighter areas may also indicate areas of sheetwash where the vegetation has been stripped from the surface. The presence of various forms of soil erosion is in most cases represented by the amount of greytone in the area (Bergsma, 1975). Aerial pictures present an integrated view of the landscape, they also save time on large scale projects. The study by Cobban & Weaver (1993) to examine the features of the Tsolwana Game Park. They worked from 1:20000 orthocorrected maps and classified soil erosion with the SARCUSS system as guideline to erosion classes. Their examination was followed up by a ground survey where the gully networks, in areas with the worst erosion, were further examined. The use of aerial photography is therefore used to record, monitor and explain changes and development in new gullies, resulting in the prediction on analogues units of land. A surface that is covered by severe gully erosion can be mapped as a gully area rather then mapping each individual gully (Williams, 1981).

The SARCCUS (Southern African Regional Commission for the Conservation and Utilisation of the Soils) system was developed as a classification system for soil erosion, that would be applicable to all areas in the Southern African sub-region at a workshop held in Gaborone (22nd - 24th April 1981). The development of this system was intended to make mapping more uniform and easier to conduct in the region; it was designed to be used in conjunction with other methods and in conjunction with aerial photographs. The report resulting from the 1981 workshop contains a classification system (Table 4.2) and examples of areas identified from aerial photographs and other photographs to help the person using this report in identifying the relevant erosion features in the study area. Water erosion is further subdivided into classifications, i.e., sheet, rill, gully, landslide, terracette, creep and streambank. A brief definition of each type of erosion is given in the report. The different classes of each type are identified and a corresponding symbol given. For example: Gully erosion (type) has classes: "none apparent" (G1) to "Very severe" – (G5). Each class is accompanied by a description of the class of erosion (SARCCUS, 1981).

The way this system was designed is indeed very simple to follow and a certain amount of subjectivity on behalf of the researcher, in deciding when a gully is "Very severe" or only "Moderate (G3)", is removed by adding to the report the visual representation of these differing classes. The descriptions of the classes are clear and simple. This tool was very helpful in determining the particular erosion types and erosion areas, as interpreted from the aerial photographs, which were indeed under the influence of erosion. The SARCCUS system classification is used in this study to determine the gullies to be mapped from the photographs. Gullies from classes G2 (some gullies apparent) to G3 (moderate gullied area) were observed and mapped. In addition, wind erosion class W3 (moderate wind erosion) was observed and mapped. No symbolical distinction was made in the erosion mapping since it is not in the scope of this study to map the severity of erosion in classes.

Aerial photographs can also be used in mapping wind erosion, as conducted by Hallward (1988) who mapped areas of potential wind erosion in the south-western Cape. The sole use of aerial photographs as an indication to wind erosion is not a very reliable method to map the impact or occurrence of wind erosion, and can not be measured quantitatively hereby. The amount of soil loss cannot be determined, all that can be seen is the general trend of wind erosion in an area, therefore indicting areas sensitive to wind erosion. The nature of wind erosion can be seen from aerial photographs by the movement of dunes in an area, as specified by Cooke & Doornkamp (1990) when doing geomorphological mapping with the use of aerial photography and satellite imagery.

The necessity of fieldwork as verification can not be under estimated. Fieldwork forms the control for the interpreter to see if the interpretation from the photographs was accurate, it also adds to data not obtainable from the photographs (Thwaites, 1986). **Figure 4.3** shows the steps that can be taken in undergoing a similar study as this one. The field verification of this study was done after all the data had been collected and analysed in August of 1994.

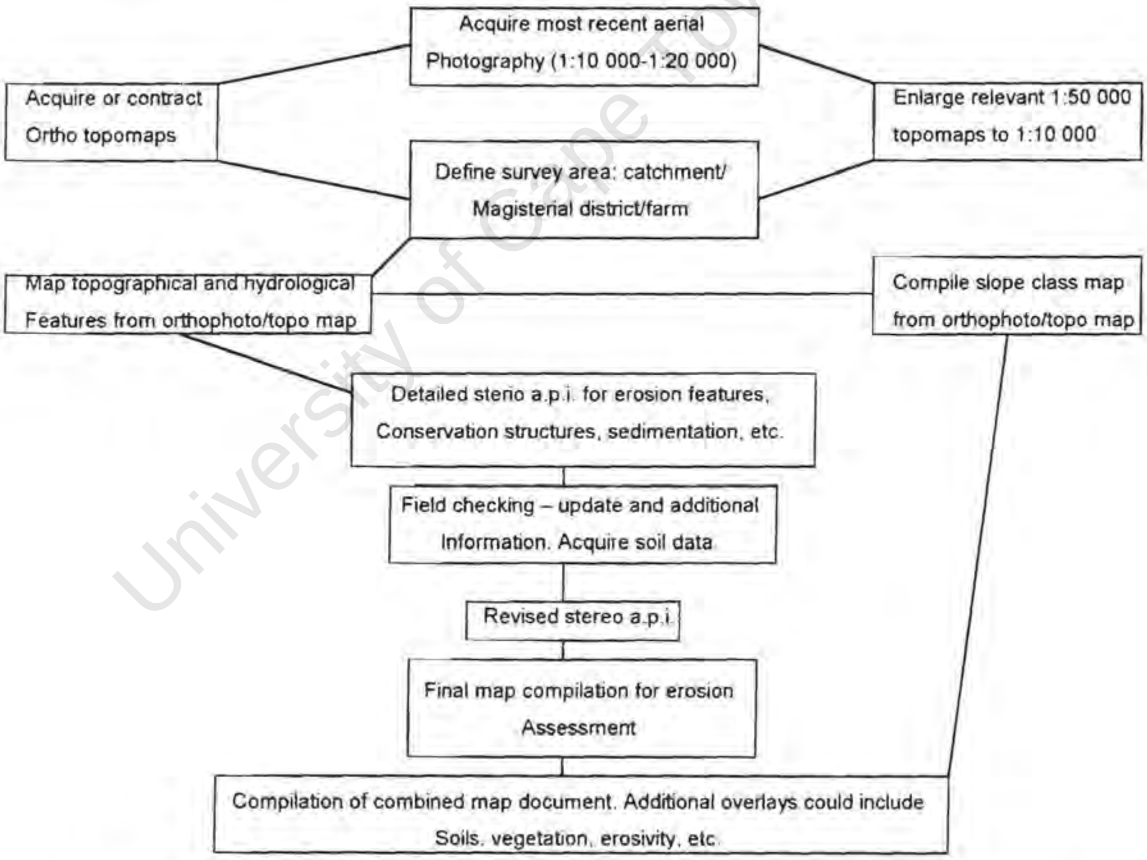


Figure 4.3 : Methodology to follow when assessing erosion (after Thwaites ,1986)

Table 4.2: SARCUSS classification for erosion mapping

TYPE OF EROSION	CLASS OF EROSION	SYMBOL	DESCRIPTION AND REMARKS
1.EROSION CAUSED BY WATER			
SHEET (SURFACE) Uniform removal of surface soil	None apparent	S1	No visible signs of erosion on air-photo. Level of management appears to be high
	Slight	S2	Areas of light-tone observed on air-photo. Erosion deduced from poor cover, sediment deposits and plant-pedestals.
	Moderate	S3	Eroded areas obvious on air-photo. 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 Removal of soil in small channels or rivulets, mainly on arable land	None apparent	R1	As for sheet erosion
	Slight	R2	Small, shallow (mainly <0.1m) rills present but not really observed on air-photos
	Moderate	R3	Rills of considerable depth (mainly 0.1-0.3 m) and intensity usually observed on air-photos.
	Severe	R4	An abundance of deep rills (less then 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) Removal of soil in large channels or gullies by concentrated runOff from large catchment areas	None apparent	G1	As for sheet erosion
	Slight	G2	Clearly observed on air-photos and usually up to 1m deep. Cannot be crossed by farm machinery.
	Moderate	G3	Intricate pattern of deep gullies (mainly 1-3m) exposing entire soil profile in places. Many 'islands'of top-soil remain.
	Severe	G4	Landscape dissected and truncated by large (3-5m) gullies. 25-30% of area unproductive.
	V.Severe	G5	Large and deep (often > 5m) have totally denuded over 50% of the area.
LANDSLIDE Soil mass slumps downwards leaving vertical scarp	Five classes rating also apply to these types of erosion, but are seldomly 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 (>15%) in high rainfall areas. Aggravated by trampling
CREEP Gradual viscose movement of slopes		C	A natural phenomenon which may be observed in mountaineous areas. Recognition aided by recognition of other features. Not readily observed on air-photos.
STREAMBANK Undercutting and slumping of stream or river banks		B	Occurs on outer curves of streams and rivers where fast-flowing water undercuts the banks. May or may not be seen on air-photos.
2.EROSION CAUSED BY WIND			
WIND Sandy materials (>85% sand) removed by suspension, saltation and creep during strong winds	None apparent	W1	Seldom observed in well vegetated and humid areas where clayey soils predominate.
	Slight	W2	Not readily observed on air-photos. Field chacks show evidence of removal and deposition and loamy soils(15-35% clay and 65-85% sand) may predominate
	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 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

There were two major phases of data collection involved in this study, followed by a field verification after results of the data capture were interpreted. All the data collected for the study were in the same season, therefore eliminating any seasonal differences caused by rainfall variation and growth season. See Table 4.1 for the scales and times of year that the photographs were taken.

4.3 **DATA COLLECTION**

Using a stereoscope and magnification the first phase of data collection of the study was done. The work was conducted at the Department of Surveys and Lands at Mowbray with the kind assistance of their staff, and using their equipment. The aerial photographs dated from 1938, 1974 and 1986(wind) and 1989(water). (Table 4.1). The 1938 photographs were only partially mapped to compare them to the map compiled by Talbot (1947); it was found that the existing maps were composed very accurately and therefore further reference was made using Talbot's map for the 1938 part of the mapping. The aerial photography available for 1974 is on a scale of 1:30000 but also on 1:10 000 orthophotos the base maps were compiled from these orthophotos, with the combination of the topographical map sheets of the area. Further mapping was done from the ortho-corrected photographs. The procedure followed was to place a sheet of transparent film over the photographs and trace the areas of erosion from there onto the film, from where it was later digitised onto PC Arc/Info and later exported to workstation Arc/Info and Arcview for further analysis. The SARCCUS system was used to determine what erosion features needed to be added to the maps. No classification of the severity of the erosion was made however. This classification was not part of the aim of this study: for water erosion the only factor taken into consideration was the occurrence of gullies in the area, while gullies that were identified as being very stable or part of the natural drainage were in most cases ignored.

Wind eroded areas on cultivated land were digitised, since Talbot only mapped the wind erosion on the agricultural lands. The areas were outlined and digitised as interpreted by the author to be areas of wind erosion. Areas of wind erosion were determined to be those areas with lighter colours on the aerial photographs, as sand would have a greater reflection than overgrown areas indicating wind blown sand to be present. A seen in Hallward's (1988) unpublished Master's thesis, the method of using aerial photography for detection of wind erosion is a good way to determine which areas are under strain. As she states "although not necessarily indicative of actual erosion, it does illustrate that potential wind erosion is high in these areas..." (Hallward, 1988. P117). It can therefore be used as a first step to determine areas worth investigating for further signs of wind erosion.

Further information was obtained by personal communication with the conservation officer for the Malmesbury conservation area (Ollie Olivier and Hennis Germishuys from Elsenburg). Questions were formulated to better structure the information capture.

This led us to the second phase of data collection, namely the data capture phase. After the data were traced onto the transparent film all data necessary to fulfil the aim of this study was captured on PC Arc/Info. The process of data capture is one of digitally storing spatial information on the computer for later use, analysis and manipulation. The data that were captured for this study are topographic data obtained from the topographic maps of the areas and aerial photo data obtained from the transparency film used to trace the erosion areas onto with the stereoscope. Each different type of data was captured on separate layers or coverages, resulting in coverages of roads, rivers, contours and gullies developed; the location of homesteads was also captured. After the data were captured they still remained in different scales; all the coverages were in the digitiser co-ordinates. To be able to overlay all the coverages and to obtain the same scales, the data had to be in real world co-ordinates. This transformation was done after all the coverages had been cleaned and checked for error, thus solving any problems of comparing data captured on different scales. The transformation took place on workstation Arc/Info, from which further analyses were performed.

After the data had been further refined and transformed, 1:50 000 maps were created as hard copies of the data. No rectification of the aerial photographs was done, because of time and funds that were in short supply. Rectification was found to be unnecessary because of the nature of the study, such precise accuracy on measurements were deemed superfluous. The location and number of gullies and wind eroded areas were of more importance for a review of the situation on how many gullies and wind action areas were found. The use of aerial photography in the measurement of gully and wind erosion will give an approximate idea of the wind erosion situation.

The mapping was based on the 1974 1:10 000 ortho corrected photographs obtained from the Survey, combined with the 1:50 000 topological maps of the areas. The topological maps were used in 1:50 000 format, but digitised and transformed via Arc/Info into real world co-ordinates, therefore taking care of the difference in scale as it was overlaid with the transformed coverage of the data digitised from the ortho corrected photographs. As Thwaites (1986) mentions, this is useful, as it relates the image directly to the aerial photograph; therefore all relevant data can be transferred with little chance of error as mentioned earlier in section 4.1.

4.4. DATA ANALYSES

The quantification of the data is represented in the form of various histograms showing the trends. Data were analysed using the Statistics command in Arc/Info determining mean area and total area of wind erosion. The data is represented in the form of a graph visually depicting each period of investigation. Climatic data comprised of the rainfall figures of the Swartland area over the past 50 years from 1945 up to 1994 is represented in a histogram showing the general rainfall trends over the entire 50 year period.

A one kilometre by one kilometre grid spacing was used to compare the different years. By using the information contained in the grids for the creation of raster images (the number of gullies in each grid for water erosion and the area covered in each grid cell by erosion for wind erosion). It was decided to use 1km^2 for the grid cell size from the decision by Watson (1990), where she decided to use 1km^2 grids for her study on the recommendation from Young (1980) and Briggs and France

(1982). They deemed one km^2 cells to be the correct size for erosion mapping, as anything larger is likely to be too general and unreliable.

The comparison of the data was done based on the pair-wise comparison as found in the IDRISI GIS package. This procedure expresses a) the differences between two dates and b) the declassification of the differences into two groups, 1) the significant change group (real change) and 2) insignificant change group (expresses ranges of variability - thresholding). This is the simplest means to differentiate between two dates. Each cell in the output image is a subtraction from the corresponding cell from one image to the other. A positive indicates negative change, a negative indicates positive change, while a zero would indicate no change. The use of raster images, as well as vector images, can be motivated in the attempt to quantify the data. Whitlow (1992) and Watson (1990) did similar studies with the combination of raster and vector data.

The final stage of the data analysis was done with the personal communication to knowledgeable persons in order to add to a possible explanation for the results of the study.

After all the data had been collected and analysed, the field verification took place. This entailed field visits to check the results obtained against the situation prevailing on the ground. The next chapter deals with the results obtained following the methodology set out in this chapter.

CHAPTER 5: SOIL EROSION IN THE SWARTLAND AND SANDVELD: RESULTS AND DISCUSSION

5.1 INTRODUCTION

In the previous chapter the steps taken to fulfil the aim of this study, as described in chapter one, were discussed. This chapter examines the results obtained from following the steps as described in the methodology (Chapter 4).

5.2 AIR PHOTO AND GIS INTERPRETATION OF WATER EROSION

The result of the re-evaluation mapping showed extensive decrease in the number of gullies found in the study area from 1938 to 1989 when Talbot last mapped the area.

In the 55Km^2 study area of gully erosion near Riebeeckwes (Figure 2.1), there were a total of 678 gullies in 1938 longer than 50 m in length (only gullies larger then 50m were mapped due to the scale problems incurred by using aerial photographs of such varying scales). In 1974 this number decreased to 249 gullies, and in 1989 there were only 99 gullies. This translates to a decrease in the number of gullies of 63% from 1938 to 1975 and 60% from 1975 to 1989. The total decrease from 1938 to 1989 is 85% as illustrated in **Figure 5.1**.

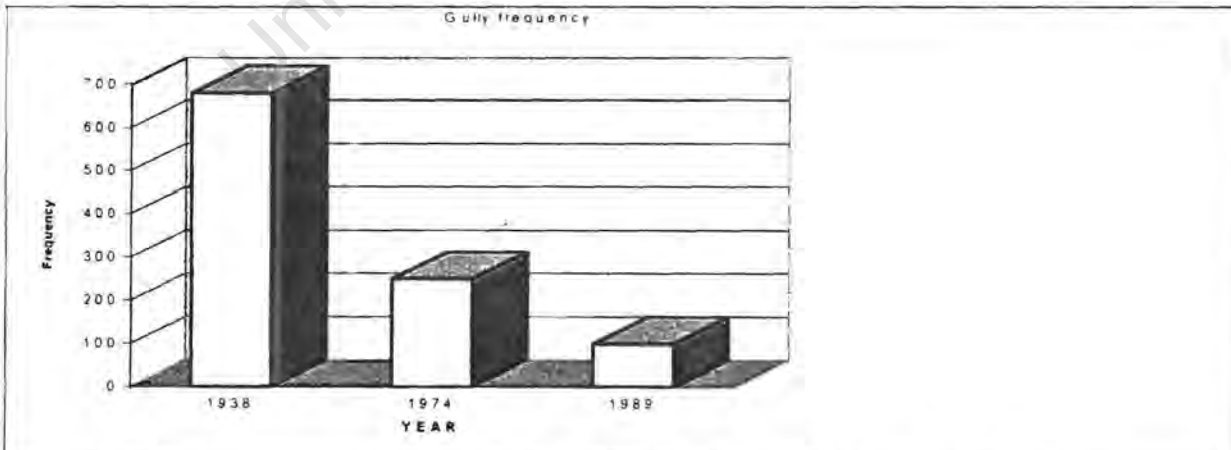


Figure 5.1: The percentage decrease in the gully density from 1938 to 1989 is 85%.

The density of gullies decreased from 12.3 km^2 in 1938 to 4.5 km^2 in 1974 and in 1989 there were only 1.8 gullies per km^2 as illustrated by the graph in **Figure 5.2**.

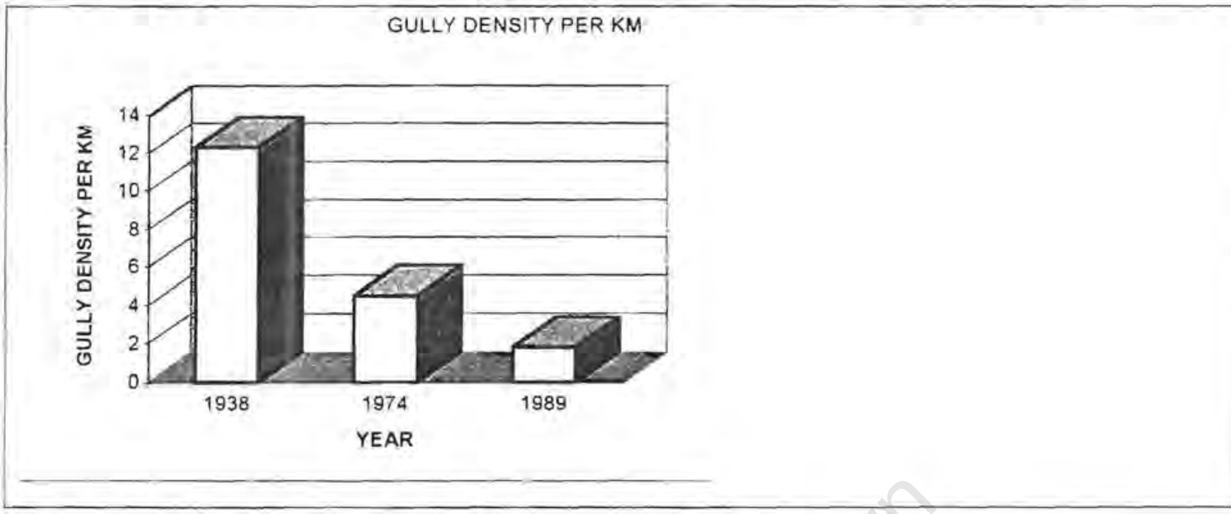


Figure 5.2: The density of gullies per km^2 decreased from 12.3 (1938) to 1.8(1989).

When visually comparing the resulting vector maps, from the data capture and transformation (**Figures 5.3a, b and c**), the change in the situations as found in 1938, 1974 and 1989 respectively, can clearly be seen on the maps. These data were quantified by imposing a grid of one km^2 on to the vector data resulting in the raster images that were later used in the pair-wise comparison. The decrease in the number of the gullies per square kilometre is clearly demonstrated by the comparison between the three years (**Figures 5.4 a, b and c**).

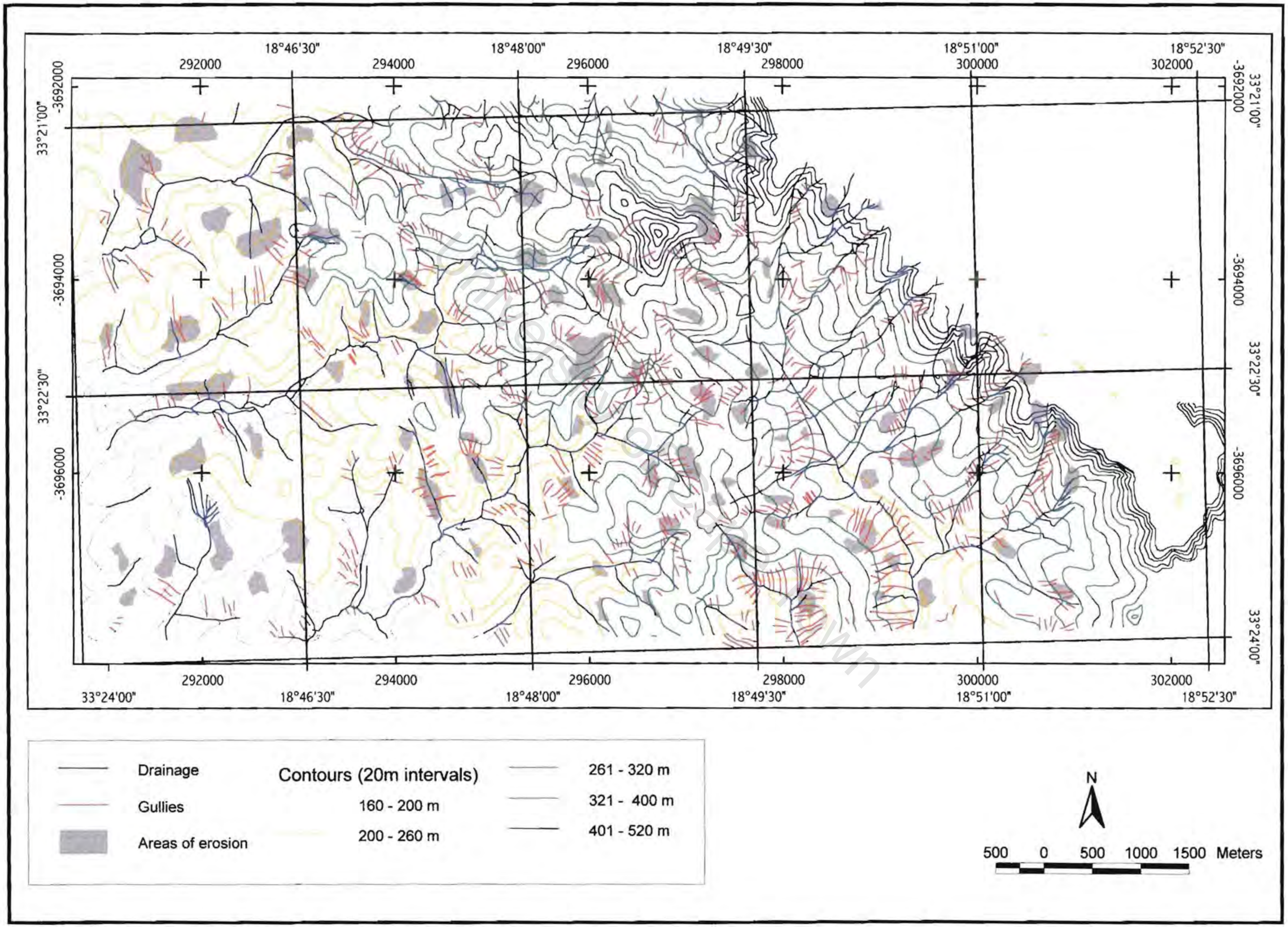
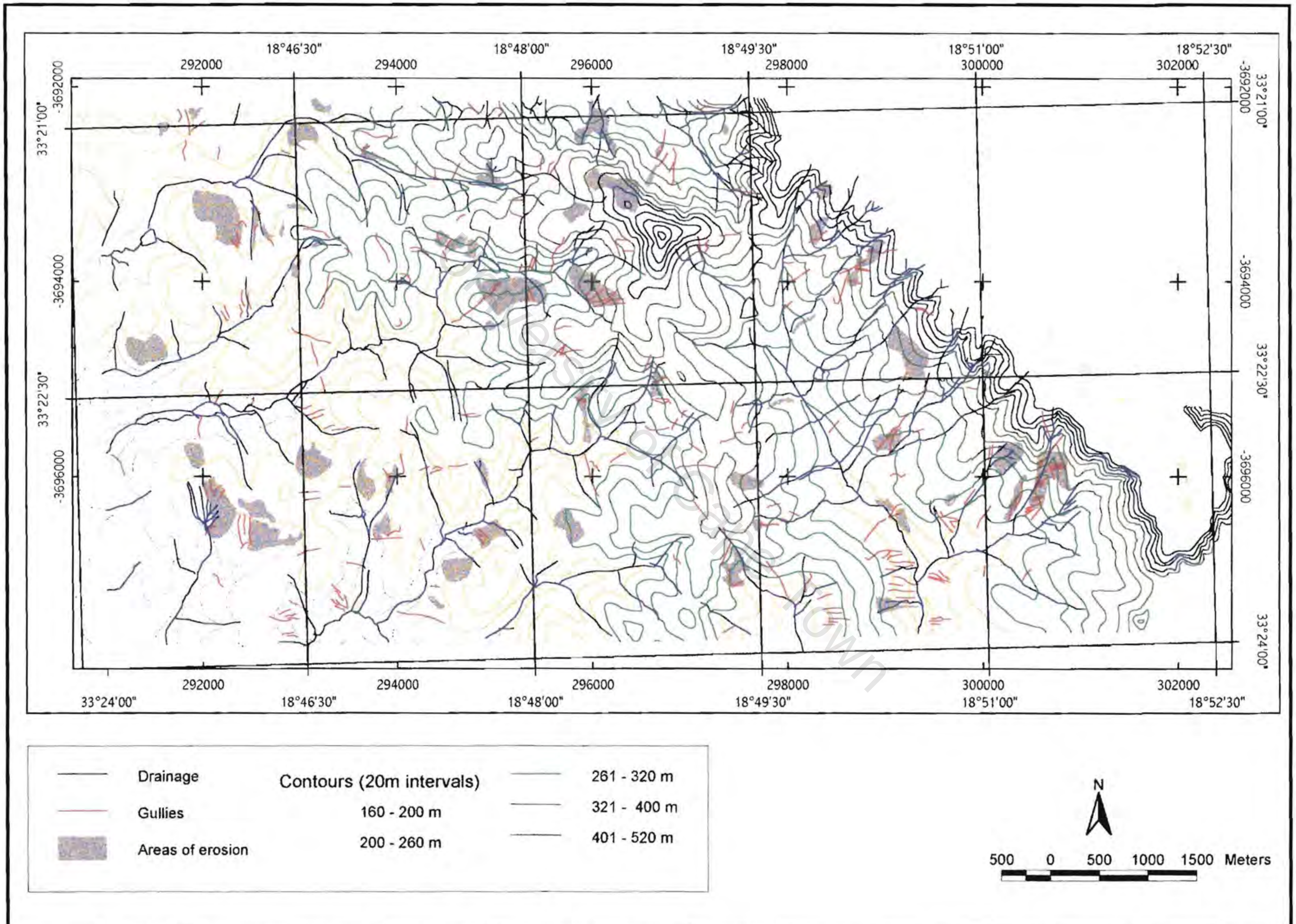


Figure 5.3a: Gully erosion in 1938

Figure 5.3b: Gully erosion in 1974



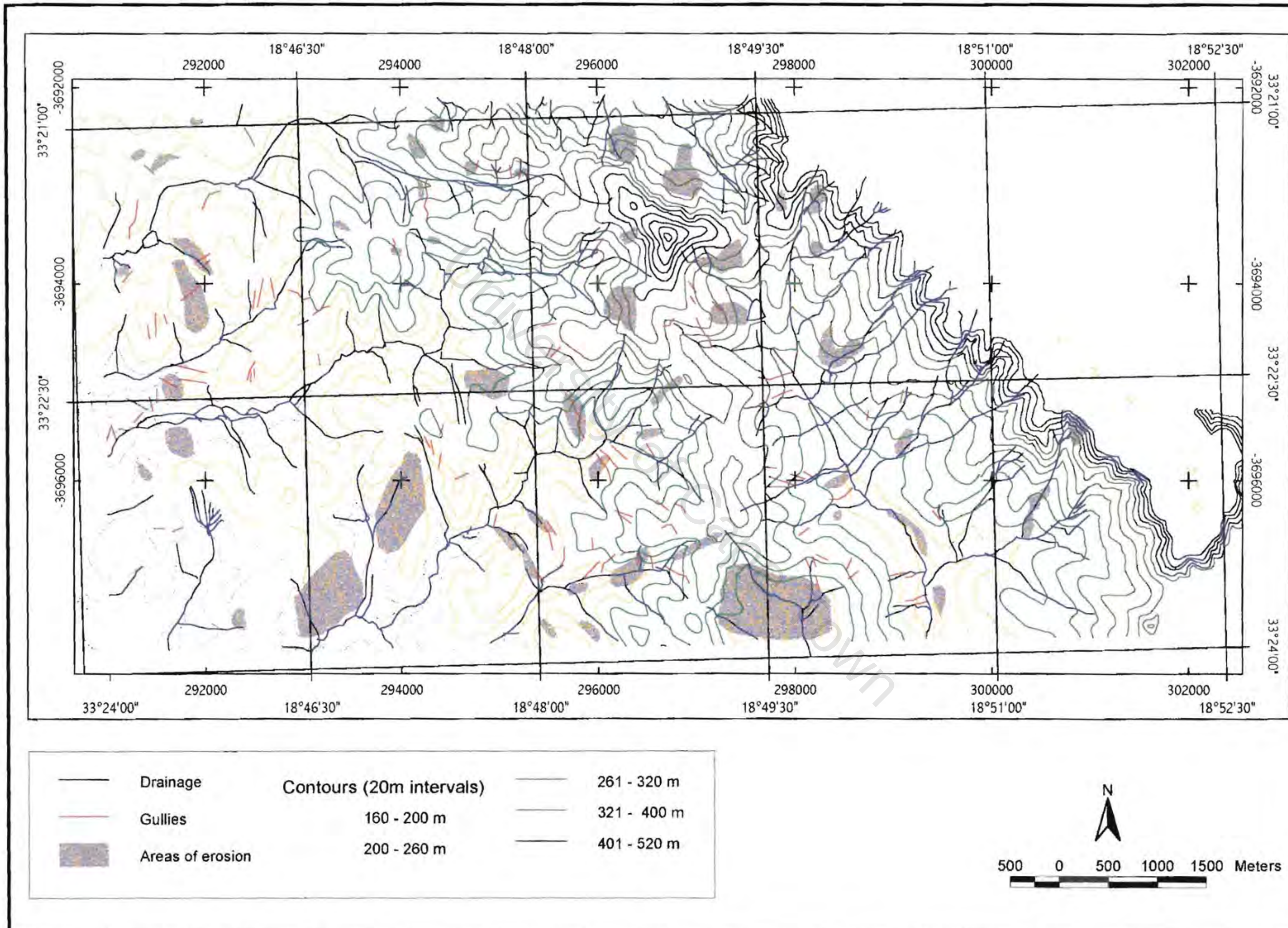


Figure 5.3c: Gully erosion in 1989

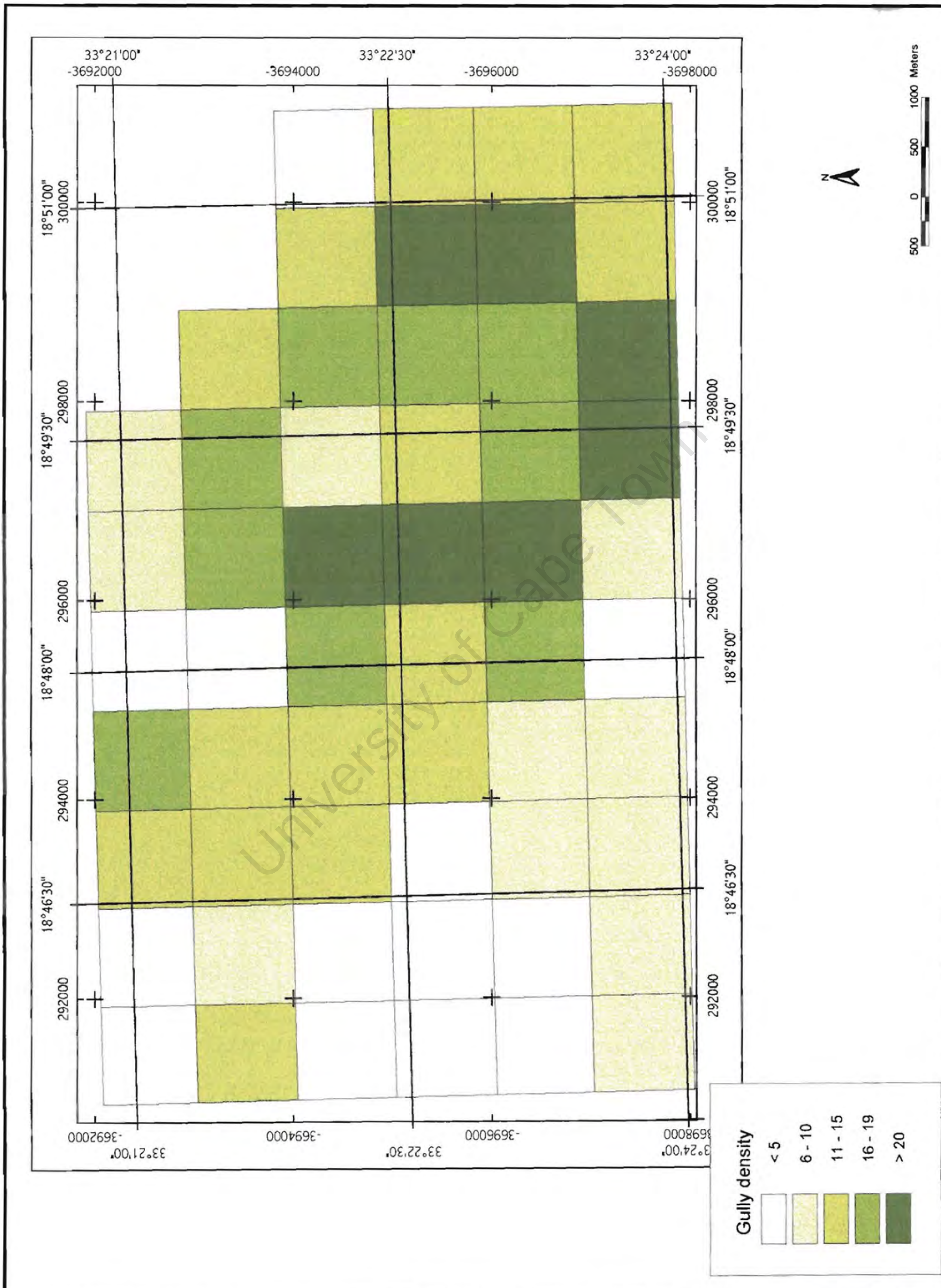


Figure 5.4a: Raster image of the gully density in 1938

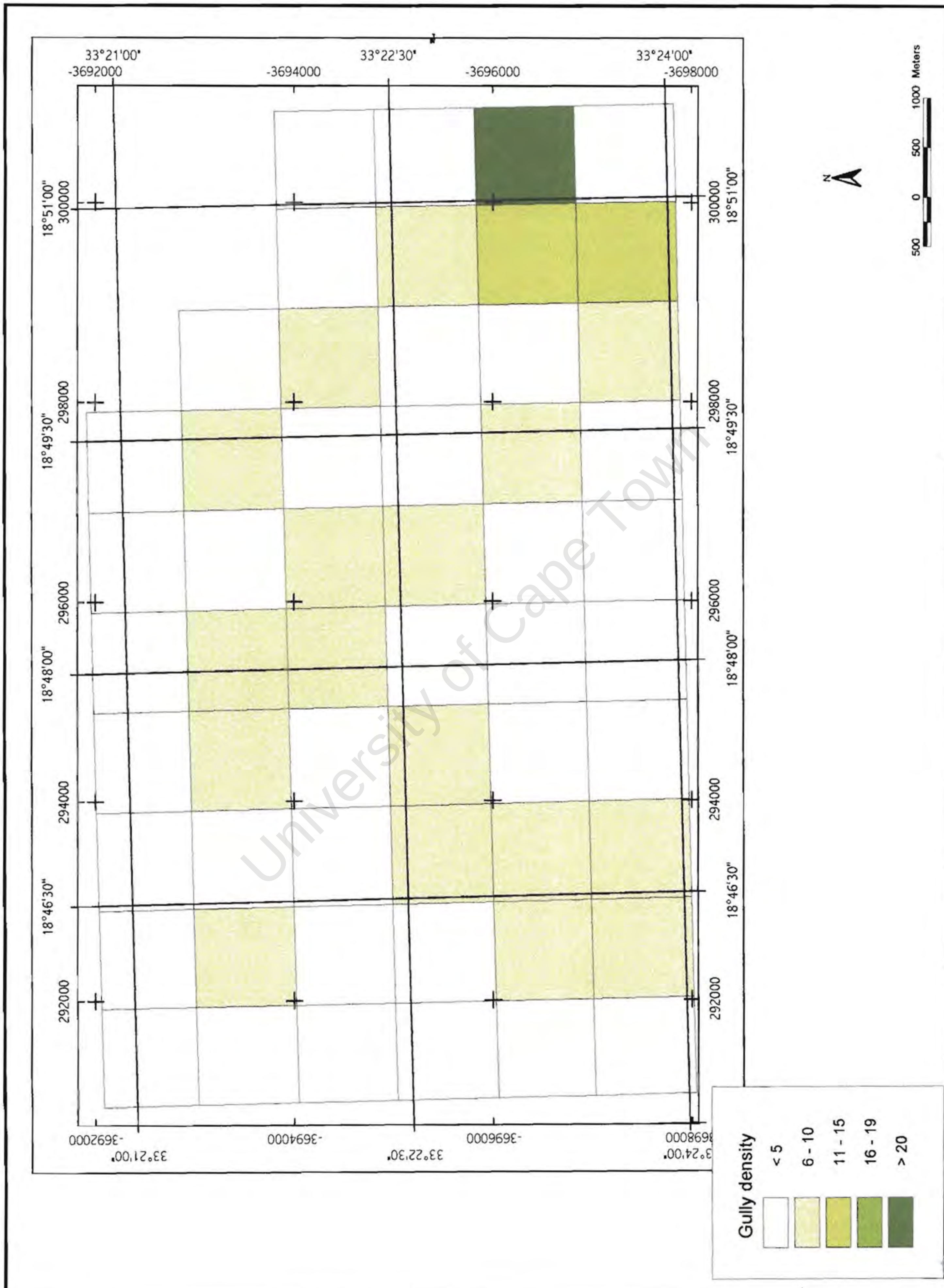


Figure 5.4b: Raster image of the gully density in 1974

Figure 5.4c: Raster image of the gully density in 1989

The decrease in the density of gullies on the eastern side of the study area is marked and it is clear that the main concentrations of gullies are found on the steeper slopes (Figures 5.3 a-c). The situation regarding the erosion on the slopes from 1938 to 1994 can be seen in **Figure 5.5a and b** where two photographs from a similar slope are compared. The photograph from 1938 (Figure 5.5a) illustrates a slope with large gullies running lengthways down the slope resulting in a huge gully where the drainage accumulated at the foot of the slope. The photograph from 1994 (Figure 5.5b) illustrates a similar slope on which contour farming is practised, with an old gully at the foot, but no gullies running down the slope. The gully at the foot of this slope indicates that this slope could have been subject to a similar situation as depicted in the slope illustrated in Figure 5.5a.

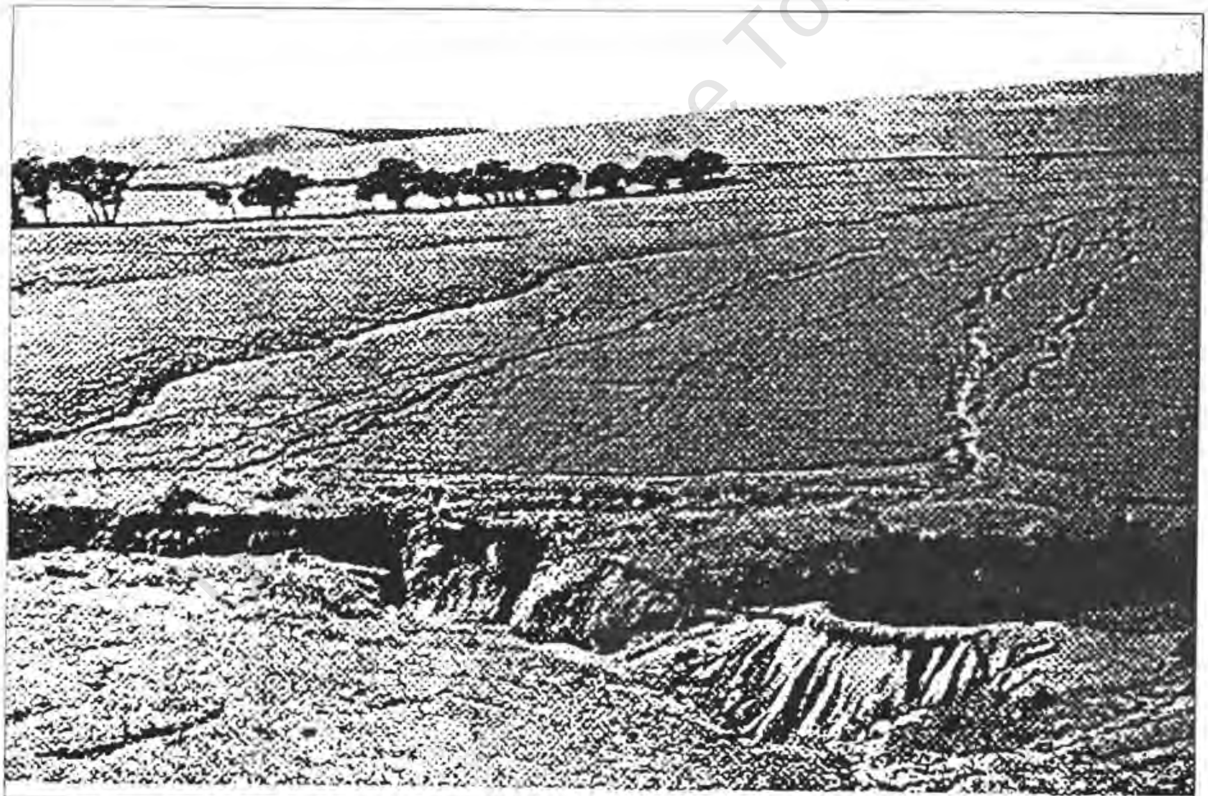


Figure 5.5a) : Gully erosion in 1938 on a slope with a resulting gully at the bottom caused by the runoff from the slope (Talbot, 1947).

The 1974 image (Figure 4.5b) shows a vast improvement in the situation as a whole except for a portion in the south-east where the gullies have actually increased in number on a steep slope at the foot of the Kasteelberg.

Figure 5.5b): A similar slope with an old gully at the bottom indicating erosion from years past, but the contour walls preventing further gullies from forming can clearly be seen in the background on the slope in 1994. The areas of light soil visible at the bottom of each contour wall show a new form of soil erosion resulting from the contour walls.

The 1989 image (Figure 5.4c) reveals that the situation on the western side, with lower gradients, actually worsened slightly compared to previous years, even though the rest of the area shows remarkable improvement. Further processing by using a pair-wise comparison of the grid data reveals the amount of change from one image to another (**Figure 5.6a, b and c**). The data was derived from the difference in the quantity of gullies present in each square kilometre. A negative number represents a decrease in the gully density, (10 gullies in 1938 and 3 gullies in 1989 yields a result of –7 gullies), with a positive number signifying an increase in the amount of gullies from one year to the next. The data on the images representing 1938, 1974 and 1989 were divided into classes of amount of gullies in each square: 0=No Change; + / - 1-5=Slight Change; + / - 6-10=Significant.

In these raster images this trend of reduction in the number of gullies can clearly be seen. From 1938 to 1974 (Figure 5.6a) most of the area shows significant negative change in the number of gullies per square kilometre. In 65.45% (36 km^2) the number of gullies decreased by between 6 to 25. Slight change was recorded in 10.9% (6 km^2)(1 to 5 improvement) and a further 10.9% showed no change. A further 10.9% showed a slight increase in the gully density (1-5) with only 1.82% (1km^2) indicating an area with significant gully density increase. In entirety the situation had a 65.45% significant decrease in the gully density, 32.72% (18 km^2) showed none to slight change with 1.82% showing a significant increase in the gully density.

From 1974 to 1989 (Figure 5.6b) 21.82% (12 km^2) showed a significant reduction in the number of gullies present per square kilometre, 54.55% (30 km^2) showed a slight change in the gully density. Areas of no change covered 1.82%, 16.36% (9 km^2) had little negative change with 5.4% (3 km^2) showing a significant degradation in gullies present. The change is therefore less severe than from 1938 to 1989 with the total situation being 21.82% of significant reduction in the gully density, 70.9% (39 km^2) of little to no change and 5.4% where the situation showed further increase in the gully density.

The total change from 1938 to 1989 (Figure 5.6c) amounts to 70.9%, with significant gully density decrease, 18.18 % (10 km^2) slight gully density decrease, 1.82% with no change and 9.09% (5 km^2) with slight gully density increase. No area has degraded significantly from the situation in 1938. Overall there was thus a significant decrease in the gully density of 70.9%, 29.09% (16 km^2) with no to slight change and no area with a significant gully density increase.

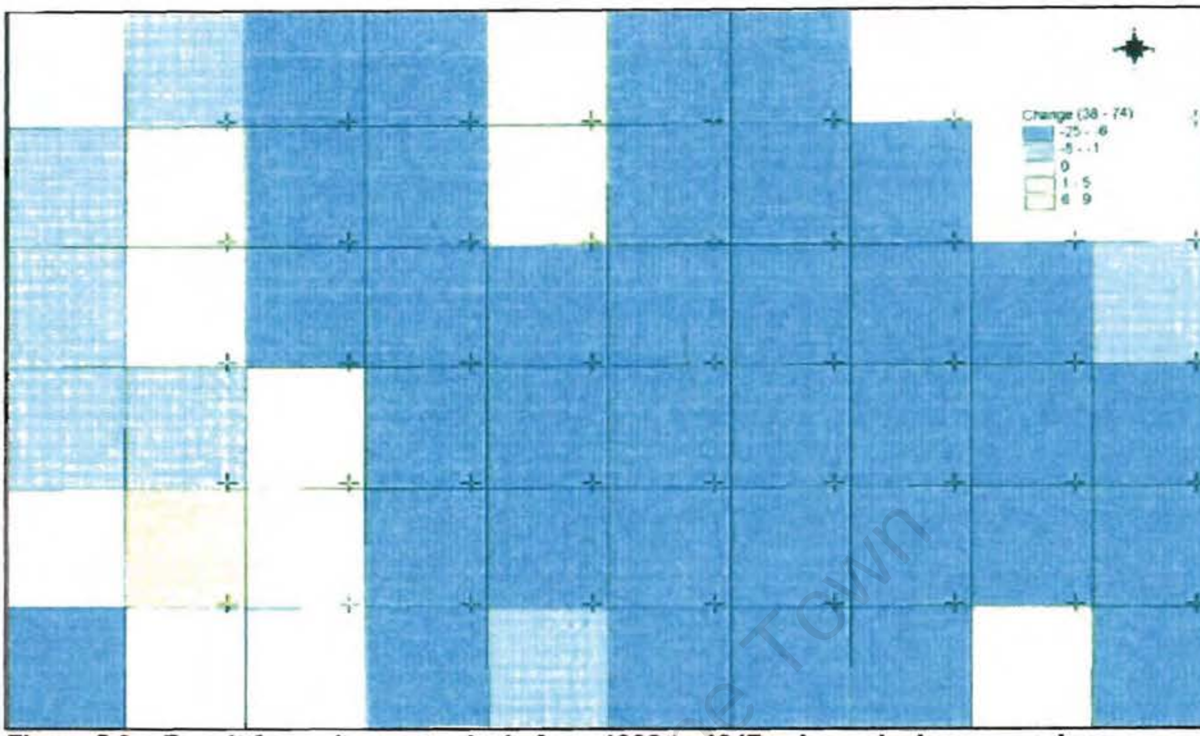


Figure 5.6a: Result from change analysis from 1938 to 1947 using pairwise comparison

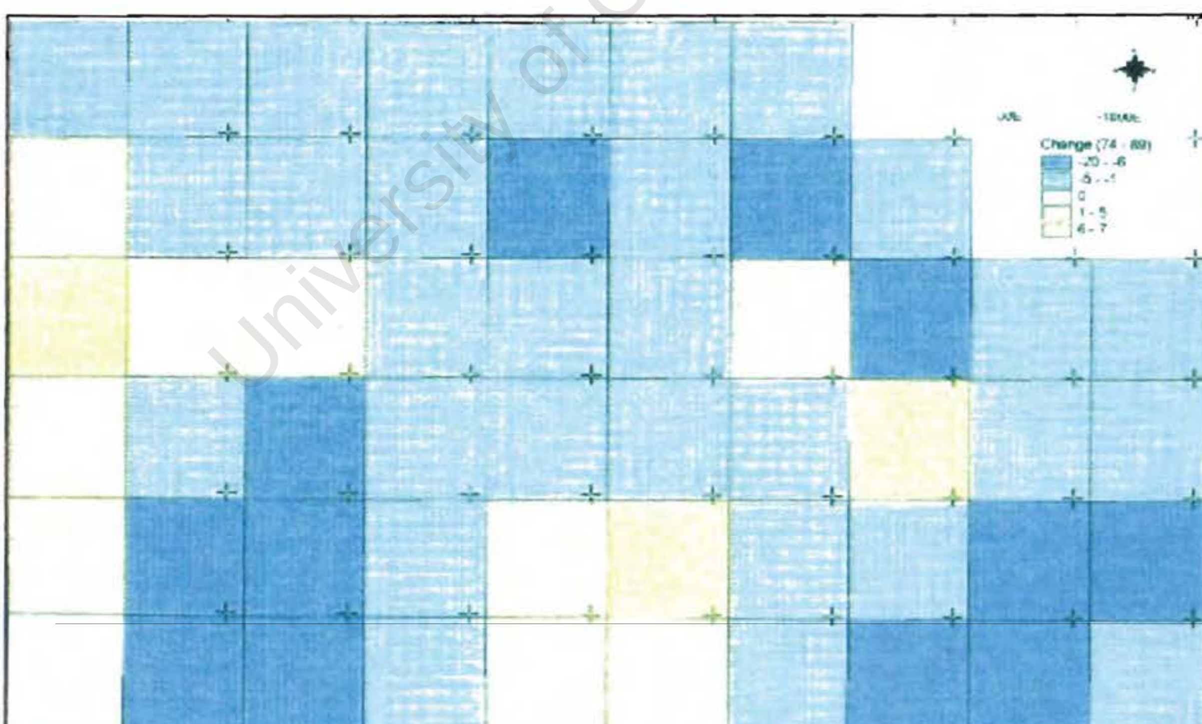


Figure 5.6b: Result for change from 1974 to 1989

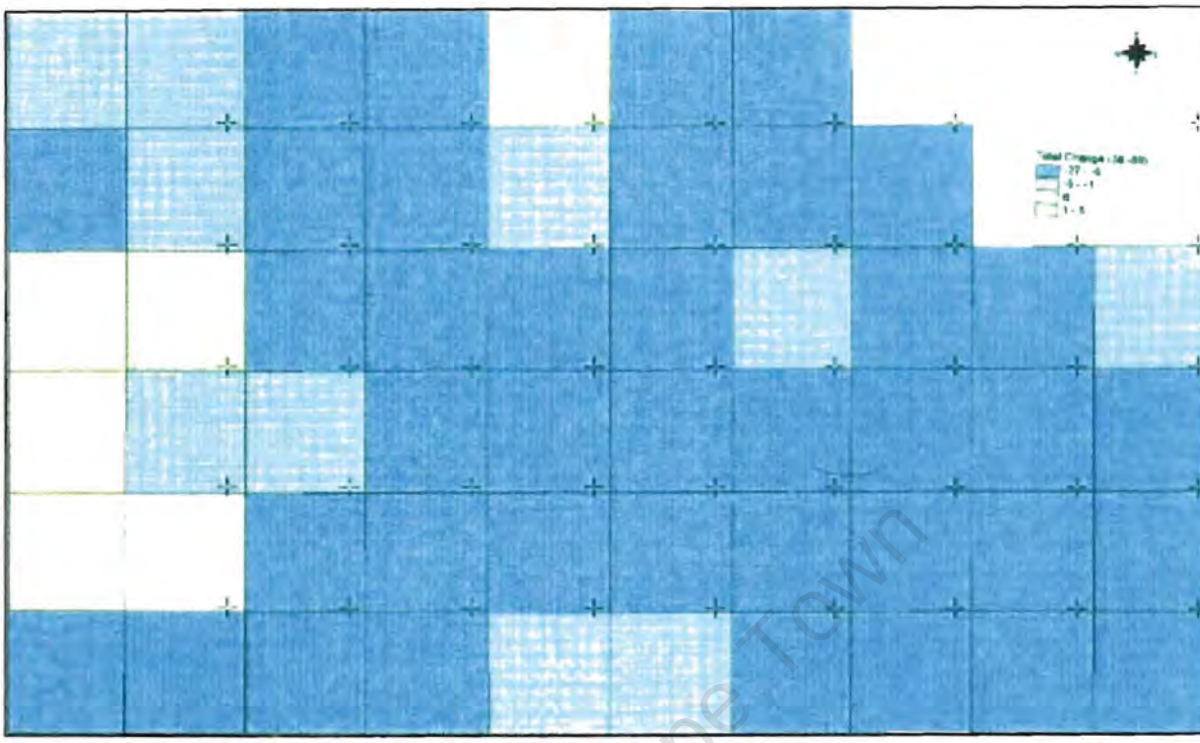


Figure 5.6c: Result from pair-wise comparison to show total change from 1938 to 1989.

Overlays were compiled using the change data (Figure 5.6a-c) illustrating the areas of gully density decrease, no significant change and areas of gully density increase from each year to the next and the spatial data of the actual gullies and erosion areas (Fig5.3a-c). The change data from 1938 to 1974 were overlain on the actual spatial data for 1938 and 1974 respectively (**Figure 5.7a,b**). Change data from 1974 to 1989 were overlaid on 1974 and 1989 spatial data (**Figure 5.7c,d**) as were the change data for 1938 to 1989 overlain on the 1938 and 1989 spatial data (**Figure 5.7e,f**) to show areas of gully density increase or decrease before and after. Showing the change of the situation by using the vector and the raster data to gives a better visual representation of change from one year to the next.

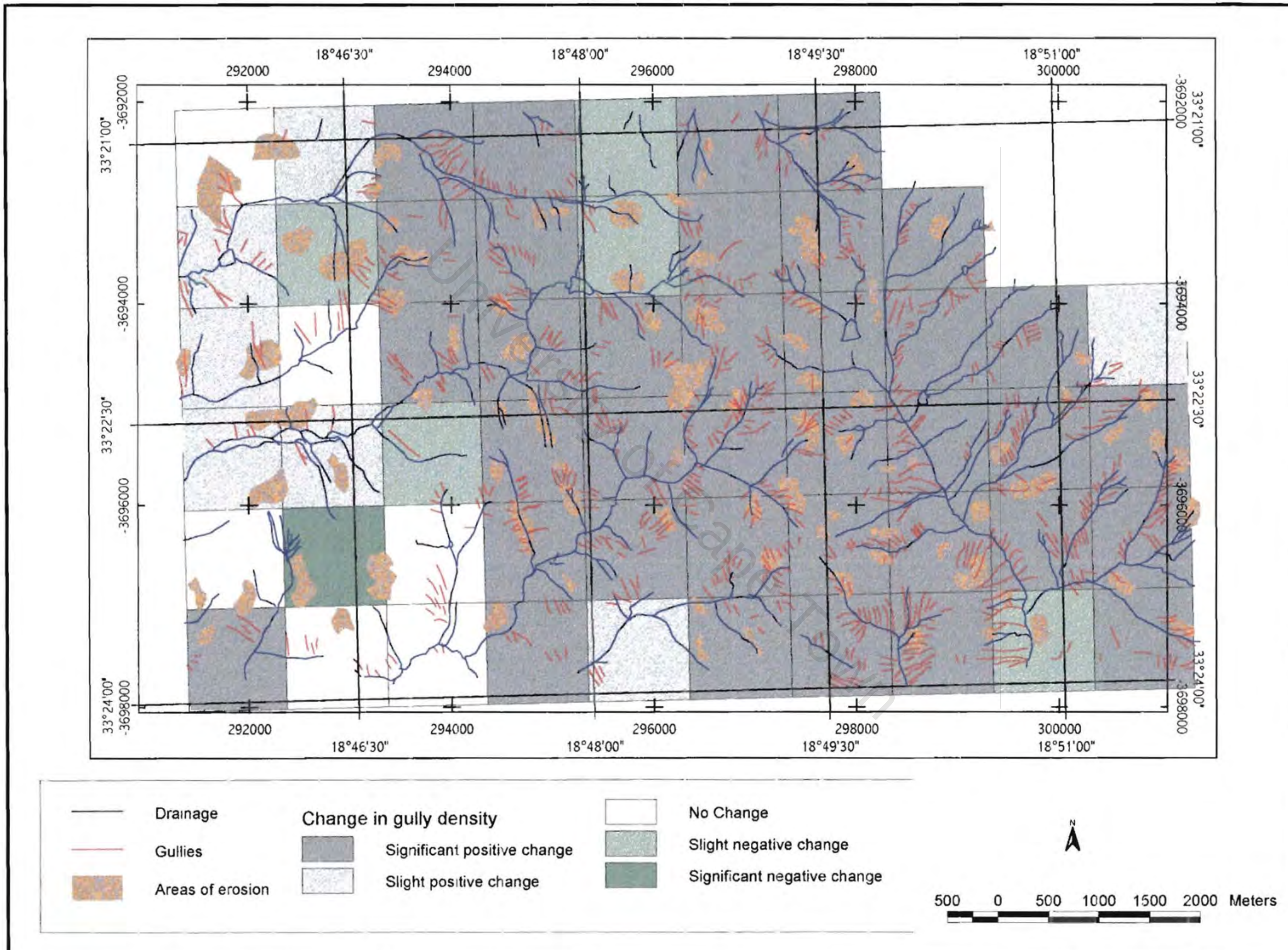


Figure 5.7a: Change in the density of gully erosion from 1938 to 1974 with the gullies and erosion area of 1938

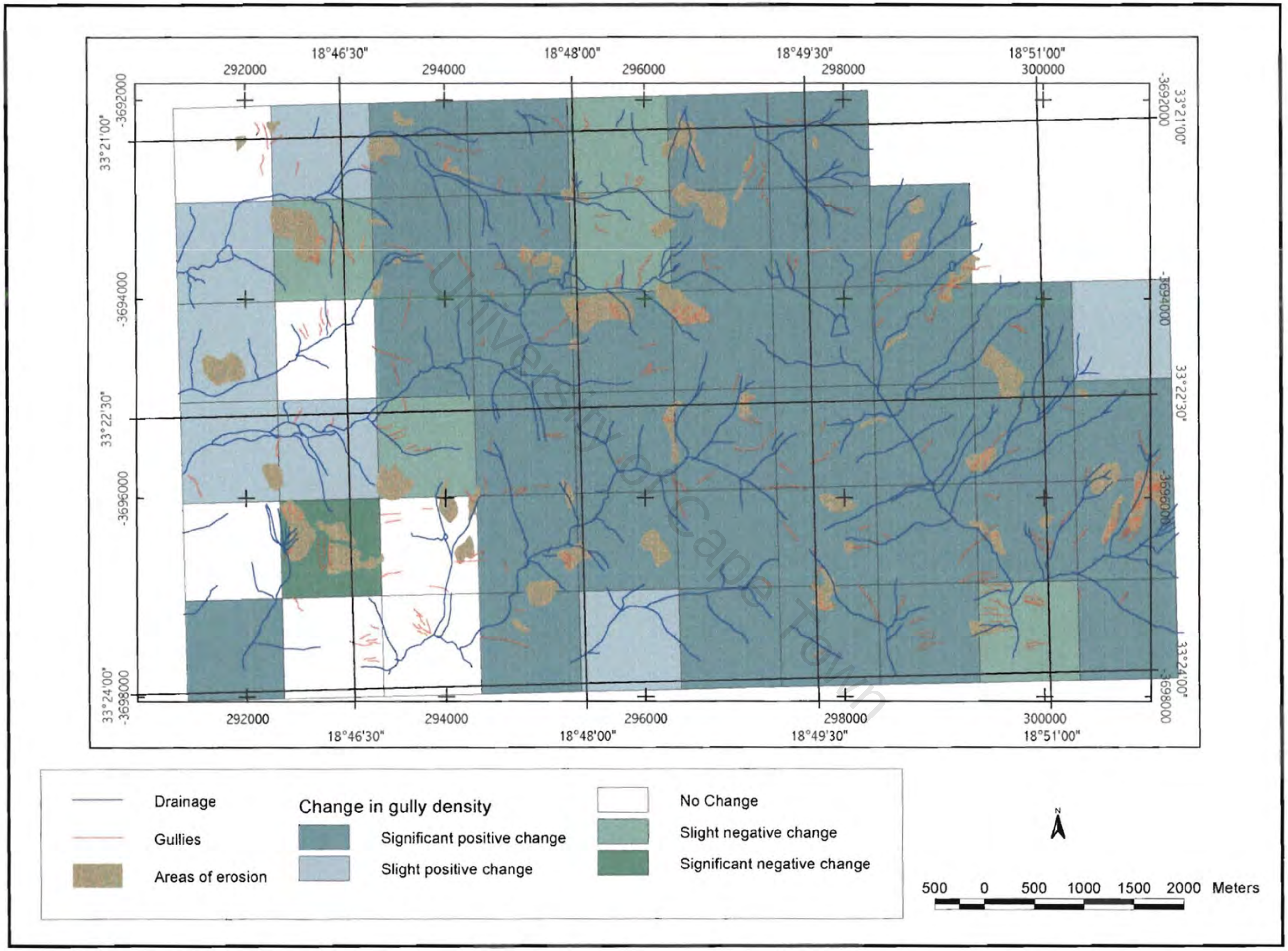
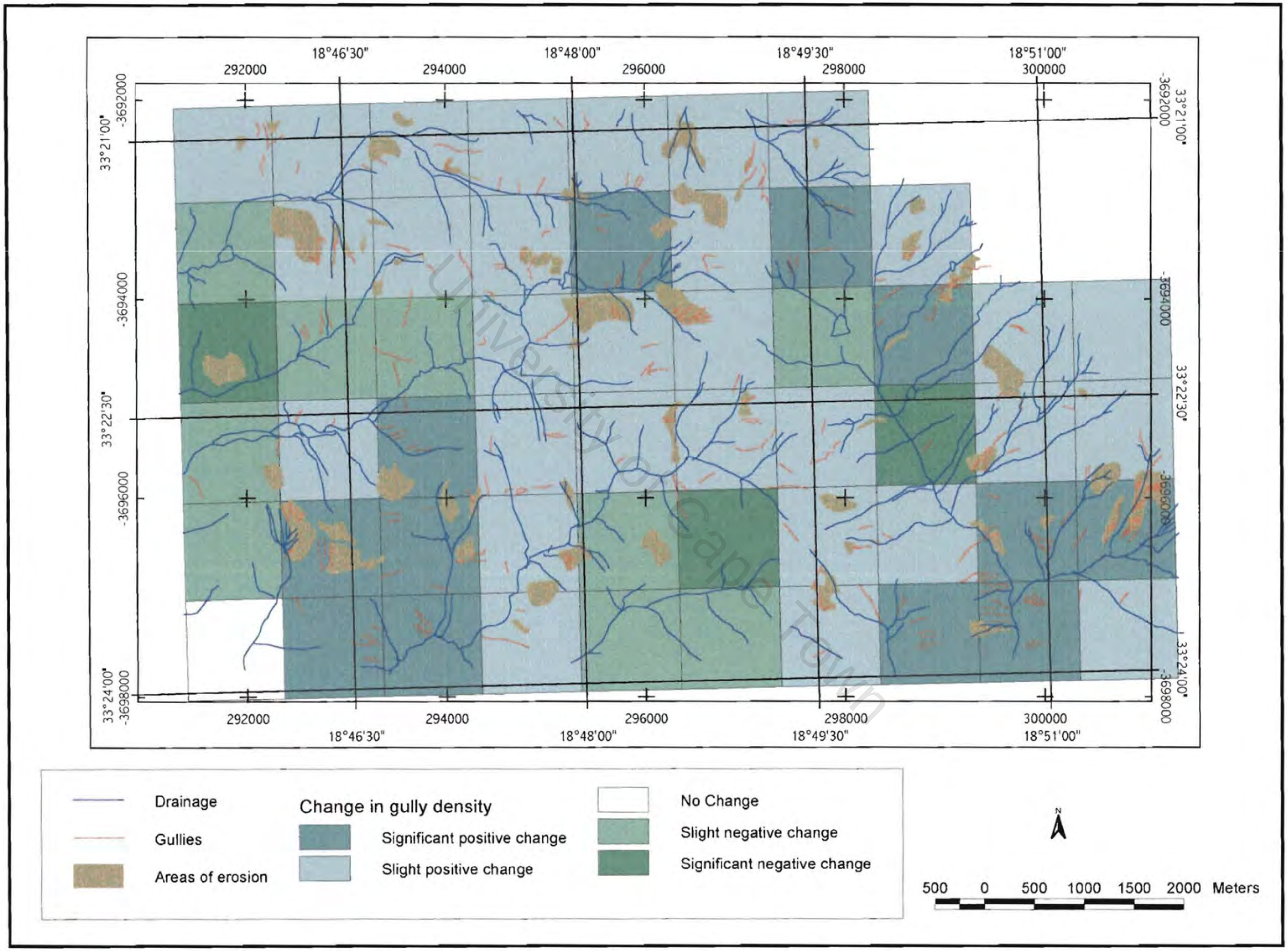


Figure 5.7b: Change in the density of gully erosion from 1938 to 1974 with the gullies and erosion area of 1974

Figure 5.7c: Change in the density of gully erosion from 1974 to 1989 with the gullies and erosion area of 1974



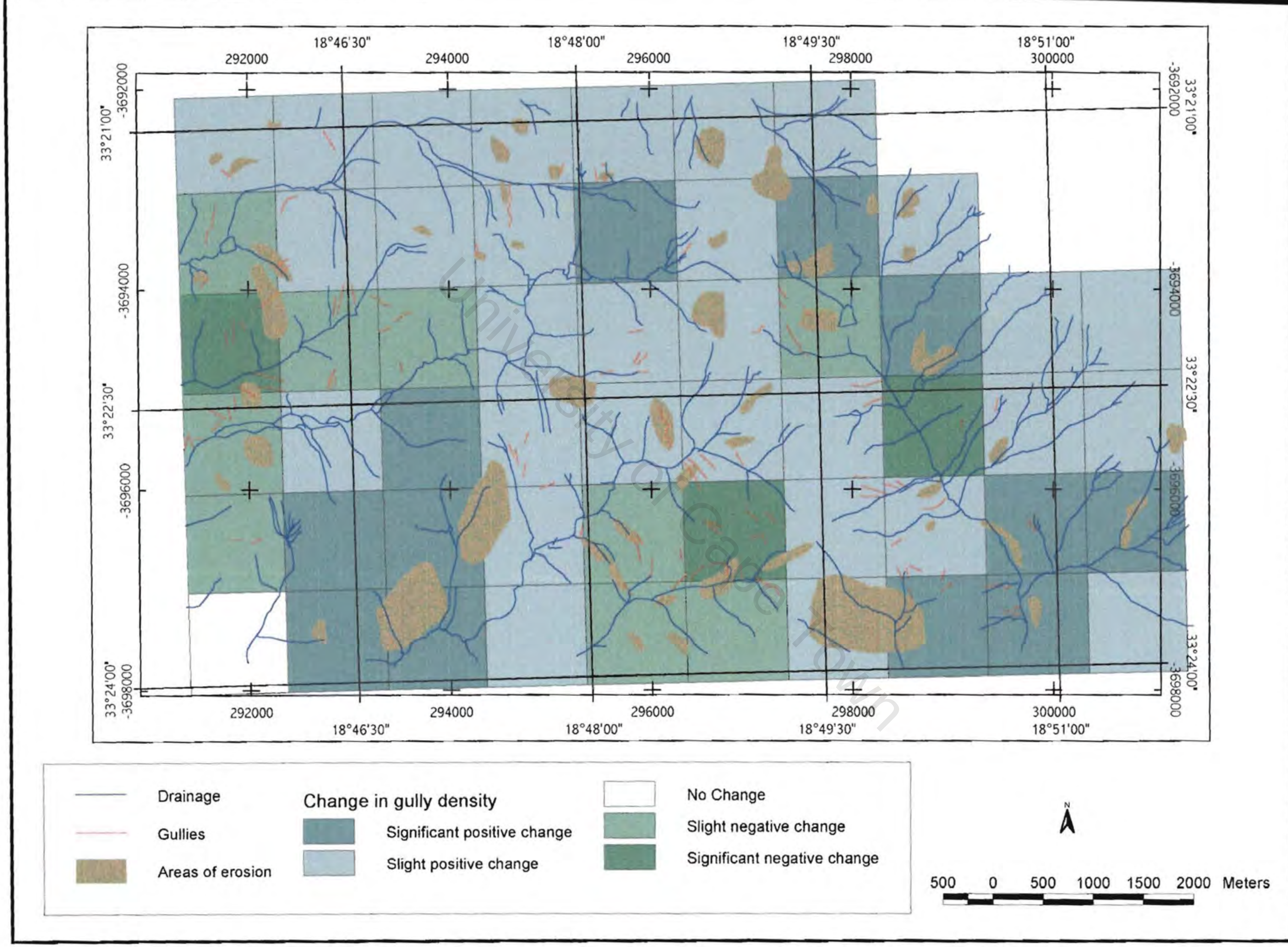


Figure 5.7d: Change in the density of gully erosion from 1974 to 1989 with the gullies and erosion area of 1989

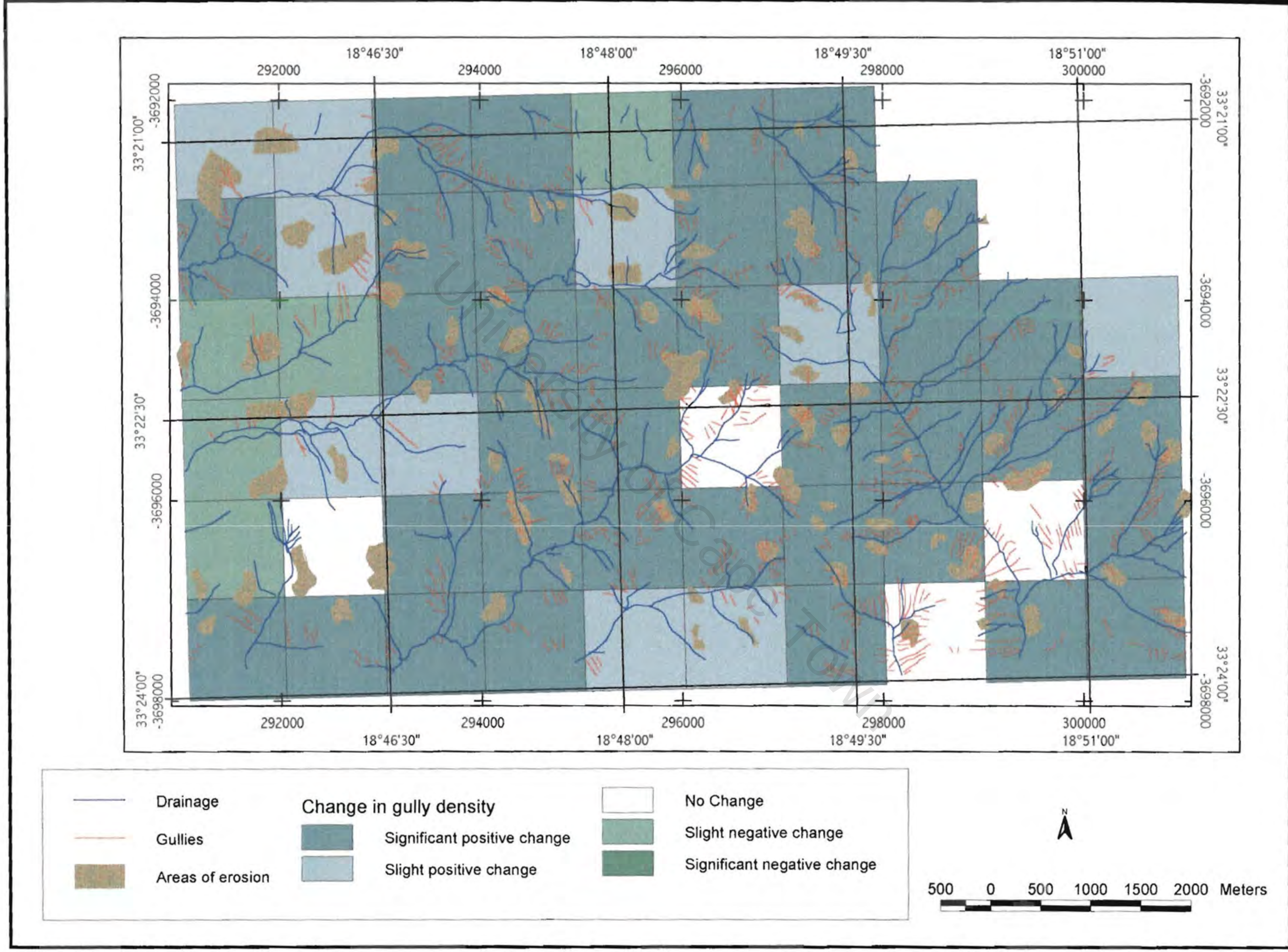


Figure 5.7e Change in the density of gully erosion from 1938 to 1989 with the gullies and erosion area of 1938

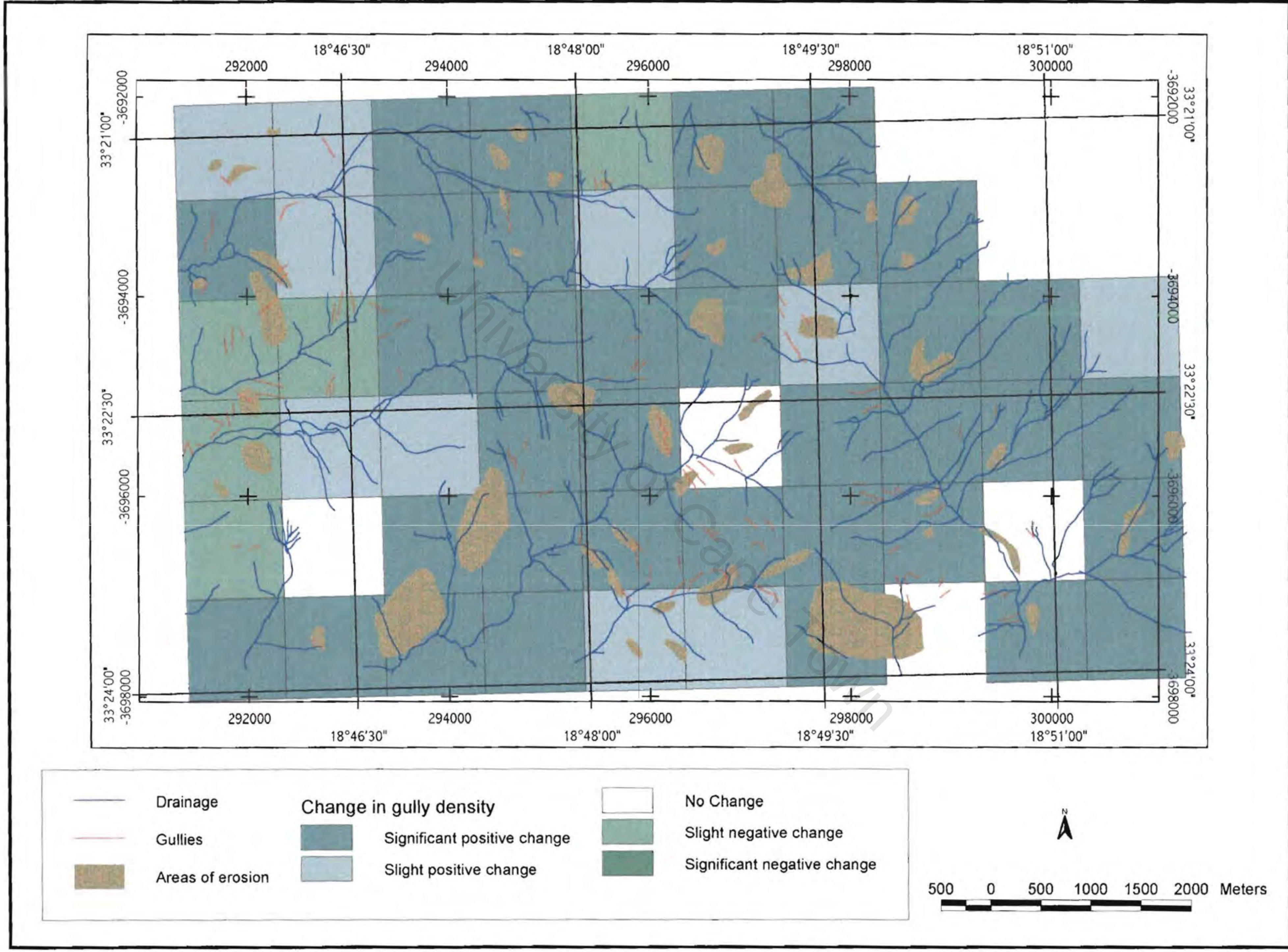


Figure 5.7f: Change in the density of gully erosion from 1938 to 1989 with the gullies and erosion area of 1989

By analysing the location of the different "erosion" areas, one can draw a comparison between the gullies of previous years to the "erosion" areas of the following year; the gullied areas are shown to have been improved to areas of "erosion". For an area to be mapped as an "erosion" area is that it has to be affected by some form of erosion, whether by sheet flow or degraded land or rills, but not containing any gullies (**Figure 5.8a, b and c**). Several gullies present in 1938 were replaced by "erosion" areas in 1974 (Figure 5.8a): the same trend can be seen on the figure showing the erosion present in 1989 as opposed to the gullies present in 1974 (Figure 5.8b) especially on the south, south-eastern and north western part of the study area. The most obvious correlation between gullies and "erosion" areas is illustrated by Figure 5.8c, which demonstrates the gullies in 1938 compared to the "erosion" areas of 1989. In this figure most of the "erosion" areas in 1989 corresponds with gullies in 1938. This demonstrates an improvement in the water erosion found in the Swartland, where gully erosion, which is the most advanced stage of water erosion, has been replaced by an area of "erosion", in this case remnants or erosion scars from previous years of severe erosion.

Field studies undertaken by Talbot (1947) in 1943 suggested that the rills observed in 1938 had grown to gullies. The gullies that were evident in 1938 had lengthened and their numbers increased in 1943, when Talbot (1947) did the field verification (Talbot, 1947; Germishuys, 1992). Field verification undertaken for the present study followed on the aerial photograph analysis and showed that only large gully systems now remain of the gullies initially identified in 1938. These gully-systems appear to be in a relative stable condition. There is still some evidence of erosion-activity but it is more localised, such as undercutting of the banks, piping and some widening after major rainstorms. Some gullies visited on field verification are eroded to the bedrock (Figure 4.2) and are actually used by the farmers as water ducts for the contour farming (H. Germishuys, personal communication, 1994). This in itself is not the ideal situation, since it encourages further erosion of the contour wall at the junction of the contour wall and the "duct" (old gully). Using old gullies instead of constructed waterways as ducts was, in most cases, a financial decision,

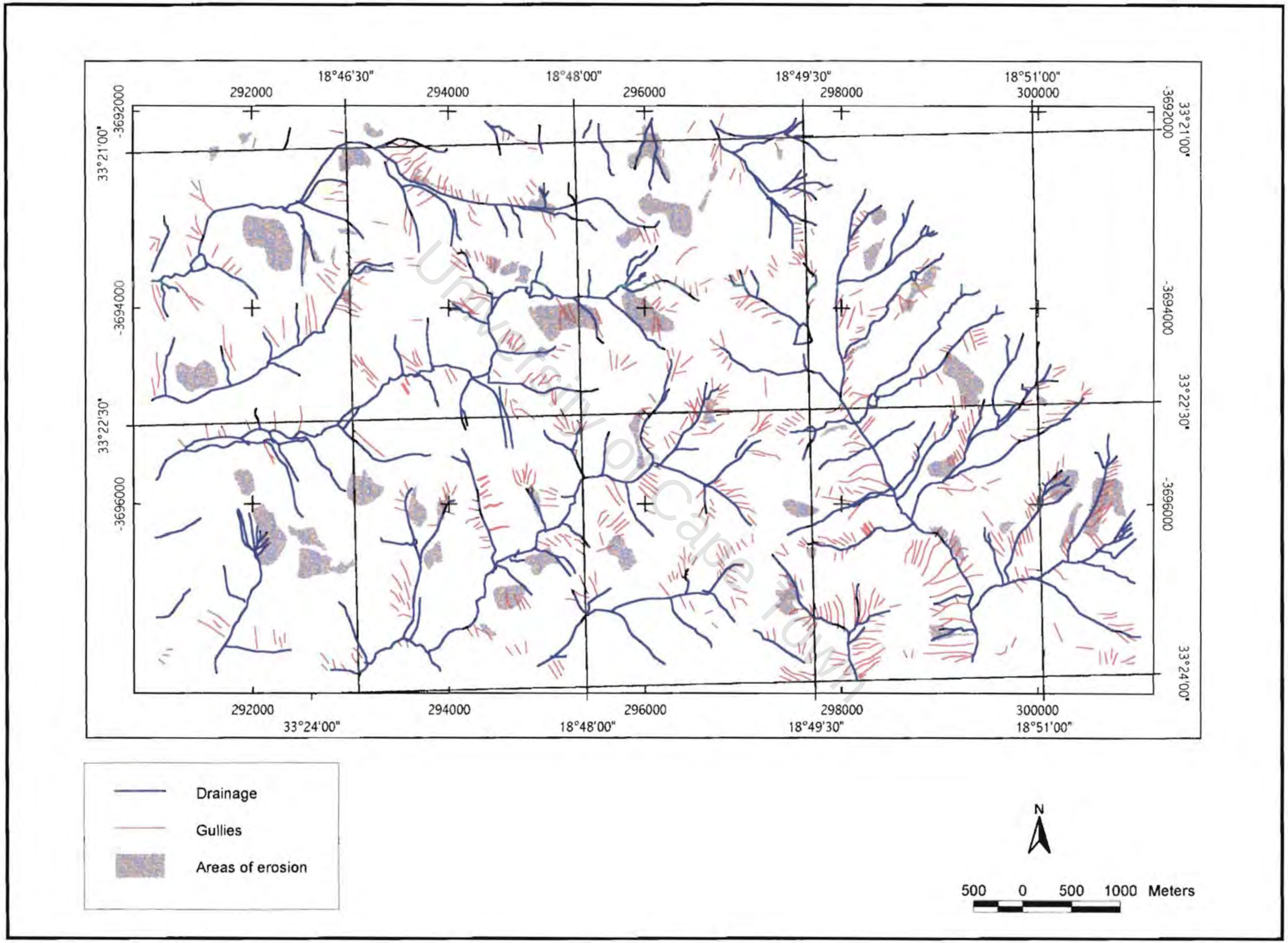


Figure 5.8a: Erosion area of 1974 with the gullies of 1938

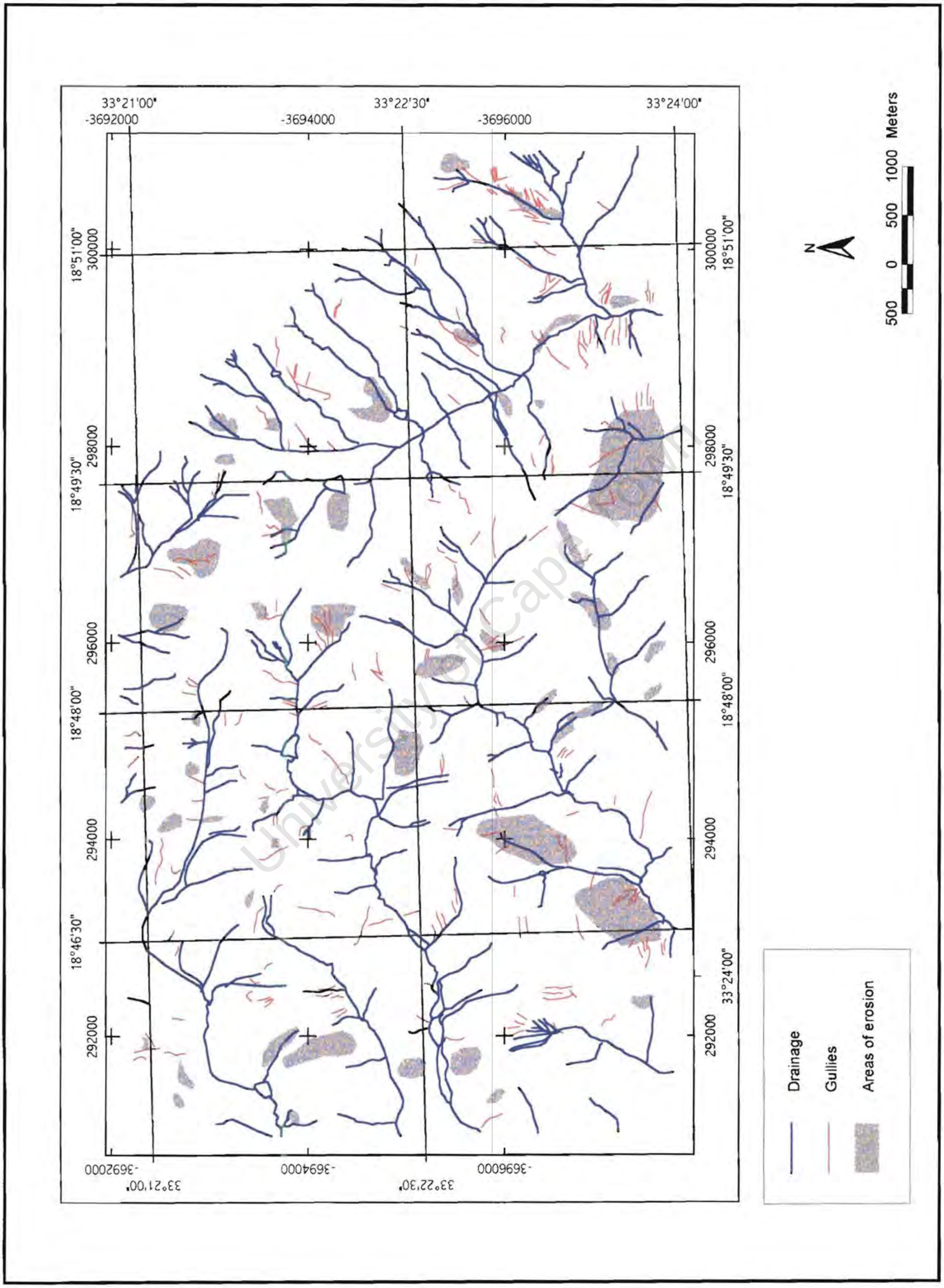


Figure 5.8b: Erosion area of 1989 with the gullies of 1974

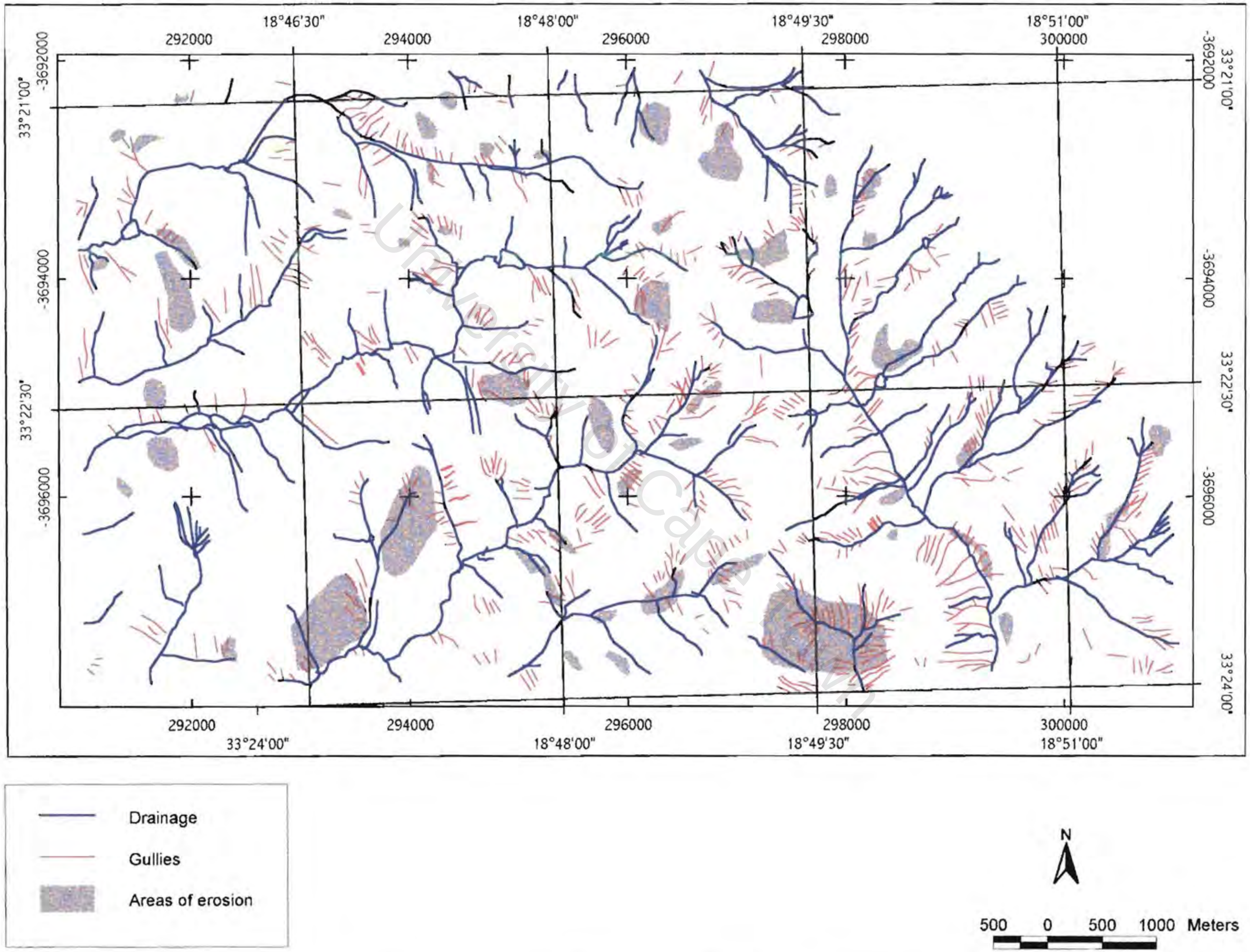


Figure 5.8c: Erosion area of 1989 with the gullies of 1938

due to the fact that the costs of soil conservation works are carried in part by the farmer because funds from the government do not cover all necessary work. From **Figure 5.9** the extent and size of one of these large systems can be seen. This photograph was taken on the Farm Boshof at the north-western border of the study area. The system starts up on a long steep slope that gently evens out.

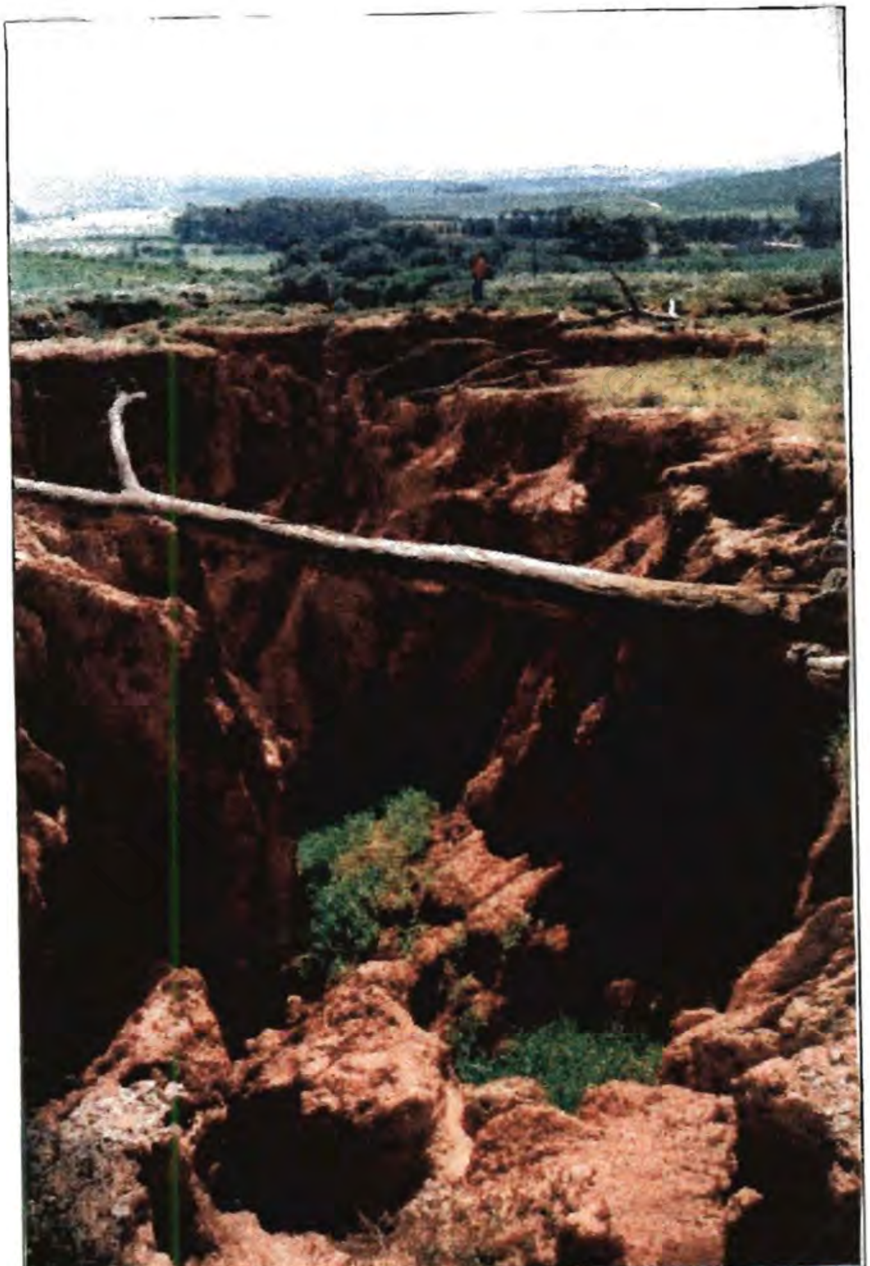


Figure 5.9: The large gully system which extends downslope on the farm Boshof.

A fact that became clear during the field verification is that new erosion is developing which is strongly associated with contour farming. Contour farming is an erosion prevention method commonly used in soil conservation, where the gradient of the slope is not too great, in accordance with the length of the slope. The interval of the different contours must be appropriate to the slope or this method is ineffective (Morgan, 1995). Contour farming implies that he farmer ploughs along the contours of the slope. These contours then act as a trap for excess water and channels the flow of water along the contours of the hills to the water ducts that lead the water down the slope of the hill without causing further gullies of erosion features on cultivated slopes (Morgan, 1995).

It can be seen that on various slopes, especially on the steeper slopes, the junction between the contour walls and the water ducts is being eroded down-slope, with associated bare soil in these areas as well as below certain parts of the contouring (Figure 4.2).

5.3 AIR PHOTO AND GIS INTERPRETATION OF WIND EROSION

Talbot (1947) only mapped the wind erosion as found on arable lands. The wind erosion mapped for the present study is a 55km^2 area in the Langebaanweg area. If one observes **Figures 5.10a, 5.10b and 5.10c and Figures 5.11a, 5.11b and 5.11c,** it is evident that the areas affected by wind erosion became less continuous and occupied smaller areas each which covered less ground. The result obtained by applying a GIS analysis method "Union" to the wind erosion situation, showed that the area under aeolian action that coincided with areas of arable land, showed a slight decrease from 1938 to 1986.

Fig5.10a : Wind erosion in 1938

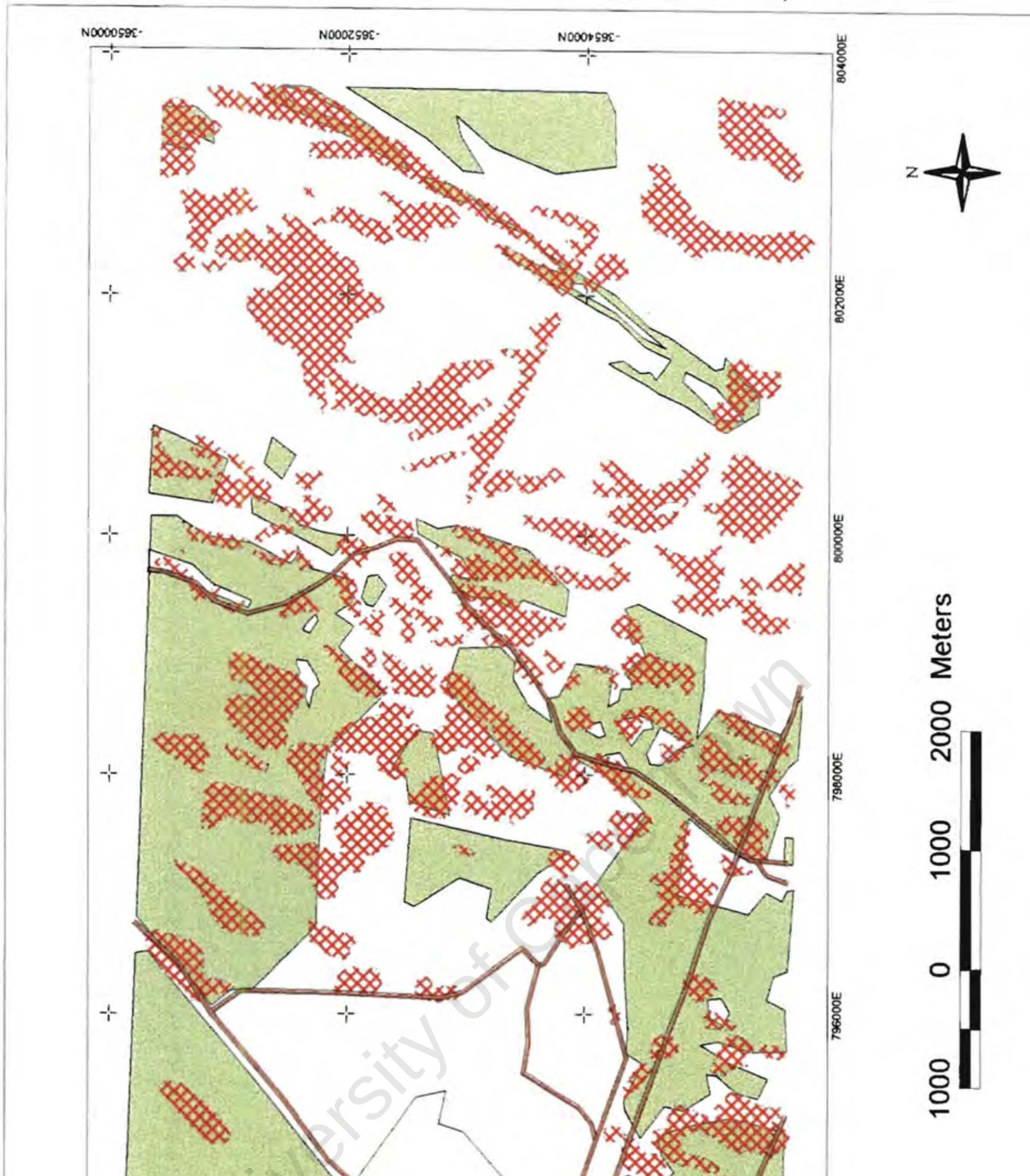


Fig5.10b: Wind erosion in 1974

Fig5.10c: Wind erosion in 1986

Fig5.11a: Wind erosion in 1974 that are overlapping or connected to areas of wind erosion in 1938

Fig5.11b: Wind erosion in 1986 that are overlapping or connected to areas of wind erosion in 1974

Fig5.11c: Wind erosion in 1986 that are overlapping or connected to areas of wind erosion in 1938

The total area covered by aeolian action that coincided with arable land in 1938 was 9.133 km^2. In 1974 it was 7.483 km^2 and in 1986 it represented an area of 7.549 km^2 **(Figure 5.12a)**.

The *frequency* of areas under wind erosion did however increase:

- 1938 - 52,
- 1974 - 131,
- 1986 - 102 (**Figure 5.12b**).

Frequency was measured by totalling all the separate wind erosion areas mapped from the photographs.

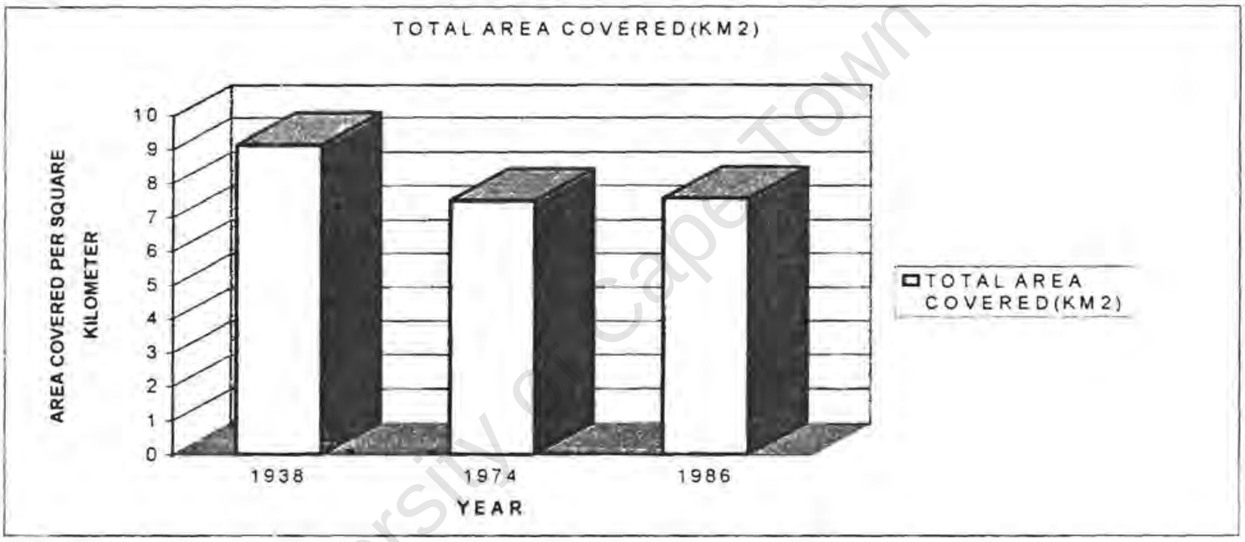


Figure 5.12a: Area covered by wind erosion from 1938 to 1986.

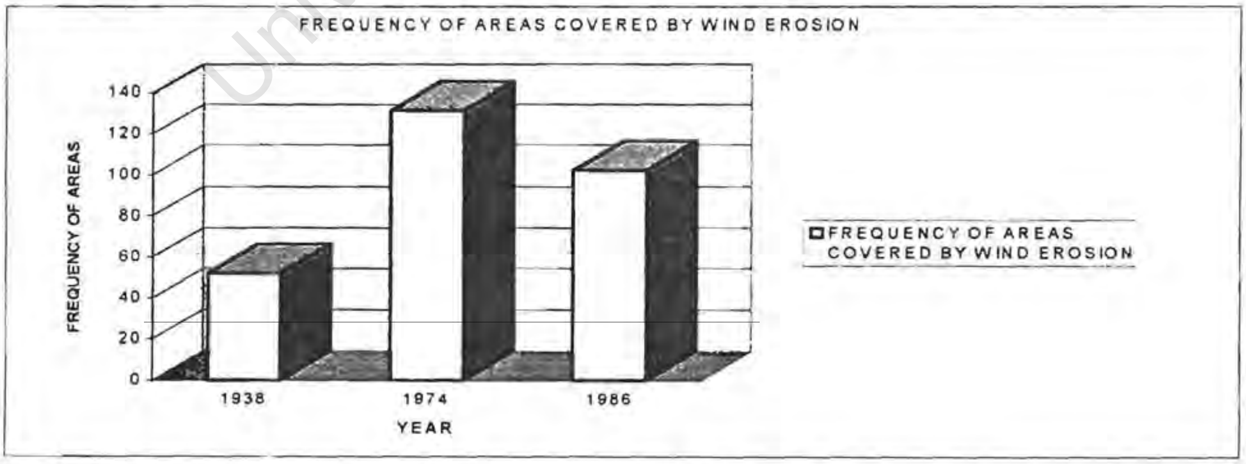


Figure 5.12b: Frequency of wind erosion areas from 1938 to 1986.

At the completion of the data capture and analysis of the wind erosion part of the study, it became clear that the method followed for determining the extent of wind erosion was not an accurate quantitative measure of actual wind erosion. It did indicate the potential for wind erosion and the presence of wind erosion in the area, but no quantitative measure can be taken in identifying the amount of soil removed from the area by simply studying photographs. The areas may not have any significant wind erosion, although they appear light on the photographs. The field verification did, nevertheless, prove that there is wind erosion present **(Figure 5.13a and 5.13b).** The erosion identified can be classified according to the SARCCUS report as belonging to class W3. The description of this class is that erosion is easily recognised on aerial photographs and with field verification reveals the presence of soil against objects and small dunes that may form as well as a sandy soil (<15% clay and >85% sand) (SARCCUS, 1981).

Figure 5.13a) Wind erosion in the Langebaanweg area (Sandveld).

Figure 5.13b) The small sandy heaps as sand cumulates around obstructions are clearly visible as well as the lack of vegetative cover.

The results of wind erosion (Figure 5.12a-b) as found by this study shows that the area occupied by wind erosion has indeed decreased by 17% from 1938 to 1986. It also became clear that the actual frequency of areas associated with wind erosion has increased, but these areas are small fragmented parts of what had been continuous areas of erosion in 1938. Therefore, the result suggests a change for the better regarding the wind erosion.

The areas overlapping and areas connected to erosion from previous years (Figure5.11a-c) demonstrated another trend also visible in the statistical analysis (Figure 5.12b), but not as clear. This trend is that the erosion area from 1939 to 1986 had indeed decreased but that the erosion area from 1974 to 1986 has increased, indicating a switch from decrease to increase. When examining the overlapping and connected areas, the tendency in 1986 shows connections between different erosion areas from 1974 to form one erosion area in 1986. There is a clear example of this in the north-north-eastern corner of the study area where a connection is maɑe in 1986 between two erosion areas from 1974 (compare Figures 5.10b and 5.11b).

5.4 DISCUSSION: EXPLANATION OF OBSERVED PATTERNS IN WATER EROSION IN THE SWARTLAND

5.4.1 Climate

Rainfall data gathered for the Swartland area are available covering the period from 1945 to 1994; this can be seen in graph illustrating the rainfall over the last 50 years in the greater study area (**Figure 5.14).** From Figure 5.14 it can be seen that the mean annual rainfall follows a cyclic pattern. Preston-Whyte and Tyson (1988) also identified a quasi 18 year cycle in the rainfall over South Africa. The rainfall decreased from 1945 to 1952, and in 1954 the highest overall rainfall was measured in the area, decreasing again after that to 1956. The rainfall peaks over 600mm per year can be seen as 1954, 1955, 1957, 1962, 1974, 1977, 1984 an 1985. From these data it can be seen that the average annual rainfall has decreased from the 1962 peak, with subsequent peaks being further apart. This could be a contributing reason for the decrease in the gully densities as seen in 1974, as the amount of runoff would have decreased correspondingly.

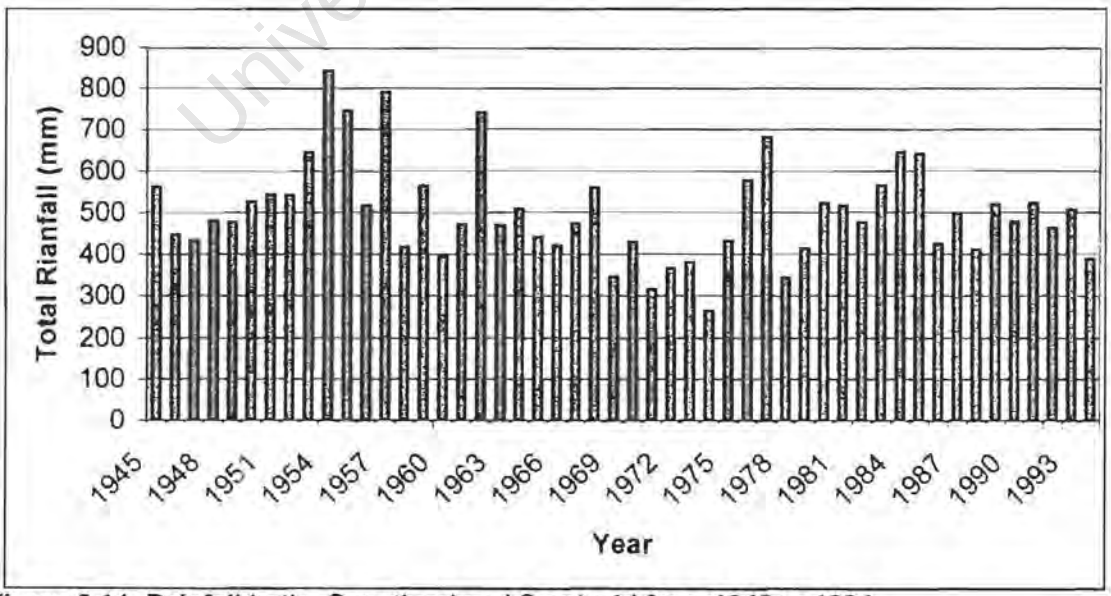


Figure 5.14: Rainfall in the Swartland and Sandveld from 1945 to 1994

5.4.2 Human Action

Due to the efforts of the conservation office in the Swartland area the following results were achieved in the construction of waterways and farming contours: (**Table 5.1**).

- A total of 25 373.8 km of contours were constructed from 1972 to 1995, at a final cost of R348 923.00.
- A total of 873 water conductors were built between 1972 and 1995 at a total cost of R4 490 208.00.

Table 5.1 suggests that the quantity of contours decreased markedly from 1982. The large number of contours developed from 1972 to 1982 is a sign of active erosion control and also the availability of funds for these conservation efforts.

The combination of active conservation effort and lower rainfall may account for the decrease in the gully densities from 1974 to further decrease in 1989.

The efforts of the conservation officers, and their close working relationship with the farmers in an advisory as well as instructive capacity would have had a marked impact on the improvement in the erosion situation in the Swartland and Sandveld.

Table 5.1 : List of conservation expenditure and works from 1972 to 1992 (Elsenburg, 1995)

YEAR	PRELIMINARY CONTOURS			FINAL CONTOURS			PRELIMINARY WATER DUCTS		FINAL WATER DUCTS	
	Quantity	Km	R/c	Quantity	Km	R/c	Quantity	R/c	Quantity	R/c
1972		14003.2			10251.4		327		192	
1973	208	1654.5	89541	247	1696.7	93674	17	16293	15	14375
1974	167	1075.2	68038	150	1060.2	70588	45	12935	19	7952
1975	161	1059.6	78211	104	586.8	47029	35	17514	3	1172
1976	271	1655.8	115807	182	1161.3	81222	41	26059	11	8942
1977	210	1603.2	173205	241	1535	146031	59	35900	10	8158
1978	410	2042	313660	324	1345.9	182453	71	50604	38	44243
1979	317	1372.5	207437	385	1748.4	274190	72	65453	71	73975
1980	165	760.8	119254	185	936.8	144366	35	44189	37	37115
1981	159	770.2	123138	115	618.9	98568	34	55994	29	71371
1982	231	977.1	216139	129	628	138494	106	467993	36	155710
1983	134	541.4	135397	96	385.8	108870	48	184661	47	215752
1984	121	488.4	104312	96	424.7	134722	45	136326	34	137047
1985	37	191.8	78879	65	290.4	70684	14	133103	33	113337
1986	130	424.4	165444	48	208.8	61113	47	275269	14	120199
1987	136	370.5	102771	102	352	99803	70	308706	49	179278
1988	59	275.9	79487	114	361.7	101471	34	222871	35	184464
1989	70	417.8	117638	47	197.6	55534	68	678495	29	181871
1990	78	477.3	143582	42	258.1	72496	67	782229	32	273177
1991	54	326.2	90891	29	214.5	61816	44	748491	21	407950
1992	150	635.7	838870	77	369.5	472719	75	1136719	48	1019507
1993	69	224.1	279213	142	593.1	770087	6	54956	59	1053611
1994	40	151.8	198553	39	149.2	195893	11	181001	11	181001
Total	3377	17496.2	3839467	2959	15123.4	3285930	1044	5635761	681	4490207

5.4.3 Extent and severity of water erosion in the Swartland

According to Talbot (1947) the cause of gully erosion in the Swartland can be traced back to the 1930's when the wheat price increased. Farmers, responding to what they saw as a reprieve from the depression, started to cultivate lands that were previously thought to be too steep to plough, or soils that were too shallow to plant. The soils were already depleted, and this further cultivation only helped to worsen the problem of land degradation. Gullies on hillsides and stream channels that were silted over became common features in the Swartland. The resulting scars were seen in the gullies that disfigured the hillsides (Talbot, 1947; 1971).

5.4.3.1 The extent of water erosion in the Swartland in 1938

Soil erosion was most severe on arable land, and only the limited areas where vegetation cover had been maintained were not obviously under threat of water erosion. Virtually all the arable land in the Swartland has suffered some loss of soil, mainly by sheet and gully erosion. In the summer of 1938, the Swartland had some 25 340 ha of gully erosion, of which 57 823 ha was severely gullied. On two thirds of the arable area covered by the survey done by Talbot (1947), soil erosion was already past the stage of sheet erosion and gully erosion was spreading. The erosion control measures in place were regarded as inadequate or wrongly applied.

5.4.3.2 The extent of water erosion in the Swartland in 1996:

The Swartland still needs erosion control against water erosion on 378 150 ha of land. Erosion control against water erosion is already found on 269 170 ha. Storm water drainage that can carry more than the expected capacity from a normal contour wall has been erected on farms in the Swartland farming district. Contour walls spaced at regular intervals compared with the haphazard methods of 1938. Drainage types are used to maximise the effect and are designed to the demands of each area. There is a major improvement in the situation of gully erosion on the hillsides, compared to the hillsides 1938, and very few gullies remain visible today, while erosion control measures are evident everywhere. But erosion seems to be developing on areas in the study area where the contour walls drain into the drainage systems, and bare soil is visible below the contour walls.

5.4.4 The potential for water erosion

5.4.4.1 Potential for water erosion in the Swartland in 1938

Prolonged cultivation of soil does not effectively maintain the structure and organic content of soils, especially duplex soils as found in the Swartland, are highly susceptible to the destruction of soil structure and therefore resistance of the soil to erosion. In 1938 cultivation is apparent on sites that are susceptible to erosion (long steep slopes). The ploughing of fields did not follow the contour on the slopes nor were there erosion measures on the roadside ditches. This meant that drainage and the discharge of runoff was into unprotected ditches. There seems to have been persistent cropping on land unsuitable for this practice, rendering the land unsuitable for later cropping. There also seems to have been a tendency among farmers to leave corrective action too late. The economic situation is often used to justify bad farming practice. However, ignorance and apathy to erosion and conservation are more likely reasons for such neglect.

5.4.4.2 Potential for water erosion in the Swartland in 1996

A suitable alternative to cereal cultivation to rotate with wheat is needed in order to prevent damage to the structure of the soil, caused by growing only one major grain on the same field throughout the years. The economic situation is still an issue as in 1938 with increasing wheat prices on the international market. The soil, on which grain is cultivated, is notoriously prone to erosion (Mispah, Swartland, and Glenrosa), while even less erodible soils (Shortland, Hutton, Escourt, Sterkspruit and Valsrivier) also need to be protected. Many of the slopes found in the area have a gradient of over 5%, while in some areas of 15% are not uncommon. Length of the slopes varies between 400 and 1200 meters, thus with the combination of slope-gradient and slope-length, the landscape is very susceptible to runoff erosion. Winter rainfall is mostly soft, but periodic heavy downpours do occur, and one needs to be prepared foı an ensuing erosion impact, especially when farmlands are bare. Veld is grazed upon and cultivated in its most vulnerable stage, which is in the spring with the germination of new seed. This leads to the degradation of the veld when it requires a rest period. The invasion of alien species due to overstocking and an inappropriate fire regime cause the quality of the veld to decrease, leaving it vulnerable to water erosion due to the lack of vegetation cover.

5.4.5 Conclusions on Water Erosion in the Swartland

Water erosion is still an issue in 1996, albeit a vastly improved situation from 1938. The potential for water erosion is still promoted by the economic situation and the possibility of bad farming practices, but the conservation officers seem to have the situation in hand as far as erosion control measures are concerned.

5.5 EXPLANATION OF OBSERVED PATTERNS IN WIND EROSION

Wind erosion on natural grazing lands develops through overgrazing and grazing too soon after a fire, and before the veld has had sufficient time to recover (Lancaster, 1986; Elsenburg, 1991; Germishuys, 1992).

5.5.1 Extent and severity of wind erosion

Wind erosion in the Sandveld was clearly visible in 1938, especially on land that was cultivated two years before the 1938 aerial photographs were taken. Land that was under cultivation for longer periods of time tended to have enough crop and vegetation cover so that drift sands could not be identified (Talbot, 1947; Germishuys, 1992: 3).

In the Sandveld it is obvious that almost all cleared and cultivated land and burned-over areas have suffered an appreciable degree of wind erosion, caused especially by the southerly winds prevalent in the summer when the dry soils are at their most vulnerable (Talbot, 1947; Elsenburg, 1991). On Swartland loam soils, on the other hand, the effect of wind erosion is less obvious and less serious than those of rill and gully erosion. Wind erosion is a hazard only on fallows and even there the surface compaction by heavy rain serves as protection. If, however, there is not enough rain to cause this compaction, the soil remains vulnerable to wind erosion

(Talbot, 1947). Coastal drift sand and coastal dunes develop due to transport of coastal sand inland. This is a natural process and care should be taken not to disturb the coastal dunes unnecessarily (Elsenburg, 1991; Germishuys, 1992). Lancaster (1986) conducted a study on what appears to be relict deflation hollows that are being reactivated by the southerly winds in the Elands Bay area (west coast of RSA), because of human activity in the area. The sand seems to have shifted from the hollows to the dune fronts by the predominant winds in the summer months. Some of this sand is eroded and moved back towards the hollows during the winter months. The extent of this movement is probably limited because of the high moisture content of the sand. This, together with the prevalence of the southerly winds, results in greater sand movement over the year towards the north, implying erosion of the hollows and advancement of the dune front (Lancaster, 1986). Wind erosion on farm land results in drift sand being deposited on cultivated fields in the Sandveld and even on farms next to the Bergriver (Germishuys, 1992). The reasons for this are:

-None or insufficient windbreaks for large land areas.

-Cultivation of farmlands at critical times (spring, summer and late summer).

-Sparse cover on the fields.

-Very clean and fine seedbeds just after corn or potatoes are planted.

-Clean and unplanted areas prior to planting or after harvest (Elsenburg, 1991; Germishuys, 1992).

5.5.1.1 Extent of wind erosion in the Sandveld in 1938

Soil erosion is most severe on arable land and only on limited areas where vegetation cover has been maintained, are its effects less evident. Uncultivated land is most severely affected in areas of light sandy soil that were degraded by woodcutting, over-grazing and poor fire management. Virtually all the arable land had had some loss of soil by wind erosion in the Sandveld. The summer of 1938 displayed wind erosion on 12 330 ha of arable land.

5.5.1.2 Extent of wind erosion in the Sandveld in 1996

Wind erosion affects 155 000 ha of arable land in the Sandveld and

Swartland. Wind erosion control is in place on affected areas, with windbreaks seen as being the most effective measure. Of the total of 394 400 ha natural grazing in the Swartland and Sandveld region, there is about 60 000 ha of natural grazing which is affected by wind erosion (Elsenburg, 1991).

5.5.2 Potential for wind erosion

According to Hallward (1988), the Sandveld area falls in an of potential wind erosion.

5.5.2.1 Potential of wind erosion in the Sandveld in 1938

The destruction of the structure and erosion resistance of the soil, prolonged cultivation that causes deterioration in the structure and organic content of the soil causes wind erosion to increase. There seems to be persistent cropping of land not suited to the practice, thereby rendering the land unsuitable to further cropping. Erosion is left too late before acting on the early signs. Economic factors, such as an increase in the wheat price, probably caused bad farming practice to take hold. The potential for wind erosion in 1938 was reckoned to have resulted the apathy and ignorance of those directly involved (Talbot, 1947).

5.5.2.2 Potential of wind erosion in the Sandveld in 1996

On 87% of the arable land there is no rotation with a soil-enriching and reconstructing crop. Soil is intensively cultivated on most of the farms in this area (Elsenberg, 1991). Care must therefore be taken in choosing a suitable replacement or rotational crop, since the use of only one major grain from year to year on the same soil will deplete the soil. The economic situation, with higher international prices for wheat, provoked major gully development in 1938 (Talbot, 1957). The erosion situation as seen in 1938 must act as a warning sign to farmers and conservation officers to be careful in their selection of crop-enhancing methods. Some of the soil on which the grain is cultivated is prone to erosion (Mispah, Swartland, Glenrosa), and demands additional erosion prevention actions. Even the less erodible soil (Shortland, Hutton, Escourt, Sterkspruit and Valsrivier) needs to be protected (Elsenburg, 1991).

Overstocking in the Sandveld is a direct cause of degradation of the veld. It causes increased wind erosion on the sparsely covered land depleted of most vegetation and therefore ground cover. Veld is grazed, or cultivated, in its most vulnerable stage, in spring with the germination of new seed, which leads to the degradation of the veld when it most needs rest. Ineffective camp layout (certain camps are always being used as grazing or passage to and from waterholes and feeding, or camps are not properly subdivided) of the farms does not suit the farming or grazing methods used, and no effective rotation can be practised. The invasion of alien species due to overstocking and an inappropriate burning practice (burning of the veld occurs too often and with no pattern compatible with the vegetation) cause the quality of the veld to decline. The grazing of dune-lands can cause wind erosion to spread or resume. No or insufficient windbreaks on land susceptible to wind erosion is a major problem in the Sandveld and will continue to be one (Elsenburg, 1991) because of a lack in understanding and research. Moreover, many farmers are reluctant to shoulder the additional financial burden to apply prudent conservation measures (H. Germishuys, personal communication, 1994).

5.5.3 **Conclusion from Wind Erosion**

Form the above it is evident that wind erosion is still a problem in the Sandveld (and Swartland). Moreover, the evidence suggests that the potential for wind erosion is unchanged from 1938. The economic situation remains a threat and bad farming is as much the negative factor that it was in the past. The onus is on the landowner and the conservation authorities in the areas to see that the situation does not deteriorate.

5.6 COMPARISON WITH OTHER AREAS IN SOUTHERN-AFRICA

5.6.1 Soil erosion in Kwa-Zulu/Natal, Eastern Cape and Lesotho

Soil erosion occurs in many parts of SA and neighbouring countries. It is considered appropriate therefore to consider the incidence of erosion in Kwa-

Zulu/Natal province and, more particularly, Lesotho. The occurrence of gully erosion in very severe forms is reported in all studies.

Most areas of severe erosion are situated in areas that were part of the old "homeland system". A question that arises is how does the improvement in the Swartland relate to conservation policies of these regions, and to state intervention in landowners' attitudes towards conservation. The land tenure regime in the Swartland and Sandveld is very different from the situation in Lesotho and the Eastern Cape (the old Ciskei and Transkei). In the Swartland and Sandveld most of the farmers are generally affluent, educated and empowered. Finance therefore seems to make all the difference between the way erosion is combated in the perspective regions. The perception of conservation from a European and African perspective is briefly discussed in the following chapter on Soil Conservation.

From the literature, it becomes clear that in selected areas elsewhere in South Africa, the fight against degradation yielding positive results. Garland and Broderick (1992) conducted a similar study to the present one on the Tugela River catchment in Kwa-Zulu/Natal. They also found a decrease in the eroded area in the Tugela catchment between 1941 and 1981, from 6,6 % in 1944 to 5,5 % in 1981. Broderick (1987) also studied the sediment loss for the Tugela catchment and found a decline in the amount of sediment since the 1950's. In another study in the Orange River catchment Rooseboom (1978) found evidence of a decline in sediment loads in the Orange River catchment. In Lesotho, evidence that the gullies in certain areas are no longer actively expanding was obtained by Stromquist *et al.* (1985). But Chakela *et al.* (1986, p12) mentions that "recent studies and surveys of the state of land degradation in the country (Lesotho) still report alarming rates of both water and resources losses". A study by Watson (1991) in the Umfolozi Game Reserve and adjacent areas, indicated that erosion had decreased from 1937 to 1983. Cobban and Weaver (1993) found evidence of gullies stabilising in certain areas in the Tsolowana Game Reserve in the then Ciskei, where gullies act as a sediment trap, but also found parallel gullies to be actively down-cutting.

Garland and Broderick (1992,p.48) explain the reversal in erosion as follows:

> *Only in exceptional circumstances is human interference likely to reverse a natural geomorphological trend, and then only on a local scale for short periods. In practical terms this means that greatest benefits from soil conservation may be expected at times of natural decline in the rate of erosion, conservation measures reinforcing the inherent tendency for soil loss reduction.*

The variation on erosion observed in the Lesotho Lowlands can be attributed to land management in combination with climatic factors (Stromquist *et al.*, 1986). So it is in the Swartland, where the erosion decrease can be contributed to the combined effect of lower rainfall and increased land management in the form of active soil conservation practice.

5.6.2 Soil erosion in the Karoo

Rowntree (1988) observes that soil erosion and degradation in the Karoo is widely believed to be severe and that degradation can be considered synonymous with this region. Studies of erosion in semi-arid regions, for example the Karoo, need to be considered in relation to the stability of vegetation in the region. Rowntree (1988) mentions that the prevalence of accelerated erosion in this region is associated with many of the plant communities, but that there need to be more studies done on the relationship between the sediment processes and the vegetation changes, in order to gain a better understanding of the situation. The danger in making predictions of erosion, when not fully understanding the factors involved in the erosional process is emphasised. Rowntree (1988) concludes that the process of gully erosion as found in the Karoo can be seen as cycles of erosion and deposition, similar to the shift in equilibrium associated with all ecosystems (Rowntree, 1988).

According to conventional wisdom, the erosion in southern Africa is generally severe and worsening under the increasing pressure of human population and pressure upon the resources, as argued in chapter one. But from the above it can be seen that individual studies on a range of different environments in the sub-continent actually suggests otherwise – indicating a reduction in the gully activity in the recent past.

The explanation for this is twofold. It can be part of long-term landscape dynamics (the erosion situation is less severe now than in the past) and / or it can be the influence of soil conservation efforts (but these efforts were less vigorously applied in the old homelands).

Erosion gullies are an integral part of the drainage system in the Karoo; the main reason why the degradation in this area is developing is attributed to exploitation and bad veld management (Rowntree, 1988, p.175). Human influence has therefore played a part in the deterioration of the natural veld (as can likewise be seen from the results on the Swartland). The type of climate and agriculture in the two areas (Karoo and Swartland), are totally different, but the commercial (farming activity) influence of humans on the landscape can in both cases be perceived to have had a marked effect on the landscape.

To assume that conservation or erosion control measures applied in one area will work in another is not correct since each individual region has its own intrinsic factors that influence erosion patterns. By observing and further researching the region at hand it should be possible to formulate an effective erosion control plan.

5.7 CONCLUSION

The south-western Cape Province as a whole shows a pronounced difference and change of morphology, chemical and physical characteristics in the soil over short distances, therefore creating conditions that are not favourable to farming practices under natural conditions (Dept. of Agric.. & Fish., 1981). In the Swartland region the dominant parent material is the Malmesbury shale of the Nama system. The soils derived from this system are mainly shallow Glenrosa and Swartland, with Shortlands and Hutton soil being sub-dominant. The parent material and therefore the soil is frequently saliferous, especially in the subsoil (Dept. of Agric. & Fish. 1981). Deep, well-drained soil, highly leached soil and shallow calcareous soil is common. On the deeper Glenrosa, Hutton, Clovely and Oakleaf soil, vineyards and fruit are cultivated; while on the shallower Mispa, Glenrosa and Swartland soil grain and grazing crops are cultivated (Dept. of Agric.. & Fish., 1981). The duplex soil found in the area are characterised by the sandy topsoil materials with the underlying clay subsoils (Deacon *et al*, 1992). It is in these duplex soils that the unstable conditions exist that are a causal factor for the gullies found in them (Germishuysen, personal communication). Table Mountain Sandstone (TMS) occurs in the central Swartland, near Piketberg so that the cultivation of fruit is well adapted on the crests on the deep yellow to red sands of the Clovelly, Avalon, and Hutton sands. Nearer the West Coast duplex soil of the Escourt and Kroonstad forms are found. These rough sands on clay can be seen as marginal wheat soil because of the lower rainfall, wind erosion and water retention during wet spells. Next to the coast normal coastal sands occur (Dept. Agric. & Fish., 1981).

The theory put forward by Yaalon (1987) and Watson *et al* (1987) that most gullies in South Africa can be found in colluvium soil has been noted. It is appropriate to remark that all the gullies that were studied at close range in the study area were found to be in colluvial fill on closer inspection from the researcher (eyeballing only). The further study of this theory in the study area is the basis for another study altogether and does not fall within the scope of this study. It can be recommended that such a study be undertaken as an extension of the present study. This study, however, does not solely consider the explanation of the occupancy of gullies or wind erosion on the basis of the underlying soil characteristics. No detailed study of the soil in the study area, as such, has been made other than references and general trends associated with certain kinds of soil found in the study area. It is acknowledged, however, that the underlying soil characteristics are a factor in the erosive potential of the Swartland and Sandveld.

The mapping of areas apparently under the influence of wind erosion by the method used in this study, is not an accurate reflection of the severity of the erosion situation in the Sandveld study area. It is for that reason that the term wind erosion should not be used to describe the results found. Aeolian action would be a better term, as the results did indicate that some kind of aeolian action was present in the area.

Research into conservation policies and laws indicated that there is a very poor literature base on the conservation policies in this country. The principal factor responsible for the improvement in the erosion situation in the Sandveld and especially the Swartland would be the efforts of the conservation officers in this area. The conservation strategies applied (like wind breaks and contouring) were done at the correct time and had an especially radical effect on the situation on the Swartland.

Limitations in the actual results were the following: photogrammetric correction of the aerial photographs to limit the offset as far as possible was out of the question due to the time and expense involved in such a procedure. Further testing and investigation of the gully systems and wind erosion areas found in the study, is not in the scope of this study and should perhaps be studied in further.

From the above it is evident that the erosional situation in the Sandveld and especially the Swartland has improved. The improvement is due to the timely intervention of erosion conservation works. From looking at results obtained by other studies (Rowntree, 1988; Watson, 1991; Garland and Broderick, 1992) in other parts of South Africa (Kwa/Zulu-Natal and the Karoo), the possibility of a "stabilisation" in the denudation process is not ruled out. The conservation efforts were probably doubly as effective because of the natural processes slowing down as well. I do believe that the intervention of conservation officers in co-orporation with the farmers caused this dramatic change to the present situation in the Swartland from the 1947 scenario, when Talbot (1947) predicted the Swartland would become a "badland" in the future.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

Schutte (1995) mentioned that wind erosion is found on about three million ha of agricultural land. Of the affected area, 13% can be considered as serious, 42% is moderate erosion and 45% slight. Of the grazing land, about 10.2 % is affected, of which six percent is considered severe and a further 17% is moderate wind erosion. Water erosion is present on 6.1 million ha agricultural land. Of that area, 15% is severe, 37% moderate and the remainder only slightly affected. On grazing land 10.9% is influenced by water erosion.

With increasing awareness of the natural environment and its importance for continued economic development, this study of the Swartland and Sandveld on land degradation is a necessary part of the soil erosion database in South Africa. This growing database will highlight those areas of potential soil erosion.

The general aim of this study was to determine the degree of soil erosion in the Swartland and Sandveld region based on a comparison of the situation as found in Talbot's 1947 study. The influence on erosion due to farming activities and the conservation measures taken to prevent further and continuing erosion has been explored. The conclusions drawn will be discussed under the original aims and objectives as found in Chapter 1.

- *To establish the nature of the soil erosion in the region, i.e. the distribution and characteristic processes involved.*
  - ✓ The main processes operating in the region is wind and water erosion. Gully erosion seems to be the most noticeable process in the Swartland area as Talbot (1947) have proved, and is highlighted in this study.
  - ✓ In the Sandveld wind erosion is especially prevalent.

- *To establish the possible causes for soil erosion and compare the situation as found in the study area in 1994 to the situation Talbot found in 1947.*
  - ✓ Even though the agricultural use of the Swartland and Sandveld has remained the same and even intensified, the erosion situation in the regions did not deteriorate.
  - ✓ A remarkable 85% decrease in the gully erosion in the Swartland from the situation in 1938, is certainly not a result to be taken lightly on the basis of the conservation effort implemented in the study area.
  - ✓ The gully density dramatically decreased from 12.3 km^2 gullies in 1938 to 1.8 km^2 in 1989.
  - ✓ The area covered by wind erosion decreased form 1938 to 1986 by 17%. Form the present study it is evident that wind erosion in the Sandveld has not shown the same improvement as water erosion in the Swartland. On the contrary there are indications that the situation actually deteriorated from 1974 to 1986 and further studies on the extent of wind erosion in the area are therefore necessary.

- *To map the spatial distribution of soil erosion, using aerial photography, as found in the study area over the last 50 years.*
  - ✓ In the Swartland and Sandveld two areas (each 55km^2 representing the 6200km^2 region of the Sandveld and Swartlan) were mapped, showing the latest areas of erosion as demonstrated by figures in Chapter 5.
  - ✓ Contemporary gullies and wind erosion areas were mapped at a scale of 1:50000 using GIS and remote sensing.

- *To investigate the effectiveness of remote sensing and GIS; can it be used and to what effect does it contribute to the spatial database ?*
  - ✓ The effective utilisation of GIS and Remote Sensing in modern erosion studies are proven without doubt. Without the analytical and spatial powers of these systems, the present results would not have been achieved as effectively and as rapidly.

- *The effect of conservation policies and practice on soil erosion needs to be researched to determine the extent to which they have contributed to the present situation in the study area.*
    - ✓ The results obtained from the present study suggest that an effective way to combat the erosion problem is by sound conservation practice backed by continuing education.
    - ✓ With further research it came to light that the erosion process also goes through cycles of denudation and rest, as has been found by various authors in studies in other parts of South Africa (Watson, 1990). It is therefore concluded that successful rehabilitation of water erosion in the Swartland was due to the combination of effective control measures and effective conservation strategies. It is my opinion, however, that the main reason for the improvement was due to effective erosion control measures.
    - ✓ The timely implementation of contour farming with the help of the local conservation officers and the education and involvement of the farmer in ad hoc consultation with the conservation officers, has indeed developed a farming community with a keen sense of cooperation, especially in the Swartland.
    - ✓ The stability of the landscape seen today in comparison to the 1930/1940 situation is a result of hard work, financial support and conservation mechanisms, such as contour walls, weirs, and windbreaks.
    - ✓ Although conservation measures (wind breaks) provide some protection against wind erosion in the Sandveld, wind erosion is still affecting the Sandveld and continued research in this area is advised.

The present study has only examined a small portion of the greater Sandveld and Swartland area, and re-evaluated the soil erosion on this area, compared to the situation found in 1938 and documented in 1947 by Talbot (1947). The data available on actual erosion rates and types in the Swartland and Sandveld are very scarce and therefore requires greater research.

The problems encountered in the study are the limits in time and funding, as well as the limited properly documented and inaccessible soil erosion database for this area. The research method used to determine the wind erosion was not sufficient to show the actual wind erosion found but it does indicate the activity of wind erosion porocesses on the landscape.

Further recommendations resulting from this study would be the use of GIS and remote sensing in determining areas susceptible to erosion on a broader national scale (e.g. a broad survey for the entire country). This could be followed by with more detailed studies in affected areas incorporating sediment yield and erosion index studies to help determine the areas that need more detailed investigation.

The south-western Cape comprises a large farming area, the farmers in the region need to be aware of the main causes of erosion of their turf so that they can take adequate precautions and thereby lessen the amount of top soil that is lost to erosion each year. The database for the erosion situation needs to be updated and re-evaluated regularly. The availability of erosion data for the Western Cape is limited and not much research has been done on a large scale. Isolated areas have been investigated, but we need to combine all of this to create a whole picture. It cannot be said that the conservation success in the Swartland is representative of the whole Western Cape region, the lack of data from other areas cannot support such a statement. But the situation is indeed a very encouraging result when compared to areas such as Kwa-Zulu/Natal, Lesotho and Eastern Cape, where some similar results were obtained, but to a lesser extent.

In conclusion, the result obtained from this re-evaluation of erosion in the Swartland and Sandveld in 1996, provides a new perspective on the efficiency of conservation efforts and policies, especially in the Swartland. There are success stories, and these successes should be analysed to find the reason for improvements. In this case the improvements were due to correct soil conservation strategies at an appropriate time in the degradation cycle, coupled with the correct climatic conditions which caused improvement in the erosion situation as found in 1938 in the Swartland. Effective conservation, understanding the physical environmental components at work in the region, education and co-operation are clearly a winning combination.

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