A COMPARATIVE STUDY OF SOIL EROSION IN THE UMFOLOZI GAME RESERVE AND ADJACENT KWAZULU AREA FROM 1937 TO 1983.

by

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ABSTRACT

This thesis describes a comparative study of actual and potential soil erosion in the Wilderness area of the Umfolozi Game Reserve, and a biophysiographically comparable adjacent traditional KwaZulu landuse area. Estimates of temporal and spatial variations in eroded surfaces, sparsely vegetated surfaces susceptible to erosion, and active gullies were obtained from five sets of sequential aerial photographs taken between 1937 and 1983. Estimates of the potential influence of rainfall erosivity, soil erodibility, topography, and changes in vegetation communities and landuse practices on these variations, were extrapolated from these aerial photographs as well as from maps, field surveys, records and other studies. Interrelationships between these potential influences, and the extent to which they actually contributed to the temporal and spatial variations in the three 'erosion' surfaces, were assessed visually using a geographic information systems thematic overlay technique, and computationally using a forward stepwise multiple regression procedure.

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CHAPTER ONE

INTRODUCTION

1.1 MOTIVATION FOR STUDY

In 1982 the Mfolozi Farmers Association (M.F.A.) requested the Natal Agricultural Union to formulate a management plan for the Mfolozi catchment. The plan was to aim at reducing flood damage to sugar cane production on the river's flood plain. The M.F.A.'s motivation made four significant assertions about accelerated soil erosion in the catchment, viz:- (i) it is the primary cause of the increased incidence and severity of flooding, (ii) it has increased progressively during this century, (iii) it is most severe in the traditional communal lands administered by the KwaZulu government, and (iv) it is primarily caused by overstocking and poor cultivation practices (Anon, 1984; Combrie Grieg, 1984). Such assertions are consistent with the general perception of soil erosion in the Republic. A perception that gained precedence in the 1880's and persisted unchallenged until the late 1970's. It was based primarily on qualitative assessments.

The only quantitative assessment of soil erosion in the Mfolozi catchment prior to the M.F.A.'s request was Schulze's (1981) study of the influence of siltation on the lifespan of dams in 48 small KwaZulu catchments. He noted that the conservation practices on arable land were generally effective and contrasted with the prominence of overgrazed veld. While soil loss estimates for most catchments ranged between 50 and 75 t ha^{-1} yr^{-1}, estimates for 13% of them were in excess of 100 t ha^{-1} yr^{-1}. According to Zachar's (1982) worldwide classification of erosion, rates in excess of 50 t ha^{-1} yr^{-1} may be regarded as very severe. Elwell (1984), and Elwell and Stocking (1984) employed a soil life span model in a bioclimatically comparable region of Zimbabwe. They predicted that erosion rates of 50 to 80 t ha^{-1} yr^{-1} would render the soil incapable of sustaining subsistence yields within 30 years.

The Mfolozi Catchment Planning Committee (M.C.P.C.) was formed in May 1983 (Anon, 1984; Combrie Greig, 1984). Its formation received further justification when estimates published later that year indicated that the mean annual load of the Mfolozi river was exceptionally high viz:- 1,5 x 10^6 m^3 (Phillips, 1983) and 2,75 x 10^6 m^3 (Fleming and Hay, 1983). The significance of the M.C.P.C.'s mandate was given impetus in late January and early February 1984 when tropical cyclone Demoina struck the catchment causing a flood which peaked at 16 000 m^3 s^{-1} in the lower reaches of the Mfolozi river and had a total estimated volume of 2 500 x 10^6 m^3- the highest ever recorded in the Republic (Kovacs, Du Plessis, Bracher, Dunn and Mallory, 1985; Looser, 1985). This flood deposited 80 x 10^6

of sediment on the floodplain (van Heerden and Swart, 1986) which resulted in a sugar cane production loss of R57 million (Begg, 1987). The estimate of the total cost of flood damage to the catchment was in excess of R100 million. It included three washed away bridges, and destroyed buildings, roads and tourist facilities (Combrie Greig, 1984).

The popular media expressed concern about the extent to which poor landuse practices in the Mfolozi catchment had contributed to the magnitude of the Demoina flood (Compton, 1984). The event stimulated a considerable research effort into the source, attenuation and delivery of sediment in the catchment by the Department of Water Affairs (Bracher, 1985; Kovacs, *et al.* 1985; Looser, 1985, 1989), the Institute of Natural Resources (Berjak, Fincham, Liggitt and Watson, 1986; Liggitt, 1988; Liggitt and Fincham, 1989), and the Natal Town and Regional Planning Commission (Anon, 1984; Anon, 1985a; Begg, 1988). Much of the initial output of this effort was presented informally, and recorded in the minutes of the M.C.P.C.'s meetings. It generally supported the views of the M.F.A.. Anon (1984) and Combrie Greig (1984) presented a table of the thirteen flood peaks recorded in the river from 1880 to 1984. They attributed the apparent trend towards increased incidence and severity of flooding to the progressive degradation of the catchment. Anon (1984) used a simple, qualitative technique to survey the natural erosion hazard potential of the catchment. Sixty seven percent of the KwaZulu area was assigned a high rating. Despite this significant natural predisposal for soil erosion the M.C.P.C.'s foundation report perceived landuse as a more important erosion contributing factor. The report described extensive sheet erosion, large gullies and totally denuded areas comprising exposed subsoil materials as being well represented throughout the KwaZulu area, and viewed overgrazing and poor cultivation practices as the predominant causative factors (Anon, 1985a). Looser (1984; cited in Kovacs, *et al.* 1985) examined areas contributing sediment on 1 : 250 000 LANDSAT images taken 26 weeks before the flood. The spectral signature of most of the KwaZulu areas was designated as representing overgrazed veld.

In overview then, the KwaZulu areas of the Mfolozi catchment were presented as suffering from serious to severe soil erosion. This erosion was primarily attributed to overgrazing. Failure to use, or inadequate use of conservation practices on cultivated land was also implicated as a lesser contributory factor. This soil erosion in addition to decreasing the land capability potential inside KwaZulu, caused very serious detrimental environmental effects outside of the KwaZulu areas, such as increased frequency and severity of flooding. The progressive increase in soil erosion was directly associated with a corresponding increase in human and livestock populations. Most projections indicated substantial future increases in these populations. The M.C.P.C.'s attempt to prescribe land management practices that would arrest or retard an associated future trend in soil erosion, highlighted aspects of the soil erosion scenario requiring further research. They formed the basis of this study, viz:- (i) an identification of the factors influencing the inherent temporal and spatial variation in susceptibility to erosion, and (ii) a comprehension of the response of these factors to traditional landuse practices.

1.2 MOTIVATION FOR STUDY AREA

The location of the Mfolozi catchment in northern Natal is shown in Figure 1. It is the Province's second largest catchment. About 6% of it's area is afforded conservation status and managed by the Natal Parks Board (N.P.B.). Fifty two percent of the catchment is administered by the KwaZulu government. This area includes Ulundi - the 'homeland' capital, as well as several large Zulu towns and villages, such as: Nongoma and Nqutu. Most of the KwaZulu area is utilized by subsistence farmers. The use of communal lands by these peasants is regulated by tribal chiefs. The major landuse in the balance of the catchment is commercial farming. The farms are privately owned by Europeans who generally employ technically advanced farming methods.

Most of the KwaZulu portion of the Mfolozi catchment lies within a physiographic region designated as "Low Lying" by Turner (1967, described in Phillips, 1973). Seventy five percent of the KwaZulu area within this region can be further categorized according to Phillip's (1973) bioclimatic classification as subregion 10b. This is a subarid riverine and interior lowland. It has a potential climax vegetation of short to medium thicket. Its seasonal temperature ranges from hot/warm, to warm/mild. The decision to carry out the present study in this subregion was additionally motivated by a report on the status of soil erosion in the bioclimatic regions represented in the Province. Scotney (1978b) noted that it was most severe and extensive in subregion 10b.

A section of subregion 10b presented itself as a unique research opportunity. It is shown as the study area in Figure 1. It comprises the Wilderness area of the Umfolozi Game Reserve, and a KwaZulu traditional landuse area adjacent and east of it. These component areas are shown in Figure 2. These areas conformed to the requirements of a classic research approach. The control versus experimental approach permits the influence of a factor to be assessed, in both a time and space context. The time context approach permits the effects of the landuse practices on soil erosion to be assessed by comparing erosion in an area before and after the introduction of the practices. The space context approach permits this assessment, by comparing the erosion in an area where the practices are present with a physiographically similar area from which they are absent. Human activities in these two areas were similar through until the early 1950's when major differences in their landuse systems emerged.

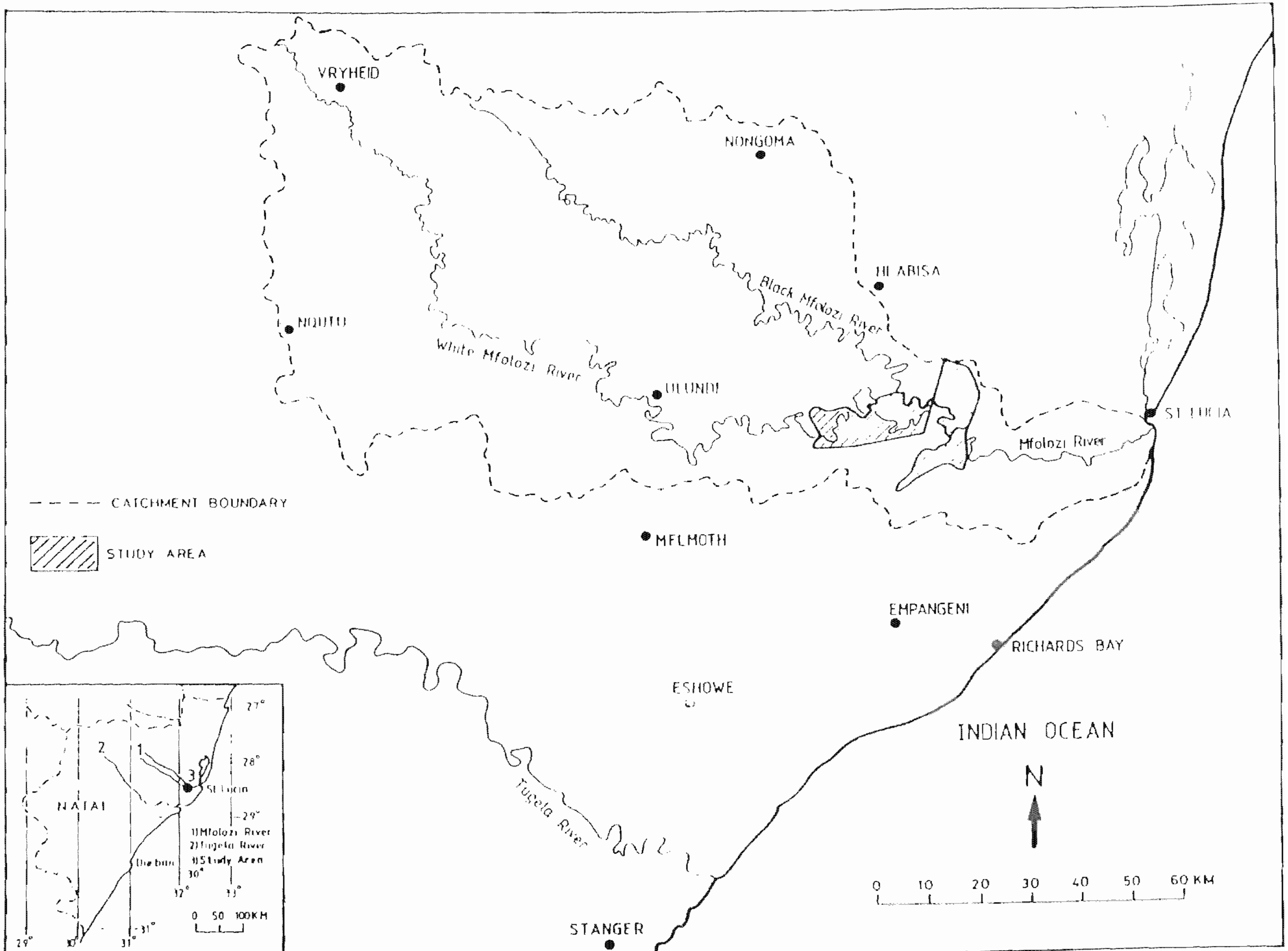

Figure 1: Showing the location of the study area in the Mfolozi catchment, and the location of the catchment in Northern Natal.

The comparatively good coverage by aerial photographs also motivated the selection of these areas for use in this study. Their full extent was photographed in 1937, 1960, 1970, 1975 and 1983. Such a sequential record represented a valuable data source on temporal variations in soil erosion, vegetation cover and landuse.

1.3 AIMS OF STUDY

This study aimed to assess (i) the influence of various physiographic parameters on the study area's inherent susceptibility to soil erosion, (ii) the influence of this susceptibility on temporal variations in the spatial distribution of erosion, (iii) the influence of changes in vegetation communities and landuse practices on changes in erosion, and (iv) the contemporary status of soil erosion in the study area.

1.4 STRUCTURE OF STUDY REPORT

The high level of biophysiographic comparability between the Wilderness Area and the KwaZulu component is apparent from the description of the study area in chapter two. Differences in parameters that have a significant influence on susceptibility to erosion are however, emphasized. The study area is predominantly underlain by shales and sandstones. Rocks beneath the Wilderness Area are virtually horizontal and contrast with the steeply tilted strata beneath the KwaZulu component. Although the topography of the study area is dominated by the river, the influence of geological attitude is apparent on the KwaZulu component's dissected landscape, and its steeper and shorter slopes. The rainfall erosivity and runoff generation threshold values in the study area are high and low, respectively. Both rainfall amount and erosivity are comparatively higher in the KwaZulu component. The study area is predominantly covered by shallow, residual clay soils. Although they have a low humus content and montmorillonite is the dominant clay mineral, they generally have a low to moderate erodibility. High and very highly erodible formations are better represented in the KwaZulu component. Although Iron Age activities converted the study area's woodland climax to grassland, they had no significant effect on soil erosion. The low ungulate biomass and virtual exclusion of fire during the first half of this century resulted in the study area becoming progressively bush encroached. By the early 1950's when the inland half of the study area became administered as a game reserve, the ungulate biomass had increased substantially while advanced bush encroachment had reduced it's carrying capacity. Veld burning, culling and bush clearance were ineffective in retarding these trends. Their coincidence was seen to be responsible for accelerated soil erosion in an increasing number of qualitative and semi-quantitative reports from the 1960's. The first scientific assessment of soil erosion

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Chapter three attempts to provide a holistic perspective of the soil erosion examined in this study in a geological time and global context. The process and resultant forms are defined. The distinction between geologically normal and accelerated erosion, and between naturally and anthropogenically accelerated erosion is explained. Periodicities within and homeostasis of the dynamic equilibrium between soil formation and erosion are explored. Tertiary erosional episodes are dispelled as having no direct contemporary relevance. By contrast, the link between the Quaternary glacial eustacy and the host material of Natal's most spectacular erosion is emphasized. Suggestions that contemporary erosion within the Province is naturally accelerated, and that active gullying commences when a wet spell follows a prolonged dry spell in which sheet and rill processes are active, gleaned from the Holocene pattern of gully incision and aggradation, are explored. The anthropogenic influence on soil erosion became significant during the Late Iron Age when the introduction of domestic stock increased sheet/rill processes, and the change from woodland to grassland favoured gully incision. Erosion progressively increased in response to landuse changes from the late 18th Century. The erosional status of the landtypes corresponding to the gradation from the introduction of maize; to the conversion from shifting to settled subsistence farming; to intensive subsistence cultivation and associated overgrazed rangeland on the traditional communal land, and from small market farms to the intensive mechanized commercial agriculture on European owned land, is assessed. The greater extent and severity of erosion on traditional communal land is largely attributed to the prevalence of overgrazed veld. Suggestions of erosion during the second half of this century decreasing or stabilizing are explored. A review of soil formation and erosion rates from a worldwide perspective indicates that South African soil renewal rates are less than half the global average, and that while very severe erosion does occur in localized areas of poor vegetation cover, the broad scale rates are weak to insignificant. Approaches to modelling the effects of erosion on soil productivity are explored in a broader review of the detrimental environmental consequences of erosion. Challenges to soil conservation initiatives in both commercial farmland and traditional communal land conclude the chapter.

Chapter four describes the detachment and transport of sediment particles by rainsplash, and unconfined and confined surface runoff. As the comparative importance of these processes varies with erosion type, the mechanics of each of the sheet, rill and gully erosion types predominating in the study area is presented separately. The processes responsible for the generation of surface runoff are also outlined.

Soil erosion occurs when the forces promoting soil movement exceed those resisting it. The balance between these forces is controlled by a wide range of interrelated factors. Chapter five examines those most likely to exert a significant influence at the spatial and temporal scale of this study viz:- rainfall erosivity; soil erodibility; topography; vegetation; and landuse, and the applicability particularly in South Africa, of the most widely used indices of their influence.

Soil loss and sediment yield estimates derived from actual measurements of the rate at which sediment is removed from slope segments, and drainage areas respectively, are costly and time consuming to obtain. They are therefore more commonly obtained from predictive models using data extrapolated from maps, field survey reports, remotely sensed sources etc. Chapter six reviews the application of such models in South Africa. Unless the extrapolated input data is verified against actual measurements, their estimates particularly when derived from conditions outside of the range for which the model was designed, are relative and only meaningful on a comparative basis. Soil erosion estimates derived from actual measurements of the density of erosion forms or areal extent of eroded surfaces using remotely sensed sources, particularly aerial photographs, are cost effective. Chapter six explains how the variety of different approaches used to obtain such estimates in southern Africa, has limited their comparability. Unless potential soil erosion estimates are verified against such actual soil erosion estimates, they do not permit more than a descriptive appreciation of the erosion risk obtained. Potential soil erosion estimates are derived from the integration of estimates of the influence of the natural and anthropogenic factors examined in chapter five. The use of the geographic information systems as the best visual and computational thematic overlay technique for producing choropleth maps of, and assessing interrelationships between erosion risk factors; and potential; and actual erosion, is motivated in chapter six.

Chapter seven is presented in three parts. The first part explains the methodological considerations that influenced the decision to carry out a comparative assessment of temporal and spatial variations in the potential and actual erosion, and to use 'purposive ground sampling' in this study. The reasons for selecting a grid based GIS system, for using a 1 km^2 grid cell size, and for deriving estimates of actual soil erosion from measurements of the extent of eroded surfaces on aerial photographs, are then explained. The inherent sources of error involved in using sequential aerial photographs of differing scales to obtain these measurements, and the influence of dry and wet rainfall cycles and seasons on their accuracy, is described. The second part describes how the three 'erosion surfaces' measured in this study were identified on the aerial photographs, and how the data on rainfall erosivity, soil erodibility, and the topographic; vegetation; and landuse influences, were extrapolated and collected from aerial photographs, maps, field surveys, records and other studies. Having first established that both the actual and potential erosion data collected was normally distributed, the third part of this chapter motivates the use of the parametric tests chosen to assess and to measure the significance of the difference, and the degree of association between the data sets respectively, and particularly the use of Forward Stepwise Multiple Regression Analysis to explain the functional relationships between the data sets.

The findings of this study are discussed in chapter eight in three parts. The first part quantifies the description of the study area presented in chapter two, and shows that notwithstanding the high level of biophysiographic comparability between the two components of the study area; significant differences do exist which render the KwaZulu component more susceptible to soil erosion. Despite significant changes in the vegetation in both components caused by rainfall cycles; variations in veld burning and herbivore utilization; the clearance and abandonment of arable land; and deforestation, and by the general trend in seral development towards the woody climatic climax, neither component experienced an overall progressive dimunition in the protection afforded to the soil by it's cover. Settlement in the KwaZulu component in the late 1950's resulted in a dramatic increase in the number of kraals, roads, tracks and paths present in it by 1960. Although they continued to increase over the study period, the very high rate of increase was not sustained after 1970. The second part shows that at the commencement of the study, the very localized eroded surfaces were similarly represented in the study area components, while the very localized sparsely vegetated surfaces susceptible to erosion were significantly better represented in the KwaZulu component. The eroded surfaces in the Wilderness area remained very localized and restricted to the riverine area throughout the study period. Prior to 1970 the surfaces susceptible to erosion were very localized and predominated in the riverine and bottomland areas. After 1970 they became localized and also occurred on the upland areas. While the expansion of both these surfaces reflects the progressive bush encroachment particularly during the "nagana campaign"; and the herbivore overutilization during the sixties and early seventies, their contraction in the late seventies reflects the shift to a burning policy aimed at attracting game to underutilized areas coincident with above average rainfall conditions, and the intensification of the culling programme. Their contraction was not reversed by the severe drought of the early eighties.

The dramatic increase in the eroded and sparsely vegetated surfaces, from very localized to localized and very extensive, respectively, following settlement in the KwaZulu component of the study area, is also apparent in the second part of chapter two. Both surfaces contracted during the wet spell of the mid seventies. Despite the drought of the early eighties the eroded surfaces continued to decrease. The sparsely vegetated surfaces however, expanded substantially. In the riverine and bottomland areas the erosion surfaces predominantly reflected the influence of cultivation, while grazing and deforestation exerted the major influence on them in the upland areas. Their density and distribution in both areas additionally reflected the influence of kraals and roads. Active gullies only occured in the KwaZulu component of the study area where they were restricted to the upland areas. Their dimensions did not change significantly during the study period. The third part of this chapter assesses the extent to which the erosion potential factors examined in the first part, have contributed to the findings described in the second part as summarized above.

Finally, chapter nine assesses the major conclusions drawn from this study in terms of (i) the general perception of soil erosion on traditional communal lands, (ii) the aims of the study, and (iii) the weaknesses of the research design employed in this study, and consequent possible sources of data error, misinterpretation and inconclusiveness. This assessment yields a perspective of the past, present and future status of soil erosion in the Mfolozi catchment. The recommendations eminating from it note the constraints on management and development options in the 10b bioclimatic subregion of the Mfolozi catchment, imposed by the findings of this study. They also identify the topics that would need to be more thoroughly researched in order to substantiate the perspective on soil erosion presented, and its country wide implications. Other findings of this study that are of special interest either because they challenge or confirm previously reported findings, or because they are not known to have been previously reported are also highlighted in this chapter.

CHAPTER TWO

DESCRIPTION OF STUDY AREA

2.1 LOCATION

The study area is shown in Figure 2. It is situated in central Zululand between 28^{0} 15' and 28^{0} 30' south latitude, and 31^{0} 43' and 32^{0} 07' east longitude. It comprises two components:- the Wilderness area of the Umfolozi Game Reserve, and a KwaZulu area. The Wilderness area is 15 720 ha in extent, and is situated to the west of the confluence of the Black and White Umfolozi rivers. It contains the southern-most management blocks of the Hluhluwe - Corridor - Umfolozi Game Reserve Complex viz:- numbers: 28, 29, 32, 33, 35, 36 and 37. The Complex is 96 453 ha in extent, and is administered by the N.P.B. as a single unit. The KwaZulu area is 16 293 ha in extent, and is situated to the east of the rivers' confluence. It incorporates Phillip's (1973) bioclimatic subregion 10b of the Hlabisa and Enseleni census districts, to the north and south of the Mfolozi river, respectively. These districts are under the jurisdiction of tribal chiefs, and are administered by the KwaZulu homeland government.

2.2 HISTORICAL SETTING

From a survey of Stone Age artefacts, Penner (1970) concluded that the study area had been regularly visited by these hunter-gatherer communities from about 500 000 BP. This conclusion was supported by Hall (1979a, and b). By 1 700 BP, the study area's river valleys were settled by Early Iron Age communities. The settlement pattern of the Late Iron Age communities from 1 000 BP, was no longer confined to the riverine environment (Hall, 1979b, 1981). By the mid 16th Century the first Nguni culture was established in the study area. It was occupied by Zulu in the late 17th Century. The clan he established dominated it until the late 18th Century. Over the following century the study area was subjected to a very limited anthropogenic influence. The political reorganization that took place during the late 18th Century resulted in the formation of two chiefdoms. The Wilderness area was depopulated to create a buffer zone between the Ndwandwe under Zwide, to the west of the Game Reserve, and the Mthetwa under Dingiswayo, in the KwaZulu portion of the study area. Dingiswayo evacuated the KwaZulu area in the early 19th Century due to the increased incidence of malaria and sleeping sickness (nagana). After Shaka defeated Zwide in 1818, he used the study area as his private hunting ground. It remained unoccupied and subjected only to a limited amount of hunting in the 1830's to 1860's during Dingane's reign. The area was resettled in the 1870's during Mpande's reign, by

Mfanawenlela. As a result of repeated raids by the Mandlakazi tribe, the area had been evacuated by 1882. When the Game Reserve was proclaimed in 1897, it was still virtually uninhabited (Forster, 1955; Vincent. 1970, 1979; Hall, 1979a; Feely, 1980; Anon, 1985b).

During the first half of this century, the "nagana campaign" dominated events in the study area. The campaign aimed to eradicate the tsetse fly from Zululand through a programme that involved the removal of woody vegetation and wild animals. The KwaZulu portion of the study area was subjected to the same treatment as the Wilderness area, as it formed part of a "buffer zone" around the Reserve. Portions of the Reserve and buffer zone were proclaimed, deproclaimed and reproclaimed up until 1932 when the administration of the area was taken over by the Division of Veterinary Services of the Department of Agriculture (Brooks and Macdonald, 1982, 1983; Anon, 1985b). From 1947 the area was sprayed with chlorinated hydrocarbons which succeeded in eradicating the tsetse fly, enabling the administration of the Game Reserve to be handed back to the N.P.B. in 1952 (Brooks and Macdonald, 1982, 1983; Anon, 1985b). In 1958, the KwaZulu portion of the study area was resettled (Vincent, 1970). Since 1964, the N.P.B. has applied a non-interventionist conservation management approach to the Wilderness area (Vincent, 1970; Brooks and Macdonald, 1982, 1983).

2.3 GEOLOGY

The study area occurs on rocks of the Ecca, Beaufort, and Stormberg subgroups of the Karoo sequence. Figure 3 shows the dominant formations represented. Their surface expression follows a chronological sequence, such that; the oldest lower Ecca shales of the Pietermaritzburg formation outcrop in the west, and the youngest Stormberg basalts of the Letaba formation outcrop in the east. The Volksrust shale and Clarens sandstone formations are relatively thin strata that are consequently poorly represented. They outcrop east of the Vryheid and Nyoka formations, respectively. Although shales and sandstones are the dominant rock types in the Emakwezeni and Nyoka formations, mudstones are also present in them. Small quantities of grit and subordinate shales are also found in the Ntabene sandstone. Karoo dolerites form extensive horizontal sills in the western and central sections of the Wilderness area. To the north-west of the KwaZulu area, these dolerites intrude through the Vryheid formation as steeply inclined dykes. Kent (1980) describes the stratigraphy of these formations in greater detail. The sedimentary formations beneath the Wilderness area have a near horizontal attitude (King, 1970). As a result of a Quaternary tilt, their surfaces together with that of the dolerite sill, decline at about one degree towards the east (Downing, 1980a). A strike orientated from the north-east to the south-west traverses the study area in the vicinity of the rivers' confluence. Most of the Vryheid formation in the north-west of the KwaZulu area has a near horizontal attitude.

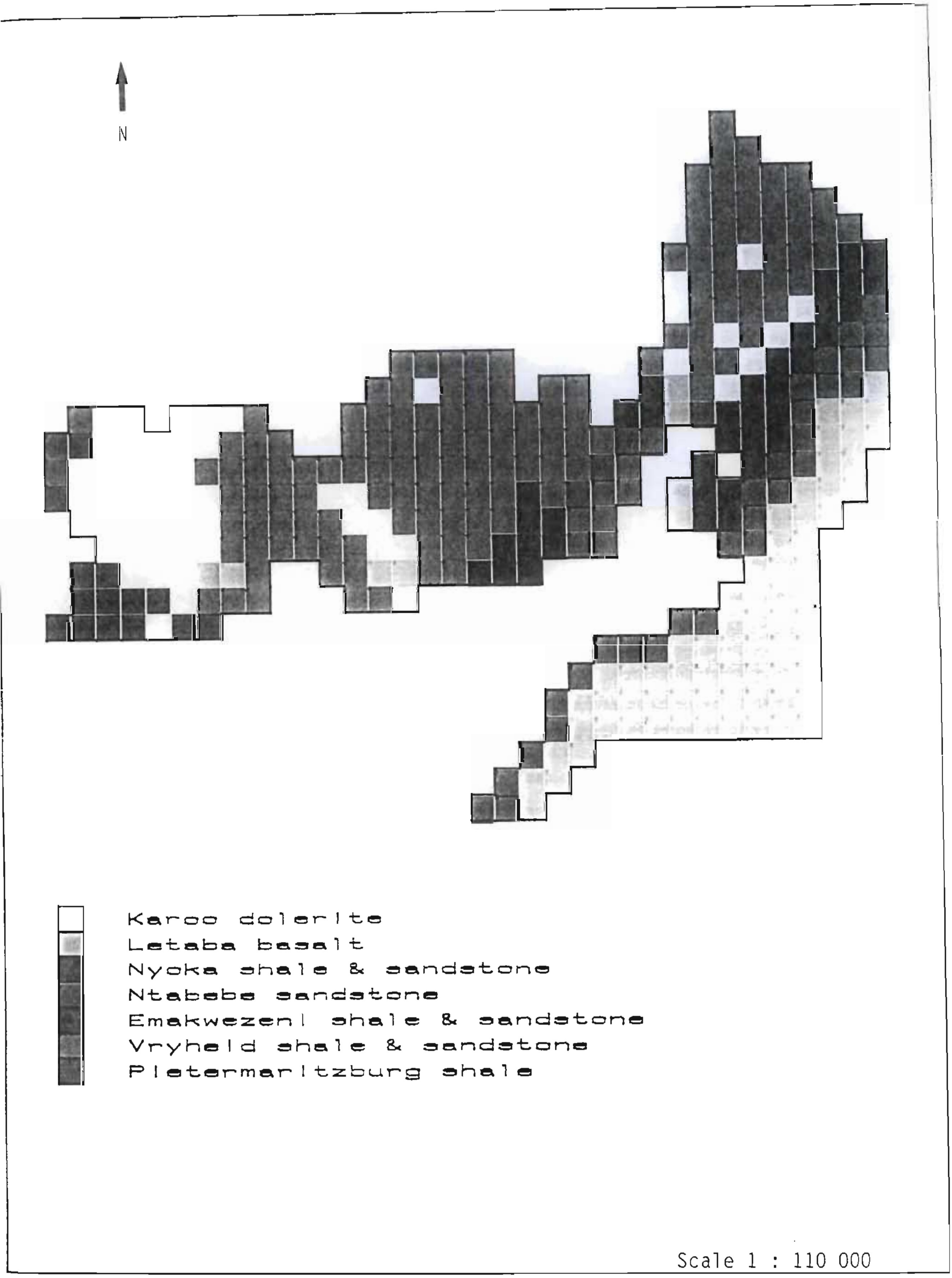


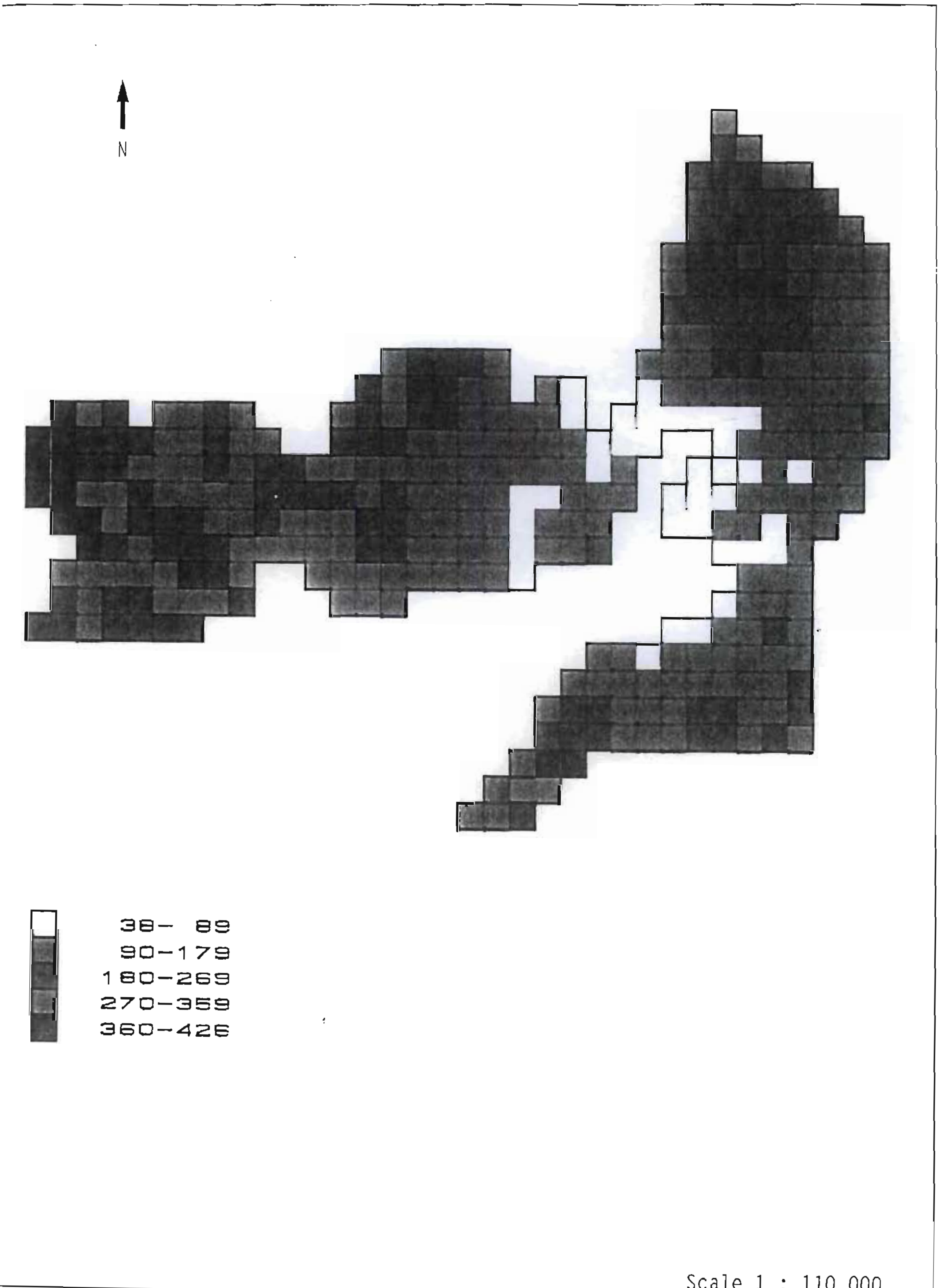
Figure 3. Dominant geologic formation.

The formations in the remainder of the KwaZulu area are tilted 23 degrees towards the sea. As a result, they crop out in linear zones parallel to the strike. According to King (1970, 1982) these formations also had a near horizontal attitude up until about 120 million years ago. Their crustal strength was exceeded when the Stormberg basaltic lavas accumulated on top of them. When they bent over towards the sea the crust was broken into blocks by a series of faults. Most of these fault lines are now filled with masses of breccia.

2.4 TOPOGRAPHY

Pitman, Middleton and Midgley (1981) delimited 43 Quaternary sub-catchments in the Mfolozi catchment. The study area is situated in four of them. The major hills, ridges, tributaries and pans present in the study area are shown in Figure 2. The western portion of the Wilderness area occurs within the Mpafa sub-catchment (Pitman, *et al.* 1981), and is dominated by the broad valley of the Umfolozi river. The river follows a meandering course. Numerous tributaries feed into it from both banks. Those entering it from the north-west drain the doleritic Kungqoloti hill. Tributaries entering the river from the south-east drain the Mfuyeni sub-catchment (Pitman, *et al.* 1981). They also originate in high ground formed by a dolerite sill. It is capped by several ridges of irregular orientation and size. The eastern boundary of the Wilderness area transverses the confluence of the Black and White Umfolozi rivers. This eastern portion occurs within the Mvamanzi sub-catchment (Pitman, *et al.* 1981) and is dominated by the merger of these two rivers. The watershed between them is formed by a dolerite ridge. The Fuyeni pan is a noteworthy feature of this portion. It drains into the White Umfolozi river to the east of Makhamisa. Figure 4 shows the distribution of land surfaces in the study area according to altitudinal maxima classes. The altitude in the Game Reserve component of the study area ranges from 426 m.a.m.s.l. on the Kungqoloti hill to 38 m.a.m.s.l. at the rivers' confluence. Figure 5 shows the relative distribution of the predominate slope gradients. Overall in the Wilderness area, the topographic characteristics corresponding to the major geologic formations are relatively homogeneous. Slope angles greater than five degrees are represented on hills and ridges of Karoo dolerite. The river valley plains and terraces on the sedimentary formations have gradients less than five degrees. The mean gradient of the section of the White Umfolozi river that traverses the study area is 0,6m km^{-1} (Downing, 1972).

Downing (1980a) describes the geomorphic origin of Miocene, Pliocene and Quaternary surfaces in the Umfolozi Game Reserve. Partridge and Maud's (1987) account of southern Africa's Post Mesozoic geomorphic evolution prompts critical reassessment of King's (1963, 1982) classic deductions particularly with regard to the African and post African landscape cycles. Downing's (1980a) frame-



igure 4. Distribution of highest relief features (altitude in metres above mean sea level).

work was not employed in the above description of the Wilderness area's topography, as it was derived entirely from King's (1963) concepts.

The central portion of the KwaZulu component of the study area, is dominated by river valley plains and terraces. The mean gradient of the Mfolozi river as it traverses this portion from the north west to south east, is 0,7m km^{-1} (Triebel, Van der Linden, Groenwald, Botha and Hill, 1981). A valley carved into the Nyoka shale formation opens into the Mfolozi river valley. The section of this valley in the south west is drained by the Mvanmanzi river, while that to the north east by the Mbukwini river. Both rivers terminate in pans, which are only in direct contact with the Mfolozi river during flood events (Begg, 1988). Tributaries draining into these rivers from the east drain the Nkata sub-catchment (Pitman, *et al.* 1981). They originate in the high ground formed by the resistant Letaba basalt formation. Those entering the west bank of the Mbukwini river drain the resistant ridges of the Ntabene sandstone and Karoo dolerite formations. Overall, the geology has contributed to a relatively simple topographic pattern. The resistant predominantly igneous formations form ridges, while the weaker sedimentary formations form valleys. Both these features are linear, sequential and orientated from the north east to south west. Faults do however, complicate this simple pattern. Runoff generated on the Dlokodlo ridge for example, is delivered to the Mbukwini pan via a fault crossing the Ntabene sandstone ridge. The altitude of the KwaZulu component ranges from 381 m.a.m.s.l. on the basaltic Kwamendo hill in the south west, to 29 m.a.m.s.l. along the Mfolozi river. Most slopes are steeper than ten degrees. Slopes declining westward tend to be shorter and steeper than the eastward facing slopes.

2.5 CLIMATE

2.5.1 **Precipitation**

The study area is situated in Natal's rainfall region 10, as delimited by Schulze (1982). The mean annual precipitation (M.A.P.) derived almost exclusively from rainfall, ranges from 650 to 850 mm. This range is deceptively high, as potential evaporation exceeds precipitation throughout the year (Downing, 1972). Schulze (1982) estimated the mean annual evapotranspiration for this area to be 1400 mm. In the study area the rainfall increases from west to east. Pitman, *et al.* (1981) estimate a M.A.P. in mm of 758, 760, 789 and 835 for the Mpafa, Mfuyeni, Mvamanzi and Nkata sub-catchments, respectively. Between 25 to 30% of the M.A.P. falls during the winter months from April to September. The proportion of the M.A.P. received during the late summer months (January, February and March) exceeds that of the early summer months by 5 to 10% (Schulze, 1981, 1982). Venter

(1988) analyzed 23 years of rainfall records from Mpila, which is situated in the Umfolozi Game Reserve a few kilometres north of the eastern portion of the Wilderness area. An average coefficient of variation of 31,6% revealed the rainfall to be highly variable. The annual precipitation ranged from less than half the long term mean in drought years to almost double it when floods occurred. A map prepared by Platford (1979) of rainfall erosivity in Natal's sugarcane producing areas, shows the erosivity in the Mpafa sub-catchment as 9×10^{-3} joules m^{-2} yr^{-1} increasing to 13×10^{-3} joules m^{-2} yr^{-1} in the Nkata sub-catchment. Smithen and Schulze's (1982) map of the Southern African distribution of average annual EI_{30} estimates, shows very high values for the study area ranging from 450 to 500.

Braune and Wessels (1980) estimate the mean annual runoff (M.A.R.) in this region, to be about 20% of the M.A.P.. The variation in M.A.R. in the sub-catchments of the study area as estimated by Pitman, *et al.* (1981), does not correspond directly to the trend in M.A.P. The sub-catchment estimates from west to east are:- 8, 5, 6, and 9×10^{-6} m^{-3}, respectively. The Mfuyeni and Biyela wards studied by Schulze (1981) are immediately south of the study area. Baseflow in them was found not to make a substantial contribution to the inflow of dams. Although runoff was commonly generated when the daily rainfall exceeded 10 mm, it was highly variable. This comparatively low threshold was attributed to shallow soils and poor ground cover.

2.5.2 Temperature

The study area experiences large diurnal and seasonal variations in temperature. From October to March the mean monthly maximum, minimum, and range in temperature is 28^{o}, 18^{o}, and 23^{o} to 27^{o}C, respectively. These estimates were extracted from temperature data recorded at Mpila, 244 above mean sea level. The temperature maxima and minima experienced in the river valleys are anticipated to be correspondingly higher and lower. The absolute summer temperature maximum recorded at Mpila is $43,3^{o}$C. The winter mean monthly maximum, minimum, and range in temperature is 25^{o}, 13^{o}, and 19^{o} to 23^{o}C, respectively. The absolute minimum winter temperature minimum recorded at Mpila is $6,7^{o}$C. During winter the study area is characterized by strong nocturnal temperature inversions. This drainage of cold air from surrounding high ground may reduce winter minima in the river valleys to below freezing (Downing, 1972, Anon, 1985b).

2.6 PEDOLOGY

2.6.1 General Characteristics

The soils of the study area belong to the subtropical Brown Lowveld group delimited by van der Merwe (1941, 1962). These shallow residual soils are generally about 300 mm deep, and seldom exceed a depth of 1m. Horizons and secondary deposits are generally absent. The climate in this region favours rapid mineralization of organic matter, eluviation of soluble constituents, mineral hydrolysis, and disruption of minerals in the colloid. The soils consequently have a low humus content, a slightly acid surface layer and a relatively low molecular silica: sesquioxides, and silica: alumina ratios in their clays. As the bases leached from the surface are not lost from the profile, the pH increases with depth (van der Merwe, 1941). The climate also favours intensive chemical rock weathering. The parent material on the Karoo dolerite consists of either undecomposed rock or a reddish brown clay in which spheroidal boulders are embedded. The Letaba basalt disintegrates to granular rock fragments that are mixed with clay infiltrated from the surface. On the sedimentary formations the parent material is a dark grey, angular stony and gravelly loam (van der Merwe, 1962).

The soil types in the study area may be classified according to the rock types from which they formed. Red blocky clays predominate on the igneous rocks (Macvicar, 1973; Fitzpatrick, 1978). According to van der Eyk, Macvicar and de Villiers, (1968) they developed under weathering intensities far greater than those prevailing today. The predominate clay minerals present in these red structured soils, as well as in the less common black clays are montmorillonite, illite and kaolinite. Shallow duplex soils occur on the sedimentary rocks. They have clay subsoils in which montmorillonite and illite predominate (Macvicar, 1973; Fitzpatrick, 1978). Downing (1972; 1980a) classified the soils in the Umfolozi Game Reserve according to their topographic position. The stony dystrophic Upland soils are less than 500 mm deep and occur on hilltops, hill slopes and debris slopes. The Bottomland soils occur on alluvial terraces, tow slopes and pediments, and are one to several metres deep. Their A horizons are impermeable and become waterlogged readily. Their B horizons are illuviated, and as a consequence contain large carbonate nodules. The Riverine soils are highly erodible, unconsolidated alluvia which may be up to five metres deep. Scotney and van Schaucwyk (1969) noted that the Game Reserve's bottomland soils are particularly susceptible to erosion. They attributed this to the abrupt textural change from a perched gley horizon to a prismatic or cutanic B horizon, and to a high montmorillonite and exchangeable sodium content. Overall the study area's soils may be described as having a moderate agricultural potential (Schulze, 1982), with the bottomland association being the most fertile (Downing, 1972; 1980a).

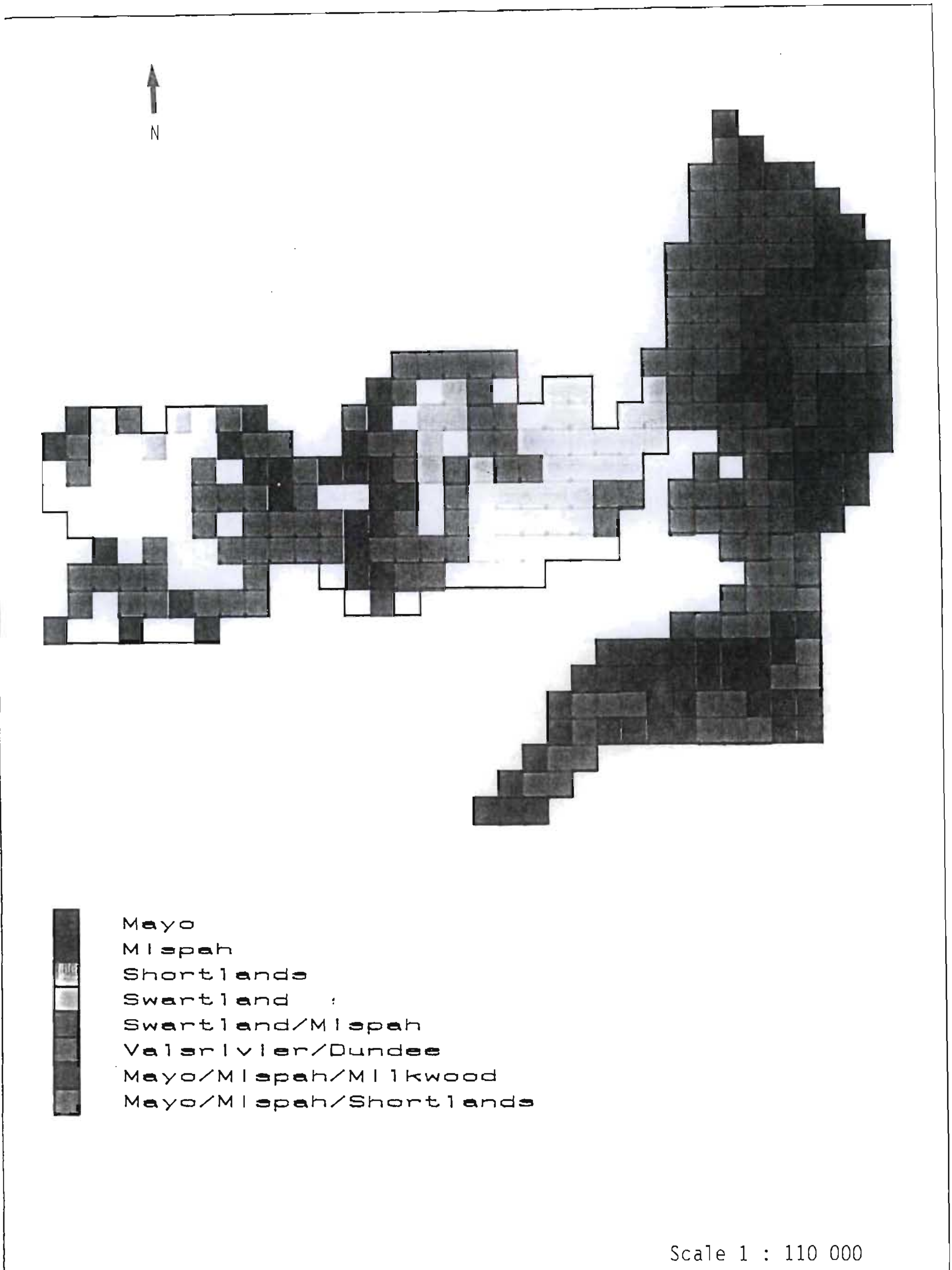


Figure 6. Dominant pedogenic forms.

2.6.2 Formations

The dominant soil forms present in the study area are shown in figure 6. A total of nine forms are present. Fernwood occurs as an independent form and is poorly represented. Dundee and Valsrivier occur only in association with each other. Milkwood is represented only in association with Mayo and Mispah. Mayo, Mispah, Shortlands, Sterkspruit and Swartland all occur independently, or in association with one or two of these forms. In the Wilderness area, the uplands underlaid by Karoo dolerite are predominantly covered by Shortlands. This form has an orthic, dark reddish brown, clay, moderate to fine subangular blocky A horizon, and a structured, red, clay B horizon (Macvicar, 1986). It has a moderate runoff potential, no interflow potential (Schulze, 1985) and a very low erodibility (Macvicar, 1973; Anon, 1976). Platford (1979) set the acceptable soil loss level for Shortlands at 13 t ha^{-1} yr^{-1}. The sedimentary rock formations in the study area are predominantly covered by Swartland and Mispah, either as independent forms, or in association. The percentage of clay in the Swartland increases down through the profile (Schulze, Hutson and Cass, 1985) from a grey, clay loam surface soil (Macvicar, 1973). In the Mispah, the clay percentage is constant (Schulze, *et al.* 1985) throughout the shallow, grey brown, clay loam that rests directly on the parent material (Macvicar, 1973; 1986). These forms have a moderate to high runoff potential, no to limited interflow potential (Schulze, 1985), and are moderately erodible (Macvicar, 1973). Anon (1976) notes that the Swartland may be highly erodible, and very highly erodible when in association with the Sterkspruit. In the Sterkspruit there is an abrupt textural transition between the orthic, sand clay loam topsoil and the prismacutanic subsoil (Macvicar, 1973, 1986), which contributes to its high runoff potential and limited interflow potential (Schulze, 1985). Mispah's acceptable soil loss rate is 4 t ha^{-1} yr^{-1} (Platford, 1979). The rate for Swartland is likely to be comparable. Platford (1979) gives a rate of 5 t ha^{-1} yr^{-1} for Milkwood, which although darker and more structured than the Mispah and Swartland, has very similar properties to them (Macvicar, 1973; 1986).

In the KwaZulu component, the upland areas underlain by Letaba basalt are predominantly covered by Mayo, and Mayo associations. Their topsoils are dark grey to black, sandy clay loams (Macvicar, 1986). The clay percentage decreases abruptly in the subsoil (Schulze, *et al.* 1985). They have a moderate to high runoff potential, no to limited interflow potential (Schulze, 1985), and have a low (Anon, 1976) to moderate erodibility (Macvicar, 1973). Their acceptable soil loss rate is 9 t ha^{-1} yr^{-1} (Platford, 1979). The predominant soil forms on the unconsolidated alluvial material of the river valley plains, are Dundee and Valsrivier. The Dundee's stratified nature depends on the materials deposited by the river. Sands, loams, clay and their intergrades are arranged as layers in a host of combinations (Macvicar, 1973). This form has a moderate runoff potential, no interflow potential (Schulze, 1985), and is highly erodible (Macvicar, 1973). The Valsrivier's surface material is orthic, red, sandy clay loam (Macvicar, 1986). The clay percentage increases down the profile (Schulze, *et al.* 1985). The Valsrivier has a moderate to high runoff potential, a limited interflow potential (Schulze, 1985), and is highly erodible (Macvicar, 1973). The Fernwood form has a limited representation in these riverine soils. It is an orthic, dark grey to brown, loamy fine sand. This material is structureless, loose and very highly erodible (Macvicar, 1973; 1986).

2.7 VEGETATION

2.7.1 General characteristics

The vegetation of the moist savanna biome in which the study area is located (Huntley, 1984), comprises a herbaceous, usually graminoid ground layer, and an upper layer of phanerophytes, which can vary from being widely scattered to forming a closed canopy. Plants in both layers are well adapted to withstand drought. Grazing pressure during drought is commonly excessive however, and serves to reduce the resistance of the hemicryptophytes. The surface fires typical of this biome seldom cause mortalities in excess of 10% in either grasses or woody plants (Rutherford and Westfall, 1986). The codominance of grasses and trees/shrubs is dependent on the fire regime, and has been the focus of a substantial research effort (Scott, 1952, 1955, 1966, 1970, 1984; West, 1958, 1971; Downing, 1974a; Trollope, 1974, 1984; Joubert, 1977; Edwards, 1984, Mentis and Tainton, 1984). The general conclusion of which is that the savanna grasslands are subclimax communities principally initiated and maintained by the periodic retarding influence of fire. Fire suppression in areas where the density of ungulate grazers is low, results in the progressive accumulation of moribund material. This mantle stifles grass growth providing woody invaders with a competitive advantage. Fires destroy juvenile shrubs and trees, and prevent more mature plants from developing through to a taller fire resistant stage. Once the phanerophyte layer has become established, it suppresses vigorous growth in the herbaceous layer depriving fires of the fuel loads necessary to attain the high intensities required to destroy woody plants. Excessiye grazing and droughts encourage bush encroachment through a similar effect on the potential fuel load of the grass layer. Mentis and Tainton (1984) however, drew attention to an interesting paradox. In areas where a regular fire regime arrests bush encroachment, periodic severe defoliation stimulates reproduction thus maintaining the grassland's high basal cover and forage production capacity.

Trollope (1974, 1984) suggested that in the past the establishment of woody plants in savanna grasslands was restricted by an interaction of both burning and browsing. The inflammable material that accumulates after a good rain season fuels high intensity fires that are generally capable of destroying the aerial growth of woody plant invaders. The resultant coppice growth is at an acceptable height and palatability for browsing by wild ungulates. This activity in turn, restricts the woody plants developing further. Such dry season fires may be ignited by lightning, but are more likely to have been caused by Stone Age/Iron Age cultures (Watson, 1981).

The moist savanna's grass component is classified as "sourveld" due to its lower dry season nutritional status and palatability. Although the woody component has a high nutrient content, most browsing animals accord it a low palatability rating. The combined nutrient/palatability status of these two components renders this biome incapable of sustaining high ungulate densities (Huntley, 1984; Rutherford and Westfall, 1986). A regular fire regime increases forage production, accessibility and palatability, thus increasing the biome's herbivore carrying capacity (Mentis and Tainton, 1984).

2.7.2 Dynamics

Two veld types as described by Acocks (1953, 1975) are present in the study area. Lowveld, a subcategory of the Tropical Bush and Savanna Types, covers most of the area. The presence of Zululand Thornveld, a subcategory of the Coastal Tropical Forest Types, is restricted to the vicinity of Mduba and Mendu in the south. Evidence of development towards the closed woodland/forest climatic climax is strong in both veld types. Their grassland constituent typically contains a range of tall coarse grasses, tall herbs and shrubs. Their woody constituents are predominantly evergreen and become progressively taller and less tangled inland (Werger and Coetzee, 1978).

Trollope (1984) is of the opinion that the establishment of the closed woodland/forest climatic climax prior to any anthropogenic influence in the study area, would have been prevented by its natural fire regime. He maintains that fires ignited by natural agents had an annual to biennial frequency, and burnt at greater intensities than those occurring in the contemporary veld types. Such a regime would have favoured a catena of woodland sere. Downing (1972) suggested that the climax vegetation was present in the Umfolozi Game Reserve prior to the 19th Century. However, King (1987) describes advanced pyrophytic adaptations displayed by many of the fire induced woody communities, that suggest that the regular occurrence of fire has played a major role in their evolution over a much longer period of time. According to Berry and Macdonald (1979) and Macdonald, Furniss, Scholes and Berry, (1980) these communities are plagiosere, as the natural incidence of fire is insufficient to maintain pyrosere. These researchers examined the ignition source of fires recorded in the Game Reserve Complex from 1955 to 1978, and found that only one percent had been ignited by lightning.

Hall (1979a; 1979b; 1981; 1984) views the anthropogenic influence as the major factor contributing to vegetation change in the study area over the last one and a half millennia, and presents the following model of this change. During and prior to the Stone Age a forest climax was present in the river valleys. The bottomland areas were covered with a closed woodland climax. The shallow, dry soils on the high hills in the western portion of the Wilderness area supported a pedalogic grassland climax. A catena of woodland sere covered the balance of the upland area. The use of fire by the Stone Age hunter-gatherers only had a localized and transient effect on the vegetation. The climax communities therefore still predominated throughout the study area when its river valleys were settled by the Early Iron Age cultivators. Their clearance and use of woody plants, and use of fire caused the riverine and bottomland communities to revert back to less mature, more open sere. The upland woodland communities, and the forests lining the tributaries remained intact throughout the Early Iron Age. When the higher altitude areas became settled during the Late Iron Age their vegetation communities were also converted to less mature, more open sere. The use of fire to improve livestock grazing became progressively more frequent and extensive, and was largely responsible for maintaining a grassland and open woodland community structure through until the late 18th Century. Bush encroachment was able to take place in the study area during the 19th Century period prior to Mpande's reign, as it was largely unoccupied. The encroachment rate was however, regulated by the use of fire in hunting activities and clan warfare. By the turn of the 20th Century a mosaic of woody sere had developed within the predominately open grassland. The above model of vegetation change is supported by Feely's (1980) assessment of the Iron Age influence on the Wilderness area.

West (1971) reported that the mechanical damage to trees caused by elephants was a significant factor restricting the development of climax vegetation in Zimbabwe's savanna regions. In South African savanna regions the annual tree loss attributable to elephant activity averages 4% (Cumming, 1982; cited in Grossman and Gandar, 1989). Elephant hunting in the study area increased dramatically during the 1850's and culminated in their local extinction in 1896 (King, 1987). Bush encroachment over this period was no doubt additionally encouraged by the declining elephant influence. Nevertheless, fire apparently continued as the dominant factor regulating the rate of seral development. According to Foster (1955) the only dense woody communities present in the Reserve when it was proclaimed in 1897, occurred along the banks of rivers and tributaries. While the study area was largely unoccupied since Dingiswayo's evacuation, the occupation of its neighbouring areas to the west and north was uninterrupted (Vincent, 1970, 1979; Anon, 1985b). Aitken and Gale (1921) and Foster (1955) observed that the regulation of livestock grazing in these neighbouring areas involved the burning of extensive portions of veld each winter. These fires may have swept through the study area fairly regularly.

Seral development proceeded imperceptibly during the early decades of this century. Aitken and Gale (1921) noted that the woody plants in this area in addition to growing densely in the vicinity of drainage lines, were sparsely scattered on the grassland slopes between them. Henkel (1937) described the vegetation of the northern Complex as predominately woodland and "parkland" savanna. Large expanses of *Themeda triandra* dominated grassland were however, still prevalent. By the late 1940's an awareness of the changes in the vegetation was apparent (Attwell, 1948). The increase in woody vegetation at the expense of grassland was described in qualitative accounts by Foster (1955), Cowles (1959), Ward (1962), Deane (1966), Bourquin (1969b), Bourquin and Hitchins (1979) and Porter (1977), and confirmed in limited field surveys by Stewart (1966) and Mentis (1969). A review of this literature reveals that succession progressed more rapidly in the moist northern section but followed the same trend throughout the Complex. Bush encroachment during the first half of this century was attributed to underutilization of the grassland by grazers and the virtual absence of fire. By contrast the encroachment from the mid 1950's to late 1970's was attributed to the ineffectiveness of fire on overgrazed veld.

Reports on vegetation changes in the Complex's northern section indicate a topographic influence. Succession was described as being most rapid on mid slope loci by Macdonald (1979a). Downing's (1980b) comparison of two vegetation maps prepared 36 years apart showed large increases in the upland woody communities which contrasted with the relatively stable lowland communities. King's (1987) quantification of changes in scrub and forest communities using retrospective aerial photographs revealed a pedohydrologic association with the topographic influence. Scrub expanded most rapidly on the drier, deep, coarse, sandy soils. These soils occur at low altitude, and on flatter terrain unaffected by drainage. The wetter, fine, shallow soils supported the most rapid forest expansion. They occur at higher altitude, on steep gradients, and close to drainage areas.

King (1987) noted an association between the expansion rates of the woody communities and the cyclic trends in this region's rainfall as described by Tyson (1986). Moisture conditions more conducive to optimal growth accelerated the forest expansion during wet cycles. King (1987) attributed the enhancement in scrub encroachment during short term dry cycles to the competitive advantage gained when dry soil conditions caused grass mortality. Such a competitive edge over grasses also stimulated the expansion of scrub during wet cycles, viz:- the increased herbivore numbers caused overgrazed veld which in turn rendered fire ineffective. Watson and Macdonald (1983) used retrospective aerial photographs to assess the success of various treatments which were applied to reverse or retard the bush encroachment. A very intense burn treatment proved the most effective method of arresting the encroachment in the short term. In common with the other treatments however, it had no long term effect on this trend in seral development. These authors concluded that the burning policy employed in the Complex since the mid 1950's would not succeed in arresting this trend. The only specific reference to the vegetation of the KwaZulu component of the study area in the above literature is that by Foster (1955). In the early 1950's he noted that the bush encroachment there was comparable to the reserve.

2.7.3 **Contemporary community structure**

The contemporary vegetation consists of riverine forest, closed woodland, open woodland, thicket, induced thicket, grassland and reedbeds that occur as distinct physiognomic types in a dynamic mosaic of seral communities. Whateley and Porter (1983) described the physiognomy, distribution, and height and percentage frequency of the component species in the different canopy strata of the woody vegetation communities in the Game Reserve Complex. Factors included in this description that influence the potential for soil erosion within these communities, are outlined below. Both the *Ficus sycamorous* - *Schotia brachypetala* and *Spirostachys africana* - *Euclea schimperi* riverine forest communities are very mature sere (King, 1987). The former is confined to the banks of the large rivers and their major tributaries. The latter occurs throughout the area as a narrow strip along seasonal water courses. Both communities contain three strata that contribute to a closed, overlapping canopy. The *F. sycamorous* - *S. brachypetala* community has a dense herbaceous ground layer comprised of stoloniferous and tufted grass species, and is well utilized by herbivores, particularly during winter. The ground layer of the *S. africana* - *E. schimperi* community is less dense. It consists mainly of tufted perennial grass species. Both these forest communities are only rarely penetrated by fire.

The *Spirostachys africana* and *Euclea divinorum* closed woodland communities are mature sere (King, 1987). The *S. africana* community covers extensive bottomland areas. The *E. divinorum* community is confined to gentle slopes on margalithic soils. The canopy of both communities ranges from closed to broken, and is contributed to by upper and lower strata. Both communities have a fairly dense herbaceous ground layer comprised of stoloniferous and tufted grass species. Fire rarely succeeds in penetrating these communities. The *Acacia burkei* open woodland community is a mature seral stage (King, 1987). It occurs on the sandy loam soils of the broad, flat, low altitude ridges, and on the sandy soils of riverine terraces. It has upper and lower strata which contribute to an open canopy. It has a fairly dense herbaceous ground layer that consists mainly of annual stoloniferous grass species. The spread of fire through this community is not restricted.

The *Acacia nigrescens*, *Acacia gerrardii*, *Acacia tortilis* and *Combretum apiculatum* open woodland communities are intermediate sere (King, 1987). Hillslopes underlaid by igneous rock formations are extensively covered by the *A. nigrescens* community. The *A. gerrardii* community covers extensive areas of the gently undulating terrain underlaid by sedimentary rock formations. The *A. tortilis* community occurs on the moist east facing slopes throughout the study area. The *C. apiculatum* community is restricted to rocky hillslopes. All four of these communities have an open canopy contributed to by upper and lower strata. The *A. nigrescens* community has a dense herbaceous ground layer comprised of stoloniferous and tufted grass species. This layer in the *C. apiculatum* community is fairly dense. It consists mainly of tufted grasses. The tufted grasses in the herbaceous layer of the *A. gerrardii* and *A. tortilis* communities provide a sparse ground cover. Fires spread readily through these communities. They often attain high intensities particularly in the *C. apiculatum* community.

The *Acacia caffra* thicket community is an immature seral stage (King, 1987). It occurs in the uplands throughout the study area. It has a single canopy stratum and a fairly dense herbaceous layer comprised of tall, tufted grass species. Fire spreads very rapidly through this community. The physiognomy of the *Acacia karroo* community is induced by anthropogenic fires. The community is an immature seral stage (King, 1987), that occurs on steep hillslopes throughout the study area. It has a scattered canopy and a dense herbaceous ground layer comprized of very tall tufted perennial grasses. This community is well utilized by both grazers and browsers, and is the most frequently burnt of all the woody plant communities.

Burning frequency and grazing pressure exert a major influence on the seral stage of the grassland communities. Grasses covering the upland dystrophic soils are less palatable than the bottomland grasses. In the Wilderness area most of the upland grassland is lightly grazed by buffalo, zebra and wildebeest only, and periodically burnt. It is consequently maintained in mature and very mature sere in which *Urochloa mossambicensis* and *Themeda triandra* predominate, respectively (Downing, 1972; 1974a). The balance of the upland grasses in the Game Reserve are underburnt and undergrazed and consequently invaded by *Acacia* spp. In the KwaZulu area overgrazing by domestic stock, and burning too early or too late, have resulted in most of the upland *T. triandra* dominated pyroclimax being replaced by 'Ngongoni veld. *Aristida junciformis* and *A. bipartita* dominate this veld. They are short densely tufted grasses of which only the young green shoots that appear after burning are palatable to grazers. The areas covered by 'Ngongoni veld are encroached to varying degrees by *Acacia* spp., *Aloe* spp. and *Euphorbia tirucalli*. According to Edwards (1967) the xerophytic shrub *E. tirucalli* is an alien species that was introduced by the Zulus as hedge material. Its encroachment of poorly covered soil surfaces is particularly successful.

Most of the bottomland grasses are moderately grazed and periodically burnt. They are consequently covered by a mid-seral community dominated by *Panicum coloratum*. Within this community areas subjected to heavier grazing pressure have been replaced by the less palatable *Bothriochloa* spp.

Overgrazing and consequently underburning in the balance of the bottomland grasses has encouraged encroachment by *Acacia* spp. *P. maximum* a palatable and shade tolerant grass species, is dominant underneath these plants. The patches between them are generally poorly covered by early seral grasses. The dominants of which are *Eragrostis* spp., *Sporobolus* spp. and *Digitaria argyrograpta* (Downing, 1972; 1974a). This early seral community is best represented on the abandoned cultivated fields in the KwaZulu area's bottomlands.

The *Phragmites mauritianus* - *P. australis* reedbed community covers sediment deposits in the major river beds, fringes the major pans and occurs in isolated patches in the smaller wetlands throughout the study area. The width of the river bed community ranges from a few metres to over 450 metres. Substantial portions of this community are damaged and/or removed during floods (Downing, 1972; Combrie Grieg, 1984). The Fuyeni reedbed covers some 15ha and is the largest of the pan communities. Although most of the pans are linked to the major rivers during floods, their reedbeds are seldom detrimentally effected (Begg, 1988). The viability of these communities as well as those of the scattered vleis, is threatened by wetland destruction. According to Begg (1988) the area of the extant wetlands in the Mpafa, Mfuyeni, Mvamanzi and Nkata sub-catchments is 97, 52, 26 and 29 percent less than it was prior to the Iron Age, respectively. He attributes this loss primarily to poor burning practices and overgrazing. Macdonald (1979b) noted that poorly sited roads and paths are additionally responsible for the more recent and greater loss in the Wilderness area's sub-catchments. Hall (1981) found stable *A. robusta* and *S. africana* communities occurring on archaeological sites that were abandoned in the 7th Century. Juvenile *E. divinorum* communities occurred on sites that had supported habitation up until the late 18th Century. The association between the Late Iron Age sites and the *A. nilotica* and *A. nigrescens* communities was so strong that Hall (1981) suggested that they should be considered as artefacts. He noted that the grassland archaeological sites were associated with *U. mosambicensis* communities which were consistently more heavily grazed than the surrounding *T. triandra* communities. Feely (1980) noted that the sandy alluvia along the Umfolozi rivers that were cultivated up until the early 19th Century support *Maytenus senegalensis* and *A. robusta* communities.

2.8 FAUNA

2.8.1 Dynamics

The study area's potential for soil erosion may have been influenced by changes in the composition of animal species and in their total biomass. The woody vegetation that prevailed until about a thousand years ago would have supported relatively stable populations of diverse browsing species. The grassland and open woodland of the Late Iron Age provided the preferred habitats of grazers and mixed feeders. The progressive encroachment of thicket scrub since the 1940's would have favoured browsers at the expense of grazers (Feely, 1980; Hall, 1981). The natural migration of browsers into the area was however, restricted by their diminished populations in potential source areas, the construction of a fence demarcating the Reserve's boundary and human settlement around the Reserve. Both the latter events commenced during the early 1950's (Brooks and Macdonald, 1982, 1983).

At the turn of the century the study area's total ungulate biomass was low. Hunting in the area had been intensive since the late 1860's and continued until 1929 despite the Reserve's proclaimed status (Vincent, 1970; Brooks and Macdonald, 1982, 1983; Anon, 1985b). Between 1880 and 1925 nine large game species had been eliminated from the area (Downing, 1979a). Most game populations took until 1905 to recover from the dampening effect of the 1896 rinderpest outbreak (Brooks and Macdonald, 1982, 1983; Anon, 1985b). With the exception of both species of rhino, populations of all game species were reduced during two stages of the "nagana campaign". Between June 1929 and November 1930, 26 162 head of game were killed in the Reserve (Foster, 1955, Vincent, 1970). The total including those killed in the "buffer zone", is given by Anon (1985b) as 37 861. The second stage continued from December 1942 until April 1950, and resulted in the elimination of 70 200 head of game (Mentis, 1970; Anon, 1985b).

Major differences in the composition and density of game within the Wilderness and KwaZulu components of the study area are only likely to have arisen after 1952, once the administration of the Reserve was returned to the N.P.B. Regular patrols along the boundary separating the two components served to decrease poaching within the Wilderness area, and to restrict game migration across to the KwaZulu area. This movement was further restricted from 1958 when it became settled by peasants (Vincent, 1970), and effectively halted from 1962 when the fence along this portion of the Reserve's perimeter was erected (Brooks and Macdonald, 1982). Hunting and habitat transformation in the KwaZulu area is likely to have resulted in a rapid decline in the population of all but the most inconspicuous of wildlife species to levels comparable to the contemporary insignificant one. By contrast the total ungulate biomass in the Wilderness area in common with the rest of the Reserve, increased to a peak in 1972. The very rapid rate of increase from the early 1950's to late 1960's dampened slightly before the peak. The decline following the peak was fairly rapid in the mid 1970's but stabilized to slower rates in the late 1970's and early 1980's (Brooks and Macdonald, 1982; 1983). According to Downing (1979a) the trebling in total ungulate biomass between 1942 and 1972 was primarily due to the increase of similar proportion in the bulk of the large grazing species. The biomass of browsing species over the same period increased by only 50%. Brooks and Macdonald

(1982, 1983) are of the opinion that the grazer stocking rate first exceeded the grazer carrying capacity in 1960, and despite the decline since 1972, was still above it in the early 1980's. Their opinion requires a critical evaluation of the accuracy of stocking rate and carrying capacity estimates.

2.8.2 **Stocking rate versus carrying capacity**

Mentis and Duke's (1976) estimate of 6 and 7,2 ha AU^{-1} for domestic stock and wild ungulates, respectively; are the most widely cited carrying capacity estimates in the literature on this area. They are derived using a scientific method recommended by the Agricultural Technical Services, and based on the observation that grazing in this bioclimatic subregion is generally viable for 300 days a year. The estimates are presented as the number of hectares required to support one animal unit, where a unit is equivalent to a domestic beast of 456 kg. Smuts (1980) advised against using Mentis and Duke's (1976) estimate as an average measure of the Reserve's carrying capacity, as it failed to account for the reduction in herbage productivity caused by bush encroachment. The 7,2 ha AU^{-1} estimate was fair for grassland but overestimated the carrying capacity of the forest and closed woodland communities which Smuts (1980) subjectively assessed to range from 10 to 40 ha AU^{-1}. He argued that as the vegetation of the Reserve was dominated by these woody communities, the use of an average carrying capacity estimate of 10-15 ha AU^{-1} would prove more accurate. The changes in the composition of the Reserve's vegetation communities caused spatial as well as temporal variations in the carrying capacity. As the grazer populations increased the palatable bottomland grasses became overutilized. Their consequent impoverished fuel loads rendered fires through them incapable of destroying the seedlings of encroaching woody plants. Once established these plants further depauperated the bottomland's carrying capacity (Downing, 1979b). The carrying capacity of areas heavily invaded by unpalatable woody species such as *Euclea divinorum* and *E. schimperi* was reduced in advance of and to a greater extent than the other bush encroached areas (Porter, 1977).

Brooks and Macdonald (1982, 1983) have tabulated all available estimates of the ungulate populations in the Reserve since the earliest of 1929. They maintain that the large gregarious grazers have always been fairly well enumerated, but that the smaller mixed feeders and browsers have been consistently underestimated. At their peak in 1972 the grazer and browser stocking rates were estimated to be 5,9 and 16,6 ha AU^{-1}, respectively. Following a subjective assessment of veld conditions Macdonald (1981) derived an estimate for the Wilderness area of 12,7 ha AU^{-1} which is considerably lower than his estimate of 10,4 ha AU^{-1} for the Complex as a whole. The 10,4 ha AU^{-1} estimate was adopted by Brooks (1981) in his revision of the Complex's culling policy. Future game removal operations were to maintain the total stocking rate at 20-30% below this average capacity in order to avoid the use of drastic control measures in response to climatic extremes. Macdonald's (1981) estimates were concluded after the worst cumulative 3 year rainfall period in its recorded history. The veld condition was therefore unlikely to have been an exclusive reflection of the ungulate stocking rate. Harvester termites are evidently particularly active during dry years. During the droughts of the early 1950's and early 1980's the proportion of herbage defoliation attributed to termites was estimated by Vincent (1970) and Emslie (1983) as 75 and 38%, respectively.

The only domestic stocking rate estimate for a KwaZulu area within the Mfolozi catchment known to this author, is that given by Anon (1985a) for the Ulundi ward immediately inland of the Wilderness area. Although Mentis and Duke (1976) estimated a carrying capacity ranging from 5 to 7 ha AU^{-1} for the type of Lowveld found in this area, Anon (1985a) was of the opinion that the extent and degree of degradation had reduced this to 11 - 13 ha AU^{-1}. The stocking rate estimate of 1,3 ha AU^{-1} therefore depicts it as severely and seriously overstocked. In comparison to the study area's KwaZulu component, the Ulundi ward has been much more densely settled over a continuous and much longer period of time (Anon, 1985b). This researcher is therefore of the opinion that such an excessive stocking rate is unlikely to have existed in any part of the KwaZulu study area during the study period.

2.9 GAME RESERVE MANAGEMENT

2.9.1 Veld burning

The management policy on veld burning, control of ungulate populations, and bush encroachment may have influenced the Wilderness area's potential for soil erosion. Prior to 1932 winter burning took place on an *ad hoc* basis in order to improve grazing or game viewing. Numerous flammable tsetse fly traps were distributed throughout the area from 1932 to 1947. Veld burning in it was therefore banned, while fires spreading into it from surrounding areas were actively extinguished and seldom affected substantial portions. From 1947 to 1955 no deliberate veld burning policy was operant. Spring burns were then implemented on a rotational basis at a frequency of once every three to five years through until 1974. This policy initially aimed to promote rotational grazing, but was subsequently used to restrict the invasion of woody plants into grassland (Anon, 1985b; Brooks and Macdonald, 1982, 1983). In reality only the upland areas had sufficient fuel to be effectively burnt at the required frequency (Downing, 1979a and b). The policy operant since 1974 aims to maintain the diverse habitat configuration created by seral development, and permits no burn, Autumn/Spring burn, and frequency options (Porter, 1976). The grazing pressure since its implementation coupled with the exceptionally dry years over the late 70's/early 80's resulted in burning frequencies and intensities that were incapable of preventing further seral development (Brooks and Macdonald. 1982, 1983).

2.9.2 Ungulate population control

Brooks (1983) noted that the overall loss in species diversity in the Reserve since its proclamation, contradicted the aims of conservation management. It was proclaimed primarily to preserve large game species. Prior to 1929 only limited culling of the most abundant ungulates took place, poaching was however, prevalent. During the "nagana campaign" the population of all ungulates excluding rhino were drastically reduced. The square lipped rhino remained a conservation priority throughout the 1950's. The populations of grazers competing with it were actively controlled. During the 1960's the culling programme was intensified and extended to include a wide range of ungulates. Predators were reintroduced to help dampen the population of others. In the 1970's the management objectives changed to maintaining the existing species diversity. The game removal programme increased progressively over the remainder of the study period (Brooks and Macdonald, 1982, 1983). Since 1964 the veld burning and game removal operations carried out in the Wilderness area have been more conservative than the rest of the Complex. This is due to the controversy associated with justifying the need for such operations in a non-interventionist management area (Brooks, 1983).

2.9.3 Bush encroachment control

In late 1942/early 1943 woody plants were removed from a substantial portion of the Wilderness area as a requirement of the "nagana campaign". These plants were mattocked out at ground level and many were burnt in their felled positions. Although a number of intensive operations using techniques such as tractor stumping and arboricides were carried out in various parts of the Reserve at various times, no further bush clearing took place in the Wilderness area (Ward, 1962; Watson and Macdonald, 1983).

2.9.4 Soil erosion control

Erosion reclamation work was first carried out in the Wilderness area in the late 1960's (Bourquin, 1969a and b), and has been repeated several times subsequently. When the Complex's management policy was revised in 1974, the importance of protecting the soil resource in the long term was specifically emphasized (Brooks and Macdonald, 1982, 1983). The current policy regarding the management of this resource aims "to ensure that accelerated erosion is attended to and that, in the long term, soil loss equals soil genesis" (Grobler, 1983). Venter (1988) noted that as it is impossible to measure progress towards this long term goal, the policy should be revised to aim "to minimize the rate of accelerated erosion". He viewed reclamation work as only being necessary in order to reduce rates accelerated by recent activities such as road construction.

2.10 LANDUSE IN KWAZULU COMPONENT OF STUDY AREA

2.10.1 Population

During the first three decades of this century substantial portions of the unoccupied KwaZulu component of the study area were burnt each dry season. Fires either spread into the area from adjacent settled areas or were ignited during hunting expeditions. Fire was excluded from the area during the "nagana campaign" as it formed part of the "buffer zone" around the Reserve. During the campaign it was subjected to the same game eradication and woody plant removal operations as the Wilderness area. The pre 1930 veld burning regime was resumed in the area when the campaign ended and persisted through until it became settled in 1958. A resumption of poaching restricted the recovery of the game stocking rate in comparison to the Wilderness area (Foster, 1955).

The 1980 National Census estimated the population density of the Hlabisa and Enseleni portions of the KwaZulu component of the study area as 1 and 0,84 p ha^{-1}, respectively. These densities are comparable with the average density for rural KwaZulu of 0,93 p ha^{-1} (Anon, 1984), despite the census having taken place little more than two decades after the area was settled. In a survey of the Enseleni portion, Watson (1983) found that although a mean of 10,6 people were affiliated to each household, on average only 7,2 people actually occupied it. The discrepancy between these figures was accounted for by the people permanently employed outside the area. In the Hlabisa portion, Infield (1986) observed that grouped versus scattered households were distributed in a ratio of 9 to 1. More than 60% of the Enseleni portion's households were situated in villages, while less than 5% of them were scattered. Despite Enseleni's more concentrated settlement, its facilities were identical to the Hlabisa portion viz. 2 trading stores and a school. The average masculinity rate in rural KwaZulu is 73%, and principally reflects the number of men who leave their tribal area in order to obtain employment in commercial agriculture, mining or urban areas. The 1980 National Census's masculinity rate for Hlabisa and Enseleni of 71 and 65 percent, respectively, indicates a higher migrant labour loss than average (Anon, 1984). However, Watson's (1983) Enseleni masculinity rate estimate of 85% was significantly higher than the average. She attributed this to the fact that 8% of the work force being N.P.B. employees, were able to live in the area.

2.10.2 Education/Employment/Natural Resource Use

Watson (1983) found that 51% of the Enseleni population that she surveyed, were under 24 years of age. Forty five percent of the population were uneducated, while 33 and 22% had primary and secondary education, respectively. Forty four percent of the population derived an income. Men comprised the major portion of the 78% of workers who derived an income from outside the area. It was mainly women who generated an income within the area. Most of them sold reeds, thatch grass and wood, much of which was collected from the Fuyeni/Makhamisa area in the nearby Game Reserve. Gandar (1983) found an average annual per capita firewood consumption of 0,74 t in KwaZulu valley Lowveld. The average household in the study area would therefore require about 4 tons per year. Most of this requirement is met by dead wood which is gathered from the abundant closed woodland communities. Deforestation is limited to the requirements of hut and kraal construction. No attempt is made to replace trees removed, by the nurturing or planting of seedlings. Both the Hlabisa and Enseleni Chiefs have however, afforded some degree of protection to the forest communities. The collection and harvesting of wood within them is prohibited (Infield, 1986). A small number of men derive an income within the area from fishing. Their main harvest from the Mvamanzi pan is obtained using seine nets. The pan supports 8 species of indigenous fish. Barbel and bream are also harvested from a number of the smaller pans (Infield, 1986; Begg, 1988). Watson's (1983) socio-economic profile of the study area is much more favourable than that depicted by Erskine (1982) for rural KwaZulu as a whole where 69% of the population are younger than 24 years of age. And where the uneducated portion of the population averages 58%, while 28, 11 and 3% have preprimary, primary and secondary education, respectively. Watson (1983) found a per capita income of 170 R yr^{-1} compared to the 1980 figure for rural KwaZulu of 12,5 R yr^{-1}, cited by Erskine (1982).

2.10.3 Cultivation

The tribal chiefs who have jurisdiction over the KwaZulu component of the study area have implemented the traditional land tenure system. Under this system each family is allocated a homestead site, an area of cropping land, and a right to graze stock on the communal grazing land (Erskine, 1985). In addition, each family has the right to collect water, thatch grass, and wood for fuel and building purposes (Simkins, 1985). Although the average land holding per family in rural KwaZulu is 8,25 ha, the majority of families occupy plots ranging from 1 to 2 ha. On average 74% of the cultivated land in rural KwaZulu is used for growing maize, sorghum and other small grain crops. About 12, 7, 6 and 1% of this land is under legumes, sugarcane, vegetables and other plants, respectively. An average rural KwaZulu household requires 1000 kg of maize per year. Maize yields in these areas increased from 256 kg ha^{-1} in 1967 to 304 kg ha^{-1} in 1982. Sorghum yields over the same period however, decreased (Erskine, 1982). Such production levels on the 2 ha holding most common in the study area, suggest that most households are unable to meet their subsistance needs. Indeed, Erskine (1982) estimated that the average rural KwaZulu family actually produces less than half of their subsistence needs. Even when most of the family members have become established elsewhere and are capable of supplying the rural household with its food requirements, the allocated plot continues to be cropped (Simkins, 1985). Land may be sequestrated if it is unutilized for a long period (Lenta, 1985). Membership of the Chiefdom provides social security, as the rural household is perceived and utilized as a means of livelihood when unemployed or retired (Lenta, 1985; Simkins, 1985).

2.10.4 **Livestock**

About 70% of the communal lands in rural KwaZulu are used for grazing (Erskine, 1982). These lands have an average carrying capacity of 2,62 ha LSU^{-1}, where a large stock unit is equivalent to one cow, six goats/sheep, or one horse/donkey. Climatic fluctuations over the period from 1958 to 1979 did not exceed critical thresholds. As a consequence, the annual increase in stocking rate was less than 0,5%. It nevertheless exceeded the carrying capacity throughout this period by an average of 26% (Colvin, 1983). The drought of the early 1980's reduced the stocking rate to a level more compatible with the carrying capacity. Gandar (1982) reported annual mortality losses during 1980 and 1981 ranging from 20,5% for goats to 23% for cattle. Erskine (1985) viewed overstocking as a product of a system whereby families failing to keep their stock numbers up are liable to surrender available grazing to other families. About half the families living in rural KwaZulu own cattle (Lenta, 1985). Fifty seven percent of these families own less than 10 head, while 26,12 and 5% own between 11 and 20, 21 and 30, and more than 31, respectively. Colvin (1983) explained why each family requires a herd of at least 20 to 25 head to be able to meet its subsistence needs, build up a herd, and withstand sale over a short run of bad years. A herd size of 30-40 head permits an annual take off of one to two beasts for meat, cash, or social/religious transactions. Families with herds smaller than the critical threshold of 20 are reliant on the use of cows and immature beasts in their plough team with consequent negative impacts on their breeding capacity. Colvin's (1983) view that it is more profitable for a family with a herd of less than 30 head to accumulate additional cattle rather than to sell them, is supported by Lenta's (1985) assertion that "even in an overstocking equilibrium, cattle ownership represents rational economic behaviour and provides the highest rate of return available".

2.10.5 **Land tenure system/Development**

Settlement within the KwaZulu component of the study area from 1958 took place under the provisions of the Land Acts and Bantu Authorities Act. These acts were motivated by in the "betterment" ideals of improving native reserve agriculture by limiting stock and ploughed land. The concentrated distribution of households in the Enseleni portion is testimony to the influence of the "betterment" ideals of demarcating residential, arable and grazing land, and establishing villages to encourage progressive farmers (Simkins, 1985). However, in common with most other rural KwaZulu areas where "betterment" was encouraged (Colvin, 1983), the contemporary level of agricultural development within the study area, is very low. There is no evidence of soil erosion prevention management within the communal grazing lands. Soil conservation practices employed on arable lands are very elementary. Contour ploughing is prevalent and strip cropping fairly common.

Erskine (1985) viewed the traditional land tenure system as the most serious obstacle to agricultural development in rural KwaZulu. He further suggested that the problems involved in implementing this development, were basically social and economic rather than technological and ecological (Erskine, 1986). As families do not own the land they utilize, they are unable to obtain credit to purchase implements, draught animals, fertilizers and superior seed (Erskine, 1982; Lenta, 1985). Without the input of these production improvement factors, the average size of an allocated cropping plot is too small to be economically viable (Erskine, 1982; Simkins, 1985). As security of land tenure is not unconditional, inhabitants of a tribal district are unwilling to contribute towards the improvement of its infrastructure. The restricted access to quality water and market outlets are additional factors that render the average arable plot size uneconomic (Erskine, 1982, 1986). An improvement in the communication, health and education infrastructure would enhance the economic viability of these small plots by creating opportunities to market produce, and by the "farmer enlightment" facilitated by greater access to agricultural technical advisors (Lenta, 1985). Erskine (1982, 1985) suggested that the failure to implement soil conservation practices was largely due to ignorance. Meyiwa (1989) however, asserted that this failure was primarily due to the insignificant status of women in tribal society. As most men are employed outside the tribal area, most of the husbandry is carried out by women. Acting on the Chief's instructions most of these women have attended several demonstrations by agricultural technical advisors. Their husband's permission is however, required in order to implement the techniques demonstrated. The low implementation rate is primarily due to the time lag between the demonstration and the opportunity to obtain permission, and failure to do so from men who have not had the benefit of enlightment via the demonstration.

Most of the arable land in rural KwaZulu is undercultivated. The utilization of many plots for social security purposes rather than food needs, is a major causative factor. Families who do not own cattle are often unable to borrow draught oxen during the optimal ploughing/planting season. These families as well as those who own herds numbering less than the critical threshold number of twenty are often forced to use stock that are incapable of draught. The general overgrazed veld condition causes physically depauperate stock. In addition, about 18% of the standing stock are weakened by excess age. Undercultivation is aggravated by a shortage of labour during peak plough/planting and weeding seasons. Most of the potential labour force seek employment outside the tribal area. The balance remaining are predominantly women who accord husbandry a lower priority than water or fuel collection (Lenta, 1985).

The shortage of draught power during the peak ploughing season is general despite the fact that on average rural KwaZulu is 20% overstocked. This factor together with the uncertainty regarding security of land tenure and droughts, encourages these people to overstock and take maximum advantage of favourable circumstances when they occur. The limited access to credit induced by the land tenure system means that the financial costs of managing livestock using fencing, rotational grazing, selective culling etc, are prohibitive (Colvin, 1983). Gandar (1983) and Erskine (1986) assert that the traditional communal land tenure system discourages the individual initiative that would be required to plant woodlots, construct soil conservation and water point structures, create market opportunities etc.

2.11 SOIL EROSION

2.11.1 Game Reserve

Hall (1981) noted that there was very little evidence of soil erosion in the study area on the scale that would be expected had this been a debilitating factor in the Iron Age. However, the mature vegetation communities established in some of the gully systems led Macdonald (1979b) to suggest that their formation preceded the Reserve's proclamation. Although Henkel (1937) reported the presence of soil erosion in the Hluhluwe Reserve's bottomland *Euclea* communities as early as 1936, active soil erosion only became evident in the western portion of the drier Umfolozi Reserve in 1958 (Vincent, 1970). Foster (1955) noted that grazing was adequate during the very severe 1930 drought. Reports on the

Umfolozi Reserve's grazing conditions were consistently favourable up until the late 1950's, by which time herbage availability in the bottomland and riverine areas had deteriorated (Vincent, 1970; Brooks and Macdonald, 1982; 1983). By the mid 1960's the deterioration in the grass component was general (Stewart, 1966), and had reached an advanced state by the late 1960's, when the only good grazable pastures were restricted to the highest ridges (Mentis, 1969). Evidence of the overutilization of browse species emerged in the late 1960's (Mentis, 1969; Downing, 1972). Evidence of active soil erosion became increasingly pronounced during the second half of the 1960's and elicited concern in a number of reports.

Stewart's (1965) view that the most severe gully erosion was caused by poorly built and maintained roads was supported by a survey of a 17km stretch of road. Gullies within the road occurred along 5% of the length, while 15% of it had gullies along both edges. Vincent (1965) observed that the bottomland areas were most severely eroded and attributed this to overgrazing by both ungulates and termites. Severe bottomland erosion was also noted by Scotney and van Schaucwyk (1969). In addition to overgrazing they cited game paths, roads and road drains as erosion causative factors. Bourquin (1969a and b) and Mentis (1969) explored overgrazing, ineffective veld burning and bush encroachment in terms of a circular association of effects, in their attempt to account for the widespread soil erosion. Mentis (1969) assessed the severity of erosion at 50 sites. Sheet erosion was found at 70% of them. Sixty percent of it was rated severe. Gully erosion was found at 46% of the sites. Forty eight percent of it was rated severe. The grass component improved steadily through the 1970's as a result of the use of control burns to attract game to underutilized areas, the game removal programme and good rainfall conditions (Macdonald, 1981). By the mid 1970's the increasing dominance of *Euclea* spp. had however, contributed to the chronic overutilization of palatable browse species (Bourquin and Hitchins, 1979; Macdonald, 1981). The degree and extent of soil erosion increased progressively during this decade despite the improved veld conditions. Porter (1977) regarded management blocks 28 and 29 as the highest priority for erosion reclamation and bush encroachment control work in the Complex. In the balance of the Wilderness area, only a number of scattered localized areas required soil conservation measures while no bush control was necessary. In the northern portion of the Complex Porter (1977) described sheet and gully erosion as being active and extensive, while Macdonald (1979b) reported gully initiation and expansion of extant systems. Macdonald (1979a) observed that soil capping was particularly prevalent in bush encroachment areas, and that such areas were most evident on mid slope positions. While the continued bush encroachment appeared to be a major factor contributing to the increase in soil erosion, poorly built and maintained roads also played a part. Porter (1972) recorded active erosion along 42% of the roadsides. According to Brooks *et al* (1980) the roads in addition to causing the erosion in close proximity to them, initiated it in other parts of the Reserve.

A progressive deterioration in the grazable pastures occurred during the exceptionally dry years from 1979 to 1983. By the early 1980's the overutilization of the preferred dry season browse species was acute (Macdonald, 1981; Brooks and Macdonald, 1982, 1983). Smuts (1980) did a repeat survey of 234 sites in the Umfolozi Reserve. In 1980 soil erosion was active at 30% of them as compared with 18% in 1978. Macdonald (1981) noted that most assessments of soil erosion in the Complex assumed that any readily detectable signs of soil erosion indicated artificially accelerated rates. Caution should therefore be exercised in the evaluation of qualitative reports and limited field surveys. The first scientific study of soil erosion in the Complex was by Venter (1988). He assessed the effect on soil erosion of an interventionist versus a non-interventionist policy. He monitored six pairs of runoff plots in the Umfolozi Reserve over a four year period from March 1982. The plots were apportioned equally between a cull and non-cull management area, and installed within the following woody vegetation communities:- *Acacia tortilus, A. nigrescens, A. nilotica/A. gerrardii*, and *Spirostachys africana*. A rainfall simulator was used to generate soil loss and runoff data from one plot of each pair. The aquisition of such data from the other plot was reliant on natural rainfall events. Venter (1988) recorded average soil loss rates from the cull area of 0,26 and 0,24 t ha^{-1} from the rainfall simulator and natural rainfall runoff plots respectively. The comparable figures for the non-cull area were 0,88 and 0,74 t ha^{-1}. The highest annual average soil loss rate of 2,2 t ha^{-1} was recorded during the 1983 drought. According to Zachar's (1982) classification of erosion the soil loss rates recorded in the cull area are insignificant as they would take in excess of 4000 years to remove 20cms of topsoil. Even the highest soil loss rate recorded from the non-cull area during the height of the drought of 3,15 t ha^{-1} would take 1600 years to remove 20cms of topsoil, and is therefore classified as weak by Zachar (1982). Venter (1988) found that the *A. tortilus* community had the highest soil loss rates, while the *A. nilotica/A. gerrardii* community had the lowest.

2.11.2 **KwaZulu**

When Acocks (1953) passed through the KwaZulu component of the study area during his Lowveld survey, he noted that soil erosion was only rarely seen. As noted earlier, the overgrazed veld evident on LANDSAT images (Looser, 1984; cited in Kovacs, *et al.* 1985) indicated that by 1983 the KwaZulu study area had a relatively high soil erosion potential. Venter (1988) did a comparative study of soil loss in the Umfolozi Reserve and adjacent KwaZulu area. Gerlach troughs were installed either side of the western boundary fence and monitored from 1984 to 1986. No significant difference in the erosion rates between the two areas was found. As the KwaZulu troughs were within 25m of the fence, the insignificant soil loss rates obtained from them may not be typical of soil erosion in KwaZulu areas more distant from the fenceline. As noted earlier most of the soil loss rates from the Mfuyeni and

Biyela catchments estimated by Schulze (1981) were very severe. These wards are located immediately south of the study area. This proximity, together with their comparable climatic regime, soil types and Lowveld vegetation, suggests a comparable soil erosion potential. These wards have however been more densely settled over a continuous and much longer period of time (Anon, 1985b). This researcher is therefore of the opinion that soil erosion in the KwaZulu study area is unlikely to have been as serious as that depicted for these wards. The only other assessment of soil erosion in a KwaZulu area within the Mfolozi catchment known to this researcher, is that by Liggitt (1988) and Liggitt and Fincham (1989). They used 1983 1:10 000 orthophotos to map sheet and gully erosion in the area immediately west of the Umfolozi Reserve and surrounding Ulundi. Sheet erosion was absent from 60% of it. The comparable figure for gully erosion was 85%. Eighty eight, 10 and 2 percent of the sheet erosion was rated slight, moderate and severe respectively. Seven percent of the gully erosion was rated moderate, while the remainder received a slight appraisal. As noted earlier, the greater anthropogenic influence in the Ulundi ward suggests it would also have a greater degree and extent of soil erosion in comparison to the study area's KwaZulu component.

CHAPTER THREE

A PERSPECTIVE ON ACCELERATED SOIL EROSION

3.1 DEFINITION OF SOIL EROSION

Zachar's (1982) review of the application of the term 'soil erosion' in relevant global literature revealed that it is most commonly employed to describe the process of predominantly mechanical removal of surface and subsurface soil constituents by the action of moving water in both liquid and solid states, and wind. The term is also used in reference to a wide range of landforms caused by soil removal processes, and to the productivity potential of the soil remaining in situ, debilitated by erosion. Within the context of this study, the term 'soil erosion' is employed to describe the process of removal of surface soil particles by rainsplash and runoff, as well as the resultant sheet, rill and gully forms. Dardis, Beckedahl, Bowyer-Bower and Hanvey, (1988) identified nine major soil erosion forms in southern Africa using a system of classification based on flow type and regime criteria, the geometry of the feature, the nature of the host material and the dominant processes. The sheet/rill, and gully forms described in the present study conform most closely to their description of the Type 1 and Type 8 forms, respectively. Although during field excursions to the study area, high velocity winds acting on dry soil surfaces were observed to be capable of removing substantial quantities of dust, particularly from the Type 1 and non-macadamized road surfaces, the influence of this aeolian activity was considered beyond the scope of this study. Most studies of wind erosion in southern Africa have concentrated on sediment sources, transport and deposition in relation to dune formation in the Namib, and Kalahari /Karoo biomes, and coastal systems (eg: Tinley, 1985; Thomas, 1988; Wilkinson, 1988). No estimates of soil loss by wind in the moist savanna biome are known to this author.

3.2 DISTINCTION BETWEEN GEOLOGICAL AND ACCELERATED EROSION

There are two approaches to the broad level classification of soil erosion. The first approach distinguishes between 'geological' and 'accelerated' erosion. Geological erosion refers to the 'natural' soil removal in a system unaltered by human activities. It occurs at 'normal' rates that are conducive to the development of a 'normal' soil profile. Various landuse practices increase the rate of normal soil removal. This human accelerated erosion is perceived as the 'soil erosion problem', and the term 'soil erosion' is commonly used in exclusive reference to it. The perceived aim of soil conservation management in human altered systems is a reduction in soil erosion rates to the geological norm.

Cooke and Doornkamp (1974), Toy (1977), Morgan (1979, 1986), Murgatroyd (1979), Hudson (1981) and Broderick (1987) are some of the proponents of this approach. The alternate approach recognizes that soil erosion rates are also accelerated by natural phenomena. In areas where such phenomena are prevalent pedogenesis will not produce a 'normal' soil profile, irrespective of the absence of human influence. Geological erosion is subdivided into 'normal' and 'accelerated or abnormal'. A distinction between 'naturally' and 'anthropogenically' accelerated erosion is therefore necessary. Proponents of this approach include de Villiers (1962), Maud (1968, 1978), Laffan and Cutler (1979), Holy (1980), Price Williams, Watson and Goudie (1982), Zachar (1982), Birkenhauer (1985), Stromquist, Lunden and Chakela (1985), Thornes (1985), Partridge and Maud (1987), Partridge (1985), Beckedahl and Dardis (1988) and Dardis (1989).

Garland (1979) noted that the distinction between naturally and anthropogenically accelerated erosion may be complicated by the time dimension. Poor landuse practices gradually reduce the soil's intrinsic resistance to erosion. Once this resistance falls below a critical threshold, a rainstorm intensity that previously had limited effect, may trigger a catastrophic event. Many such events are mistakenly perceived as being caused solely by natural phenomena, the contributing influence of human activities remaining unidentified. Zachar (1982) has critized the general perception of erosion altered by human activities as necessarily accelerated, and pointed out that the implementation of soil conservation measures may inhibit rates to levels below the geological norm. The fact that human activities may stimulate the rate of soil formation further complicates the perception of anthropogenically accelerated erosion. A global average figure that has general acceptance in the literature is that under natural conditions it takes of the order of 300 years to form 25mm of top soil. Cultivation practices increase the rate of formation. Estimates of this increase vary from a factor of 10 (Bernett, 1939; cited by Hudson, 1980) to 3 (Pimental *et al.* 1976; cited by Mannering, 1980).

3.3 CONCEPTUALIZATION OF RELATIONSHIP BETWEEN SOIL FORMATION AND SOIL EROSION

The relationship between the formation and erosion of the soil is generally conceptualized within a systems framework (eg. Chorley and Kennedy, 1971; White, Mottershead and Harrison, 1984). As soil accumulates on the parent material the weathering front becomes progressively more protected from mechanical processes. In addition, the water reaching the front becomes progressively more chemically saturated and hence inactive. A paradox of this relationship is therefore that the factors that stimulate the rate of soil removal also serve to enhance the rate of soil production. The increases in the input and output rates are not directly equivalent, as increased surface runoff tends to be associated with increased soil erosion. The amount of material removed from the weathering front in solution in subsurface flow is therefore reduced (Kirkby, 1980; Thornes, 1980).

The alternation of periods when weathering predominates with periods when soil erosion predominates, is generally perceived as the dynamic equilibrium of a cybernetic system. Periods of rapid erosion are initiated when geomorphic thresholds are exceeded by intrinsic and extrinsic changes (Schumm, Harvey and Watson, 1984). The former includes decreases in shear strength caused by weathering and increases in slope gradient caused by aggradation. The latter includes modifications to slope hydrology and/or decreases in surface resistance to erosion associated with changes in climate and/or landuse (Rowntree, 1988). The pattern of soil mass expansion and contraction may reflect climatic periodicities. The assessment of anthropogenically accelerated soil erosion needs to ascertain whether rapid increases in erosion reflect a new directional trend triggered by a human activity or homeostatic adjustments to the post glacial environmental conditions of the Holocene (Deacon, 1988a; Trudgill, 1988). The adjustment to these intrinsic or extrinsic changes reflects the soil system's resilience and self regulatory capacity. Anthropogenically accelerated soil erosion may well fall within the limits of the system to bounce back. Evidence of this ability may become apparent with the passage of millennia, and is therefore of little relevance to the contemporary view of the problem (Maud, 1978).

3.4 SOUTH AFRICAN EROSIONAL ACTIVITY

3.4.1 During the Tertiary

Tectonic uplift of the subcontinent has occurred episodically with intervening periods of stasis since the Mesozoic. The recession of the eastern coastline associated with each movement resulted in a lengthening of the rivers which in turn lead to an intensification of erosional and aggradational activity inland (Maud, 1968; Maud, 1978; Birkenhauer, 1985; Partridge and Maud, 1987 Partridge, 1988). The pedogenic response to these erosional episodes exerts no influence on Natal's contemporary erosion scenario as these late Tertiary soils were subsequently entirely removed. The relevance of these episodes to contemporary erosion lies in the fact that they moulded the Province's extreme topography. This influence may be apparent in this study where the KwaZulu component's steeper and shorter slopes owe their origin to the tilting of the underlying rock strata (sections 2.3 and 2.4).

3.4.2 During the Quaternary

During the Pleistocene the equilibrium between the formation and erosion of Natal's soils was controlled by climatic changes. The low sea levels associated with sub-humid to semi-arid glacial periods rejuvenated erosional and aggradational activity. Infilling and pedogenesis occurred during the humid interglacial periods (Maud, 1968; Maud, 1978; Partridge and Maud, 1987; Partridge, 1988). A consequence of the Quaternary eustasy is that the Province's soils are very 'young'. The oldest date from the last major erosional episode which occurred during the Main Wurm about 25 000 BP, and include the more deeply weathered red soils of the study area. The younger podsolic soils are post glacial in age (Maud, 1968; Maud, 1978). A portion of the soil removed from the upland landscape during erosional episodes occurs as a stratified deposit in low lying areas. A succession of five aggradational phases is discernable within the deposit. Each phase is punctuated by periods of dissection which indicate that even during an erosion active period, erosion is somewhat episodic (de Villiers, 1962; Van der Eyk *et al.* 1968; Maud, 1978; Price Williams *et al.* 1982). This partly consolidated, bedded deposit ranges in depth from 3 to 15 metres, and is known as the Masotcheni formation. It's profile consists of boulder beds, overlain by red sands containing lines of silcrete nodules and scattered calcrete nodules, and capped by laterite. It characteristically contains a poor crystalline montmorillonite group of clays that cause the sediments to slake readily in water (Kent, 1980). The formation's profile and physiochemical properties contribute to its high erodibility and account for the extensive gullying that subsequently took place in it (Maud, 1978). According to van Wyk (1963, cited by Kent, 1980) more than sixty percent of the gullies in Natal occur in this formation. Laffan and Cutler (1977) outline comparable responses to the Quaternary eustasy by New Zealand's soil cover.

3.4.3 During the Holocene

Since the sea rose to its present level 7 000 BP, the shoreline has remained approximately constant. The infilling response to this elevated level has directed the Holocene equilibrium trend in the Province's soil cover, and continues to do so as the infilling is as yet incomplete (Maud, 1978). Variations in precipitation have superimposed cycles of soil mass expansion and contraction on this trend. The cycles ranged in duration from 600 to 3 500 years. They commenced with gully incision initiated by increased rainfall following periods of desiccation, and culminated in pedogenesis of colluvial sediments (de Villiers, 1962; Partridge, 1988). Stocking (1980b) noted comparable cycles in gully systems in Zimbabwe.

A review of the relevant literature indicates a consensus in the perception of the Natal landscape as currently experiencing a naturally accelerated erosional phase, but a discrepancy in the estimates of the onset of this phase. De Villiers (1962), Kriel (1966, cited by Hall, 1981), Deacon (1988a) and Dardis (1989) perceive this phase as having commenced approximately 2 000 BP, while Maud (1978) and Partridge (1988) favour a more recent onset of approximately 290 BP. Both onset dates seem feasible. The earlier date corresponds to a period of increased temperature and precipitation that followed a period of minimum temperature and environment aridity. The later date corresponds to a period of increased precipitation that commenced in the 1760's and followed six relatively dry decades (Tyson, 1986). As different erosional phases may be dominated by different processes, the discrepancy in the onset dates favoured may reflect preoccupation with a particular erosion process. The researchers favouring the earlier date have tended to concentrate on sedimentological and stratigraphic evidence from aggradational material, while those favouring the later date have concentrated on characteristics associated with gully incision. Dardis (1989) noted that the Quaternary erosional phases were dominated by sheet/rill processes. Gullying intensified progressively from 2 000 BP and became the dominant process during the last 250 years. Rowntree (1988) perceives the alternation of phases of active sheet/rill erosion with phases of active gully erosion as a mechanism to maintain the equilibrium between erosion and deposition. As such, it is not necessarily reliant on extrinsic changes. In a stable semi-arid environment for example, the mechanism is a response to intrinsic geomorphological changes, whereby the infilling of a gully is dependent on active sheet/rill erosion upslope, and eventually oversteepens the lower gully reach, which in turn renews gully incision processes.

Any attempt to estimate the onset of the contemporary phase of naturally accelerated erosion, or to assess the dominant associated processes, is complicated by the fact that anthropogenically accelerated erosion has become progressively more significant over the last two millennia. In the present scenario the anthropogenic influence is considerably greater than any natural influence since the late Tertiary (Maud, 1978). Murgatroyd (1979) estimated anthropogenically accelerated erosion rates in the Tugela basin to be 28 times greater than the geologically normal rates. Martin (1987) estimated that modern rates of sedimentation from east coast rivers exceed the average rates of sedimentation in major offshore depocentres during the past 100 Myr, by a factor of at least twenty.

3.4.4 During the Iron Age

The presence of hunter gatherer communities in the Province from about 1,5 Myr and their regular use of fire from about 150 000 BP had no significant long term environmental effect. Any accelerated erosion associated with the Stone Age culture is likely to have been of a localized and transient nature, and dependent on how long groups stayed at and how frequently they returned to, their temporary camps (Hall, 1979a and b, 1981, 1984; Deacon, 1988b). The Early Iron Age communities who settled in the Province's river valleys and coastal lowlands around 1 700 BP are also unlikely to have significantly accelerated erosion. Their village sites seldom exceeded two hectares in extent. They used 'slash and burn' techniques to clear the forest/woodland cover to establish plots for the cultivation of sorgum and millet. The predominantly sandy soils evidently leached rapidly necessitating the aquisition of new plots after a few years. Significant anthropogenically accelerated soil erosion in Natal evidently commenced with the introduction of sheep and goats around 1 400 BP, and was enhanced by the introduction of cattle about a century later. By the dawn of the last millennium the distribution of the Late Iron Age communities was no longer geographically restricted. The spatial extent of their village settlements and the associated deforestation had increased ten fold. Deforestation was caused by the use of fire in the clearance of cultivated plots and honey collection; and by the harvesting of wood for fence and hut construction, and for fuel to smelt iron. The increase in grassland at the expense of woodland was additionally promoted by the extensive use of fire on an annual basis to enhance stock grazing (Hall, 1979a and b, 1981, 1984, Broderick, 1987; Deacon, 1988b).

The Late Iron Age culture may have had both a direct and indirect influence on soil erosion. The direct influence relates to the fact that stock-based communities were able to occupy localities for substantially longer periods of time than cultivation-based communities (Deacon, 1988b). The indirect influence relates to the hydrological response to vegetation change. Grassland is more resistant to sheet erosion processes and more susceptible to gully erosion processes, than woodland communities (Roux, 1981). Watson (1981, 1984) and Rowntree (1988) cite numerous references documenting an increase in the generation of surface runoff from grassland in response to burning and grazing, respectively. Gullying processes would have been additionally favoured throughout the Late Iron Age as burning and grazing represented the predominate landuse influence. Dardis's (1989) observation that gully erosion became more significant than sheet erosion after 2 000 BP may in part reflect this anthropogenic influence. Marker and Evers (1976) found evidence of accelerated erosion including terraces and walled livestock tracts, in association with Iron Age sites in the eastern Transvaal. As noted in section 2.11.1, Hall (1981) found little evidence of Iron Age overexploitation of the soils in central Zululand. Likewise, Broderick (1987) found a poor correlation between the distribution of Iron Age sites and sites currently exhibiting evidence of accelerated soil erosion in the Tugela basin. Deacon (1988b) has however cautioned that such poor correlations may be due to the fact that many of Natal's Late Iron Age sites, particularly the lowland sites, may have been destroyed in the Zulu wars of the 18th and 19th centuries or by subsequent European farming activities.

3.4.5 During the Nineteenth Century

Several sources indicate that accelerated soil erosion peaked early in the 19th Century. Tyson's (1986) report of a severe drought spanning a decade both before and after 1800 indicates a natural influence. An anthropogenic influence is implicit in Gluckman's (1960, cited by Broderick, 1987) suggestion that the Zulu nation was showing signs of overpopulation by 1800, and in Marks's (1967) assertion that the introduction of maize accelerated soil exhaustion. Maize cobs found in Natal date from 1780 (Deacon, 1988b). Both Marks (1967) and Guy (1980) view this peak as having been instrumental in spurring Shaka's rise to power, and as having been maintained by the environmentally destructive nature of his conquests. These conquests resulted in the widespread depopulation of the Province and an associated decrease in the anthropogenic influence on soil erosion through until the arrival of the European settlers (Hurwitz, 1953; Broderick, 1987). Deacon (1988a) noted that the absence of a documented and continuous data series has often resulted in the accumulated effects of the prehistoric anthropogenic influence being underestimated. An overview of this influence in Natal suggests that not only has soil erosion been accelerated by human activities since at least the Late Iron Age, but that gully erosion processes have been selectively favoured. Comparable trends have been noted in other parts of the world. For example in New Zealand, Laffan and Cutler (1977) showed that both an increase in soil erosion, and a change in the dominant erosion processes, accompanied the Polynesian occupation around 1 000 BP. They ascribed this to the change from forest climax to lower density herbaceous cover in response to the use of fire.

The Zulus' use of the Province's major gully systems for concealment in ambush situations against, and as escape routes from the early Dutch settlers, suggests that their development had already reached an advanced stage prior to European colonization (Broderick, 1985; 1987). Although the anthropogenic influence evidently decreased after Shaka's reign, soil erosion levels remained high enough to elict concern from the early European settlers. Broderick (1985, 1987) studied travellers notes, farmer's and local authorities' records, historic photographs and other possible sources of reference to the soil erosion scenario in Natal prior to the availability of aerial photographs shortly before the Second World War. She found that the earliest documented concern about soil erosion in terms of its effect on water quality was in 1844. Concern about the effects of deforestation and veld burning on soil erosion was first documented in 1865. Warnings about soil erosion causing dessication and land degradation were common in these sources from 1880. She cautions however, that as large gully systems and silt laden rivers were not characteristic features of the countries of origin of most these settlers, their perception of the scale and magnitude of erosion may have been exaggerated. A point that is apparent from the discussion so far, and one that is emphasized repeatedly in the literature, is that soil erosion processes are accelerated by a *change* in landuse.

3.4.6 During the Twentieth Century

3.4.6.1 Pre 1946

Braune and Wessels (1980) suggested that the progressive increase in soil erosion associated with European settlement in the Province had already caused some of the most serious veld deterioration before the turn of this century. Hurwitz (1953) identified two phases of landuse change associated with European settlement. The initial phase spanned the second half of the last century and involved a change from shifting subsistence to settled, small scale market farming. The second phase commenced at the turn of this century and involved an intensification and commercialization of agriculture that laid the foundation for increased mechanization. The European settlers confined traditional farming to designated tribal areas, and coincidentally facilitated an increase in the Zulu population and in their livestock numbers. The subsequent intensification of subsistence production was achieved by shortening fallow periods. Broderick (1987) argues that this response constitutes another category of landuse change. Okigbo (1977), Faber and Imeson (1982), Egboka and Okpoko (1984), and Otieno and Rowntree (1986) describe a rapid increase in soil erosion following European settlement in Upper Volta, Lesotho, Nigeria and Kenya, respectively. They attribute the increase to the response noted above of a growing tribal population confined to a restricted area.

Soil erosion rates evidently increased rapidly during the early decades of this century. Tyson's (1986) documentation of wet spells commencing in 1915 and 1934 after prolonged dry periods suggests a significant natural influence. As the early availability of meterological data was not sufficient to permit recognition of this influence, the erosion was perceived as being anthropogenically accelerated (Rabie and Theron, 1983). In 1914 the Report of the Select Committee on Droughts, Rainfall and Soil Erosion ascribed erosion in South Africa to the destruction of natural vegetation by veld burning, overgrazing and deforestation, as well as injudicious road and railway construction (Rabie and Theron, 1983). In 1923 the classic Report of the Drought Investigation Commission reached the same conclusion as the 1914 Report regarding the causes of soil erosion, and additionally attributed the dessication of rivers, the lowering of water tables, and the increased severity of droughts and floods, to the progressive acceleration in soil erosion (Rabie and Theron, 1983). In 1929 the National Soil Erosion Conference was held in Pretoria, this was followed by the establishment of the Soil Erosion Advisory Council in 1930, and the creation of the Division of Soil and Veld Conservation in 1939 (Scotney, 1988). The Forest and Veld Conservation Act (No. 13 of 1941) was the first legislation to address the seriousness with which this trend was perceived. It provided a scheme to assist in financing the reclamation of eroded areas. Bennett's (1945) classic description of severe anthropogenically accelerated erosion throughout South Africa but particularly in the designated tribal areas, stimulated the favourable public response to the Soil Conservation Act (No. 45 of 1946). The Act extended the financial aid scheme to measures aimed at preventing erosion, and enabled farmers to initiate action. Its effectiveness was however, jeopardized by the fact that responsibility for its implementation lay with district committees composed mainly of farmers who proved reluctant to implement action against members of their own community (Rabie and Theron, 1983).

3.4.6.2 **Post 1946 Stabilization**

Ross (1967) estimated that although sediment losses in South Africa over the two decade period after the 1946 Act continued to increase, the loss was half that of the equivlent period preceding the Act. The official view strongly supported by Scott (1967), was that the trend of steadily increasing anthropogenically accelerated erosion was continuing into the second half of the century. The weaknesses of the 1946 Act were addressed in an amendment to it (No. 76 of 1969) notably, the state appointment of district committees with authority to direct the implementation of soil conservation measures. The Mountain Catchment Areas Act (No. 63 of 1970); The Subdivision of Agricultural Land Act (No. 70 of 1970); The Conservation of Agricultural Resources Act (No. 43 of 1983); the announcement in 1985 of a National Grazing Strategy, and the 1986 Economic Advisory Council investigation into restructuring agriculture, all contained further directives aimed at preventing soil erosion (Scotney, 1988). A failing common to all the legislation relating to soil erosion control in the Republic, is that it is not mandatory in homeland areas (Rabie and Theron, 1983).

Rooseboom (1977) and Rooseboom and Harmse (1979) reported a fifty percent decrease in the sediment load of the Orange River at Upington between 1929 and 1970. As this decrease occurred before soil conservation measures were common in the catchment, it was attributed to the decreased availability of erodable soils and increased sediment retention in dams. Even though only a fraction of the soil conservation programs implemented in response to the improved legislation were sufficiently monitored to show a conclusive reduction in erosion, Scotney (1978b) expressed confidence in the gradual improvement of the overall erosion scenario. Braune and Wessels (1980) also viewed the widespread implementation of soil conservation measures as having been instrumental in accounting for a general country wide reduction in mean annual runoff and consequently sediment yield. This reduction was apparent from their analysis of hydrograph records spanning a period ranging from 20 to 50 years from 50 reservoirs. Scotney (1978a) suggested that erosional activity had attained a measure of stability even in those areas where no active soil conservation measures were implemented. He used aerial photographs to examine gullies in the vicinity of Dundee in Natal. Over the period from 1940 to 1970 the systems had become extensively bush encroached, and no significant increase in their dimensions was apparent. Broderick (1985, 1987) suggested that the main phase of accelerated soil erosion initiated by major changes in landuse early this century, was over. Such suggestions are not anticipated from a review of census data on the portion of the Province under annual and perennial field crops and permanent pastures. This portion decreased from 10,7 to 8% early in the twenties. Although it increased marginally in the thirties, it comprised about 8% through until the late fifties, when it virtually doubled. The Province's total commercially cultivated area continued to increase through the sixties and seventies, and comprised 20,7% in 1981 (Scotney, 1988).

Broderick (1985, 1987) used aerial photographs taken in 1944/1945 and 1976/1981 to compare eroded surfaces at one hundred sites in the Tugela Basin. No active soil conservation measures were implemented at any of the sites over the study period. Her delimitation of eroded areas did not distinguish surfaces affected by sheet/rill processes from gullied surfaces. The eroded areas were examined within four landuse categories, viz:- veld; which included abandoned cultivated fields, commercial farming, subsistence farming and forests. Erosion increased only in the veld category, and decreased in the other categories. In both sets of photographs the total eroded area on European owned land was greater than on communal land administered by KwaZulu. The decrease in erosion was also greater in KwaZulu. Broderick's (1985, 1987) finding appears to contradict numerous reports, as well as the long standing general public perception. She explained this anomaly by the fact that a large proportion of the sample sites on European owned land were 'tenant' farms. Such farms were legalized in 1913. Owners rarely lived on the farm or put it to productive use. They permitted Africans to carry out their traditional subsistence livelihood on the farms in return for labour rendered during peak periods on other commercially viable farms. The 'tenant' farms were generally severely overstocked. Several notable conservationists such as Bennett (1945), Hurwitz (1953), Edwards (1967) and Scotney (1978a) saw them as having caused some of the most severe soil erosion in the country. They subsequently became illegal.

The concept of a rapid increase in soil erosion initiated by a change in landuse, stabilizing at decreased rates, once adjustment to the new landuse has taken place, is consistent with general systems theory (Chorley and Kennedy, 1971; White *et al.* 1984), and has been described in other parts of the world. For example in Michigan, U.S.A. Davis (1976) compared the rate of sediment accumulation in a small lake during primeval time when the landscape was forested, with the rate during a 146 year period after it was settled and converted to farmland. On settlement erosion increased, peaking at 30 to 80 times the presettlement rate during the first few decades. After 70 years it stabilized at 10 times the presettlement rate. As noted in section 3.4.6.1, the effect of European settlement on soil erosion elsewhere in Africa was similar to that identified in South Africa. Suggestions that erosion is stabilizing elsewhere on the continent are therefore of particular interest. Retrospective aerial photographs have been used to compare erosion in Kenya in 1948 and 1972 (Thomas, 1974; cited by Ahn, 1977), in

Tanzania in 1960 and 1970 (Rapp, 1975), and in Lesotho in 1951 and 1980 (Schmitz, 1980). All three studies found insignificant changes in gully erosion. Resultant claims that the main phase of gully expansion is over, should be treated with caution as each study also noted that the periods of gully stability coincided with significant increases in sheet/rill eroded areas. This coincidence suggests that the equilibrium mechanism of alternating phases of active sheet/rill and gully erosion described in Section 3.4.3 may be involved.

3.4.6.3 **Stabilization Challenged**

In the summer rainfall region of north eastern South Africa periods of above average rainfall (wet spells) have alternated with periods of below average rainfall (dry spells). Tyson (1981, 1986) identified these oscillations and found that they have had an average periodicity of 18 years during the twentieth century. These rainfall oscillations are viewed by Stromquist *et al.* (1985) as a major extrinsic factor regulating the alternation of periods of active sheet/rill and gully erosion. They examined soil erosion in Lesotho using sequential aerial photographs. Gully expansion from 1951 to 1961 was three times greater than from 1961 to 1981. They attributed the difference between the two periods to differences in the consistency and extremity of wet and dry spells, as viewed the combination of an extremely dry number of years followed by an extremely wet period as necessary to reach the threshold initiating gully incision. They suggested that sheet/rill processes will continue to contribute most of the sediment only until the next temporal of climatic threshold is reached, and gullies become the most important sediment source. Both Maud (1978) and Partridge (1988) have suggested that erosional responses in South Africa during this century, reflect rainfall oscillations.

Although the influence of variations in rainfall is indicated in several other soil erosion studies elsewhere in South Africa, an overall trend of a continuing increase in erosion is most apparent. Le Roux and Roos (1979) found a 21% increase in the average rate of sediment accumulation in the Bulbergfontein dam in the Orange Free State over the period from 1972 to 1978 compared with the period from 1942 to 1971. They suggested that the considerable increase in rainfall during the seventies may have been partially responsible for this increased rate. By contrast Marker (1988) found a decrease in erosional activity coinciding with the above average rainfall of the seventies. She used sequential aerial photographs taken in 1949, 1963, 1972, 1975, 1976, 1980, 1984 and 1987 to examine erosion in a small catchment near Alice in the Ciskei. The slight improvement during the seventies contrasted with the study periods both before and after when a progressive increase in both sheet/rill and gully erosion was noted. The most dramatic increase coincided with the severe drought of the early eighties. Weaver (1988a) used aerial photographs taken in 1975 and 1984 to examine soil erosion in the Yellowwoods catchment in the eastern Cape. Although erosional activity increased throughout the catchment, sheet/rill processes predominated on land owned by Europeans while gully processes predominated on land in the Ciskei. Le Roux's (1990) examination of sedimentation rates in 87 major storage dams with records exceeding 15 years, the catchments of which cover 23% of South Africa's total load area, is the most extensive study to date. No conclusive evidence for either a decrease or increase in denudation rates over the last 10 to 50 years was found.

3.5 SOUTH AFRICAN SOIL FORMATION RATES

Although erosional activity in Natal since the Mesozoic is discussed in section 3.4 with reference to an equilibrium with soil formation, an equivalent review of temporal variations in soil formation was considered beyond the scope of this study. The fact that soils in the Province are very 'young' (Maud, 1968, 1978), and that pedogenesis was favoured during humid phases of both the Pleistocene and Holocene (de Villiers, 1962; van der Eyk *et al.* 1968; Maud, 1978; Price Williams *et al.* 1982) was noted in sections 3.4.2 and 3.4.3. Very little is known about the dominant weathering processes operant in the Province since the Mesozoic, and much less is known about temporal and spatial variations in these processes. Hall (1988) concluded from his review of southern African weathering studies that such studies "have yet to begin". He found a few rigorous, quantitative studies dealing directly with weathering, in engineering and geological literature. The bulk of the information was however gleaned indirectly from broader geomorphological studies, and much of it "is presented either by implication, or as a generalized, unquantified and unverified statement". Weathering reflects the composite influence of the most significant soil forming factors viz:- parent material, climate, micro- and macro-flora and fauna, and time. The complete pedogenic process also includes a complex sequence of internal reactions and rearrangements that produce the distinct horizons of a mature profile (Buol, Hole and McCracken, 1973). The focus of concern in soil erosion studies is the mass of sediment removed from a unit area over a unit time eg: t ha^{-1} yr^{-1}. Soil formation studies are not so much concerned with the mass or depth of soil particles added to a unit area over a unit time, as with the time it takes for a mature profile to form (Buol, *et al.* 1973).

A comparison of estimates of contemporary rates of soil formation in southern Africa with those from other parts of the world, indicate that they are towards the lower end of the range. According to Smith and Stamey (1965, cited by Young, 1980) igneous rocks have weathered at an average rate of 8,2 t ha^{-1} yr^{-1} throughout the earth's history. The equivalent rate for sedimentary rocks estimated by Jenny (1941; cited by Young, 1980) is 45 t ha^{-1} yr^{-1}. Buol *et al.* (1973) tabulated soil formation estimates from various parts of the world. The differences in these estimates do not only reflect differences in the types of soils represented, but also in their texture, depth, parent material and degree of maturity. Most of the estimates ranged from 0,3 to 24 t ha^{-1} yr^{-1}. The 187 t ha^{-1} yr^{-1} estimate for a one metre solum of tropical African oxisol was the most rapid rate listed. As noted earlier, a global average figure that has general acceptance in the literature is 2 t ha^{-1} yr^{-1}. Rabie and Theron's (1983) estimate of 2,1 t ha^{-1} yr^{-1} as an average for South Africa compares favourably with the global average. Other estimates for southern Africa are however, half to less than half the global average. On the basis of Owen's (1974, cited by Anon, 1976) finding that the renewal rate of light textured granitic soils in Zimbabwe was 0,4 t ha^{-1} yr^{-1}, the Natal Division of the Department of Agriculture recommended that a renewal rate of 0,4, 0,3 and 0,2 t ha^{-1} yr^{-1} be assumed for southern African light, medium and heavy soil classes respectively (Anon, 1976). Owens (1979, cited by Nyamapfene, 1982) found that while a soil renewal rate of 0,4 t ha^{-1} yr^{-1} was generally applicable to the high rainfall region of Zimbabwe, it was about 2,6 times faster than the rates found in that country's low rainfall region. Le Roux and Roos (1982a and b) estimated a soil renewal rate of 0,5 t ha^{-1} yr^{-1} in semi-arid central South Africa. Elwell and Stocking (1984) and Stocking (1984) proposed a general rate of 1 t ha^{-1} yr^{-1} be accepted as a 'rule of thumb' for Zimbabwe. Le Roux (1990) mapped weathering regions in South Africa based on Le Roux and Roos's (1982a and b) estimate and the rate of chemical reactions as influenced by the average annual rainfall and mean annual temperature. Three regions were identified viz: a western, central (including the south-western Cape), and eastern (including the south-eastern Cape) region with corresponding rates of 0,3; 0,3 to 0,5; and 0,5 to 1,2 t ha^{-1} yr^{-1}.

3.6 SOUTH AFRICAN SOIL EROSION RATES

Stocking (1984) presented an overview of Africa's soil erosion scenario based mainly on rates from West and East Africa and Zimbabwe. He found that the continent's broad scale rates are below world averages, and that very high rates are locationally concentrated. He concluded that vegetation cover is the principal determinant of specific erosion rates, such that:- where cover is poor (<30%) rates in excess of 100 t ha^{-1} yr^{-1} are common, where cover is intermediate (30 to 60%) rates are generally high and may well be determined by other factors, and where cover is good (60 to 100%) rates less than 5 t ha^{-1} yr^{-1} are common. Zachar's (1982) worldwide classification of soil erosion rates in t ha^{-1} yr^{-1} viz:-

<0,5 - insignificant
0,5 to 5 - slight/weak
5 to 15 - moderate/medium
15 to 50 - severe/serious
50 to 200 - very severe/very serious
>200 - catastrophic

is used in the following brief overview of soil erosion rates in the Republic. Although very severe erosion is generally localized and corresponds with poor vegetation cover, the country's broad scale rates appear to be below the continent's average. Weak erosion rates have been reported for areas with intermediate cover, while the erosion in good cover areas is insignificant.

Schulze's (1981) study on the influence of siltation on the lifespan of small dams in the Mfuyeni and Biyela wards of the Mfolozi catchment was noted in section 1.1. The very severe soil erosion rates estimated for most of the 48 subcatchments surveyed were attributed to poor vegetation cover caused by overgrazing. Poor cover caused by poor cultivation practices and overstocking was also viewed by Weaver (1989) as the major factor responsible for the very severe soil erosion rates in an African traditional subsistance farming area in the Ciskei. He used the rates of sediment accumulation in the Roxeni dam to derive an estimate of 113,7 t ha^{-1} yr^{-1} for its catchment.

Most estimates categorize soil erosion as slight to weak as they have been derived under intermediate to good cover conditions. Estimates in t ha^{-1} yr^{-1} derived from sediment yield data include 1,9 (Schwartz and Pullen, 1966) and 2,0 (Kriel, 1983) for the Republic; a range from 1 to 6 (Rooseboom, 1978) for Natal; 1,5 (Phillips, 1983) and 2,7 (Fleming and Hay, 1983) for the Mfolozi catchment. Estimates derived from sediment yield data tend to be underestimates as a portion of the soil eroded from a catchment is temporarily stored in wetlands, dams, river channels, the flood plain etc, en route to the sea. This tendency increases with increasing catchment size as larger catchments have larger areas suitable for deposition (Golubev, 1982). Estimates derived from sediment accumulation rates in dams, runoff plots and wash traps do not however differ substantially from those presented above. Average soil erosion rates in t ha^{-1} yr^{-1} derived from sediment accumulation rates in dams include 0,7 and 0,9 for the catchment of the Bulbergfontein dam near Reddersberg for the periods from 1942 to 1971, and 1972 to 1978, respectively (Le Roux and Roos, 1979); 0,9 for the Republic, a range from 1,3 to 3,3 for Natal; and a range from 2,0 to 2,7 for the lower reaches of th Mfolozi catchment (Le Roux, 1990). Average soil erosion rates in t ha^{-1} yr^{-1} derived from natural and/or simulated rainfall runoff plots on natural veld include 0,8 and 1,3 for ungrazed and grazed veld near Pretoria (Haylett, 1960); 0,9 for well managed veld near Reddersberg (Le Roux and Roos, 1982b); 1,5 and 4,2 for climax and pioneer veld near Bloemfontein (Snyman, van Rensburg and Opperman, 1985); and 0,3 and 0,8 for the cull and non-cull management areas of the Umfolozi Game Reserve (Venter, 1988). Soil erosion rates in areas of the Natal Drakensberg that are densely covered by a lightly grazed grassland pyroclimax are insignificant. Watson (1981, 1984) derived estimates of 0,13 and 0,16 t ha^{-1} yr^{-1} from sediment yield measurements from first order catchments at Cathedral Peak, while Garland's (1987a) estimate of 0,02 t ha^{-1} yr^{-1} was derived from natural runoff plots at Kamberg. These values are less than and equivalent to the geologically normal rate of 0,16 t ha^{-1} yr^{-1} calculated for the Tugela Basin by

Murgatroyd (1979). Le Roux's (1990) comparative analysis of maps of surface lowering rates and weathering rates indicated that the rate of erosion during the past ten to fifty years is twice to more than three times the rate of soil formation in the Republic's important agricultural areas.

3.7 EROSION RATES CORRESPONDING TO DIFFERENT LANDTYPE SURFACES

Even though contemporary soil erosion rates over most of the Natal landscape are low from both an African and worldwide perspective, the Province's total soil removal rate is more than twenty times faster than the geologic norm (Murgatroyd, 1979; Martin, 1987). The review of temporal variations in the Province's erosional activity presented in section 3.4 suggests that major thrusts in the trend of increasing anthropogenically accelerated erosion corresponded to changes in landuse. A comparative review of erosion rates associated with the range of predominate landtype surfaces represented, and with the conversion from one landtype to another, is therefore deemed appropriate.

3.7.1 Forest vs. Shifting Subsistence Cultivation

The first significant thrust corresponded with widespread deforestation during the Late Iron Age. While there is little doubt that deforestation per se increased soil erosion, the erosional status of the resultant landscape is open to speculation. Whitlow (1980b), Chang, Roth and Hunt (1982), and Allen and Barnes (1985) amongst many others have shown that the consecutive stages of selective thinning, partial clearance and woodland destruction are associated with a progressive increase in sediment production rates. Collinet and Valentin (1984) reported a five fold increase in soil loss following manual clearance of a tropical rainforest. An eighty fold increase occurred when the clearing process was aided by the use of fire. Lal (1981, cited by Lal, 1985) found that mechanized deforestation increased soil erosion by several orders of magnitude more than manual clearing methods.

Shifting subsistence cultivation and grassveld maintained for stock grazing by annual winter burning were the predominate landtypes present in the Province following deforestation. Ahn (1977) attributed the insignificant soil erosion under shifting subsistence cultivation systems in East Africa to the fact that the soil surface was covered by vegetation most of the time. In these systems, small plots are cleared within the natural vegetation. As they are planted with a number of different crops harvesting occurs over a prolonged period. Cover is also secured by the lack of weeding and maintenance which in turn contributes to the plots' abandonment. Notwithstanding the importance of cover in shifting cultivation systems in West Africa, Okigbo (1977), and Olayide and Falusi (1977) noted that soil erosion increased significantly once the increased demand for land, caused a shortening of fallow periods.

3.7.2 Forest vs. Grassland

Soil loss from grassland is not necessarily significantly greater than from forest/woodland as it is dependent on a wide range of factors including seral stage, percentage basal and canopy cover, and burning and grazing management. Bennet (1955, cited by Holy, 1980) found that soil loss from grass ranged from 1,5 times less than to 5,8 times more than from forest, and concluded that the erosion control efficiency of good grass cover is not significantly different to that of forest. In a study of sediment production potential within the vegetation communities of Oregon's Blue Mountain, Buckhouse and Gaither (1982) found that dry grass communities in good condition had a similar potential to most of the forested ecosystems. The influence of degree of cover is most apparent in Collinet and Valentin's (1984) findings in West Africa. While soil loss from good grass cover was similar to that from tropical rainforest, the rates from poor grass cover after a drought were 235 times greater than from forest. A management influence is apparent as soil loss from burnt grassland was 80 times more than from forest. Roose's (1976, 1977) work also carried out in West Africa reflects the influence of grazing management. Compared to forest, the soil loss from good grass cover and overgrazed grassland was 10 and 100 times greater, respectively. A more extreme response to overgrazing in Colombia was reported by Van Vuuren (1982). Compared to forest, the soil loss from natural rangeland and overgrazed pasture was 15 and 750 times greater, respectively. On a global basis, Golubev (1982) estimated that soil erosion rates under grassland are 100 times greater than under forest.

3.7.3 Forest vs. Settled Subsistence Cultivation

As Natal's population increased during the Late Iron Age subsistence cultivation became more settled and extensive. It constituted a distinct landtype in place of the original woody climax. While there is a general concensus in the literature that soil loss from cultivated areas is greater than from forest, estimates of the magnitude of the difference range from 2 (Golubev, 1982) to 7 (Okigbo, 1977), to 125 (Van Vuuren, 1982) to 550 (Roose, 1976, 1977) times.

3.7.4 **Intensive Subsistence Cultivation vs. Overgrazed Rangeland**

European settlement in Natal led to a substantial increase in the tribal and livestock populations in the designated traditional communal areas. This in turn led to a shortening of fallow periods and excessive grazing pressure over extensive areas. A comparison of soil loss from an intensive subsistence cultivation landtype and from overgrazed rangeland is therefore pertinent. As Young (1977) noted such a comparison is hindered by the lack of soil erosion rates actually measured within traditional landuse areas in African environments pressurized by human and stock populations. Experimental plot work in West Africa by Roose (1976, 1977) showed that the production of sediment from land planted with maize, millet and sorghum using traditional techniques was 5,5 and 55 times greater than from overgrazed rangeland and grazing land in good condition, respectively. By contrast, air photo surveys of traditional landuse areas in Kenya by Thomas (1974) and in Uganda by Stephens (1971) both cited by Ahn (1977), revealed that the overgrazed rangeland areas were more severely eroded than the cultivated areas. Also in Kenya, Thomas *et al.* (1980, cited by Lal, 1985) found soil erosion from overgrazed rangeland was 50 times greater than from well maintained pasture. Soil erosion on rangeland in Canada was found to be more severe than on commercially cultivated lands by Neill and Mollard (1982). While Van Vuuren (1982) found that overgrazed rangeland in Colombia had soil loss rates six times greater than cultivated land, the rates from grazing land in good condition were eight times less than the arable land rates. The general consensus in the literature is that cropland sediment production is greater than rangeland production Jones, Eyk, Smith, Coleman and Hauser (1985). On a global basis Golubev (1982) estimated that cropland production is ten times greater.

3.7.5 **Commercial Farmland vs. Traditional Communal Land**

The landtype on European owned land in Natal progressed from the settled subsistence farming, of the mid 19th Century to small scale market farming to the present day intensive mechanized commercial agriculture. Partridge (1988) viewed the rapid spread of mechanized agriculture as being as important as overgrazing in the traditional communal areas, in accounting for the major thrust in anthropogenically accelerated erosion during this century. Fauck (1977), Greenland (1977) Kalms (1977) and Lindstrom, Voorkees and Randall (1981) amongst many others have noted that mechanization generally increases soil erosion. The magnitude of the increase on Natal's sandy soils with their susceptibility to crusting or compaction is however, unlikely to be as great as that found in more structured soils elsewhere. Rapp (1975) in Tanzania and Lesotho, Ahn (1977) in Kenya and Uganda, Okigbo (1977) in West Africa from Zaire to Sierra Leone, Olayide and Falusi (1977) in

Nigeria, Elwell (1984) in Zimbabwe, Otieno and Rowntree (1986) in Kenya, and Whitlow (1980a, 1986, 1988) in Zimbabwe, amongst many others have noted more severe soil erosion on communal peasant lands when compared to commercial farmland.

3.7.6 **Erosion on South African Landtype Surfaces**

Research carried out in the Republic indicates that the erosional status of forest as compared to grassland or arable land; of intensive subsistence cultivation as compared to overgrazed rangeland; of traditional communal land as compared to commercial farmland; anticipated from the above review, is applicable to the equivalent South African landtypes, and substantiates the proposed responses in erosional activity to changes in landuse in Natal. Averaged over a period of thirty six years, Broderick (1987) found that less than one percent of the forested areas in the Tugela Basin were affected by sheet/rill and/or gully erosion. The equivalent percentages for rangeland, subsistence cultivation and commercial farmland areas, were 5,9; 8,2 and 5,5; respectively. In developing an erosion hazard assessment model for the central Ciskei, Weaver (1988b and c) used aerial photographs taken in 1984 to map five classes of soil erosion in the region between the central plateau and the Winterberg escarpment. About 90% of the forested areas were designated to the "no erosion" class. By contrast, less than 5% of the grazing and arable areas were designated to this class. The class exclusively for sheet and rill erosion was three times better represented on the arable areas than on the grazing areas. Obvious sheet and rill erosion in combination with evidence of gullies was found on about 75% and 35% of the grazing and arable areas, respectively. Less than 10% of both these landuse categories had intricate and/or severe gullying. Weaver (1988a) found that soil erosion in the Yellowwoods catchment in the Ciskei averaged over a nine year period, was active on 61% of the traditional communal land as compared to 48% of the commercial farmland. Differences in the surfaces affected by sheet and rill processes between these landtypes, were not great. These surfaces were included in the slight to moderate erosion class and accounted for 50% and 46% of the traditional communal land and commercial farmland, respectively. Gully erosion was included in the severe and very severe erosion classes which were 3 and 7 times better represented in the traditional communal land, respectively. Berjak *et al.* (1986) used 1983 orthophotos to map gully and sheet/rill erosion in a 525 km^2 area surrounding Ulundi - the KwaZulu capital. Erosion severity was classified according to the proportion of the sampling unit affected. Four classes were used: no erosion, less than 10, 10 to 25, and more than 25% representing slight, moderate and severe erosion, respectively. Liggitt (1988) and Liggitt and Fincham (1989) extended this study and showed that gullies affected 15% of the traditional communal land as compared with 11% of the commercial farmland. Sixty percent of the traditional communal land was unaffected by sheet/rill erosion compared to 77% of the commercial farmland. Slight sheet/rill erosion was 1,9 times better represented in the traditional communal land than on the commercial farmland. Representation of the moderate and severe sheet/rill erosion classes in the two landtypes was virtually the same.

Urban and industrial development has no doubt also contributed to this century's trend in anthropogenically accelerated erosion. A comprehensive review of soil loss from the Republic's non-agricultural areas was considered beyond the scope of this study. Scotney (1978a) however, was of the opinion that soil losses from roads, construction sites and mines are not generally appreciated in South Africa, and cited estimates from the U.S.A. of soil losses of 780 t ha^{-1} yr^{-1} from road cuttings, and of 10% of the sediment yield of catchments originating from roads and construction sites. O'Sullivan, Coard and Pickering (1982) found that the sediment yield from a catchment where intensive mining and agriculture were the dominant landtypes decreased by 30 to 35 times when mining ceased.

3.8 ENVIRONMENTAL CONSEQUENCES OF ACCELERATED SOIL EROSION

3.8.1 On-site Effects

In order to gain a more comprehensive perspective of anthropogenically accelerated soil erosion, a brief appraisal of its detrimental environmental consequences is considered pertinent. Soil productivity is the capacity of the soil in its normal environment, to produce a particular plant or sequence of plants under specified management systems (Gifford and Whitehead, 1982). Accelerated soil erosion decreases soil productivity. The magnitude of the decrease is dependent on the original thickness and quality of the topsoil, as well as the nature of the subsoil. Frye, Ebelhar, Murdock and Blevins (1982) reported grain yield decreases of up to 21% on eroded soils, as compared with non-eroded soils. They found substantial yield decreases on some soils caused by relatively moderate soil loss rates, and a reduced productivity potential still in evidence sixty years after a cultivated area was abandoned to grass. Young (1980) noted that the short term effects of accelerated erosion on soil productivity are related to the top soil's decreased water and nutrient status, and structural degradation, while the long term effects are related to the shallowing of the top soil. Pierse, Larson, Dowdy and Graham (1983) explained that the shallowing of the top soil enhances the influence of unfavourable subsoil characteristics on the root zone. These characteristics include poor water holding capacity (Williams, 1981), hinderance to downward root development (Hudson, 1981), toxic concentrations of bicarbonate and chloride, an excess of magnesium and a deficiency of iron (Walker and Elliott, 1982). Frye *et al.*

(1982) observed that the finer the subsoil's texture, the greater is its detrimental influence on productivity.

Gifford and Whitehead's (1982) review of research on the effects of erosion on productivity showed that arable lands have been the focus of attention. While the effect on rangeland cover density and nutrient deficiencies have been studied, they have not been linked to productivity. Non-uniform removal of soil from arable land produces variable emergence of crops which in turn necessitates higher energy inputs in harvesting and in preparation for replanting (Williams, 1981). In commercial arable lands production costs are substantially greater on eroded soils. Their reduced water holding capacity and nutrient status necessitates increased irrigation and fertilizer inputs. The nutrient status is primarily affected by the loss of phosphorus and nitrogen. Phosphorus is known to be absorbed to the surface of colloidal particles (Hudson, 1981; Osuji and Babalola, 1983), while Schuman, Burwell, Piest and Spomer, (1973) found that 92% of the total nitrogen lost in runoff was associated with sediment. The cost of replacing nutrients removed from South African soils by erosional processes, with commercial fertilizers was estimated to be in excess of R1 000 million per annum by Huntley, Siegfried and Sunter, (1989). A common response to the reduced water holding capacity of eroded soils in traditional communal lands is a delay in planting until after the commencement of the rainy season. This strategy exacerbates the erosion and results in yields a fraction of their former level. Further responses to the progressive decline in yields includes more intensive cultivation by a reduction in fallow periods, planting crops with a shorter maturation period, and cultivating more land (Stocking, 1988). Darkoh (1982) suggested that the cultivation of marginal areas following the saturation of more viable arable areas, contributed to desertification in Tanzania. Anon (1990) estimated that on a worldwide basis accelerated soil erosion renders $5,5 \times 10^6$ ha of cropland unproductive each year.

3.8.2 Models of Effects on Soil Productivity

The effects of accelerated erosion on soil productivity may be masked by management techniques such as fertilizer application, and proceed unrecognized until cultivation is no longer economically viable (Williams, 1981). A number of approaches are evident in the attempt to model these effects. The most common involves establishing a *soil productivity index*. It is based on the assumption that soil as the root growth medium, is the major determinant of yield. Optimal management conditions are assumed, and each horizon is rated in terms of the suitability of its characteristics to plant growth. As the full range of management techniques operant are seldom optimal, and are often changed before their full effects on erosion are registered, evaluation of the sensitivity of these models is reliant on testing correlations between its predictions and yield data from simulated erosion, rather than from non-experimental long term yield records (Rijsberman and Wolman, 1985). Another approach involves establishing the *soil loss tolerance*, which is the maximum rate of annual soil erosion that will permit a high level of productivity to be sustained economically (Djorovic, 1980; Pierse *et al.* 1983). This threshold rate is alternatively referred to as the *acceptable rate of erosion* (Kirkby, 1980a). Its calculation permits economic choices between improved technological inputs and increased erosion control (Young, 1980). On a global basis estimates of soil loss tolerance range from 2 to 11 t ha^{-1} yr^{-1} (Mannering, 1980; Hudson, 1981). The acceptability of a progressive shallowing of agricultural soils is implicit given that most estimates of soil renewal worldwide are less than 5 t ha^{-1} yr^{-1} (Mannering, 1980). The calculation of the tolerance threshold involves the input of the depth of the favourable rooting zone as well as rates of soil renewal (Young, 1980). The corresponding range in favourable rooting depth is 250 to 1 500 mm (Morgan, 1980c). The soil loss tolerance rates of 4,3 and 2 t ha^{-1} yr^{-1} set for light, medium and heavy South African soils respectively, are about ten times faster than their respective soil renewal rates (Anon, 1976; Scotney, 1978a). Some of Platford's (1979) soil loss tolerance estimates for the most important soil formations in Natal's sugar cane producing areas, have been noted in section 2.5.

A further approach employed by Elwell (1984) and Elwell and Stocking (1984) in Zimbabwe, involves estimating the *soil life span*. These estimates may facilitate the decision to provide resources to extend the life span, or to make contingency plans for agricultural collapse in an area. In addition to inputs common to the calculation of soil loss tolerance, bulk density, soil loss rates and the minimum depth of soil required to produce an economically acceptable yield, are required to calculate soil life span. The minimum depth as well as being plant and soil specific, is specific to acceptable yield criterion which may vary according to whether a commercial or subsistence farming system is being appraised. The aquisition of data on the effects of erosion on productivity is costly and time consuming. The consequent limited data together with the masking effects of improved technology make models based on empirical relationships difficult to formulate. Williams (1981) suggested that the development of mathematical models based on physical processes may prove a more promising approach. Larson, Pierce and Dowdy, (1983) criticized all the existing approaches to research on the relationship between erosion and production, for neglecting to take offsite damage into account.

3.8.3 **Off-site Effects**

The reduced infiltration of rain and irrigation water into eroded soils, coupled with their reduced water holding capacity increases the severity of dry periods. This in turn increases sediment availability and erosion initiation particularly gully incision, when rains commence. Swart and Allanson (1988) have confirmed that the sediment yields of South African rivers are greater during flood events following dry spells, than following wet spells. The effect on drought was the first effect of accelerated soil erosion to be recognized in South Africa. Its recognition stimulated the earliest research into the causes and consequences of soil erosion, and motivated the earliest soil conservation legislation in this country (Rabie and Theron, 1983). The reduced moisture status of eroded soils gives a selective advantage to woody plants. Bush encroachment generally exasperates the soil's erosional status, as it is seldom associated with a corresponding decrease in grazing stock (Scott, 1952, 1981; Trollope, 1974, 1984; Braune and Wessels, 1980; Grossman and Gandar, 1989).

The replenishment of wetlands by throughflow is reduced in eroded catchments. Desiccated wetlands are more readily burnt to create grazing for domestic stock and ploughed for crop cultivation. The destruction of wetlands diminishes their role in water storage, stream flow regulation, flood attenuation, water purification, nutrient assimulation and sediment accretion as described by Begg (1986). Begg (1988) found that 58% of the Mfolozi catchment's former wetland resource has been lost since the Iron Age. In addition, 57% of the extant wetlands showed evidence of accelerated soil erosion. The reduced throughflow from eroded catchments coupled with the diminished seepage from wetlands increases the incidence and severity of river flow cessation and reduces winter flow. The increased runoff from eroded catchments coupled with its diminished attenuation by wetlands increases the incidence and severity of flood flow. The increased sediment removal from eroded catchments coupled with its diminished accretion by wetlands increases sediment delivered to river channels (Begg, 1986). This in turn leads to increased deposition of sediment within the channels during periods of low flow, and increased sediment accumulation rates in dams, estuaries and harbours. Rooseboom (1983) presented a bibliography of South African studies on siltation in rivers and dams. A spectacular example from Natal cited by Begg (1986) is of the Gilbert Eyes dam on the Umzimkulwana river. It lost 41% of its capacity in six years. A single storm in May 1959 resulted in a capacity loss of 25%. Sediment accumulation in dams decreases their water storage and flood attenuation capacity and increases their evaporative loss (Kriel, 1983). Sediment deposits in river channels reduce their ability to accomodate peak flows. The resultant increased incidence and severity of bank scouring increases the proportion of the river's total sediment yield derived from this source (Scotney, 1978a). The amount of sediment delivered from eroded catchments by average rain events is commonly sufficient to increase the sea's turbidity to shark menace levels, and poses a threat to the economic viability of coastal resorts (Begg, 1978, 1984). The incidence and severity of flood damage associated with extreme rainfall events is greater in eroded catchments. Flood damage in the Mfolozi catchment during cyclone Demoina was described in section 1.1. In addition to flood damage, increased costs associated with the disruption of river flow dynamics relate to increased pumping and cleaning effort in the maintenance of a constant supply of quality water, the loss of dam storage capacity and harbour dredging (Kriel, 1983).

In addition to nutrients, eroded sediments carry sorbed pollutants ranging from pesticides, herbicides and fertilizers applied to agricultural land, to contaminants and pathogens from liquid and solid domestic, industrial and radioactive waste disposal sites (Singer, Blackard, Gillogley and Arulanandan, 1978; Holy, 1980). The increased removal of chemical pollutants from eroded catchments coupled with the diminished water purification and nutrient assimulation function of wetlands further decreases the quality of water in rivers and dams thus encouraging their eutrophication. This in turn increases their evaporative loss and health risk, and decreases their recreational, productive and consumptive use value (Singer *et al.* 1978; Begg, 1986). The accumulation of sediments within, and nutrient enrichment of the majority of Natal's estuaries has resulted in their rapid eutrophication through to an advanced reed encroachment stage. Their consequent decreased viability as feeding, breeding and nursery areas for the majority of marine organisms (Begg, 1978, 1984) is reflected in the fisheries catch trends, particularly those of endemic species (Van der Elst and de Freitas, 1988). De Kock and Lord's (1988) analysis of measurements of chlorinated hydrocarbon residues taken in South African offshore sediments and marine organisms since 1974, showed that while there is moderate contamination at specific sites, the average level is relatively low. Darkoh (1982) describes the role of accelerated soil erosion in desertification. Its role in marginalization of land by salinization is described by Singer *et al.* (1978) and Stephens (1983). Holy (1980) describes a number of detrimental environmental consequences of accelerated soil erosion, in addition to those outlined above.

3.8.4 Socioeconomic and Political Effects

Stocking (1988b) reviews the socioeconomic and political costs of accelerated soil erosion in developing countries. At a local level, the poorer diets caused by the declining yields of traditional subsistence farmers, increases child malnutrition and general susceptibility to disease. The migration of active males to towns in search of cash employment in addition to disrupting to local family structure, further exasperates the productivity decline. In paternal societies, the response to this trend in rural materfamilias is a decline in government subsidized inputs of seed, fertilizer, etc, and a lowering of the priority rating accorded to rural development schemes. At a national level, the abandonment of marginalized land and consequent migration to towns and cities presents urban development planners with a multitude of challenges, not least of which involves averting the serious detrimental socioeconomic and political implications of unemployment and overpopulation. At an international level, the reduced ability to produce food has increased the reliance of developing countries on developed countries for food aid. It has also encouraged their conversion to intensive technologically advanced agricultural schemes. Their capital investment needs and hence foreign exchange demands have therefore increased, further entrenching their reliance on first world financial aid. Stocking

(1988b) suggested the cost benefit analysis provides the best framework for organizing information about the on- and off-site effects of erosion. The choice of an appropriate conservation strategy should therefore be reached using this method.

3.9 SOIL CONSERVATION

Accelerated soil erosion continues despite (i) a well established soil conservation methodology, (ii) soil conservation legislation; (iii) government subsidization of the cost of soil conservation work, (iv) the relatively insignificant cost of a large range of erosion preventative measures, and (v) the enormous costs of its detrimental environmental, socioeconomic and political consequences. In order to comprehend this paradox, Stocking (1988b) maintains that the costs and lack of benefits of soil conservation must be recognized.

3.9.1 Commercial Farmland

The widespread implementation of soil conservation measures in South Africa's European owned commercial farmland was retarded through until the early sixties by (i) a lack of conviction of the effectiveness of these measures (Scotney, 1978a), (ii) a lack of awareness of the benefits of their implementation (Scotney, 1978a; Rabie and Theron, 1983), and (iii) the ineffectiveness of soil conservation legislation (Rabie and Theron, 1983). The first major soil conservation effort took place during the 1930's depression. As part of an employment creation scheme, the government subsidized the construction of stone walls across gullies. Much of this effort in Natal was concentrated on the spectacular gully systems found in the Masotcheni formation. As noted in sections 3.4.2 and 3.4.3, the initiation and development of these systems is unrelated to any anthropogenic influence. The control structures being unable to hinder the basic cause of gullying were subsequently bypassed or undermined. Their failure initiated a general lack of conviction about the effectiveness of conservation measures (Scott, 1952; 1981). This attitude was entrenched by the failure of the veld burning policy initially prescribed by agricultural extension. Although erosion prevention initially motivated this policy, it encouraged bush encroachment (Scott, 1952, 1981). As noted in sections 2.11.1 and 3.8.3 this in turn generally exacerbates soil loss. The continued overemphasis of the role of physical works by agricultural extension maintained this attitude (Scotney, 1978a). It has however, diminished substantially over the past two decades. Perrens and Trustrum (1984) observed that there is worldwide recognition of the fallacy of assuming that the most spectacular erosion forms represent the major sediment sources. Expensive remedial works carried out to these forms commonly yield only moderate returns. A worldwide recognition of gully control measures as being too costly to be considered practicable, was observed by Stephens (1983). The diversion of the soil conservation effort in this country away from gullies has contributed to credibility of conservation measures prescribed by agricultural extension. Their credibility has been additionally enhanced by the recognition of the equivalent and complimentary role of biological control measures to that of physical control measures (Scotney, 1978a).

The lack of awareness of the benefits of soil conservation was due in part to the general shortage of well-trained and enthusiastic agricultural extension staff (Scotney, 1978a; Rabie and Theron, 1983). The relatively intangible nature of economic gains resulting from soil conservation works also contributed to it. These gains may only be realized five to ten years after the expenditure on conservation measures, and seldom compensate for the non recovery of expenditure on conservation in the farm's selling price (Rabie and Theron, 1983). Over the past two decades the media, particularly television, has played a more active and responsible role in progressively increasing the level of general public awareness of and concern for environmental issues. This in turn has contributed to a greater awareness of the long term costs of soil erosion to society at large, amongst the farming fraternity (Huntley *et al.* 1989). The increased level of awareness of the benefits of soil conservation by farmers also reflects substantial improvements in agricultural extension services. The Department of Agriculture has made available a large range of comprehensive and easy to comprehend guides to the most appropriate choice of control measures. As these publications are either free of charge or very reasonably priced, they are readily accessible. A classic amongst them:- Matthee's (1984) "A Primer on Soil Conservation", is a case in point. Its local price excluding G.S.T. is R3.00. A wide range of additional data sources and techniques have become available, for example: high quality, small scale aerial photographs and orthophoto maps; satellite images; computerized statistical packages, graphic and cartographic displays, and simulation models; and geographic information systems. The additional data and advances in managing it, have aided extension staff in the estimation of soil loss rates, in the setting of soil loss tolerance limits and ultimately in the design of land use plans for farmers. Scotney (1978a, 1988) gives a detailed account of these improvements, and lists the future challenges facing agricultural extension.

The democratic provisions of the 1946 Soil Conservation Act were largely responsible for its ineffectiveness. The declaration of soil conservation districts, as well as preparation and enforcement of soil conservation schemes by district committee's, were dependent upon the initiative of farmers. The committees were mainly composed of farmers who proved loath to take action against members of their own community. As noted in sections, 3.4.6.1 and 3.4.6.2 this weakness was redressed in the 1969 Soil Conservation Act. Its proclamation coupled with the relative weakening of the power of the rural vote has seen a substantial improvement in the effectiveness of the legislation (Rabie and Theron, 1983).

3.9.2 Traditional Communal Land

The fact that South Africa's traditional communal lands have yet to enjoy the widespread implementation of soil conservation measures can be attributed to (i) the non feasibility of measures which have proved effective in commercial farmland, (ii) the lack of awareness of the effects of soil erosion and the benefits of soil conservation, (iii) the ineffectiveness of conservation legislation, (iv) the land tenure system and (v) the location of most of these lands in marginal areas. The socioeconomic resource base of small market and subsistence farmers cannot meet the costs of implementing commonly recommended physical conservation measures such as terraces, contour banks and drains (Okigbo and Lal, 1977). Erskine (1986), Ahn (1977), Okigbo (1977), Morgan and Scoging (1981), Lal (1984) and Morgan (1986) give examples of African subsistence farming areas where their implementation under government subsidized schemes increased soil losses because they were incorrectly constructed and/or inadequately maintained. Their incorrect orientation alternatively encourages damming and channelling which due to their associated saturation and slumping, and scouring and undercutting, in turn encourages mass failure. Highly erodible subsoils may be exposed by their construction in very shallow topsoils.

Smithen (1983) found that seven Natal soils lost an average of six times more soil when conventionally tilled as compared to no tillage. Lindstrom *et al.* (1981) reference a large number of studies with similar findings worldwide. Minimum and no till systems also offer the advantage of reduced labour input in seed bed preparation. Despite this, Aina, Lal and Taylor (1976), Fauck (1977), Kalms (1977), Lal (1977b, 1982) and Okigbo and Lal (1977) indicate that they are not widely used in African subsistence farming areas. When they have been used they often contributed to increased soil erosion as have been used on consolidated soils without a mulch. Smithen (1983) found soil loss from seven conventionally tilled Natal soils was reduced by as much as a third when 40 to 60% of their surface was covered by maize stover. In addition to the proportion of the soil surface covered, the effectiveness of a mulch in reducing soil loss is dependent on slope angle (Morgan and Scoging, 1981), slope length, tillage induced roughness, mulch type, placement on and degree of incorporation into the surface (Cogo, Moldenhauser and Foster, 1984). For slopes from 2 to 20^{0} in subsistence farming areas in West Africa, Lal (1984) found 6 to 8 t ha^{-1} of crop residue gave adequate soil erosion control. African subsistence farmers find it difficult to procure such mulch rates as tend to plant poor yielding single crops in low densities (Lal, 1984), and use crop residue for livestock feed. Its consumption by termites

(Ahn, 1977) and rapid decomposition under hot and humid conditions pose additional constaints. Mulching with either crop residue or crops that rapidly develop a canopy close to the soil surface eg: legumes, is generally unfavourably perceived by these farmers because of the associated increased weed and other pest control requirements (Okigbo and Lal, 1977). Increasing planting densities may result in substantial reductions in soil loss, eg: Adams, Richardson and Burnett, (1978) found that reducing the spacing between rows of crops resulted in reductions in soil loss of up to 39%. Most African subsistence farmers are unable to increase their planting densities as the row spacing they use is a function of the requirements of, and their reliance on oxen drawn ploughs. Soil loss rates may be substantially reduced by the use of fallow periods, crop rotation, and mixed and strip croping, eg: Aina *et al.* (1976) found soil loss from maize grown by subsistence farmers in West Africa was 1,6 times greater than from mixed crops of maize and cassava. These alternative systems to monoculture are however, not widely employed in African subsistence farming areas because of their heavy reliance on a limited number of stable crops, and the shortage of suitable arable land (Okigbo and Lal, 1977; Olayide and Falusi, 1977).

As explained in section 2.8, preventing erosion on communal grazing land by reducing stock pressure is not feasible because of the economically rational value attached to livestock by African tribal communities. Olayide and Falusi (1977) concluded that the failure of the above outlined measures challenged soil conservationists to develop technically feasible, economically profitable and socially acceptable measures for traditional communal lands. As tenant subsistence farmers may readily abandon unproductive land, they are not affected by or consequently aware of on-site erosion to the same degree as commercial farm owners. Their low literacy level precludes an awareness of the off-site effects of erosion. The awareness of the benefits of soil conservation created by the very limited agricultural extension work in these traditional communal lands, is seldom reflected in field application. As explained in section 2,8, the extention generally reaches the materfamilias who has no decision making status in these male dominated communities. In addition, the fabric of the land tenure system provides no incentive for the consideration of long term benefits. Most traditional communal lands are located in areas of marginal agricultural potential, they are consequently more severely affected by natural hazards. Otieno and Rowntree (1986) noted that a severe drought dampened much of the initial enthusiasm for soil conservation in such lands in Kenya.

CHAPTER FOUR

MECHANICS OF SOIL EROSION PROCESSES

4.1 DEFINITION OF EROSION TYPES

As noted in section 3.1, the erosion found in the study area conforms most closely to Dardis *et al.'s* (1988) southern African Soil Erosion Types 1 and 8. Although sheet erosion predominates in the Type 1 category, rill erosion is also represented. Surface processes predominate in the origin and development of gullies in the Type 8 category. Sheet erosion refers to the removal of a relatively uniform thickness of soil (Smith and Wischmeier, 1962) by rainsplash and unconfined surface runoff (Morgan, 1979, 1986). Rill erosion refers to the removal of soil by surface runoff confined to temporary microchannels or depressions (Dunne, 1983). Gully erosion refers to the removal of soil by drainage channels that transmit ephemeral flow (Morgan, 1979; 1986).

4.2 SHEET EROSION

4.2.1 Rainsplash

Rainsplash is generally considered to be more efficient in detaching sediment particles than in transporting them (Hudson, 1980; Singer and Walker, 1983). As raindrops striking the soil do not have time to drain, their implosive load compacts the soil, and deforms the surface into convex cavities that bulge around the perimeter. These depressions transform the vertical impact force into a lateral shear that disrupts the drop (Al-Durrah and Bradford, 1982a and b). Wind driven raindrops, and/or drops impacting at an angle, and/or on irregular surfaces are associated with substantially greater lateral and tangential shear stresses (Young and Onstad, 1982). As the jets radially dispersed within the cavity return to the point of impact, they attain velocities far greater than the original drop impact velocity, which are sufficient to detach sediment particles and splash them out of the cavities. At this stage the sediment particles have already become available for detachment by slaking and shear failure of aggregate bonds. More sediment particles are detached from soils of low shear strength because for a given rain drop size and diameter, they have greater cavities and splash angles. Particles detached from soils of high shear strength are splashed further because the converging radial jets attain greater velocities in the relatively shallow cavities (Al-Durrah and Bradford, 1982a and b).

The compaction of soil by the implosive load of raindrops coupled with the compression of soil air ahead of the wetting front as rainfall rapidly infiltrates down through a dry soil, causes particles to disperse and slake (Yee and Harr, 1977; Oades, 1984). The internal strength of aggregates decreases once the soil is saturated. They do not however, disintegrate until their adhesive and chemical bonds are sheared by the direct force of raindrop impact. Fine particles liberated by dispersion, slaking and disaggregation, clog surface pores and develop into a dense surface seal or crust (Morgan, 1979, 1986). Rainsplash selectivity detaches particles ranging in size from 63 to 250 um. During the course of an individual rain event and rainy season, particles outside this range progressively accumulate on the surface thus protecting the vulnerable size range from further removal. This process is known as surface armouring. It acts together with surface crusting/sealing to reduce the splash detachment capacity (Loch and Donnollan, 1982a; Morgan, 1986). Splash detachment and splash transport increase as slopes become steeper. The response by splash transport is however, more sensitive (Quansah, 1981). As more particles are splashed downslope than upslope, slope angle increments are also reflected in corresponding increases in the net removal of sediment particles (Statham, 1977). Singer and Walker (1983) working in Australia, found that splash transport accounted for between 14 and 25% of the soil removed. The higher end of this range represented dry soils where runoff was restricted. Most of the sediment particles detached and transported by rainsplash are subsequently entrained by and transported in unconfined and/or confined surface runoff. Soil removed by surface runoff was reduced by 99% when Hudson (1980) prevented rainsplash detachment and transport experimentally. Soil compaction and crusting by rainsplash serves to decrease the detachment potential and increase the transport potential of surface runoff (Morgan, 1979; 1986). Surface loci protected from the uniform action of rainsplash over prolonged periods by stones or plants, remain as pedestals or soil pillars. Provided there is no evidence of undercutting of their bases by surface runoff, their height gives an approximation of the depth of soil removed by rainsplash (Barber, Moore and Thomas, 1979).

4.2.2 Unconfined surface runoff

Surface runoff forms shallow flows of infinite width referred to as sheet or overland flow. These flows are rarely of uniform depth and commonly occur as a mass of anastomosing or braided unchannelled water courses (Morgan, 1979, 1986). Surface runoff is generated in response to at least four distinct mechanisms viz:- (i) infiltration excess, (ii) saturation excess, (iii) restrictive soil conductivity and (iv) surface impermeability.

When a rain event commences water infiltrates down through an unsaturated soil at a rate primarily determined by its structural, textural and biological characteristics. During the course of the event the swelling of colloids and 'rain packing' causes the infiltration rate and capacity to decline to a constant value (Cooke and Doornkamp, 1974). Surface runoff is generated when the rainfall intensity exceeds this value (Horton, 1945). As this mechanism is mainly controlled by permeability rather than moisture content, the infiltration capacity of soil over an extensive area may be reached more or less simultaneously. Surface runoff generated by this mechanism is therefore relatively more extensive and independent of position on slope profile (Weyman, 1975). Infiltration excess is the predominant means by which surface runoff is generated in arid and semiarid regions. When it occurs in humid regions it is either associated with perturbations that have substantially reduced the vegetation cover, or with clay soils that have saturated conductivities low enough to be exceeded by relatively frequent rainstorms. In the latter case, it may occur under dense vegetation cover (Dunne, 1983).

In humid well vegetated regimes runoff is commonly generated where rainfall is unable to infiltrate into a saturated surface horizon. The horizon may be saturated by (i) throughflow from upslope (Kirkby, 1980b), (ii) vertical percolation above an impeding horizon (Dunne and Black, 1970), and (iii) the perennial ground water table rising to the surface (Dunne, 1983). As the rainy season progresses the saturated layer extends towards the surface, and runoff is generated under much lower rainfall intensities than those required to produce infiltration excess overland flow (Dunne, 1983). Where throughflow is responsible for the saturated surface layer, runoff generation tends to be spatially restricted to the base of slopes and topographic depressions (Kirkby, 1980b; Tanaka, 1982).

Runoff may be generated on coarse textured soils, or on soils with large structural openings under dense vegetation cover, at rainfall intensities less than their infiltration capacities. Such high conductivity soils have low levels of capillary storage that limit the soil moisture content. Ponding occurs when this limit is exceeded, due to the reduction of pore water pressure at the surface to zero (Dunne, 1983; Morgan, 1986). Runoff may also be generated where rainfall irrespective of its intensity, is unable to infiltrate into a dense surface seal (Scoging, 1980). Dunne (1983) has however, noted that the turbulence and shear stress generated by very intense rainfall events, is sufficient to remove surface crusts of up to several millimetres thick. Irrespective of how the runoff is generated, it will only flow across the soil surface once the storage capacity of its depressions has been satisfied (Morgan, 1986). Localized sediment deposition and inundation reduces this microtopographic influence once the runoff volumes and rates of flow increase (Dunne, 1983). Runoff generation in the sheet eroded parts of the study area is most likely to be in response to infiltration excess and/ or surface crusting. Over its moist, densely vegetated remainder, runoff generation by other mechanisms is more likely. For example, given their perched gley horizon and topographic distribution (refer section 2.6.1), saturation excess is indicated as the main runoff control mechanism in the Bottomland soils.

Unconfined surface runoff is more efficient in transporting sediment particles than in detaching them (Smith and Wischmeier, 1962). Particles are detached by turbulence generated by raindrops impacting the surface of sheet flow. The detachment capability of sheet flow is therefore proportional to the rainfall energy (Wischmeier, 1977). It also increases in proportion to the depth of flow up to a critical depth, beyond which it decreases as the rainfall impact energy is dissipated in the water (Morgan, 1986). The shearing action created by turbulence does not reach the surface, once the flow depth is more than three times the average raindrop diameter (Thornes, 1980). Most of the particles detached by sheet flow are smaller than 20 um and are transported in suspension. The bulk of the particles transported by sheet flow range in size from 100 to 300 um. They are mostly detached by rainsplash, and transported as bedload (Loch and Donnollan, 1982a and b). The transport capability is related to the velocity of flow. The velocity must attain a threshold value before moving large grains and fine cohesive clays. The velocity of flow is influenced by the depth of flow and surface roughness factors such as stones and vegetation. It therefore varies greatly over short distances and encourages localized scouring and deposition (Morgan, 1986). As both the volume and velocity of flow increase with increased slope length, the transport capability is greatest at the base of long slopes (Loch and Donnollan, 1982a).

The particle size distribution of sediment removed by sheet flow from non and strongly aggregated soils is unimodal and generally shows little temporal variation. Sediment removed from such soils is therefore more likely to be influenced by the transport capacity of overland flow, than by the supply of detached material. The size distribution of sediment removed from weakly aggregated soils is bimodal. A small peak reflects particles removed intact, while fine clays from ruptured and dispersed aggregates are represented in a large peak. The selective removal of clays, and corresponding relative enrichment by less transportable grain sizes protects the remaining aggregates from detachment. Over time sheet erosion from weakly aggregated soils may therefore become detachment limited (Loch and Donnollan, 1982a and b). The particle size selectivity of sheet erosion processes has been noted in South African research. Le Roux and Roos (1982a, 1983) suggested that the higher percentage of sand, and the lower percentage of silt and clay in the soils of the Wuras Dam catchment in comparison to the accumulated sediment in the reservoir, was evidence of surface armouring. Garland (1987a) found path/burn, winter and spring burn treatments of natural runoff plots in the Natal Drakensberg all resulted in a coarsening of the soil surface.

4.3 RILL EROSION

Rills are initiated in a number of different ways:- (i) at a critical distance downslope the depth of runoff may be great enough to develop an erosive force sufficient to initiate channelling (Kirkby, 1980b), (ii) water may suddenly burst through the soil surface near the base of a slope. The cavity so formed rapidly extends headwards upslope as a channel (Morgan, 1979; 1986), (iii) the convergence of sheet flows diverted around surface obstacles at loci of variable soil resistance may initiate channelling (Dunne, 1983) and (iv) sheet flow may be concentrated into linear depressions on the soil surface created by the distribution of stones, plant bases, litter, collapsed animal and root subsurface passages, animal, human and vehicle tracks, tillage marks etc. (Alberts, Moldenhauser and Forster, 1980). The determination of the rill initiation mechanisms operant in the study area was beyond the scope of this study. The prevalence of the rill heads on mid slope positions on grazing land, and their association with cultivated fields indicates that (i) and (iv) above predominate in their formation. Once initiated rills may be (i) obliterated almost immediately, (ii) function for the duration of the rain event, and (iii) persist over several rain events and ultimately facilitate gully initiation. This category will be discussed in section 4.5. Rills in the first category drain away the runoff, become laterally isolated and filled in. Those in the second category change their course repeatedly throughout the rain event as they become obstructed by bank collapse and localized sediment deposition. On slopes with poor vegetation cover these rills become filled in with sediment derived from weathering processes, wind erosion, trampling etc. On well vegetated slopes they are obliterated by litter and bioturbation. An entirely new network of rills is therefore generally associated with each rain event (Morgan, 1979; 1986).

Runoff and sediment may be delivered into rills from interrill areas. These are portions of the slope area between rills that slope laterally into them. Rowntree (1982) found that variations in the sediment yield from a laboratory catchment during storms were related to variations in the relative importance of rill and interrill processes, while variations between storms were related to changes in the location of rills. Sediment detachment by interrill flow is by rainsplash and raindrop impact on shallow surface flow (Alberts *et al.* 1980), as described in sections 4.2.1 and 4.2.2, respectively. Sediment removed from the interrill areas is mostly carried as suspended load by the rills. This load is therefore relatively constant (Loch and Donnollan, 1982a and b), and comprized of selected particle sizes (Alberts *et al.* 1980).

Confined surface flow is substantially deeper than unconfined surface flow. Most of the raindrop impact energy is therefore absorbed by rill flow and does not contribute significantly to particle detachment (Loch and Donnollan, 1982a and b). Sediment detachment within rills is primarily associated with the shearing force of flowing water, collapse of undercut side walls, and headcutting activities (Wischmeier, 1977). Bedload comprises the greater portion of the sediment transported by rills. Rill erosion is therefore controlled more by the transport capacity than the detachment capacity of its flow (Loch and Donnollan, 1982a and b). The transport capacity is related to the effect of slope angle and length on flow velocity (Lattanzi, Meyer and Baumgardner, 1974). Increases in the volume of flow do not increase the transport capacity significantly, as they cause rills to widen rather than deepen (Loch and Donnollan, 1982a and b). As most of the sediment detached by bank slumping is transported as bedload, the bedload yield from rills is intermittent (Loch and Donnollan, 1982a and b). Confined surface flow is capable of transporting much larger sediment particles than unconfined surface flow. The particle size distribution of the sediment yield from rills indicates that neither their detachment nor transport processes are particle size selective. Most clay particles are however, transported within or absorbed to the surface of soil aggregates (Alberts *et al.* 1980). Three to fivefold increases in soil loss have been reported following rill initiation (Loch and Donnollan, 1982a and b).

4.4 GULLY EROSION

Gullies form in response to a wide range of surface and subsurface processes. The following discussion will therefore be restricted to the surface processes that appear to have predominated in the origin and development of gullies in the study area. Most of the gullies in the study area appear to have originated as rills. Rills may be transformed from ephemeral to permanent features by the interaction of micropirary and cross-grading. Within a series of parallel rills on a slope a particular rill may erode faster than the others due to localized variations in soil erodibility or slope roughness. As the local slopes towards the dominant rill develop, flow is diverted laterally into it. In the process the neighbouring rills are overtopped and destroyed. Sub-parallel rilling may begin anew on these local slopes. A progressive increase in runoff associated with a wet spell or poor landuse practices may deepen and widen the dominant rill to the extent that it is classed as a gully (Schumm *et al.* 1984). The balance of the gullies in the study area either occur within existing water courses or are continuous with them. They appear to owe their origin to the channelling of surface runoff by animal and human footpaths, and roads. Faber and Imeson (1982) found that the origin of many of the gullies occurring on lower valley slope and pediment positions in Lesotho was facilitated by the channelling of surface runoff along cattle tracks and roads. Beckedahl and Dardis (1988) also found that many of the gullies in the Transkei owed their origin to both surface and subsurface channelling facilitated by poorly sited roads. No evidence of (i) cyclic reworking of colluvial material, in the form of stone-lines or buried horizons, and (ii) subsurface processes in the form of surface cracks, seepage voids or pipes in gully walls, was found in the gullies in the study area.

Sediment particles from distinct catchment areas are detached and transported to gullies by the rainsplash, and unconfined and confined surface flow processes described in sections 4.2 and 4.3. Much of this sediment is retained in storage in deposits within the gully for variable periods of time. When water flows through the gully, most of it is carried in suspension. Most of the sediment transported by gullies is detached by head retreat and channel wall failure processes. Two processes are involved in head retreat. Firstly, throughflow from the scarp face detaches particles. Secondly, surface flow concentrated over the head scarp scours a plunge pool at its base. As it deepens it undercuts the scarp, leading to its collapse. The failure of gully banks also involves two processes. Firstly, saturation during flow may lead to slumping. Secondly, the scouring action of flowing water undercuts the base of the banks leading to their collapse. A relatively small quantity of sediment detached by weathering and bioturbation is shed into the gully channel between flows. As most of the sediment transported by gullies is carried as bedload, their total sediment yield is controlled more by the transport capacity of channel flow than by the combined capacity of the above detachment processes (Schumm *et al.* 1984). Gullies are capable of transporting very large loads that seldom reflect particle size selectivity. Their very erratic flow behaviour makes it extremely difficult to define the nature of the relationship between the transport capacity of flow and various flow parameters. An assessment of their relative contribution to the total long term soil loss scenario is consequently also extremely difficult (Morgan, 1979; 1986).

CHAPTER FIVE

FACTORS INFLUENCING SOIL EROSION

5.1 INTRODUCTION

Soil erosion occurs when the forces promoting the detachment and transport of sediment particles by rainsplash and runoff exceed the forces resisting these processes (Wischmeier, 1977). The balance between these forces is controlled by a wide range of interrelated factors. The relative importance of these factors varies according to the spatial and temporal scale over which they are being considered. At a macroscale corresponding to a large drainage basin, climate exerts a dominant influence over these processes. At a mesoscale corresponding to the subcatchment or valley system of a drainage basin, geology and topography as reflected in drainage density exert the dominant influence. Vegetation type may also exert a strong influence. At a microscale ranging from an individual hillslope to an area of a few square metres, these processes are predominantly influenced by the frequency and intensity of individual climatic events, the soil type, seasonal variations in vegetation cover and surface roughness. Landuse generally exerts a very strong influence at the microscale. Dependent on the type, its history and intensity, and the degree to which it is masked by the response of other variables, landuse may also exert a strong influence at the mesoscale (Morgan, 1979, 1986; Bryan and Campbell, 1982). Short and medium term studies may over or under estimate the influence of the factors controlling these processes during infrequent events that contribute to the greater proportion of soil loss. This is dependent on whether these events are included in or excluded from the study period. Over a 26 year period in New South Wales, Australia, Perrens and Trustum (1984) found 72% of the soil erosion occurred in 4 storms. Roose (1976) noted that most soil erosion in the Mediterranian and coastal regions of North Africa is caused by exceptional 50 to 100 year frequency rainfall events.

Most research on the factors influencing soil erosion has employed an empirical approach whereby statistical techniques particularly correlation and regression analysis, are used to find the most significant relationship between soil loss data and a wide range of presumed controlling variables. Morgan (1986) noted that the multiplicity of significant variables identified, and discrepancies regarding their comparative significance could be attributed to the approach being employed in a wide range of environments worldwide. Such a multiplicity of variables posed "the problem of determining which variables merely express the same relationship, and which identify truly separate relationships with soil loss". Given the spatial and temporal scale of this study, the factors most likely to be of influence are:- rainfall, soil, topography, vegetation and landuse. Although these factors are interrelated, this chapter examines each in turn for the sake of convenience.

5.2 RAINFALL EROSIVITY

Rainfall erosivity refers to the potential of rainfall and its associated runoff as a soil erosion promoting force (Wischmeier, 1977; Osuji, Babalola and Aboaba, 1980). It is directly influenced by the impact force of falling raindrops which regulates the detachment and transport capacity of rainsplash, and the detachment capacity of sheet flow (section 4.2). It is indirectly influenced by the affect of rainfall on the following interrelated processes:- surface sealing, infiltration capacity and rate, and runoff generation; and hence on the transport capacity of both unconfined and confined surface flow. As the detachment and transport capacity of both rainsplash and runoff is influenced by slope angle and length, surface roughness (sections 4.2 to 4.4), and antecedent soil moisture, these factors also exert an indirect influence on rainfall erosivity (Wischmeier, 1959). The degree of saturation of the soil is regulated by how much rain has fallen in the previous few days. If a first storm leaves the soil close to saturation, a second storm of comparable amount and other rainfall characteristics shortly thereafter, will generally contribute to a greater soil loss (Morgan, 1986).

The question of whether the impact force of falling raindrops is a function of their kinetic energy or momentum (that is ; $^1/2\ mv^2$ or mv, where m = mass, and v = velocity), is still a matter of debate (Lal, 1977a). Neither property is routinely recorded at meteorological stations. The mass and impact velocity of raindrops is related to the drop size distribution. This in turn varies with the intensity of the event such that: the median drop size increases with increasing intensity up to about 100mm h^{-1}. As the intensity continues to increase the median drop size decreases because the associated greater turbulence makes larger drops unstable (Morgan, 1986). The maximum drop sizes appear to be in the order of 5 to 6mm in diameter (Cooke and Doornkamp, 1974). Rainfall intensity is routinely recorded at meteorological stations. It can also be calculated from the traces obtained from automatically recording rain gauges showing the amount of rain that fell and the duration over which it fell. The network of these gauges is progressively increasing in density and geographic range (Hudson, 1980). Most drops impact the surface at their terminal velocity. This velocity may however, be increased or decreased by wind dependent on its velocity, and whether it is directed towards or away from the surface. The slope gradient may also affect this velocity because of its influence on the angle at which the drop strikes the surface (Lal, 1977a). The influence of surface roughness and antecedent soil moisture is primarily related to the amount of rain and the duration over which it falls. Two categories of rain event are of particular relevance to soil erosion, viz:- the high intensity storm of short duration where the infiltration capacity of the soil is exceeded, and the prolonged storm of low intensity which saturates the soil (Morgan, 1986).

5.2.1 **Rainfall erosivity indices**

In order to be valid as an index of potential erosion, an erosivity index must be significantly correlated with soil loss (Morgan, 1986). Rainfall amount is also recorded by standard rain gauges. The density and geographic range of their network is greater than that of the automatically recording rain gauges. Of all the rainfall variables data on rainfall amount are therefore the most readily available (Roose, 1976, 1977). At a macroscale rainfall amount may be reasonably correlated with sediment yield. Langbein and Schumm's (1958) world scale examination of this relationship showed that maximum soil erosion occurs at a M.A.P. of 300mm. As M.A.P. decreases below this threshold, erosion decreases because of the deficiency in runoff. As M.A.P. increases above this threshold, erosion decreases because of the increased rainfall interception and runoff impediment efficiency of the correspondingly denser vegetation cover. A similar study by Douglas (1967) however, indicated that soil erosion progressively increased as M.A.P increased from 600mm, due to the associated increased runoff. Since these studies, the availability of sediment yield data and particularly suspended load data has increased enormously (Morgan, 1986). Walling and Webb (1983) were therefore able to use a much larger data base in a comparable study. They found that sediment yield increased monotonically with rainfall, suggesting that the increased rainfall erosivity associated with increased M.A.P. and runoff levels, is not offset by the increased vegetation cover. Fournier's index (1960, cited by Morgan, 1986) which is the ratio p^2/P, where p is the highest mean monthly precipitation, and P is the mean annual precipitation, appears to be more significantly correlated with sediment yield data in macro+ and mesoscale studies. It was satisfactorily employed by Doornkamp and Tyson (1973) to delineate areas of similar sediment production within South Africa, and has been adopted for use in the FAO/UNEP/UNESCO assessment of world wide soil degradation (Arnoldus, 1980). Morgan (1986) suggested that Fournier's index is a better indicator of the risk of gully erosion than of the risk of erosion by rainsplash, and unconfined and confined surface flow.

Soil loss at the microscale by rainsplash, and sheet/rill processes, is generally poorly correlated with both rainfall amount and intensity (Hudson, 1980). Wischmeier and Smith (1958) found that over 80% of the variability of individual storm, seasonal and ten year period soil loss from an unprotected field was explained by their "rainfall-erosion" or EI_{30} index. It is a compound index of a storm's total kinetic energy and its maximum 30 minute intensity. Smith and Wischmeier (1962) claimed that as rainfall energy is a function of the specific combination of drop velocities and rain amount, and as the maximum 30 minute intensity is an indication of the excessive rainfall available for runoff, the index is an approximation of the erosivity of rainsplash and runoff combined. Although the EI_{30} index has been widely and satisfactorily employed in temperate regions, it has been criticized on two accounts. Firstly, kinetic energy is derived from the equation $KE = 11.87 + 8.73 \log_{10} I$ where I is the rainfall intensity (mm h^{-1}) and KE is the kinetic energy (Jm^{-2} mm^{-1}), which is not valid universally (Morgan, 1986). Secondly, it does not satisfactorily account for soil loss in tropical regions (Aina *et al.* 1976). Given the major differences in the rainfall-erosion relationship between temperate and tropical regions, its limited applicability may be anticipated. The mean intensity and overall erosivity of tropical rain events is 2 and 16 times greater than temperate rain events, respectively. Whereas most of the annual total soil eroded in the tropics is removed during a few very intense storms, most soil erosion in temperate regions occurs during frequent low intensity events (Hudson, 1981).

Hudson (1961, 1963, 1965 cited by Hudson, 1981) found that the threshold intensity for soil removal in Zimbabwe is 25mm hr^{-1}. At intensities less than this threshold, removal is restricted by insufficient runoff. The cumulative energy of rainfall at intensities greater than 25mm h^{-1}, the KE > 25 index, gave the best correlations with soil loss from bare field plots on both an individual storm and annual basis. Elwell and Stocking (1973a) rexamined this data and found KE above an intensity threshold of 4.3mm h^{-1} to be exponentially related to annual soil loss. Using data derived from field plots under a range of crop covers Elwell and Stocking (1973a and b) found that total cumulative momentum, followed by total cumulative energy of all rain falling within the measurement period, gave better correlations with soil loss than the KE index. A subsequent analysis of all these data on a daily basis led Stocking and Elwell (1973b) to recommend that the use of the EI_{30} index in the subtropics be restricted to bare soil surfaces. With sparse and dense covers they obtained better correlations with soil loss using the maximum 15 and 5 minute intensities, respectively. They also combined soil loss data from grazing trails on a sandveld (Elwell and Stocking, 1974) with the earlier data, and determined that rainfall amount is as good as energy or momentum as a predictor of soil loss from bare and vegetated surfaces.

Work in the humid tropics has also indicated that the EI_{30} index may be reliably used for bare soil conditions, and that rainfall amount gives a reliable estimate of rainfall erosivity. Lal (1976, 1977a) correlated several rainfall parameters with single storm soil loss from bare plots in Nigeria. While AI_m, where A = rainfall amount, and I_m = maximum rainfall intensity for a minimum duration of 7,5 minutes, gave the best correlation, it could be linearly approximated by A alone. He also found high correlations and insignificant differences between EI_{30}, KE > 25, total KE, A, I_m and AI_m.

Comparable studies by Osuji *et al.* (1980) also in Nigeria, showed that while soil loss was better correlated with I_{45}, KE > 25, and total KE, a correlation of 0,80 with EI_{30} indicates it as an adequate erosivity index. They proposed that rainfall amount being highly correlated with KE > 25, total KE, EI_{30} and AI_m was just as adequate, and should rather be used as it was not reliant on any inputs calculated from non-calibrated equations.

The geographic range of the reliability of the EI_{30} index has been increased by Wischmeier and Smith's (1978) subsequent modifications to it viz:- (i) excluding rain events below a threshold amount, and (ii) setting the maximum value for rainfall intensity at 76 mmh^{-1} for the calculation of kinetic energy per unit rain. This limit was imposed because Carter, Greer, Braud and Floyd (1974) had shown that median drop size does not increase with intensity for intensities greater than about 76 mm h^{-1}.

The Department of Agriculture has accepted the EI_{30} as the best index of erosivity for use in the Republic. Over most of the country long term intensity records are however, not available for the production of EI_{30} values (Crosby, McPhee and Smithen, 1983). The iso-erodent lines on Platford's (1979) rainfall erosivity map of Natal's sugar cane producing areas (section 2.5.1) were extrapolated from total annual rainfall energy values, based on the highly significant correlation between total storm energy and EI_{30} found by Stocking and Elwell (1976). Schulze's (1980) maps of the mean annual, summer and winter distribution of rainfall kinetic energy in the Republic were extrapolated from values calculated with SLEMSA's equation $E = 29{,}82 - 127{,}51/I$ (Jm^{-2} mm^{-1} rainfall) (Anon, 1976). Smithen and Schulze's (1982) motivation for the derivation of EI_{30} values for an iso-erodent map of southern Africa, noted that the use of rainfall kinetic energy alone is not always sufficient to describe the relative rainfall erosivity in any two locations in which the intensity of rainfall may vary considerably.

Smithen (1980) examined the relationship between EI_{30} and the following rainfall parameters: (i) total rainfall, (ii) effective rainfall or rainfall greater than 12,5mm, (iii) modified Fournier's index and (iv) burst factor. All four parameters are readily available from daily rainfall data, and can therefore be used to extrapolate EI_{30} where autographic data are not available. He found the suitability of these parameters as predictors of EI_{30} varied regionally. In the area of interest in this study where the convectional rainfall is characterized by short bursts of very intense erosive rain, the burst factor gives the best correlation with EI_{30}.

The burst factor = 12_{mipi}

p

i = 1

where mi = maximum 24 hour rainfall for month i,

pi = effective rainfall,

and p = annual rainfall.

Smithen and Schulze's (1982) iso-erodent map of southern Africa was based on Smithen's (1980) findings. In calculating EI_{30} they used the upper rainfall intensity limit of 76 mmh^{-1}, and included only rain events exceeding 12,5mm. This latter threshold resulted in their annual EI_{30} values seldom representing more than twenty storms. Weaver and Hughes (1985) found a significant relationship between EI_{30} and daily rainfall in the Ciskei. Le Roux (1990) noted that the general west to east increase in the rate of surface lowering over the central part of the subcontinent coincided with an increase in annual rainfall, rainfall intensity and the "Fournier index".

5.3 SOIL ERODIBILITY

Erodibility defines the resistance of soil to both detachment and transport (Morgan, 1986). Olson and Wischmeier (1963) found that long-term average soil losses may vary more than thirty fold due to differences in soil erodibility alone. Erodibility is not a constant property. It varies temporarily and spatially with variations in rainfall, microtopography, vegetation and landuse, and spatially from one slope facet to another (Vanelslande, Rousseau, Lal, Gabriels and Ghuman, 1984; Lal, 1985). Surface sealing and armouring may decrease erodibility during a rain event. Generally erodibility increases as more aggregates are disrupted with the progressive saturation of the soil. Variations from one rain event to another are dependent on whether the internal shear strength of aggregates is predominantly decreased by compression forces associated with the rapid onset of intense rain or by disintergration of adhesive and chemical bonds associated with gradual saturation by low intensity rain (Yee and Harr, 1977; Oades, 1984; Onstad, Kilewe and Ulsaker, 1984). Erodibility generally increases with increasing slope angle, increasing proximity to the slope base and increasingly drier aspects. It also generally increases with decreasing vegetation cover, and decreased litter production and decomposition (Bryan, 1968). Variations induced by landuse practices are dependent on whether they increase or decrease the surface roughness (Tienseemuang and Ponsana, 1977; Johnson, Mannering and Moldenhauer, 1979), and organic matter content (Greenland, 1977; Garland, 1987a).

Soil erodibility is a function of complex interactions between a substantial number of physical, chemical and biological properties including:- texture, surface armouring, aggregate stability, surface sealing, infiltration capacity, shear strength, organic and inorganic constituents, and flora and fauna. The combination of interacting properties is dependent on the type of erosion occurring (Young and Onstad, 1982). All these properties are regulated to a greater or lesser degree by the soil's structural stability. Soil structure refers to the arrangement of particles and aggregates, and the corresponding size, shape and arrangement of pore spaces between them. As the surface soil layer is subjected directly to the disruptive forces of raindrops and runoff, its structure exerts the predominate influence on erodibility. The structure of the subsoil may also exert a substantial influence, for example, when an impermeable horizon is instrumental in the generation of saturation excess surface flow (Greenland, 1977). Structural stability is dependent on the interaction of aggregate stabilizing and disruptive forces (De Meester and Jungerius, 1978).

Microaggregates consist of domains of clay particles and silt particles stabilized by (i) electrical forces, (ii) interparticle bonding, (iii) interparticle cementing, (iv) cation bridging, and (v) particle interlocking. The strength of the electrical forces depends on the number of contact points and the thickness of the water film between the clay domains. It is generally relatively weak and does not significantly enhance microaggregate stability (Greenland, 1977). Interparticle bonds are formed by polysaccharides mainly mucilages produced by bacteria, plant roots and fungal hyphae (Yee and Harr, 1977; Oades, 1984). The stability of microaggregates therefore increases with increasing organic matter content, except where particles are cemented together by precipitates of inorganic hydroxides. Although the strongest and most common cementing agents are active aluminium and iron oxides, inactive iron oxides, amorphous iron, aluminium hydroxides and allophane are also efficient cementing agents in the appropriate soil environment (Greenland, 1977). Multivalent cations act as bridges between organic colloids and clays. The most common are Ca, Mg and Al. Fe, Mn, Zn and Cu may also be present in small amounts (Oades, 1984). Macroaggregates consist of microaggregates and sand particles (Greenland, 1977). They are stabilized by enmeshed living and decomposing plant roots (Oades, 1984), and particle interlocking. Particle interlocking accounts for a substantial portion of the total shearing resistance of loose, cohesionless soils. Its influence decreases as the soil nears saturation (Yee and Harr, 1977). According to De Meester and Jungerius (1978) soil properties created by pedological processes play a secondary role to those inherited from the parent material in determining aggregate stability. According to Bryan (1968) the influence of soil properties on aggregate stability is minimal when the soil is saturated, due to the increasing influence of the water layer at the surface.

The disruption of aggregates by raindrop impact and surface flow shearing following a reduction in their internal strength by imploding compressed air ahead of the wetting front and by disintergration of their adhesive and chemical bonds on saturation was discussed in detail in section 4.2.1. In addition aggregates are weakened by the layered orientation, and disrupted by the differential swelling of clay minerals. The planes between the layers form zones of weakness that determine the rate of slaking (De Meester and Jungerius, 1978). Certain clay minerals are capable of absorbing water and therefore swell on wetting and shrink on drying (Bruce-Okine and Lal, 1975; Rhoton, Smeck and Wilding, 1979). The three most common clay minerals in this study's research area are kaolinite, illite and montmorillonite. They have no, negligible and substantial swelling properties, respectively. All three are layered minerals (MacVicar, 1973).

The influence of each of the biophysiochemical properties listed earlier, on erodibility will be examined briefly. Fine textured soils containing a high percentage of cohesive clays are most resistant to detachment. The large, irregularly shaped predominantly sand sized particles of coarse textured soils require a greater entrainment force, and are most resistant to transport. Medium textured soils containing a high silt percentage are therefore the most erodible (Olson and Wischmeier, 1963). Variations in erodibility with soil depth are most commonly caused by textural variations (Moresco and Gray, 1976). Surface armouring or the accumulation of the least transportable sediment fraction may decrease erodibility. The effect is generally transient as weathering and bioturbation maintain a relatively constant supply of erodible sediments (Thornes, 1980; Vanelslande, *et al.* 1984). Elwell and Stocking (1974) observed that the protective surface layer of coarse sand that accumulated during more frequent minor storms in Zimbabwe, was totally removed during less frequent major storms. Soils with weak aggregate stability are not necessarily more erodible than soils with more stable aggregates. Surface sealing occurs more readily and rapidly on weakly aggregated soils. The surface seal protects fine particles immediately below it from detachment. Although it serves to generate more runoff, a consequent increase in surface sediment removal is dependent on the availability of the transportable size fraction (Stocking and Elwell, 1976; Thornes, 1980; Vanelslande, *et al.* 1984). A soil's infiltration capacity is primarily determined by its pore size distribution, pore stability and profile form. Where soil properties vary with depth, it is the horizon with the lowest infiltration capacity which is critical. Coarse textured soils do not necessarily have a lower erodibility on account of their higher porosity and permeability. Where soluble bases drawn to the surface by evaporation develop into crusts (Statham, 1977), runoff is generated even though the underlying soil may be dry, and surface soil removal is restricted by the availability of the transportable sediment size fraction. Weakly aggregated soils with swelling clays or minerals that are unstable in water tend to have low infiltration capacities. However due to the interacting affect of surface sealing as noted above, they are not necessarily more erodible (Stocking and Elwell, 1976; Morgan, 1986).

A soil's shear strength is determined by its cohesiveness and resistance to shearing. The cohesiveness is a function of chemical bonding of clay minerals, and surface tension forces within the moisture films in unsaturated soils. The resistance to shearing is dependent on the extent to which stresses created when component particles are forced to slide over one another, or to move out of interlocked positions, are absorbed by solid-to-solid contact among the particles (Morgan, 1986). The most erodible medium textured soils have the lowest shear strength. Fine and coarse textured soils derive most of their considerable strength from cohesiveness and particle interlocking, respectively. Shear strength exerts a negligible influence on the erodibility of saturated soils (Yee and Harr, 1977). Pall, Dickinson, Green and McGirr (1982) noted that the influence of shear strength on erodibility varies temporally. They found significant changes in the shear strength of Canadian soils in response to seasonal changes in bulk density and hence soil water content.

With the exception of soils where inorganic hydroxides exert the major influence on aggregate stability, erodibility decreases as the organic content increases. There is some consensus that erodibility decreases linearly with increasing organic content over the range of 3,5 to 10%. Below 3,5% soils are considered erodible irrespective of the influence of organic matter. Above 10% the influence of organic matter on erodibility is considered to decline to negligible at the 15% maximum of most soils (Wischmeier and Mannering, 1969; Wischmeier, Johnson and Cross, 1971; Morgan 1979, 1986). The relationship between erodibility and organic content may be influenced by the type and stage of decomposition of the organic matter, and the soil texture. Yee and Harr (1977) found fresh organic matter decreased erodibility, while Chandra and De (1982) found cattle manure only decreased erodibility after sufficient time had elapsed for its decomposition. The stabilizing affect of organic constituents is more pronounced in soils with a low clay content (Wischmeier and Mannering, 1969; Yee and Harr, 1977; Chandra and De, 1982).

Hydrous oxides, clay minerals and exchangeable bases; are the categories of inorganic constituents that exert a significant influence on erodibility. Erodibility decreases as the content of oxidic and amorphous interparticle cementing constituents increases (Greenland, 1977). El-Swaify and Dangler (1976) and El-Swaify (1977) suggested that the role of these constituents in aggregation is greatest in tropical soils. Aluminium serves to additionally encourage the flocculation of the clay in acid soils (Greenland, 1977). Erodibility therefore decreases in association with decreasing pH in fine textured soils (Wischmeier and Mannering, 1968). The relationship between erodibility and clay content is dependent on the type of clay mineral predominating. Erodibility increases as the content of layered and/or expandable minerals increases. Erodibility decreases as the content of stable cohesive minerals increases (Bruce-Okine and Lal, 1975; Rhoton *et al.* 1979). Erodibility increases as the exchangeable sodium percentage (E.S.P.) increases (Lal, 1985). Singer *et al.* (1978) found that E.S.P.

exerts a greater influence on the erodibility of cohesive soils. Singer, Janitzky and Blackard (1982b) found an increase in E.S.P. from 0 to 2 percent doubled erodibility. Above 2% the rate of increased erodibility was dependent on clay content and exchange capacity.

Most organic matter present in soil is derived from macroflora. It is converted into microaggregate bonding agents by microflora. Filamentous microflora also contribute to microaggregate stability, while the roots of macroflora enmeshed in macroaggregates contribute to their stability. Erodibility therefore decreases as microfloral populations within and macrofloral populations covering the soil increase (Yee and Harr, 1977; Gasperi-mago and Troeh, 1979; Oades, 1984). The activities of soil microfauna generally (i) increase soil porosity and permeability, eg, worm and ant burrows, (ii) increase the surface roughness of the microtopographic slope profile, eg, worm and ant burrow openings and casts, (iii) increase the proportion of less erodible sediments on the surface, that is: surface armouring, eg, rock fragments brought up from the weathering front by termites. Erodibility therefore generally decreases as soil microfaunal populations increase (Greenland, 1977). The activities of macrofauna generally increase erodibility by (i) increasing the availability of erodible sediments on the surface, eg, rodent and mole heaps, and scuffing by ungulates, (ii) increasing the transport capacity of runoff, eg, compaction by trampling, and (iii) decreasing the rate of organic matter replenishment, eg, grazing (Scott, 1952; Garland, 1987a).

5.3.1 Soil erodibility indices

There are two basic approaches to the estimation of a soil's erodibility. The first approach involves obtaining soil loss measurements and using them to calculate erodibility from soil loss equations. Soil loss measurements are generally obtained from runoff plots using natural or simulated rainfall. In order to obtain soil loss data adequately representing the large variety of natural rainstorm, antecedent soil moisture and surface conditions, natural rainfall runoff plots need to be operated over substantial periods of time. They are therefore the most time consuming and costly method of obtaining soil loss measurements (Olson and Wischmeier, 1963). Although obtaining measurements from simulated rainfall runoff plots is less time consuming, it is still costly, particularly when erodibilities of many soils need to be determined (El-Swaify and Dangler, 1976). Bruce-Okine and Lal (1975) and Lal (1985) caution that soil loss measurements obtained using simulated rainfall on standard plots are more an indication of the soil's detachability than its erodibility as these conditions may not permit the build-up of runoff over sufficient length to include its effect on sediment detachment and transport. The most commonly used equation is the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1962) viz:-

$E = R.K.L.S.C.P.$,

where E is the mean annual soil loss (t ha^{-1} yr^{-1}) by interrill and rill erosion processes.

R is the rainfall erosivity index (section 5.2.1),

K is the soil erodibility index.

L and S, the slope length and steepness respectively, are combined into a single index,

C is the vegetation/crop cover factor,

and P is the cover and conservation practice factor.

$K = E/R.S.L.C.P.$

As noted by Olson and Wischmeier (1963), provided S, L, C and P conform to standard specifications of 5^{0}, 22m, bare soil and no conservation practice, respectively,

$K = E/R$

The second approach involves the isolation of certain soil properties as indices of erodibility. They can usually be derived from normal analytical data permitting rapid assessment of a large number of soils. Their efficiency is rated according to how well they correlate with estimates derived using the approach outlined above, where soil loss measurements are obtained from standard runoff plots using simulated rainfall (Bryan, 1968; El-Swaify and Dangler, 1976; Lindsay and Gumbs, 1982). Bryan (1968) tested the efficiency of indices developed since Middleton's pioneer work in 1930 and presented a theoretical assessment of their validity and limitations. He found that none of the indices were efficient for all groups of soils. Indices based on dispersion and slaking characteristics are not applicable to soils with stable aggregation characteristics. Indices based on infiltration characteristics are not applicable to soils where rainsplash processes predominate. Indices based on shear strength characteristics are not applicable to saturated or dispersive soils. Bryan (1968) concluded that indices based on aggregation characteristics are most efficient. Their subsequent widespread application has however been restricted by methodological considerations. The most commonly used wet sieving technique fails to adequately simulate the affect of raindrop impact (Singer *et al.* 1978). Bruce-Okine and Lal's (1975) raindrop technique does not adequately simulate disaggregation under saturated conditions or lateral shear (De Meester and Jungerius, 1978), and its efficiency is dependent on the wetting and drying history of the aggregates (Lindsay and Gumbs, 1982).

Wischmeier and Mannering (1969) used multiple regression techniques to examine the influence on erodibility of 15 soil properties and their interactions. They concluded that an efficient erodibility indicator would have to incorporate the complex interaction of a substantial number of soil properties as no single property or interaction term proved suitable. Wischmeier *et al.* (1971) developed a nomograph for predicting erodibility based on the interaction of five soil properties viz:- percent silt and very fine sand, percent sand greater than 0,1mm, organic matter content up to four percent, structure and permeability. The first four properties are for the uppermost 18 cms of soil, while the permeability is for the whole profile. Wischmeier *et al.'s* (1971) erodibility nomograph has been widely utilized and its predicted values have generally correlated well with measured values. Where it has not performed well soil properties in excess of the nomograph range, or not included as nomograph inputs, have been found to exert a dominant influence on erodibility. In temperate regions these include:- surface sealing (Holzhey and Mansbach, 1976) and high calcium carbonate content (Becher, Schafer, Schwertmann, Wittmann and Schmidt, 1980). In subtropical regions these include:- high sodium and/or dithionite extractable iron content (Barnett, 1976; Singer, Blackard and Janitzky, 1980). In tropical regions these include:- surface armouring by gravel and rock fragments, high organic matter content, high expandable clay mineral content (Roose, 1976, 1977), high content of aluminium and iron amorphous and oxidic constituents (El-Swaify and Dangler, 1976; El-Swaify, 1977) and surface crusting (Barber *et al.* 1979; Vanelslande *et al.* 1984).

The erodibility of Natal's most significant soil formations in the Tugela basin, Howick extension area, and sugar cane producing area was rated by Van der Eyk *et al.* (1968), Scotney (1970), and MacVicar (1973), respectively. Their ratings were based on the textural and infiltration characteristics of the entire profile. Although no erodibility class threshold values for these characteristics were set, there is generally close agreement between these studies. The erodibility of most of South Africa's soil series was rated by Anon (1976) using the erodibility index of the Soil Loss Estimator Model for Southern Africa (SLEMSA). The F index is obtained from an equation depicting the relationship between E, the seasonal rainfall energy, and K a component of the equation

$$Z = KCX$$

where Z is the rate of soil loss (t ha^{-1} yr^{-1}),
K is the basic rate of loss from a standard plot (t ha^{-1} yr^{-1}),
and C and X are modifiers dependent on vegetation/crop cover and slope factors (Elwell and Stocking, 1975; Elwell, 1979, 1980).

Working with important soils in Natal's sugar cane producing area, Platford (1982) correlated the USLE's K values calculated from measured soil losses from standard simulated rainfall runoff plots, with K values derived from Wischmeier *et al.'s* (1971) erodibility nomograph. He found the values for less structured soils were highly significantly correlated, while those for well structured soils were less well correlated. Schieber (1983) correlated the degree of erosion in the landscape of the Natal midlands and north eastern Cape with K values derived from Wischmeier *et al.'s* (1971) erodibility nomograph. He found good correlations in sandy soils and suggested that the poor correlations in clay soils could be improved by incorporating an aggregate stability factor into the nomograph. This inclusion was however not found necessary in an intensive Republic wide programme carried out by the Department of Agriculture. The programme involved correlating the USLE's K value calculated from measured soil losses from standard simulated rainfall runoff plots, with Wischmeier *et al.'s* (1971) erodibility nomograph's K values. With the exception of three forms, all forms were highly significantly correlated. The poor correlations in the Mayo, Oakleaf and Kroonstad forms were attributed to their organic matter contents exceeding the 4% maximum permitted by the nomograph (McPhee, Hartmann and Kieck, 1983; McPhee, Smithen, Venter, Hartmann and Crosby, 1984; Smithen, McPhee and Schmidt, 1985). Watson and Poulter (1987) rated Wischmeier *et al.'s* (1971) nomograph as a more efficient method of estimating the erodibility of Hutton soils in the Natal Drakensberg than Bruce-Okine and Lal's (1975) raindrop method. Both these methods were rated more efficient than the method based on water stable aggregates larger than 3,5mm recommended by Bryan (1968). Efficiency was rated by comparing estimates of K obtained from these methods, with USLE's K values calculated from measured soil losses from standard natural rainfall runoff plots. Hartman, McPhee and Bode, (1987) used standard simulated rainfall runoff plots to obtain soil loss measurements from five soil forms in the vicinity of East London. The measurements were used to calculate SLEMSA's F value and USLE's K value. The soil loss equations yielded similar estimates of erodibility.

Although reasonable estimates of the average erodibility of most soil formations are now available, the assessment of the influence of erodibility on soil erosion in Natal is restricted by the absence of information on the soil formations present. Good large scale maps are available for (i) sugar cane producing areas (eg, Beater, 1970; MacVicar, 1973), (ii) most Natal Parks Board/Department of Environment Affairs conservation/research areas (eg, Watson, 1981; Garland, 1987a; Venter, 1988), and (iii) some areas of high development potential or agricultural extension interest (eg, Van der Eyk *et al.* 1968; Scotney, 1970). The Department of Agriculture has mapped land type units at a scale of 1:250 000 in the 2 x 1 degree areas centred around Mkuze, Vryheid, Richards Bay and Durban. The soil formations associated with these units are detailed in the map memoirs (eg, MacVicar, 1986).

Information on soil formations present in the central inland and southern portions of the Province and most of the KwaZulu areas is largely unavailable. In contrast to the situation regarding soil formation maps, geological formations throughout the Province have been delineated at a scale of 1:50 000 and are published as 1:250 000 maps. As soils throughout the Province are very young, (section 3.4.2) parent material exerts a substantial influence on soil erodibility (MacVicar, 1973). The susceptibility to weathering of rock minerals is well established (eg, Carol, 1970). Geological formation maps can therefore substitute for soil formation maps in erodibility assessments as shown in the Umfolozi catchment where gullying was found to be least severe on dolerite and most severe on Dwyka tillite (Berjak *et al.* 1986; Liggitt, 1988; Liggitt and Fincham, 1989). Weaver (1988b and c) also found that erosion in the Ciskei is less severe in soils underlain by dolerite than in those underlain by sedimentary rocks.

5.4 TOPOGRAPHIC INFLUENCE

Various slope parameters including angle, length, shape, aspect and location within the catchment may interact to increase or decrease the efficiency of soil removal processes. The efficiency of sediment detachment by rainsplash increases with increasing slope angle over the range between very low and very high angles. Over this range the sloping surface imparts a horizontal force to the drop that increases the velocity of water dispersing from and returning to the point of impact (section 4.2). On very gentle slopes generally less than 3^{o}, both unconfined and confined surface flow attains sufficient depth to protect the surface soil from the direct impact of raindrops (Murphree and Mutchler, 1981). Rainsplash detachment decreases on very steep slopes as drops do not impact the surface directly. The critical angle above which drop impact diminishes varies from 35^{o} (Singer and Blackard, 1982a) to 52^{o}, dependent on the cohesiveness and surface roughness of the soil, and may be as low as 22^{o} on vegetated slopes (Gumbs and Lindsay, 1982). Rainsplash throws a greater portion of particles greater distances downslope as slopes become steeper (Section 4.2). Splash transport is more sensitive to increments in slope steepness than splash detachment (Quansah, 1981). Sediment detachment and transport by unconfined and confined surface flow is more efficient on steep slopes as both the velocity and turbulence of flow increases with increasing slope angle. Lattanzi *et al.* (1974) found that for a given increase in slope steepness the increase in the efficiency of rill erosion was greater than interrill erosion. Singer and Blackard (1982a) however found that slope angle had a greater influence on interrill erosion.

The influence of slope length on soil loss is largely dependent on the predominate erosional processes operant. Sediment particles thrown downslope by rain drop impact only travel a limited distance. Subsequent drops may throw them back upslope. In order for particles to be entirely removed from a slope by rainsplash they need to be repeatedly detached and transported (section 4.2). Where rainsplash is the major agent of soil removal, soil loss decreases with increasing slope length. Where sheet flow and rill erosion processes predominate, soil loss generally increases with increasing slope length. This is generally attributed to the increased volume of surface flow (Morgan, 1979, 1986). Irrespective of the mechanism of generation, runoff is initiated at a critical downslope distance, and generally accumulates progressively downslope (section 4.2.2). Wischmeier (1960) found slope length had a negligible influence on runoff, while Wischmeier and Smith (1978) and Lal (1983) found runoff decreased with increasing slope length. Rough surfaces and/or concave sections of the profile concentrate and reduce the velocity of surface flow, encouraging its infiltration into the soil. Under these conditions increasing the slope length increases the opportunity for infiltration, and while the total soil loss may increase with increasing length, the loss per unit area generally decreases (Roy, Jarvis and Arnett, 1980, Rooseboom and Mulke, 1982; Lal, 1983).

Slopes seldom have a uniform straight shape. In cross section their profile usually comprises a variety of convex, straight and concave sections. The convex sections tend to occur towards the crest of the slope and experience the highest soil loss rates. The mid slope sections of the profile tend to be straight. The concave sections are more common towards the base of the slope and have the lowest soil loss rates. The steepness of the downslope face of the convex sections enhances the detachment and transport capability of rainsplash, and the velocity of surface flow. The convex sections' generally shallower and drier soils enhance the volume of surface flow generated and the availability of detachable sediments respectively. Sediment particles have to be transported against the force of gravity in order to be removed downslope of concave sections of the slope profile. Rainsplash therefore tends to be more efficient at rearranging the distribution of detached particles and compacting the surface. These concave sections concentrate and decrease the velocity of surface flow, thereby encouraging its infiltration and reducing its sediment detachment and transport capability. Their generally deeper and moister soils favour dense vegetation cover which further enhances infiltration of surface flow and reduces the availability of detachable sediments (Kirkby, 1978; Tregubov, 1982; Zachar, 1982).

Slope aspect has an indirect influence on soil erosion. In the southern hemisphere winter and annual radiation receipt values are highest on north facing slopes and lowest on south facing slopes. In comparison to south facing slopes, north facing slopes therefore have higher soil temperatures, higher rates of organic matter decomposition, higher evapotranspiration losses, a greater degree of salt accumulation and a lower soil moisture content. The vegetation on north facing slopes tends to be comprised of more xerophytic and unpalatable species that sparsely cover the soil and have limited litter production capabilities. The proportion of raindrops intercepted by a vegetation canopy, the proportion of runoff impeded by vegetal basal components, and the rate of organic matter replenishment are all therefore lower on north facing slopes. Seral development also tends to be slower on north facing slopes. The interaction of all these factors results in the coincidence of greater availability of detachable sediments, and greater detachment and transport capability of both rainsplash and runoff. Although north facing slopes are more susceptible to erosion, south facing slopes in Natal's moist savanna region commonly exhibit evidence of more intense erosional activity. Two factors may account for this. Firstly, south facing slopes are likely to be more directly affected by raindrop impact as south-westerly winds are the prevalent rain bearing winds. Secondly in areas where grazing is not managed, animals tend to overgraze the more palatable sweetveld on the moister south-facing slopes (Granger, 1976, 1984; Granger and Schulze, 1977; Edwards, 1967, 1981).

Individual slopes or sets of slopes within a region are most commonly employed in studies on the influence of various slope parameters on soil erosion. While several researchers have recognized that this influence may vary according to (i) the type of landform unit in which the slope occurs, (ii) the position of the slope in relation to the catchment as a whole, and (iii) variations in individual catchment characteristics, and have recommended more dynamic approaches to incorporate landform classification and the concept of a variable source area of the catchment contributing sediment to its drainage channel, very few studies have actually analyzed slope-soil erosion relationships within the context of hydrological and/or geomorphological units (Morgan, 1979, 1986; Kirkby, 1980b). Roy *et al.'s* (1980) literature search found no previous studies that examined these relationships within the context of the drainage basin. They found that these relationships were a function of valley size, depth of channel incision, intensity of erosion on the crestal convexity and the development of a floodplain at the slope base. Variations in soil texture and horizon thickness on a slope were related to location within a catchment with respect to the junction, which separated net erosion on the upper slope from net deposition on the lower slope. The decrease in sediment yield per unit area with increasing catchment size, is generally attributed to the greater topographic diversity of larger catchments affording greater opportunity for deposition in depression areas and in response to surface obstacles (Kirkby, 1980b). However, Subramanian (1982) found slope-soil erosion relationships varied with catchment size.

5.4.1 Topographic Indices

As slope angle and length appear to be the slope parameters that exert the greatest influence on soil erosion they are the major components of indices devised to assess the topographic influence.

Most of these indices are expressed by equations equivalent to

$$Qs \ \tan^{m} QL^{n}$$

where Qs is the soil loss per unit area,
Q the gradient angle,
and L the slope length.

The value of the exponent m is dependent on the rainfall erosivity, soil erodibility, slope shape, vegetation cover and the predominate erosion processes. The type of erosion operant also influences the value of the n exponent (Morgan, 1979, 1986). The topographic index of the USLE and SLEMSA incorporates the influence of slope steepness and length. The index values may be calculated from such equations but are more commonly obtained from nomographs (Anon, 1976, Hudson, 1981, McPhee *et al.* 1983, 1984). The nomograph values are ratios of soil loss for a given combination of slope angle and slope length, to soil loss from standard 5^{o} slope, 22m runoff plots. Concern about the validity of both equation and nomograph derived topographic index values stems from the fact that they are based primarily on experimental research that has generally employed slopes less than 15^{o} and standard runoff plot lengths. Such conditions may restrict the accumulation and confinement of surface flow (Murphree and Mutchler, 1981; Loch and Donnollan, 1982a and b; Singer and Blackard, 1982a).

Stocking (1972) found that average slope exerted the greatest influence on the distribution of soil erosion in Zimbabwe from his multi-variant analysis of the following topographic parameters:- drainage density, proximity to natural drainage, highest stream order, three relative relief parameters, slope shape and average slope. Weaver (1988b and c) found a significant relationship between slope aspect, LS, slope angle and altitude on soil erosion in the Ciskei, while three slope shape parameters and slope length appeared to exert no influence. Liggitt (1988) and Liggitt and Fincham (1989) found that gully erosion in the vicinity of Ulundi was most severe in areas with a high drainage density and on slope gradients less than 9^{o}.

5.5 VEGETATION INFLUENCE

Soil removal processes may be substantially modified by the interaction of numerous structural and density compositional characteristics of vegetation. As most of these characteristics change during the growing season and vary from one growth season to another their net influence on soil loss is time dependent (Elwell and Stocking, 1974, 1976; Stocking and Elwell, 1976). There is general concensus in the literature that vegetation is the key variable controlling soil erosion, as well as the variable most readily altered by landuse practices. While the emphasis in soil conservation management has changed from the construction of physical measures to the more efficient utilization of the benefits of both living and non-living vegetation cover, Thornes (1985) observed that "in recent years several counter-intuitive results have been demonstrated in relation to the generally held belief that vegetation cover inhibits erosion". Stocking (1988a) noting these ambivalent results cautioned against viewing "vegetation cover as the panacea for soil erosion control".

Vegetation affects soil erosion both indirectly and directly. The indirect effects are through its influence on (i) pedogenesis, (ii) aggregation, (iii) infiltration capacity, and (iv) biological activity. Soil, by definition is composed of both mineral and organic constituents and is essentially biologically conceived. From the earliest stages of seral colonization, vegetation enhances the weathering of parent material, and consequently the production of primary sediment particles. The oxidation of organic constituents modifies the soil's pH balance which in turn regulates the complex sequence of internal reactions and rearrangements that modify the primary mineral particles and produce the distinct horizons of a mature profile (section 3.5). Vegetation plays an active role in the formation and stabilization of both micro and macroaggregates. In addition to their more aggregated structure, the high infiltration capacity of soils with a significant vegetative influence is due to the root matrix. Soil microflora and fauna are stimulated by good vegetation cover. Their activities create soil conditions that further increase the vegetation's productivity and the soil's infiltration capacity, and decrease the availability of detachable sediments (section 5.3).

The direct effects of vegetation include (i) the interception of raindrops by the canopy cover, and (ii) the detention of runoff by basal cover. The intercepted drops collect on the leaves and stems until their weight is sufficient to overcome the surface tension retaining them. They may then drip from the leaves and fall through canopy voids to the soil. Or they may trickle along stems and branches and down the trunk to the soil. Interception storage increases as a rain event progresses, becoming relatively constant once the interception capacity is reached as additional drops intercepted are almost entirely offset by throughflow and stemflow (De Villiers, 1975; Ward, 1975). Interception storage is dependent on (i) the configuration, orientation and surface area of the canopy's stems and leaves, (ii) the canopy's depth, degree of vertical stratification and horizontal continuity, (iii) the canopy's transpiration rate and ratio of transpiring to non-transpiring surfaces (Burgy and Pomeroy, 1958), and (iv) the number of drops evaporated off or absorbed by the canopy (Ward, 1975). The interception loss is that portion of the rainfall evaporated off or absorbed by the canopy both during and after the rain event (De Villiers, 1975). In common with the interception storage, it is regulated by a wide range of meteorological parameters the most important of which are wind speed, rain event duration and frequency (Ward, 1975). Beard (1962) estimated that between 35% and 45% of the total rain falling on the type of savanna grassland represented in the study area reached the soil surface as stemflow. Estimates of these grassland's interception loss range from 13% (Beard, 1962) to 30% (Edwards, 1961) to 40% (Wicht, 1959) of the gross rainfall. In the type of open savanna woodland represented in the study area De Villiers (1976, 1982) and De Villiers and De Jager (1981) estimated that about 5% of the gross rainfall reaches the soil surface as stemflow, while interception losses account for between 15% and 20% of the gross rainfall.

In comparison with raindrops that strike the soil surface directly, raindrops intercepted by crops, grassland and woody communities of low to medium canopy height reach the soil surface with a reduced kinetic energy. This reduction directly reduces the splash detachment and transport capacity (Wischmeier and Smith, 1958; Wischmeier, 1977), and indirectly reduces the runoff detachment and transport capacity as a greater proportion of drops are able to infiltrate into the soil (Kirkby, 1978, 1980a). Raindrops intercepted by woody communities with high to very high canopies may impact the soil surface with a force equivalent to or greater than the unintercepted drops. Drops, often larger in mass than the unintercepted drops, may reform on the leaves. In falling to the ground they may accelerate sufficiently to have a sizeable kinetic energy (Elwell and Stocking, 1976; Stocking and Elwell, 1976). According to Stocking (1988a) a 2mm diameter raindrop with a terminal velocity of 6m sec^{-1} has about the same kinetic energy as a 3mm drop falling at 3,25m sec^{-1}, a speed that is reached well within the first meter of fall. Morgan (1986) reports that drops falling from 7m may attain over 90% of their terminal velocity. Mosley (1982) found that on average the kinetic energy of a New Zealand beech forest's throughfall was 1,5 times greater than that of the rainfall. Most studies have found that soil loss from forest communities is substantially lower than from other vegetation communities (sections 3.7.1 to 3.7.3). Morgan (1986) suggested that this is due to the reduced volume of runoff in forests caused by their generally higher interception losses and infiltration rates. A few studies have found greater soil losses from forest communities. Mosley (1982) for example: found 1,3 times more soil was splashed from sample cups under forest than in the open, and suggested a forest's basal cover particularly the litter fraction, is more significant in absorbing the impact of falling drops than the canopy cover. This suggestion is supported by Thornes (1985). Stocking (1988a) suggested that the greater soil loss from tall forests where shading and/or alleopathy had severely restricted the basal cover was additionally due to the increased detachment and transport capability of the unimpeded runoff. When a substantial proportion of the tall forest species are smooth barked, stemflow may make a significant contribution to the volume of runoff generated, and attain velocities with sufficient energy to scour rills around the base of the trunk (Elwell and Stocking, 1976; Stocking and Elwell, 1976).

Basal cover comprises three distinct fractions:- living rooted bases, dead rooted bases, and litter lying loose on the surface and partially intergrated into it (Edwards, 1961). All three fractions mechanically impede the flow of water over the soil's surface. Provided the soil is not already saturated the consequent reduction in the runoff's velocity encourages its infiltration into the soil, reducing its volume. The sediment detachment and transport capability of the runoff is therefore decreased (Kirkby, 1978). A number of other factors associated with the basal cover indirectly affect this capability. The shading effect of basal cover reduces the evaporation loss from the surface soil, and consequently the availability of detachable sediments (Weyman, 1975). The transpiration loss from the living rooted cover, and capillary loss from undecomposed vascular tissues in the dead rooted cover, enhances the potential pore space available to receive infiltrating water (Edwards, 1961). The ponding of water behind the basal components reduces the effectiveness of raindrop impact (Morgan, 1986). Increased basal cover generally decreases soil loss. The inverse of this has however, been reported. Edwards (1961) suggested that the increased soil loss was due to the concentration of runoff into channels caused by the tendency of the litter fraction in grassland to thatch the surface. On grassed slopes steeper than 8^{o} De Ploey (1981) found that increased soil loss was associated with the generation of turbulent eddies downstream of the grass blades. Rowntree (1988) suggested that the contrasting effects of different vegetation types on surface resistance and runoff generation results in their association with different soil erosion types. She notes that sheet/rill erosion is more prevalent on scrubland than grassland because grass cover offers a greater surface resistance to erosional processes. She attributes the more intense gullying on grassland to the greater volume of runoff they generate as compared to scrub.

5.5.1 **Vegetation Indices**

Most research on the influence of vegetation on soil erosion has been directed at the C or cover factor of the USLE (Thornes, 1985; Stocking, 1988a). The C factor is the ratio of soil loss from an area with specified cover and management, to that from an identical area in tilled, continuous fallow. The growth stage of the crop and the degree of cover afforded by its canopy when mature determine the cover specifications. The management specifications incorporate the influence of crop rotation, tillage and mulching. Both groups of specifications are dependent on the type of crop as well as husbandry factors such as plant spacing, yield potential and fertility (Wischmeier, 1960). Based on many years of plot data Wischmeier and Smith (1978) tabulated C values for a wide range of crops under a wide range of cover, management and husbandry conditions. As the influence of each combination of conditions is dependent on the interaction between rainfall characteristics and a wide range of antecedent conditions, the C values are weighted according to the erosivity of each growthstage, and finally represent average annual soil loss ratios. The large number of interrelated variables incorporated in the C factor makes its evaluation a comparatively complex procedure. As it does not describe a relationship with soil loss it offers no means of interpolating values. Worldwide the C factor research effort has predominantly involved obtaining measurements from rainfall simulator runoff plots for C value interpolation and calibration (Elwell and Stocking, 1976; Stocking, 1988a). In South Africa it has concentrated on obtaining values for sugarcane (Platford, 1979), maize (Smithen, 1983), and wheat and pineapples (McPhee *et al.* 1983; Crosby *et al.* 1983).

Developed from the finding that soil loss from both grazing (Elwell and Stocking, 1974) and arable land (Elwell and Stocking, 1976) in Zimbabwe, is a function of mean seasonal vegetal cover, SLEMSA's C factor is a measure of the percentage of energy intercepted by the cover (Anon, 1976; Elwell, 1979, 1980). As such it reflects only those management treatments that directly affect canopy cover. The procedure for determining its values involves classifying the vegetation in terms of the protection afforded to the soil by its architectural characteristics, and superimposing seasonal distribution curves of percent cover and rainfall erosivity. The percent cover input from grazing land includes both canopy and basal cover. This input from arable land includes the standing crop, residues and weeds. The most significant finding of the SLEMSA C factor research effort is that the inverse relationship between percent vegetal cover and runoff/soil loss is curvilinear. The rate of soil loss increases substantially as vegetal cover decreases below 30% (Elwell and Stocking, 1976), but remains relatively unchanged as cover increases above 60% (Stocking, 1988a).

The influence of the degree of protection afforded to the soil surface by vegetal cover is apparent in accounting for South African research findings already detailed in sections 3.6 and 3.7, viz:- (i) Snyman *et al.'s* (1985) and Venter's (1988) finding that soil loss rates decreased as the stage of seral development of the vegetation community increased, (ii) Crossby *et al.'s* (1981), Weaver's (1988b and c), Liggitt's (1988) and Liggitt and Fincham's (1989) finding that the potential for and severity of soil erosion decreased as the faciations of vegetation represented in the veld types and bioclimatic regions became moister, and (iii) Broderick's (1987) and Weaver's (1988b and c) findings that the severity of soil erosion increased as the type of cover changed from forest to veld to arable crop.

5.6 LANDUSE INFLUENCE

A wide range of landuse practices are capable of substantially modifying soil removal processes. On non-agricultural land soil loss rates are generally dramatically increased albeit for limited periods of time by deforestation, mining, and earth removal operations associated with the development of urban areas and communication links. While soil erosion on agricultural land is generally progressively accelerated by poor/conventional landuse practices, it may be reduced to rates equivalent to or less than the geological 'norm' by soil conservation management practices (Zachar, 1982). Poor/conventional landuse practices tend to increase the detachment and transport capability of rainsplash and/or runoff by increasing the availability of removable sediments, and/or decreasing the proportion of rainfall capable of infiltrating into the soil. On arable land they include:- ploughing too deep; ploughing parallel to the slope; cultivating slopes that are too steep; continuous use of the land for the same crop without fallow or rotation; inadequate use of fertilizers and organic manures; encouraging stock to graze, burning and/or physically removing potential mulch material such as crop residue and stubble; planting too far apart, and leaving the tillage disrupted soil devoid of either standing crop or mulch cover during periods when high velocity, desicating winds, and/or high intensity rainstorms are prevalent. This latter practice gains particular significance in Natal as the coincidence of these meteorological conditions occurs in Spring immediately after planting. Irrespective of whether rangelands are utilized for controlled or uncontrolled grazing by domestic stock, or afforded conservation/ conservacy status for utilization by wild ungulates, poor/conventional landuse practices on them include:- overstocking; burning during a season and at a frequency that is detrimental to the sustained viability of the palatable grass species; poor siting and overutilization of non-macadamized roads and footpaths.

Morgan (1986) recognized three approaches to soil conservation management. The first, an agronomic or biological approach, emphasizes the role of vegetation in decreasing sediment detachment and transport by both rainsplash and runoff, and includes measures such as:- mulching; high density planting; multiple, cover and strip cropping; rotating crop types and fallows; planting pasture; supplementary stock feeding; and burning during a season and at a frequency that enhances the productivity of the palatable grass sward. The application of fertilizers, organic manures and soil stabilizers is perceived as a second approach concerned with soil treatments that promote dense vegetative growth and improve soil structure thus affording it increased protection against erosive agents and simultaneously increasing its resistance to erosion. The third; a mechanical or physical approach, is dependent upon manipulating the surface topography to control the energy available for erosion and includes measures such as:- ploughing across slopes on the contour; ridging and ridge tying; minimum tillage and no-till; constructing contour bunds, terraces and drainage channels, and stepping and zigzagging footpaths.

The positive or negative effect on soil erosion of most of the wide range of landuse practices noted above have been briefly considered in sections 2.9 to 2.11; 3.4.4 to 3.4.6; 3.6 and 3.7. With the exception of those landuse practices that exert a major influence in the study area, a detailed examination of the mechanics of their influence on soil erosion is considered beyond the scope of this study. When ploughing is carried out parallel to the slope, sediment particles detached and transported from the ridges, predominately by rainsplash, are readily removed by runoff flowing downslope in the furrows. When ploughing is carried out on the contour, sediment particles removed from the ridge accumulate in the runoff stored in the furrows. Morgan (1986) reported that soil loss from slopes ploughed on the contour may be half of that from up and down ploughed slopes. The erosion control effectiveness of contour ploughing decreases with increasing slope angle, slope length and rainfall intensity.

Heavily utilized, poorly sited non-macadamized roads have been identified as significant non-point sediment sources in arable and range lands in various parts of the world eg, El-Swaify and Cooley (1980); Neill and Mollard (1982) and Stephens (1983). The increased soil loss associated with these roads is due to the increased volume and velocity of surface flow, due in turn to their compacted surfaces and long slope lengths. Okigbo (1977) identified footpaths particularly those leading to cultivated plots; wood and water sources; and used by livestock, as significant non-point sediment sources in African traditional communal lands. Dunne (1979, cited by Venter, 1988) estimated that non-surfaced rural roads, vehiclar tracks and footpaths contributed 15 to 35% of the sediment yield from agricultural catchments in Kenya. Quinn *et al.* (1980) used laboratory experiments to demonstrate that most vegetation wear on dry soils and gentle slopes is caused by the compacting action of the heel, while on wet soils and steep slopes it is caused by soil deformation and smearing associated with the shearing action of the toe. On dry soils the shearing action of the toe is more important in loosening and crushing surface particles. They also showed that trampling caused a deterioration in soil structure before there was any visual evidence of vegetation wear, and that soil losses increase with trampling pressure, and with slope angle up to about 20^{O} when the transition from walking to climbing decreases the influence of the shearing action. Garland (1979; 1983) and Garland, Hudson and Blackshaw (1985) drew attention to the serious erosion caused by footpaths in the Natal Drakensberg. Using natural rainfall runoff plots in the Central Drakensberg, Garland (1987a and b) found that soil loss rates from an experimental footpath were 80 times greater on average, than the rates from the control plot under a *Themeda triandra* dominated grassland pyroclimax 3 to 4 years after a burn. While soil loss rates from burn treatments were 5 to 10 times greater than the control's rates, burning the grass adjacent to the path increased soil losses to 135 times the control's rates. He suggested that this disproportionate increase indicates that the simultaneous application of landuse practices has a reinforcing effect, and creates a sediment detachment and transport system far more efficient than could be produced from their separate application. He also found that both the path and path/burn plot treatments resulted in a coarsening of the surface soil, and a decline in its organic matter content.

Estimates of the magnitude of the difference in soil loss from overgrazed rangeland compared to grassland in good condition range from 2 (Hofmann, Ries and Giley 1983), to 10 (Roose, 1976, 1977), to 50 (van Vuuren, 1982) times. Thornes (1985) identified three ways in which overgrazing enhances soil removal processes viz:- (i) by eating the plants; the percentage canopy and basal cover, and organic matter replenishment is decreased; (ii) by selecting palatable herbaceous species; unpalatable herbaceous and woody species gain a competitive advantage; (iii) trampling compacts the soil decreasing its infiltration rate, while scuffing loosens surface particles.

Watson's (1981) review of South African literature on the effects of veld burning on the compositional and physiological characteristics of savanna grasslands, and the biophysio- chemical properties of their soils, and Cass, Savage and Wallis's (1984) review of South African literature on these effects in a wider range of biomes, indicate that burning has bivalent effects on the detachment of sediment particles. The decrease in percentage canopy and basal cover; and in the soil's organic matter content, and hence in its aggregate stability all serve to increase detachability, while the increase in surface crusting serves to decrease it. They also indicate that burning generally increases the transportability of sediment particles by (i) increasing surface crusting; (ii) decreasing the soils organic matter content and causing associated decreases in aggregate stability, porosity, permeability, exchange and water holding capacity; and (iii) decreasing the soil's micro- and macro-organism, nitrogen, carbon and exchangeable base content. The net effect of these changes is a decrease in the infiltration rate and capacity, and an increase in runoff. However, a significant portion of the research reviewed by these authors either found that burning had no effect, or an effect opposite to that noted above.

The wide range in the response of vegetation and soil to burning has fueled considerable controversy regarding its use as a range management tool, and may be attributed to several factors. West (1958) suggested that the contradictory reaction of grass to burning may be explained in terms of how critical its effect is on the soil moisture regime. In dry regions and seasons, burning may cause the soil's moisture to drop below a critical threshold resulting in an adverse affect on growth. In moist regions and seasons the affect on soil moisture is unimportant, and growth may be stimulated by the burning off of the moribund mantle. Durgin's (1985) finding that ash leachate increases both the dispersion and flocculation of clays, suggests that discrepancies in reported changes in soil erodibility attributed to burning, may be due to the influence of the seral stage of the vegetation on the chemical composition of the leachate. Another source of contradiction in the literature is suggested by Biederbeck, Campbell, Bowren, Schnitzer and McIver (1980) and Helvey's (1980) finding that the short term effects of burning on soil biophysiochemical properties are quite distinct from the long term effects. Garland (1987a) cautions that the dramatic effects of single fires in areas where they seldom occur are not comparable with the small transitory effects of several years of systematic burning in areas where fire has a long history of regular and frequent occurrence. The relative unimportance of organic matter in determining the aggregate stability of southern Africa's grassland and savanna soils reported by Cass *et al.* (1984) may be an indication of a form of equilibrium with burning, as postulated by Garland (1987a).

5.6.1 Landuse indices

As noted in section 3.7, different erosion types and intensity classes are generally significantly and strongly correlated with different landtype surfaces. While an estimate of the proportion of an area on which a particular landuse practice is carried out gives an indication of its potential influence on erosion relative to other practices represented, it does not reflect the relative intensities of these practices in terms of the degree to which they influence soil erosion. As the spatial extent and intensity of landuse practices generally increases with increasing population, population density may be anticipated to be a reliable indicator of their composite influence. Stocking (1972), Stocking and Elwell (1973) and Whitlow (1988) found it to be a satisfactory index of erosion in Zimbabwe. Weaver (1988b and c) found that it did not indicate erosion in the Ciskei satisfactorily. A wide range of indices have been developed to describe the influence on soil erosion of specific practices and groups of practices. The following discussion however, will only deal with those relating to practices carried out in the study area.

The landuse or P factor of the USLE accounts for the erosion control effectiveness of physical soil conservation practices. The values for these practices given in Wischmeier and Smith's (1978) table represent the ratio of soil loss from an area where an individual practice is present, to an identical area from which it is absent. When the USLE is applied to areas where more than one practice is present, the individual practice values are multiplied to obtain a composite P value. When the equation is applied to areas where terracing is present, or is used to determine terrace spacing, the LS factor is adjusted accordingly (Forster and Highfill, 1983). Weaver (1988b and c) found that soil erosion in the non-forested areas of the Ciskei was significantly correlated with footpath intensity, but the coefficient value was too low for this variable to merit consideration as a landuse index. Although Weaver (1988b and c) found that soil erosion in the Ciskei was significantly and strongly correlated with stock density, he discounted it as a reliable index because of difficulties in justifying cause and effect relationships. He questioned whether the high degree of erosion in areas with high densities of small stock units representing mainly browsers eg, goats, is a reflection of their greater suitability to bush encroached areas with poor grass cover. And whether the relatively low degree of erosion in areas with high densities of large stock units representing mainly grazers eg, cattle and equines, is a reflection of their greater dependence on good grass cover. Venter (1988) suggested that the absence of a relationship between stock density and soil loss in the Umfolozi Game Reserve reflected the insignificance of grazing pressure on grass cover in comparison to the influence of rainfall. He explained that rainfall exerted the dominant and controlling influence on the composition and productivity of the herbaceous layer by virtue of its extreme variability. In this area the rainfall's coefficient of variation averages about 32%.

CHAPTER SIX

ACTUAL AND POTENTIAL SOIL EROSION ESTIMATION

6.1 INTRODUCTION

Estimates of actual and/or potential soil erosion are required for a wide range of purposes including predicting the effects of landuse change (Garland and Humphrey, 1980), providing a reference datum for monitoring changes in erosion and assessing the effectiveness of conservation measures (Whitlow, 1986), planning agricultural development, designing soil conservation strategies and evaluating off-site environmental impacts (Albaladejo Montoro and Stocking, 1989; Stocking, 1989). In mapped form, these estimates are additionally used to assess factors of influence, and to delineate areas of similar erosion risk and hence landuse suitability (Morgan, 1979). Soil erosion estimates are the critical input to *erosion hazard assessment*. This specialized form of land resource evaluation identifies areas where excessive soil loss or the potential for it threatens the maximum sustained productivity from a given landuse (Morgan, 1986).

There is no general agreement on the most appropriate scale and technique to use in erosion hazard assessment (Morgan, 1980a and b), let alone on methodological approaches to soil erosion estimation. In fact when considering this methodology it is clear that the terms soil loss, sediment yield and soil erosion are not used synonymously. Soil loss refers to the soil removed from a particular slope segment. Sediment yield refers to the soil removed from a catchment area and delivered to a particular measuring point. Soil erosion refers to the gross amount of soil moved by raindrops and runoff. Most slopes have biophysiographic and cultural irregularities that encourage both erosion and deposition to occur. The erosion rates at selected points along slope segments therefore generally differ from soil loss rates at the base of such segments. As further deposition occurs on footslopes, both these rates generally differ from the rates at which sediment is delivered to a particular measuring point (Kent Mitchell and Bubenzer, 1980). Ideally the estimation technique selected should satisfy the conflicting requirements of reliability, universal applicability, easy usage with a minimum of data, comprehensiveness in terms of factors included, and the ability to take account of changes in landuse and conservation practice (Morgan, 1979). In reality however, its selection is dependent on the scale at which the results will be presented and used, and on the reliability and accuracy of the available data (Hudson, 1980).

6.2 SOIL LOSS

Soil loss estimates derived from natural and/or simulated rainfall runoff plots are costly and time consuming to obtain. specific only to single treatments, and may not reflect loss by surface flow adequately (section 5.3.1). These estimates are therefore more commonly obtained from soil loss models, of which the USLE is the most widely and frequently used and misused (Wischmeier, 1976a and b). As noted in chapter five where its development and structure is outlined, it was designed as a soil conservation planning tool to predict long term average soil losses in sheet and rill flow from small field areas under specified cropping and management conditions (Wischmeier and Smith, 1962, 1978). It is a wholly empirical model and reliant on the accuracy of the values inserted for the five factors in the equation. While the factors themselves have an underlying rationale, their index values cannot be extrapolated as have no meaning other than as a comparative measure intergrating many separate influences and non-linear relationships, some known but many unknown. The factor values tabulated in the USDA Handbook Number 537 are strictly only valid for conditions pertaining to cropland east of the Rocky Mountains in the USA, in which they were experimentally determined, and should only be used in different physiographic conditions once they have been experimentally verified (Abel and Stocking, 1987; Albaladejo Montoro and Stocking, 1989).

The USLE has often been misused and consequently unjustly criticised. Evans and Kalkanis (1976) attribute its misuse to misinterpretation of the term 'universal', and to the fact that it became available at a time when regulatory agencies were anxious to quell increasing public criticism of soil erosion problems. Albaladejo Montoro and Stocking (1989) maintain that the temptation to apply it to conditions outside the range for which it was designed also stems from its fundamental simplicity and ease of application. Its application to single rainfall events, extreme environmental conditions eg, very low and variable rainfall, major landuse disturbances eg, logging and construction, areas where sheet and rill erosion are not the major sediment contributors, and large areas, yields unreliable estimates. Equating its estimates with soil erosion or sediment yield also constitutes a misuse of the model (Wischmeier, 1976a and b). Where the index values have been experimentally calibrated to local conditions, the USLE has proved capable of yielding reliable estimates from arable microscale areas in regions physiographically radically different to the eastern USA, and from non-arable mesoscale areas eg, Chinnamani, Sairam Venkata and Sakthivadivel's (1982) cropped field estimates in semi-arid and humid mountainous watersheds in tropical India, and Osborn, Simanton and Renard's (1976) estimates from small rangeland catchments, respectively.

In their study of a 65 km^2 watershed in Texas, USA, Morgan and Nalepa (1982) used iso-erodent and topographic maps, soil survey reports, and colour infrared aerial photographs and field survey reports to extrapolate R and LS, K, and C and P values for each of the study area's grid sampling units, respectively. The 5,6 t ha^{-1} yr^{-1} mean soil loss estimate they derived from the extrapolated factor values compared very favourably with the estimate of 6 tha^{-1} yr^{-1} derived from field experimental data. Stephens, Macmillan, Daigle and Cihlar (1985) also found a highly significant correlation between USLE values extrapolated from such sources, and those derived from field data. USLE estimates derived using factor values extrapolated from maps, survey reports, remotely sensed sources etc. without experimental verification are relative and only meaningful on a comparative basis eg, Smithen and Schulze (1979) compared USLE and SLEMSA estimates of soil loss rates in three catchments at Cedara in Natal; Stephens, Daigle and Cihlar's (1982) comparative study of soil losses from potatoe farms with and without soil conservation measures in New Brunswick, Canada, based on extrapolations from sequential aerial photographs taken 35 years apart; and Giordano's (1984) comparison of 'actual' and 'potential' soil losses in drainage basins and regional areas of North Africa's Maghreb countries. The 'actual' losses were based on values reflecting a 'normal' anthropogenic influence, while those on which the 'potential' losses were based reflected an 'extreme' anthropogenic influence.

As noted in chapter five the Department of Agriculture has recommended that the USLE be employed for estimating soil losses from arable lands in South Africa (Crosby *et al.* 1983). Most of the USLE related research to date has focussed on calibrating the factor values to local conditions and supports its potential to provide reasonably reliable soil loss estimates eg, Crosby, Smithen and McPhee (1981), McPhee *et al.* (1983, 1984), Smithen (1980, 1983), Smithen and Schulze (1979, 1982), and Smithen *et al.* (1985).

SLEMSA was developed because soil loss estimates derived using the USLE in Zimbabwe were very poorly correlated with actual measured rates of soil loss. To improve on the USLE estimates would have required a massive experimental effort costing several times the total agricultural research budget. SLEMSA's structure is outlined in chapter five. While it was also developed as a soil conservation tool to give reasonably accurate estimates of average annual soil losses from small field areas under specified cropping and management conditions, it was additionally developed to be simpler, less data hungry and therefore cheaper, and more capable of extrapolation to unmeasured conditions than the USLE (Elwell and Stocking, 1975, 1976, 1984; Anon, 1976; Elwell, 1979, 1980, 1984). As noted in section 5.5.1 SLEMSA's C factor is the mean seasonal interception of erosive rainfall. As it is equivalent to the mean cover of the ground layer of vegetation, a variable that can be measured on the ground and extrapolated from remotely sensed sources relatively simply, cheaply and rapidly, SLEMSA has a greater potential for application to larger arable lands (eg, Elwell, 1984) and rangelands (eg, Abel and Stocking, 1987), than the USLE. Albaladejo Montoro and Stocking (1989) suggest that SLEMSA has not attracted the same degree of criticism as the USLE even though as a parametric model it suffers the same constraints, because it is less well known.

Although SLEMSA's conceptual framework was introduced to and extended by the Department of Agriculture in 1976 (Anon, 1976), it has not been widely employed in the Republic. The probable reason for this is that the USLE particularly once it has been adapted to local conditions, performs satisfactorily to the extent that its use has been officially recommended since 1983 (Crosby *et al.* 1983). Schulze (1979) applied SLEMSA to an area of Natal's northern Drakensberg and found that while it was useful to differentiate areas of high and low erosion potential, it was extremely sensitive to KE and F value inputs. Smithen and Schulze (1979) found that it predicted much lower rates of soil loss than the USLE did in three catchments at Cedara in Natal. Neither study verified the estimates against measured rates of soil loss. Hudson (1987) found SLEMSA's estimates were two to three times greater than measured soil loss rates in the Cathedral Peak area of the Natal Drakensberg.

The development of deterministic models that use mathematical equations of the laws of mass and energy conservation to describe soil removal processes, is still in its infancy. Although Morgan (1979) viewed this form of theoretical modelling as the ultimate objective of research into soil erosion models, he pointed out that their complexity would preclude them finding a market in developing countries. Alexander (1981, cited by Hudson, 1987) noted that estimates derived from empirical models are often more accurate than those derived from deterministic models. Inherent in empirical models are the effects of various unknown variables and processes which influence the outcome of the system. Owing to their concealed nature these effects cannot be quantified and are therefore excluded from deterministic models. This suggests that the so-called 'noise' of parametric models should actually be seen as an additional source of information on the soil erosion process, which future research may elucidate.

The most widely used deterministic model is CREAMS which is an abbreviation for Chemicals, Runoff, Erosion from Agricultural Management Systems (Stocking. 1989). As the USLE predicts long term average soil losses, CREAMS has been used in the Republic where estimates of soil losses from single rain events are required eg, Platford (1983, 1985) found that although its estimates were much higher than measured soil losses, they could be used on a comparative basis to assess the protection afforded to the soil under various sugarcane management systems.

6.3 SEDIMENT YIELD

Sediment yield or the total output of sediment from a catchment, can either be estimated from equations describing the influence of the catchment on this output, or extrapolated from measurements of the output. There are a large number of equations available for estimating sediment yield. Most of them are empirical developed from best statistical relationships between measurements of catchment variables and sediment output, and generally only have regional applicability. The most common catchment input, storage and output variables included in these equations are rainfall intensity or amount, catchment or contributing area and shape; altitudinal range; slope gradient and length; geologic, soil and landuse descriptions, and amount or peak rate of runoff, respectively.

Kent Mitchell and Bubenzer (1980) tabulated the catchment variables employed in the most widely used equations. Two types of equation are apparent. The first provides a direct estimate of the total output of sediment from the catchment. The Modified Universal Soil Loss Equation for Estimating Sediment Yield termed MUSLE used by Schulze (1981) to assess the influence of siltation on the lifespan of small dams in KwaZulu (sections 1,1; 2.11 and 3.6) is an example of this type of equation. In it, the R factor of the USLE is substituted with a runoff factor. The second type of equation involves multiplying an estimate of the gross erosion from a catchment by an estimate of its sediment delivery ratio. As noted in section 3.6 this ratio is the fraction of the gross erosion delivered to a particular measuring point after deposition in the catchment. It varies approximately inversely as the 0,2 power of the drainage area (Kent Mitchell and Bubenzer, 1980). The USLE is most commonly used as a basis for estimating the gross erosion. The sediment delivery ratio for zones of increasing proximity to the contributing area is commonly increasingly weighted to account for the fact that sediment moves in a series of steps toward stream channels, and the further the sediment has to move before it reaches the channel, the more likely it will be temporarily deposited on slopes (Lewis, 1980).

Sediment yield estimates may be extrapolated from measurements of the total load of sediment transported through a particular point on a stream or river channel per time period, or from measurements of the rate at which sediment accumulates in reservoirs. Variations in the accuracy of measurement of the sediment load of rivers, and in the trap efficiency of reservoirs are commonly adjusted for in the extrapolation procedure. The suspended sediment load of rivers is generally taken as being equivalent to the total sediment load unless the bed load is known to comprise a significant portion of the total load (Kent Mitchell and Bubenzer (1980). South African estimates by Rooseboom (1977, 1978), Rooseboom and Harmse (1979), Braune and Wessels (1980), and Rooseboom and Mulke (1982) noted in section 3.4.6 were extrapolated from the first type of measurement, while those by Le Roux and Roos (1979, 1982a), Weaver (1988a), and Le Roux (1990) also noted in section 3.4.6, were extrapolated from the second type of measurement. From a historical overview of sediment studies in South Africa Rooseboom (1983) concluded the sediment yield figures obtained from regular stream gauging since 1929 and surveys of deposits in existing reservoirs, gave a fair indication of the average erosion rates of larger catchments. He noted however that detailed information on spatial and temporal variations in erosion rates were not available from these sources.

6.4 SOIL EROSION

There are three general approaches to estimating the gross amount of soil moved by raindrops and runoff. The first involves the use of remotely sensed sources to measure the frequency of occurrence and/or the area affected by different types of erosion. It gives estimates of the intensity of *actual* erosion. The second involves using data extrapolated from maps, field survey reports and remotely sensed sources to rate the influence of one or more natural and/or anthropogenic factors on an area's susceptibility to erosion. It gives estimates of the intensity of *potential* erosion. The third involves comparing an area's actual and potential erosion estimates. It indicates the extent to which the erosion risk factors have actually contributed to the erosion. Those factors found to have contributed significantly may be incorporated into models developed to assess the erosion hazard of areas where they are likely to exert a comparable influence.

As soil erosion estimates are derived from areal sources their basic statistics are commonly presented in mapped form. Isoline maps are used to display statistics on erosion occurrence at sampling points. Choropleth maps display average values per unit area. They are therefore used to display statistics on the areal extent of erosion as well as on frequency of occurrence. They are the more common graphics as are better suited to both the visual and computational assessment of factors of influence from successive overlays of thematic maps (Millington, Robinson and Browne, 1982).

Numerous authors cited by Douglas (1981) predicted that future soil erosion estimation work would involve more intensive and extensive use of satellite imagery particularly of the more recently developed multispectral LANDSAT systems which include a chlorophyll absorption band and have greater spatial resolution. This initial enthusiasm has however, not been sustained by subsequent applications (Abel and Stocking, 1987). Millington and Townshend (1984) concluded that none of the satellite imagery systems available in Africa were likely to be more fully utilized in the estimation of soil erosion, as the acquisition and interpretation of their data is costly and time consuming, and they are only reliable for the assessment of erosion processes uniformly operant over extensive areas. Abel and Stocking (1987) list a number of technical factors that impair the accuracy of vegetation cover estimates from satellite images, which further restrict their potential value in soil erosion estimation. Looser's (1984 cited by Kovacs *et al.* 1985) study described in section 1.1, includes the only South African soil erosion estimates from satellite imagery known to this author.

Of the range of remotely sensed sources currently generally available for soil erosion estimation, Morgan (1979, 1986), Keech (1980) and Gelmoth (1981) amongst others, asserted that the stereoscopic use of aerial photographs is the most valuable and cost effective. The spatial extent of most erosion forms can be readily quantified on aerial photographs. A scale of approximately 1:25 000 is generally considered the most efficient to use. Smaller scales lose resolution and larger scales involve sacrifice in terms of the synoptic view (Keech, 1980). Weisser, Backer and Van Eeden (1988) list twelve advantages of aerial photographs as a long-term data source for vegetation studies, most of which are equally applicable to soil erosion studies. Aerial photographs have been used to estimate soil erosion in several South African studies including Scotney (1978b), Broderick (1987), Marker (1988) and Weaver (1988a, b and c).

Satisfactory soil erosion estimates from 1:10 000 orthophoto maps are reported in several South African studies eg, Berjak *et al.* (1986), Thwaites (1986), Liggitt (1988), and Liggitt and Fincham (1989). These maps are cheaper than aerial photographs, and can be more rapidly assessed as they do not require scale and distortion adjustments. However, compared to aerial photographs they have the disadvantages of not yet being available for as large a portion of the country, of not permitting as synoptic a view, and of not being able to provide a three dimensional image. Such an image may be critical to the accurate identification of erosion forms and demarcation of eroded surfaces.

Notwithstanding the fact that aerial photographs are presently the best remotely sensed source of soil erosion estimation, the accuracy of these estimates is dependent to a large extent on the observer's experience in air photo interpretation and knowledge of erosion (Whitlow, 1986). Where more than one erosion process is operant extreme subjectivity may be involved in identifying the dominant process, and in delimiting the areal extent predominantly affected by it. In order to minimize this influence the Southern African Regional Commission for the Conservation and Utilization of the Soil recommended that a common systematic approach to soil erosion identification and assessment be adopted for use throughout southern Africa (SARCCUS, 1981). The approach they developed is known as the SARCCUS system for classification of soil erosion. It identifies seven types of soil erosion caused by water in southern Africa. Each erosion type is further identified as belonging to one of five erosion severity classes based on various characteristics visible on aerial photographs, and on the proportion of the land area they affect. Attempts to use the SARCCUS system by Whitlow (1986), Berjak *et al.* (1986), Liggitt (1988), Weaver (1988a), and Liggitt and Fincham (1989) proved unsatisfactory because it was seldom possible to designate a sampling area to a single erosion class.

The unsuitability of the SARCCUS system has meant that different approaches to soil erosion estimation continue to be used in southern Africa. Therefore, unlike soil loss or sediment yield estimates, estimates of soil erosion derived from different parts of the sub-continent are generally not directly comparable. The relationship between scale, and cost and time constraints appears to be the major factor influencing the approach selected. In a national survey of erosion in Zimbabwe Whitlow (1986, 1988) used 1:25 000 aerial photographs to record the presence and type of erosion in each grid cell equivalent to one ha on the ground. Each cell was assessed because the generally patchy distribution of erosion indicated that estimates based on a sample of cells were likely to be biased. Given the number of cells involved on the nearly 8500 photographs used, the cost and time of a more detailed data extraction would have been prohibitive. Based on the observation that areas with severe gully erosion were usually associated with severe rill and sheet erosion, Weaver (1988a) reduced the 16 SARCCUS classes for these erosion types to five viz:- no erosion; sheet and rill erosion only; sheet and rill with evidence of gullies; intricate gullies, and severe gullies. This system was found to be practicable and cost effective in surveys of the Ciskei at both a drainage basin (Weaver, 1988a) and national scale (Weaver, 1988b and c). A constraint of this system posed by the ordinal scale of measurement is that only non parametric statistical tests can be used to analyse the data obtained with it.

Thwaites (1986) developed a technique for estimating soil erosion at a local scale. Different types of erosion forms and different groups of erosion risk factors were identified on 1:10 000 orthophoto maps and represented by symbols on an overlay map. The density of erosion symbols gave an estimate of erosion intensity. The density of associated erosion risk factors indicated their potential influence. Thwaites (1986) recommended that this technique be used in local studies nationwide so that a comparable data base could be built up, ultimately facilitating assessment of the national erosion status as originally envisaged by the proponents of the SARCCUS system. This author is not aware of any local scale soil erosion studies in the Republic that have employed this technique. Most such subsequent studies have used aerial photographs to measure the area of eroded surfaces or of specific types of erosion forms eg. Broderick (1987) and Marker (1988).

The approach employed in estimating potential erosion is very similar to that employed in the extrapolation of USLE factor values, described in section 6.2. That is; maps, field survey reports and remotely sensed sources, etc. are used to rate the influence of one or more natural and/or anthropogenic factors on an area's susceptibility to erosion. A detailed examination of an assessment of potential erosion in Zimbabwe by Stocking and Elwell (1973a) will serve to illustrate the major weaknesses of this approach to soil erosion estimation. A 1:1 000 000 base map was divided into 184 km^2 grid units. The erosivity, erodibility, slope, ground cover, and human occupation of each unit was rated on a scale of 1 to 5 in terms of its potential influence on soil erosion. The total score for each unit obtained by summing the five factor scores, was assigned to an erosion risk class. A map delineating areas of similar risk was finally produced.

The first weakness of this approach is associated with the method of rating the factors of influence. Information on these factors is derived from various sources, obtained from various agencies, and available at various scales. The scores assigned to factors for which there is a good, large scale information source available, are more accurate, and tend to exhibit a greater spatial variability (Douglas, 1981). The assumption that the relationships between the factors of influence and erosion are linear, and the rating of each factor independently, may also reduce the accuracy of the scores allocated (Stocking, 1975, 1980a). As noted in chapter 5, the findings of a large number of studies suggest that at least some of these relationships are curvilinear, and that the relation of a particular factor to soil erosion is often appreciably influenced by the levels at which the other factors are present. Another weakness of this approach is associated with the method of assessing the combined influence of the factors. In common with Stocking and Elwell (1973a), most such studies weight each factor equally, despite the fact that the number describing the natural influence generally greatly exceeds that describing the anthropogenic influence. The choice to add or multiply individual factor scores, and of threshold values delimiting erosion risk classes, is arbitrary, and constitutes a weakness that influences the comparability of such studies. Bergsma (1980), Richter (1980), and Millington *et al.* (1982) motivated their use of multiplication on the basis that it is used in the USLE.

Given the weaknesses inherent in the estimation of potential erosion, the poor correspondence between the risk of erosion in Zimbabwe as estimated by Stocking and Elwell (1973a), and the extent of actual erosion as estimated from aerial photographs using the method described by Whitlow (1986), reported by Whitlow (1988), is not totally unexpected. These weaknesses have been acknowledged as major factors limiting the applied value of much of the potential erosion assessment work carried out in South Africa to date eg, Garland and Humphrey (1980) and Garland (1987a). Unless potential erosion estimates are verified against actual erosion estimates, they do not permit more than a descriptive appreciation of the erosion risk obtained (Morgan, 1980b; Young, 1980). A number of studies claiming to have carried out this verification, have in fact compared potential erosion estimates based on the influence of natural factors, with those based on the influence of both natural and anthropogenic factors eg: Bergsma (1980), Richter (1980), Williams (1981), and Millington *et al.*

(1982). This discrepancy is due to the use in such studies of the term 'potential soil erosion' in reference to the influence of relatively stable factors such as climate, pedology and topography on the soil erosion expected in an area. The term is most often used, as it is in this study, in reference to the influence of these stable factors as well as the unstable factors such as vegetation cover, land use and population density.

A few southern African studies have compared estimates of potential erosion based on both natural and anthropogenic factors with estimates of actual erosion derived from aerial photographs or orthophoto maps. In their investigation of the 525 km^2 area surrounding Ulundi, Liggitt (1988) and Liggitt and Fincham (1989) found that the most intense erosion occurred in bioclimatic groups 8 and 10 - the sourveld areas with a MAP in excess of 900 mm, on the least resistant rock types, on slopes less than 16%, in the highest drainage density classes, and in areas administered by KwaZulu. Weaver (1988b and c) correlated spatial variations in erosion intensity classes with spatial variations in 24 variables. Significant correlations were found with the following variables:- MAP, altitude, EI_{30}, soil type, geology, slope steepness, LS factor, profile; lateral; and three dimensional slope shape, veld type, and densities of both large and small stock units. The inverse relationships found between erosion and EI_{30}, slope steepness and large stock unit density were however, contrary to those expected. Although the dependence on landuse category of the influence of these variables, indicated that landuse had the most marked effect on erosion, no significant association with the three anthropogenic variables i.e. population density; distance from village; and footpath intensity, was found. The primary factors identified for incorporation into an erosion hazard assessment model were MAP, parent material, veld type and the landuse influence on the presence or absence of forest. Contrary to Weaver's (1988b and c) conclusion that spatial variations in soil erosion observable at the macro-scale are predominantly controlled by natural factors, Whitlow's (1988) comparative assessment of potential and actual erosion in Zimbabwe showed that anthropogenic factors were more crucial determinants of erosion than natural factors. Regression analysis of the six variables used as indices of potential erosion, showed that population density was the best single predictor of the extent of erosion. The predictive ability of the three anthropogenic variables - population density, land tenure and cultivated area, combined, was only slightly better than that of population density alone. Combining the natural variables - rock outcrop, natural region and Stocking and Elwell's (1973a) erosion hazard, with the anthropogenic variables, did not facilitate the prediction of a greater proportion of the erosion.

As is apparent from the above discussion, any assessment of the influence of the erosion risk factors on potential and/or actual erosion involves the capture and intergration of large volumes of spatially orientated data from a variety of sources. Millington and Townshend (1984), Pelletier (1985) and

Walsh (1988) amongst others, have asserted that the geographic information systems (GIS) is the best technique for such assessments. The GIS is a computerized overlay technique for storing, retrieving, manipulating, analyzing and displaying spatially referenced data in tabular, map or other graphical form. The technique exerts a strong influence on data collection and inputting. The systems are either grid based or vector orientated. With the former system, spatial information is aggregated by the superimposition of a grid, and subsequently coded for the location of each cell, creating a data matrix or thematic layer in the database for each environmental parameter considered. The vector approach is a more sophisticated and realistic handling of points, lines and polygons as strings of x and y cartesian co-ordinates. In GIS development first the grid based and then the vector orientated systems were favoured. At present, given the technological advances in computer speed, data storage capability, and resolution, neither system merits preference. The choice of system to use is dependent on what is deemed to be the greater disadvantage - the loss of boundary detail associated with using the simpler grid-based system, or the complexity and hence high development costs of the vector system. The GIS is valuable in erosion assessment because it permits the searching for and testing of interactions between factors of influence, as well as the appraisal of their coefficients in the development of predictive models (Walsh, 1988). The GIS has been used in most recent soil erosion assessment work in South Africa viz:- Berjak *et al.* (1986), Weaver (1988b and c), Liggitt (1988), and Liggitt and Fincham (1989).

CHAPTER SEVEN

METHODOLOGY

7.1 METHODOLOGICAL APPROACH

The selection of the methodological approach used in this study was influenced by the following considerations:- (i) the aims of the study as listed in section 1.3, (ii) the available data source, (iii) practical constraints imposed on the study, and (iv) the requirements for use of, and implications of using the various approaches discussed in chapter six. A comparative assessment of temporal and spatial variations in the area's susceptibility to erosion, and in it's actual erosion was required in order to fulfill the aims of this study. The available data source for the entire study area comprized:- five sets of sequential aerial photographs, one set of orthophoto maps, and two sets of topocadastral maps. An additional source for the game reserve component of the study area comprized:- a series of maps showing the extent of the area burnt during different years, a map of the Iron Age sites, a geology map, a soil map, a vegetation map, and numerous research reports many of which are cited in chapter two, on various ecological aspects. Geological and landtype field survey reports represented an additional data source for the KwaZulu component of the study area.

With the exception of rainfall, the available data source was adequate for estimating the influence of the most likely erosion risk factors at the temporal and spatial scale of this study, using the approach for estimating potential erosion described in chapter six. The approach to estimating actual erosion based on data extracted from aerial photographs was deemed the most suitable for this study. The alternate approaches, entailed entering estimates of the potential influence of the erosion risk factors into soil loss or sediment yield models. The available data however, does not include field measurements of either, against which the estimates derived using these models could be verified. Acquiring soil loss or sediment yield measurements would involve setting up runoff plots or gauging weirs, respectively. The following constraints rendered consideration of such installations impracticable:- limited time in, and funding with which to carry out the study, and restricted access particularly to the game reserve component of the study area.

The decision to use the GIS for data storage, retrieval and display was based on its motivation as the best technique for the type of comparative assessment involved in this study, presented in section 6.4. Although the manipulation and analytical functions of the GIS were explored for visual assessment, they were not employed for computational assessment. A detailed motivation for the use of forward stepwise multiple regression analysis for this purpose, will be given in section 7.3. The available GIS software had to be developed in order to meet the specific needs of this study. As a grid based programme describes a simpler system it would be easier and cheaper to develop, and was therefore chosen in preference to a vector orientated programme. An additional reason for choosing a grid based system noted by Briggs and France (1982), is that individual cells are readily definable within the framework of the national co-ordinate system. A disadvantage of the vector system that reaffirmed the preference for the grid system, is the subjectivity involved in delimiting landfacet or hydrological response unit boundaries - the reference against which spatial patterns are generated (Briggs and France, 1982).

Young (1980) asserted that the degree of spatial variability inherent in erosion risk factors at a mesoscale was such that estimates of their influence over grid cells larger than 1 km^2 were necessarily unreliable. In a mesoscale study of south Yorkshire, Briggs and France (1982) found that a 1 km^2 grid cell size was the most reasonable compromise between the need to interpolate variables measured on a coarse spatial basis and to aggregate more detailed data. They also found that this cell size was the most practicable in terms of identifying and abstracting broad patterns without losing local nuances. The grid cell size of 1 km^2 selected for use in this study was based on the above recommendations.

None of the methods of estimating actual soil erosion from aerial photographs recommended for general use in South Africa and described in section 6.4, were deemed suitable for this study. In common with the attempts by others, the pilot study's application of the SARCCUS system proved unsatisfactory. Most grid cells were classified into the same erosion class because localized areas of sheet erosion predominated. A reconnaissance survey of the study area revealed that active and extensive gullies were not common, and indicated the impracticability of using Weaver's (1988a, b and c) method. The discernable dominant consistent and random grouping of the factors influencing the distributional characteristics of the erosion risk factors, gave a priori grounds for expecting a normally distributed data base. A method that was amenable to an interval scale of measurement, and analysis using the much stronger parametric statistical tests was therefore sought in preference to Weaver's (1988a, b and c) method. A pilot application of Thwaites' (1986) method showed that grids with a few small patches of erosion were accorded a much more serious erosion status than grids with a single very large expanse of erosion. It was therefore deemed unacceptable.

The method of estimating actual soil erosion ultimately accepted for use in this study involved tracing the eroded surfaces identified on aerial photographs onto transparent overlays superimposed with a scale adjusted grid framework, and then measuring the proportion of the grid cells covered by these surfaces. The same method was used for estimating the proportion of grid cells influenced by the different physiognomic vegetation classes and landuse practices from aerial photographs. The method used for estimating the proportion of grid cells covered by different rock and soil types, and vegetation communities, involved superimposing the grid framework onto the relevant map, and measuring directly from it. A reconnaissance survey of the study area revealed that the distribution of the eroded surfaces, as well as that of some of the attributes of the erosion risk factors, was patchy. As noted by Whitlow (1986), the estimates obtained from sampling such distributions are likely to be biased (refer section 6.4). All these data sources in every grid cell were therefore digitized. Measurments of the proportion of these surfaces within the 1 km^2 grid cells were expressed as a percentage of them. The measurements obtained from the peripheral cells which were transected by the boundry of the component parts of the study area, were expressed as a percentage of the proportion of the grid cell within the study area. The 'erosion surfaces' were then classified following the system used by Whitlow (1988) in Zimbabwe, viz:-

CLASS DESCRIPTION	PERCENTAGE OF GRID CELL ERODED
Not present	
Very localized	< 4
Localized	4.1 to 8
Moderate	8.1 to 12
Extensive	12.1 to 16
Very Extensive	> 16

TABLE 1: SPECIFICATIONS OF AERIAL PHOTOGRAPHS EMPLOYED IN THIS STUDY.

JOB NUMBER	SCALE	YEAR	MONTH	SUPPLIER
117/37c	1:25000	1937	September	Directorate of Surveys + Mapping
442	1:40000	1960	April	Directorate of Surveys + Mapping
608	1:20000	1970	June	Directorate of Surveys + Mapping
752	1:50000	1975	May	Directorate of Surveys + Mapping
6 : 83	1:30000	1983	June	Air Survey Co. of Africa Ltd.

The method used in this study based on measuring surfaces identified on sequential aerial photographs which ranged in scale from 1:20 000 to 1:50 000 (refer Table 1) contains a number of inherent sources of error including:- scale of photography; scale and accuracy of base map; data source relative to photograph's principle point; data source relative to junction between two or more base maps; variations in the relief of the data source surface; principle distance of camera lens; identification of control points, and pointing error in digitizing. Their influence in this study was minimized by the use of SPAM - a computerized 'Single Photo Aerial Mapping' technique developed by Barnes (1982). In digitizing the traced surfaces this technique 'corrects for' their influence using space resection and relief inputs for each photograph. The space resection computes the air station co-ordinates, and tilts or rotations of the camera axis using four control points from the photograph. The 1:10 000 orthophoto maps produced from 1:30 000 aerial photographs taken in 1983, were used as the base map to obtain the ground co-ordinates and altitude of the control points. When these points fell close to the junction of two or more orthophotos maps, their co-ordinates and altitude were checked against the 1985 edition of the 1:50 000 topocadastral maps drawn from the 1975 air survey work. Although the 1977 edition of these maps was drawn from the larger scale 1960 aerial photographs (refer Table 2), significant differences in the accuracy of the two editions in terms of the requirements of this study, were unlikely. The later metric edition was therefore selected for use.

The SPAM programme gives the user the option to check the pointing error. This is the operator's skill in returning the sensor to the commencement point, and keeping it on the traced line. This option involves redigitizing to obtain a second value. An error message is generated if either of the areas deviates by more than 10% from the mean value. This option was used to digitize the erosion and landuse surfaces. As the boundaries around the generally larger vegetation class surfaces were more subjective, such a high degree of accuracy of measurement was not merited. A pilot application of SPAM revealed that there was a high probability of the error message being triggered when measuring areas less than 2 mm^2. In using sequential aerial photographs of various scales, the threshold for data extraction is set by the smallest scale photographs (Broderick, 1987). The 2 mm^2 threshold set by the pointing error meant that areas smaller than this, or the ground equivalent of 0,5 ha, were not traced from the smallest scaled set of aerial photographs used in the study i.e. 1:50 000. A different threshold area was used on each set of aerial photographs, as it was scale adjusted to be equivalent to 0,5 ha on the ground.

Several studies discussed in chapter three indicate that the dry and wet rainfall cycles described by Tyson (1981, 1986) exert a significant influence on erosional activity. The use of sequential aerial photographs to estimate temporal variations in eroded surfaces may exaggerate this influence as they tend to be overestimated during dry cycles and underestimated during wet cycles. As will be explained more fully in section 7.2, the lightness of the tone of the panchromatic black and white vertical aerial photographs used in this study, is a key factor in the identification of eroded surfaces. During dry cycles surfaces that are not actively eroding may be identified as such, because of their lower antecedent soil moisture and sparser vegetal cover, and consequent higher reflectivity. During wet cycles eroded surfaces may be 'masked' by vegetative growth, and 'softened' by the generally darker tones associated with the generally higher antecedent soil moisture (Broderick, 1987).

In order to facilitate the assessment of the influence of wet and dry cycles on the erosion estimates obtained in this study, the percentage deviation of each year's M.A.P. from the study period's M.A.P. was computed for both components of the study area, as shown in Table 7. The procedure used to interpolate the rainfall data used is described in section 7.2.2. The M.A.P. for the study period was computed from 44 non-consecutive years of records between 1934 and 1983. The percentage deviation of the M.A.P. for the three year period before each set of photos were taken, from the M.A.P. for the study period was also computed as shown in Table 2. The three year M.A.P. was calculated as this period was perceived as the most likely to have exerted a significant influence on antecedent soil moisture and vegetal cover, and hence on the tonal characteristics of each set of aerial photographs. The accuracy of estimates of temporal variations in eroded surfaces obtained from sequential aerial photographs may also be influenced by variations in the season in which the sets were taken. Dry and wet rainfall seasons operate in the same manner as rainfall cycles described above, to over- and underestimate eroded surfaces, respectively. In order to facilitate the assessment of this seasonal influence, the month in which each set of aerial photographs was taken, is indicated in Table 1.

The restricted access to the Wilderness area component of the study area was the major consideration that influenced the selection of *purposive sampling* as the 'ground truthing' methodological approach for use in this study. Justice and Townshend (1981) recommend purposive sampling as the most practicable approach when faced with access constraints. The approach involves subjectively identifying 'typical' data source surfaces on the aerial photographs, and then checking their corresponding characteristics on the ground. Where there were several 'typical' surfaces to choose from, those closest to transport routes were examined on the ground, despite the likelihood that they were less typical than those further away. The systematic measurement of the ground attributes corresponding to these images was not perceived as necessary on three accounts. Firstly, the approach does not permit a formal statement of the representativeness of the attributes. Secondly, Justice and Townshend (1981) assert that the field verification obtained using it is very reliable provided the researcher has a local knowledge of the area. As this author had conducted research in the game reserve complex over several years, prior to the commencement of this study, this condition was perceived as having been met, refer Watson (1983), and Watson and Macdonald (1983). Thirdly, the field verification of these typical images took place from 3 to 49 years after they were captured on film.

7.2 DATA COLLECTION

7.2.1 Soil erosion

A Sokkisha mirror stereoscope fitted with X8 magnification lenses was used to trace surfaces affected by erosion from the five sets of sequential aerial photographs described in Table 1. Variations in the tone, texture, shadow and pattern of the photo image were used to identify and delimit the surfaces affected by erosion. As noted in section 7.1, in comparison to surfaces that are not actively affected by erosion, eroded surfaces generally have a lower antecedent soil moisture content and sparser vegetal cover, and consequently a higher reflectivity. Most of the soil formations present in the study area have B horizons that are distinctly lighter in colour than the A horizon (refer section 2.6.2). In such areas the lighter tone of eroded surfaces may be due to the higher reflectivity of the subsoil exposed in places where the topsoil has been removed. Photo images with non directional tonal patterns generally reflect ground surfaces affected by rainsplash and sheet erosion processes, while those with an anastomosing pattern of linearly arranged tones orientated downslope generally reflect the presence of rilling on the ground. In addition to their unvegetated banks, active gullies are distinguished from stable gullies by shadow patterns indicative of slumping (Keech, 1980; Gelmoth, 1981; Morgan, 1986).

As noted in section 7.1, when using sequential aerial photographs of various scales, the amount of detail extracted from each set has to be synchronized with that available on the set with the smallest scale. Photographic enlargement of the limiting set cannot restore details to the equivalence of that of the larger scaled sets as the scale at which the photograph is taken determines the amount of detail captured on film (Broderick, 1987). Stable gullies in the study area were not traced from the aerial photographs, as information on them was not perceived as essential for the fulfilment of the aims of this study. The spatial extent of active gullies was readily discernable on all the sets of aerial photographs used in this study, and formed a distinct data category. The ground verification of these gullies involved noting the presence of or evidence of two sets of attributes. The first set enabled confirmation of the gully as active, and included undercutting of the head; bank scouring; head, bank and piping seepage; evidence of flow from the depositional pattern and textural characteristics of the sediment on the channel bed; exposure of plant roots along the channel bed; exposure of bedrock along the channel bed; the type and extent of cover of any vegetation within the channel. The second set of attributes enabled identification of the gully type according to Dardis *et al.*'s (1988) classification of soil erosion forms in southern Africa (refer section 4.1). These attributes included:- the cross-sectional and plan geometrical form of the gully; the relative resistance of the surface layer of the host material; the relative homo- or heterogeneity of the texture of the host material and bed deposits; soil pipes; stone lines; calcrete nodules; Stone Age and Iron Age artefacts.

While sheet eroded surfaces were discernable from rill eroded surfaces on the larger scale sets of air photos, they could not be reliably distinguished on the smaller scale sets. Two categories of photo images associated with eroded surfaces could be identified on all sets of air photos. For the purposes of data collection, the very light, virtually white toned category, and the light, grey toned category were designated as 'actively eroding or eroded surfaces', and 'susceptible to erosion', respectively. Ground surveys showed that the very light category reflected two types of soil surface, both of which were virtually devoid of any type of vegetal cover. The first type was predominately represented by river deposits and comprised loose readily erodable sediments. Muddied grass blades bent downslope and splays of coarse material orientated downslope were noted as evidence of active erosional processes. The second type was not as spatially restricted, and comprized sealed or crusted surfaces. The following attributes were additionally noted as evidence of active erosional processes on these surfaces:- a slightly higher soil level on the upslope sides of stones and plants; soil pedestals capped by stones and protected by plants; and exposed plant roots. All the attributes noted above are listed in guides to the field detection of active erosion eg, Gelmoth (1981) and Morgan (1986).

Ground surveys showed that the light toned photo images reflected sparsely vegetated soil surfaces corresponding to overgrazed and overbrowzed rangelands throughout the study area, as well as abandoned and cultivated arable lands in the KwaZulu component of the study area. Following a technique described by Watson (1981), a $1m^2$ quadrat frame was used to estimate the percent basal and canopy cover at 30 randomly selected points in each of the areas surveyed. Without exception the estimates for the canopy and basal cover components were less than the 30% threshold below which the protective influence of vegetation diminishes, reported by Elwell and Stocking (1976). The potential for erosion therefore exists on these surfaces, hence their designation as 'susceptible to erosion'.

7.2.2 Rainfall erosivity

A two year record from Makamisa (refer Figure 2) comprised the only rainfall data available for the study area. Temporal variations in the M.A.P. of its component parts therefore had to be interpolated from rainfall stations outside the study area. The standard method used by the United States Weather Bureau described by Gilman (1964) was chosen for this purpose. Data for the 10 stations closest to the study area with the longest and most reliable records, were supplied by the Agricultural Catchments Research Unit of the University of Natal, Pietermaritzburg.

TABLE [illegible] : STATIONS USED TO INTERPOLATE RAINFALL DATA FOR STUDY AREA.

	FAIRVIEW	KWAMBONAMBI	ETEZA	RIVERVIEW	MTUBATUBA	KANGELA	MPILA	HLABISA	HLUHLUWE GAME RESERVE	EMPANGENI MILL
Years of Data	51	47	60	40	62	49	19	12	49	60
Altitude m.a.m.s.l.	76	30	46	47	38	76	244	472	427	74
Distance from the Sea - kms.	19,5	16,5	22,5	22	23,5	22,5	44,8	50	44	16
Direction from Study Area	SSE	SSE	SE	E	E	E	NW	NW	NNE	S
Mean Distance from Game Reserve Sites	31	34	30	33	32	33	10	27	28	43
Mean Distance from KwaZulu Sites	27	27	18	24	19	20	17	29	32	30
Mean Annual Rainfall - mm.	982,4	1387,0	973,7	845,6	929,3	882,4	673,6	1006,3	960,0	1093,5
% Deviation from MAR* 1935+1936+1937	+2,3	-23,0	+4,8	-5,6	-12,0	-4,4	-	-	+3,7	+4,3
% Deviation from MAR* 1958+1959+1960	+0,5	+ 1,5	-3,8	-	- 4,7	+1,6	-	-	-10,5	-1,7
% Deviation from MAR* 1968+1969+1970	-11,6	-13,7	-13,6	-18,5	-14,9	-17,4	-10,7	-4,3	-27,3	-7,2
% Deviation from MAR* 1973+1974+1975	+ 7,5	- 4,4	- 8,4	+ 7,0	+ 9,1	+ 4,0	+ 5,1	+0,9	+ 5,7	+1,8
% Deviation from MAR* 1981+1982+1983	- 4,3	- 8,3	-16,0	- 6,0	-20,6	-10,6	-29,7	-5,6	-14,3	-9,5

MAR* = mean annual rainfall.

This data was extrapolated to three sites spread over each of the study area's components, by adjusting for the influence of altitude, direction from the sea, direction and distance to sites from stations. Statistics on these inputs are given in Table 2. The average M.A.P. for the three sites was then computed.

A pilot application of the above method to 30 grid cells showed that the altitude inputs controlled the rainfall values computed. It's use to interpolate spatial variations in rainfall over the study area was not considered practicable as the lowest and highest altitude within each grid cell were already designated as data inputs to assess the topographic influence on erosion (refer section 7.2.4). As these data inputs were directly and accurately recorded from 1:10 000 orthophoto maps they also represented a more reliable data source. Given the paucity of data from automatic rain gauges and consequent reliance on interpolated rain amount data, the use of the EI_{30} or equivalent index described in section 5.2.1 to estimate temporal and spatial variations in rainfall erosivity was also not considered practicable.

7.2.3 Soil erodibility

The decision to use geology maps in association with soil maps to assess the influence of spatial variations in the study area's ground surface's resistance to erosion was based on the following considerations:- (i) as the soils in the study area are very young, the parent material is likely to exert a substantial influence on soil erodibility (refer sections 2.6 and 3.4.2; (ii) similar studies carried out in areas with very young soils cited in section 5.3.1, have found a significant relationship between the intensity and type of erosion, and the type of parent material; (iii) geology maps are more readily available than soil maps in other parts of the Mfolozi catchment where the results of this study may be of some relevance; and (iv) geology maps are primary maps used to a large extent in the production of soil maps. They may therefore represent a more reliable data source. Data on the geology of the Wilderness area were extracted from Downing's (1980a) map. Field verification of this data was not considered necessary as the original field work for the map had been carried out in association with by the late Professor L. King, a recognized exponent in this field (Downing, 1972). Data on the geology of the KwaZulu component of the study area was obtained from the Department of Geological Survey, Pietermaritzburg, at a stage when the maps covering the area were still in the process of being prepared. Field verification of this data resulted in substantial reductions in the area in the vicinity of Dlokodlo (refer Figure 2) mapped as Karoo dolerite, and consequent increases in the area mapped as Vryheid shale and sandstone. The data from this preliminary source was however, found to be very reliable for the remainder of the area.

Data on the soil formations present in the Wilderness area were extracted from an unpublished map prepared by the Department of Soil Science, University of Natal, Pietermaritzburg based on surveys carried out by Dr P.T. Spear in 1980, and earlier surveys carried out by Dr J.M. de Villiers. Although Venter's (1988) field verification of this map in an area immediately north of the Wilderness area, resulted in fairly substantial modifications to it, no such requirements were indicated by it's field verification in this study. Data on the soils in the KwaZulu component of the study area were extracted from a map prepared by this author by intergrating data extrapolated from the following sources (i) the modified geological survey map described above; (ii) a land type map that was still in the process of being prepared by the Department of Agriculture; (iii) descriptions of the soil formations associated with these land type units from MacVicar (1986) - the memoir of the published Mkuze land type map; (iv) unpublished field notes on the profile within 16 pits dug in the area, and laboratory reports on the samples taken from them, supplied by the Department of Agriculture; and (v) this author's field survey work.

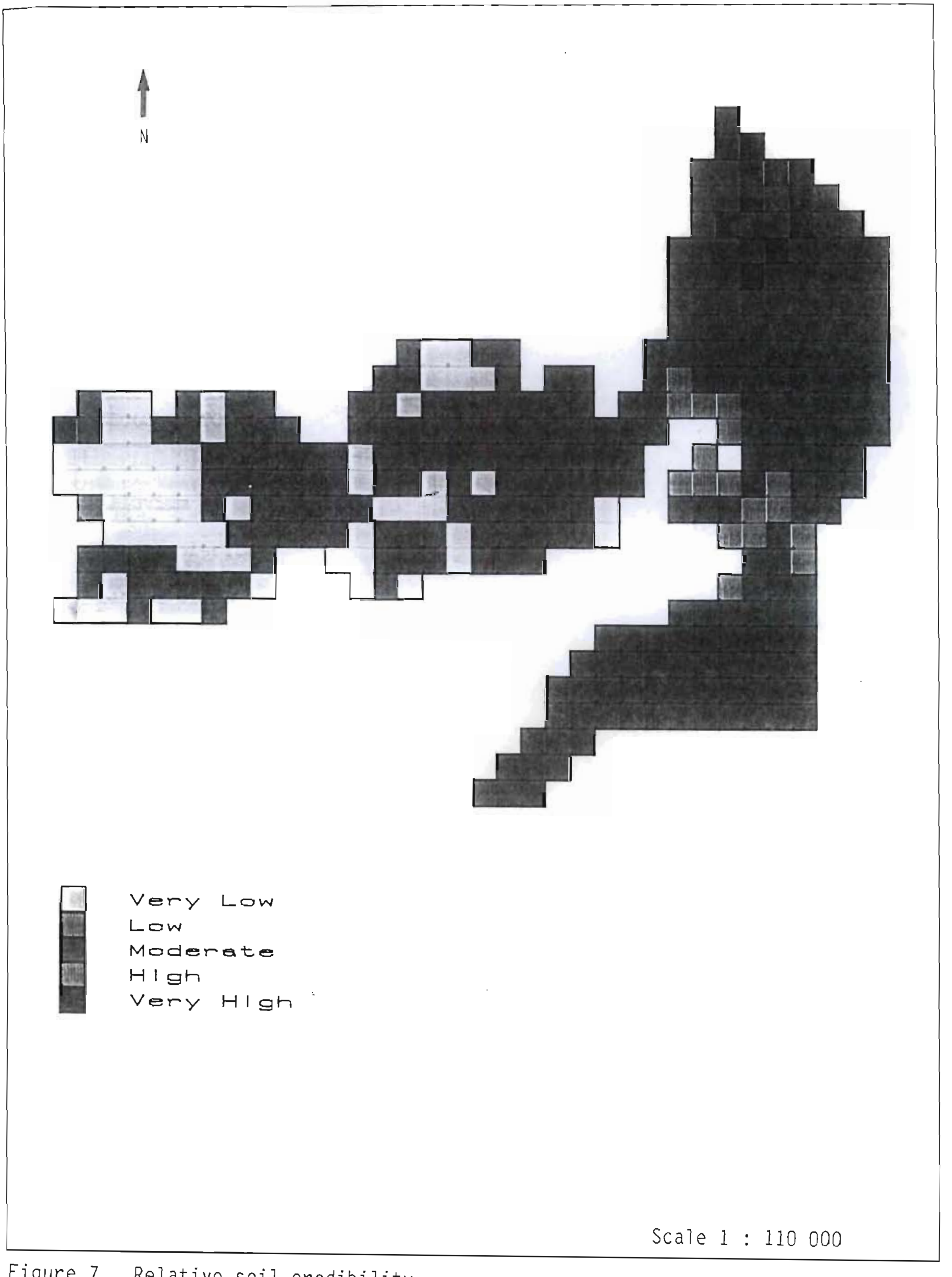


Figure 7. Relative soil erodibility.

The geology and soil maps for both components of the study area described above, were all prepared at a scale of 1:50 000. A scale adjusted 1 km^2 grid framework was superimposed directly onto each map. An electronic Tamaya planimeter was used to digitize the proportion of each grid square underlain by each geological formation, and covered by each soil formation.

TABLE 3 : SHOWING THE RELATIVE ERODIBILITY OF THE GEOLOGIC FORMATIONS.

GEOLOGIC FORMATION	K VALUE	RATING
Alluvium	0,85	Very High
Karoo Dolerite	0,19	Low
Letaba Basalt	0,19	Low
Clarens Sandstone	0,25	Low
Nyoka Shale + Sandstone	0,50	Moderate
Ntabene Sandstone	0,07	Very Low
Emakwezeni Shale + Sandstone	0,50	Moderate
Volksrust Shale	0,70	High
Vryheid Shale + Sandstone	0,38	Moderate
Pietermaritzburg Shale	0,70	High

The Department of Agriculture prescribed the following soil erodibility classification system for general use in South Africa (Crosby *et al.* 1983):-

ERODIBILITY CLASS	K VALUE RANGE
Very high	> 0,71
High	0,50 to 0,70
Moderate	0,25 to 0,50
Low	0,13 to 0,25
Very Low	< 0,13

This system was adjusted slightly so that the threshold values at for each class were exclusive to it. As no equivalent index relating erosion intensity to rock resistance was available, the above system was used to classify the geological formations' resistance to weathering as shown in Table 3, based on their descriptions presented in section 2.3 and more detailed stratigraphic information extracted from Kent (1980). Characteristics influencing and research findings on the relative erodibility of the soil formations are discussed in section 2.6.2. The consequent erodibility class ratings and corresponding K values accorded, are shown in Table 4. In calculating the overall soil erodibility class for each grid cell geology and soil were weighted equally in an attempt to minimize the duality of weaknesses associated with the geology maps being more accurate than the soil maps, and the soil's erodibility class ratings being more accurate than the geology's resistance to weathering class ratings. The overall K value for each grid square was calculated as follows:-

$$\frac{\frac{(G_1 \times K_{G1}) + (G_2 \times K_{G2}) + \ldots}{A} + \frac{(S_1 \times K_{S1}) + S_2 \times K_{S2}) + \ldots}{A}}{2}$$

where G_1 to G_{10} represents the proportion of the grid cell underlain by each of the ten possible geological formations in ha;

K_{G1} to K_{G10} represents the corresponding K value of each of these geological formations;

S_1 to S_{12} represents the proportion of the grid cell covered by each of the twelve possible soil formations in ha;

K_{S1} to K_{S12} represents the corresponding K value of each of these soil formations;

and A represents the proportion of the study area that falls within the grid cell in ha.

Once computed the overall K value for each grid square was stored for analysis, and it's corresponding erodibility class used in the choropleth map (refer Figure 7).

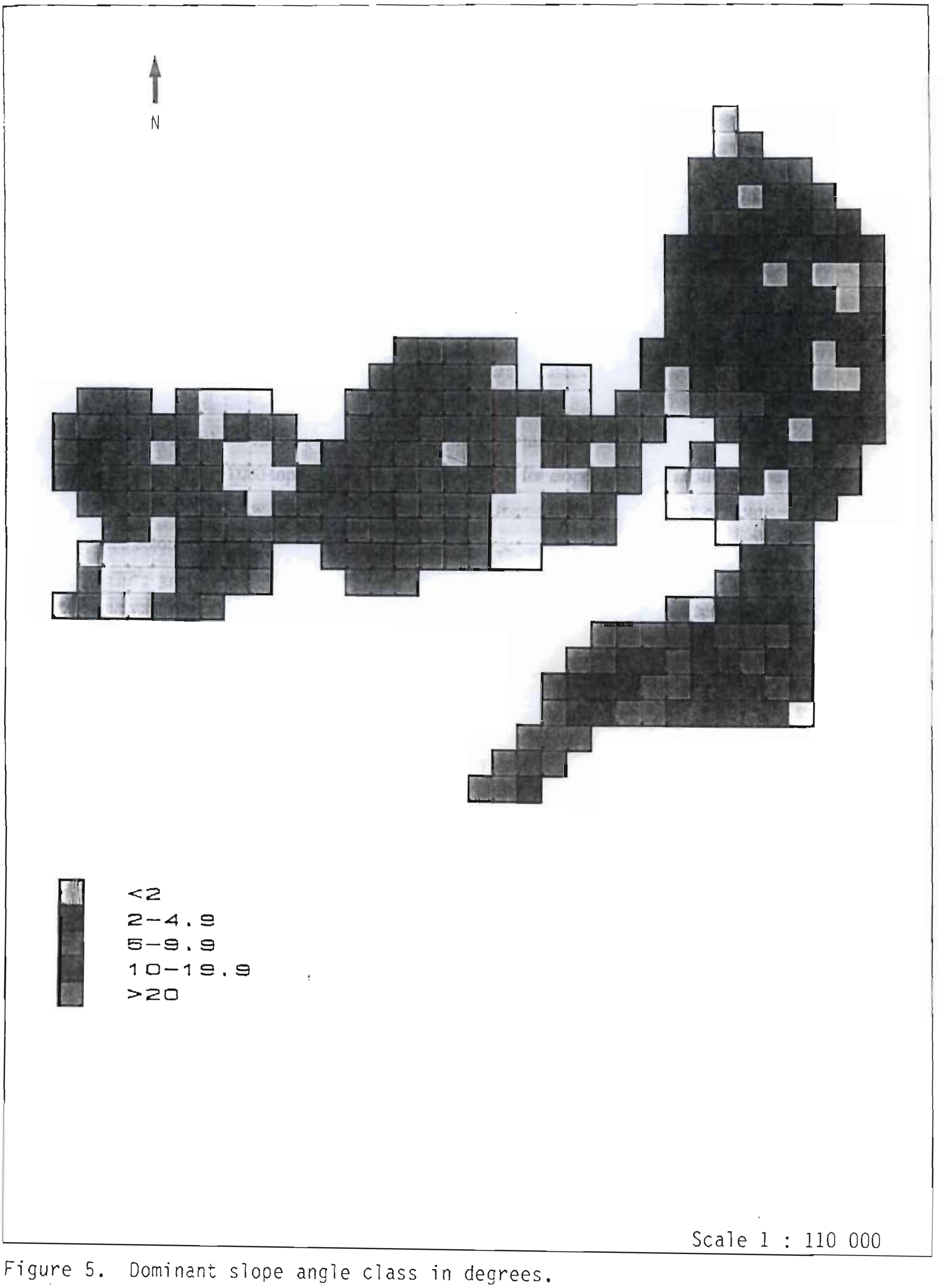


Figure 5. Dominant slope angle class in degrees.

7.2.4 **Topographic influence**

Based on the discussion on the influence of various topographic parameters in section 5.4, altitude; slope angle; slope length; and an index of the relationship between erosion and slope, were selected as those most likely to exert a significant influence in this mesoscale study. The control that altitude exerted on interpolated rainfall values at the microscale noted in section 7.2.1 reaffirmed it's significance. Altitude and slope length data were extracted from 1:10 000 orthophoto maps. A scale adjusted 1 km^2 grid framework was superimposed onto each map. The lowest and highest point above mean sea level; and

the length of the longest and shortest slope; and that of two other slopes subjectivity assessed as being representative of the majority present in the cell, were recorded.

Although the photo image on the 1:10 000 orthophoto maps facilitated easy and accurate identification of slopes, the 1:50 000 topocadastal maps were chosen for slope angle data collection because they gave a better synoptic view. Based on the distance between consecutive pairs of contours, slope segments were colour coded as one of the following slope angle classes:- less than 2^{O}; 2^{O} to 5^{O}; $5{,}1^{O}$ to 10^{O}; $10{,}1^{O}$ to 20^{O}; greater than 20^{O} (refer figure 5). The segments assigned to each class within each scale adjusted 1 km^2 grid cell superimposed directly on the topocadastral sheet, were digitized using a Tamaya planimeter and recorded. The following equation Qs $\tan^{m}$ QL^{n} described in section 5.4.1, was used as an index of the relationship between erosion and slope. A value of 1.8 for m was chosen for use in this study, based on Morgan's (1986) review of values assigned to exponent reflecting the influence of different soil erosion risk factor characteristics. Following Holy's (1980) recommendation a value of 0.6 or 0.5 was used for n dependent on whether Q was greater than or less than 10^{O}.

7.2.5 **Vegetation influence**

Using a X3 magnification mirror stereoscope, four vegetated textural surfaces were discernable on all five sets of aerial photographs. They were designated as:- grassland/reedbeds; wooded grassland; open woodland; and closed woodland/forest. A scale adjusted $500m^2$ grid framework was superimposed on 30 randomly selected areas of each of the textural classes, on each set of photographs. The vegetation at each intercept was identified as grass, scrub or tree on the basis of tone and canopy height, using a parallax bar in association with X8 magnification lenses. A woody canopy < 2m and > 2m in height, was identified as shrub and tree, respectively, following Watson and Macdonald (1983). Where vertical estimates were precarious because of poor photo resolution, identification was made on the basis of lateral canopy spread and similarity to other intercepts previously identified by canopy height.

Differences in the number of intercepts falling on grass, shrubs and trees in each of the textural classes, between the sets of photographs, were not significant. On average grass, shrubs and trees were identified at 84, 14, and 2% of the intercepts within the wooded grassland class, respectively; at 20,78, and 2% of the intercepts within the open woodland class, respectively; and at 6,7, and 87% of the intercepts within the closed woodland/forest class, respectively.

Field verification of these vegetation textural classes revealed that with the exception of the wooded grassland, the physiognomic terms used to designate the classes conformed very closely to their corresponding type descriptions in section 2.7.2. The ground layer of the wooded grassland class although apparently physiognomically very similar to the grassland type, contained a generally higher density of forbs and herbs, as well as a very variable density of inconspicuous young shrubs and trees. While the density of woody components rising above the ground layer was very variable, their canopies were generally too widely separated to form a distinct layer. They seldom attained heights in excess of three metres.

TABLE 4 : RELATIVE ERODIBILITY OF SOIL FORMATIONS.

SOIL FORMATION	K VALUE	RATING
Shortlands	0,13	Very Low
Rocky Shortlands	0,13	Very Low
Fernwood	0,85	Very High
Valsrivier/Dundee	0,60	High
Alluvium	0,70	High
Swartland/Sterkspruit	0,85	Very High
Sandy Swartland/Mispah	0,38	Moderate
Mayo	0,38	Moderate
Swartland	0,38	Moderate
Mayo/Mispah/Milkwood	0,38	Moderate
Mispah	0,38	Moderate
Mayo/Milkwood/Shortlands/Swartland	0,38	Moderate

The fourteen vegetation communities present in the study area were assigned to one of five relative soil erosion potential classes, as shown in Table 5. Their erosion potential rating was based on their following characteristics described in section 2.7.2:- (i) stage of seral development, (ii) the ground layer's presence; growth habit of dominant components; nature of cover afforded; density; height; and grazing pressure, (iii) the canopy layer's presence; vertical and horizontal structure; density; height; and browzing pressure, (iv) the overall effectiveness of fire within the community, and (v) factors promoting and/or resisting erosion associated with the soil and landfacets on which the communities characteristically occur, and the influence of these characteristics as described in section 5.5. Venter's (1988) percent canopy and basal cover, and soil loss (t ha^{-1} yr^{-1}) measurements for some of the above combination of community type; seral stage; and herbivore utilization pressure enabled the following threshold limits to be set for these classes:-

EROSION POTENTIAL CLASS	'C' VALUE RANGE
Very high	> 1,04
High	0,85 - 1,04
Moderate	0,65 - 0,84
Low	0,45 - 0,64
Very Low	0,24 - 0,44

The 'vegetation cover factor' values shown in Table 5 are the midpoints of the corresponding soil erosion potential classes.

Whateley's (1978) 1:20 000 unpublished map of the vegetation communities of the Umfolozi Game Reserve was used to determine the proportion in which each community was present in each textural class, because access to the Wilderness area component of the study area was restricted. As Whateley's (1978) map was based on the 1:20 000 aerial photographs taken in 1970, the boundaries of the textural classes defined in this study and traced from the 1970 set of photos, were superimposed on the map. A scale adjusted 500m grid framework was also superimposed on the map. Randomly selected areas of each textural class covering a total of 33% of the Wilderness area were used to extract two sets of data. Firstly, the area covered by each community within each textural class was expressed as a percentage of the total area covered by the respective classes. A Tamaya planimeter was used to digitize the areas directly from the map. Secondly, the number of grid intercepts recorded on each community within each textural class, was expressed as a percentage of the total number of intercepts examined within the respective classes. The percentages given in Table 6 are the average of these two data sets. As there was no significant difference between these data sets, the following method based on the same rationale as the second data set, was considered adequate to

TABLE 5 : RELATIVE SOIL EROSION POTENTIAL OF THE VEGETATION COMMUNITIES.

VEGETATION COMMUNITY	SOIL EROSION POTENTIAL VALUE	RATING
Ficus sycamorous - Schotia brachypetala	0,34	Very Low
Spirostachys africana - Euclea schimperi	0,34	Very Low
Spirostachys africana	0,54	Low
Euclea divinorum	0,74	Moderate
Acacia burkei	0,74	Moderate
Acacia nigrescens	0,54	Low
Acacia gerrardii	0,74	Moderate
Acacia tortilis	0,94	High
Combretum apiculatum	1,14	Very High
Acacia caffra	0,94	High
Acacia karoo	1,14	Very High
Themeda triandra - Urochloa mossambicensis	0,54	Low
Panicum coloratum	0,94	High
Phragmites mauritianus - Phragmites australis	0,54	Low

obtain field estimates in the KwaZulu component of the study area. Each woody species encountered on ten transects spaced 500m apart through each of the target areas of each textural class, selected using the purposive sampling procedure described in section 7.1, were identified and recorded. The number of strikes for each species or pair of species in the case of the forest communities, was expressed as the percentage of the total number of strikes within all the target areas of the respective classes, as shown in Table 6.

The 'vegetation cover factor' or 'C index' values for each textural class was computed as follows:-

$$\frac{(V_1 \times C_{V1}) + (V_2 \times C_{V2}) + \ldots}{100}$$

where:- V_1 to V_{14} represents the proportion of the textural class covered by each of the fourteen possible vegetation communities in percent (as taken from Table 6),
and C_{V1} to C_{V14} represents the corresponding soil erosion potential value of each of these communities (as taken from Table 5).

These values were then used to assign each textural class to a corresponding soil erosion potential class. As there was no significant difference in the average 'C' values of the respective textural classes between the two components of the study area, their respective averages given below, were used to compute the 'C' value for each grid cell, for each data set. That is, the area in ha of each cell covered by each textural class on each of the five sets of aerial photographs, was multiplied by the 'C' value corresponding to that textural class, and divided by the study area in ha within the respective cell.

TABLE 6: PROPORTIONS OF COMMUNITIES PRESENT IN THE VEGETATION CATEGORIES IN PERCENT.

VEGETATION COMMUNITIES	GRASSLAND/REEDBEDS		WOODED GRASSLAND		OPEN WOODLAND		CLOSED WOODLAND/FOREST	
	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU
Ficus sycamorous - Schotia brachypetala							16	20
Spirostachys africana - Euclea schimperi							9	15
Spirostachys africana							24	24
Euclea divinorum							7	
Acacia burkei					9		4	
Acacia nigrescens			12	8	26	27	18	22
Acacia gerrardii			5	8	27	12	7	
Acacia tortilis			17	27	14	18	15	19
Combretum apiculatum			9	14	11	15		
Acacia caffra			12	21	3	14		
Acacia karoo			34	22	10	14		
Themeda triandra - Urochloa mossambicensis	31	24	11					
Panicum coloratum	8	44						
Phragmites mauritianus - Phragmites australis	61	32						

VEGETATION TEXTURAL CLASS	SOIL EROSION POTENTIAL VALUE	RATING
Grassland/Reedbeds	0,61	Low
Wooded Grassland	0,75	Moderate
Open Woodland	0,74	Moderate
Closed Woodland/Forest	0,62	Low

7.2.6 **Landuse influence**

A scale adjusted 1 km^2 grid framework was superimposed on Penner's (1970) 1:50 000 archaeological map of the Wilderness area, and the number of Iron Age sites within each grid cell was recorded. An identical framework was superimposed on each of a series of unpublished 1:50 000 maps obtained from the N.P.B. showing the extent of the Wilderness area affected when veld burning took place over the years from 1955. The number of times each grid cell was burnt, and the average area burnt each time; over the four time periods between the five sets of aerial photographs (refer Table 1), was recorded. In order to obtain some measure of the influence of burning on the temporal and spatial variations in erosion, the above values were multiplied, and the resultant value entered as a 'burning factor'. Following the requirement noted in section 7.1, that the amount of detail extracted from each set of aerial photographs used, be synchronized with that available on the set with the smallest scale, vehicular and animal tracks clearly discernable on the larger scale sets were not recorded as only occasional segments of them, could be distinguished on the 1:50 000 set, using a mirror stereoscope with 8x magnification lenses.

In the KwaZulu component of the study area, roads; vehicular and animal tracks; and footpaths discernable on the 1:50 000 aerial photographs were traced first. A stereopair of photographs from this set with a high density of clearly discernable examples of these three route surface categories, was selected as a standard against which similar surfaces on the other sets of photographs, were distinguished as traceable. Purposive field verification of these route categories showed that the road surface, or span of a series of closely spaced, narrow, parallel tracks and paths, was generally wider than 3m. The area within each scale adjusted grid cell on each set of aerial photographs, affected by these route surfaces was calculated by multiplying their total cumulative length by a constant equivalent to this threshold width. Eight times magnification lenses were also used to determine the number of kraals or homesteads within each scale adjusted grid cell superimposed on the KwaZulu component of the study area, on each set of aerial photographs. The number of huts or free standing units per kraal, in a systematic sample of 100 kraals traversing the central portion of the KwaZulu component, on the largest scale 1970 aerial photographs, were counted.

The decision to collect the above available data on Iron Age sites and burning in the Wilderness area, and on kraals and roads; tracks; and paths in the KwaZulu component of the study area was motivated by the respective discussions of their influence on erosion, in section 3.4.4; 2.7; 2.9; 2.10; 5.6 and 5. . As noted in section 7.2.1 photo images of sparsely vegetated surfaces exhibiting evidence of being grazing land, and abandoned; fallow; or cultivated arable land, were recorded in the 'susceptible to erosion' data category. They were not additionally designated according to their landuse attributes, and separately recorded. An additional data set was recorded for those grids superimposed on the river and Mbubwini pan (refer figure 2), i.e. the proportion of the cell's surface covered by water.

The following lists provide an overall summary of the main data sets collected as described in section 7.2 above.

(i) Stable data sets obtained for:-

(a) the whole study area - grid number
study area within grid
10 geological formations
12 soil formations
K factor
2 altitude measures
4 slope length measures
5 slope angle classes
LS factor

(b) the Wilderness area - Iron Age sites

(ii) Unstable data sets from each of the five sets of aerial photographs, obtained for:-

(a) the whole study area - eroded surface
surface susceptible to
erosion
gullied surface
water surface
4 vegetation textural
classes
C factor

(b) the Wilderness area - 3 veld burning measures

(c) the KwaZulu component - roads

kraals

Additional sets collected to compute the K and C factors, included:- 5 soil erodibility classes for the whole study area, and 2 measures of 14 vegetation communities for a third of the Wilderness area.

7.3 DATA ANALYSIS

In total 126 data sets were collected. The number of 1 km^2 grid cells they were applicable to, ranged from a third of the Wilderness area; to the Wilderness area; to the KwaZulu component of the study area, to the whole study area (section 7.2). These data sets in matrix form were stored, manipulated, retrieved and displayed using a GIS grid based computerized overlay technique (section 6.4). The manipulations were very basic as were directed solely at enhancing the visual assessment of the choropleth maps. eg, identifying the dominant formation in each cell from the 10 data sets entered describing their geology. Although all data sets and various combinations of them were displayed as choropleth maps, only those maps contributing significantly to the visual assessment of erosion or of factors influencing erosion, are included in this thesis.

The first step in the computational assessment of this data base, involved determining whether the a priori grounds noted in section 7.1 for expecting it to be normally distributed, were operant in reality. Three techniques described by Fisher and Yates (1953) were used to achieve this. Most of the data sets were able to be classified as parametric using only the first technique. This involved plotting the frequency distribution of each data set, and ascertaining whether it's resultant form approximated the characteristic bell shaped curve of a normal distribution. Most of the balance of the data sets were found to be parametric, using the second technique. This involved ascertaining whether the positions of their mean, median and mode plotted on their respective distribution curves, approximately coincided. The parametric nature of the remainder of the data sets was indicated from the approximate straight line obtained when their distributions were plotted on semi-logarithmic graph paper.

Having established that the data base was normally distributed, the following parametric statistical tests were selected for use as they are recognized as being much stronger than the equivalent distribution free tests:- (i) The standard Analysis of Variance or F ratio test to assess the significance of difference between data sets. (ii) The standard Pearsons Product Moment Correlation Coefficient to measure the degree of association between data sets. (iii) Forward Stepwise Multiple Regression Analysis to explain the functional relationships between the data sets. A computer programme known as NWASTATPAK (Anon, 1988) that was capable of retrieving data directly from the GIS matrix, was used to carry out these tests.

The differences, degrees of association, and relationships between data sets tested for in this study, were accepted as significant at a 95% confidence level, i.e. if the probability of their being due to chance was less than 5%. Three probability levels are generally used viz:- 99,9%; 99% and 95%. The level selected is not dependent on objective criteria being met as they are actually arbitrarily chosen values indicating the degree of confidence the researcher can place in his results, and implemented in the interests of standardization (Shaw and Wheeler, 1985). The upper limit was selected for use in this study as small chance occurrences are unlikely to be of dire consequence in any future application of the findings of this study. As close to 400 1 km^2 grid cells were superimposed on the study area, with the exception of the vegetation community data sets, the number of data inputs for each variable was in excess of the degrees of freedom limit at which a coefficient as low as 0,146 is significant at a 5% probability. To improve this value the data for each set was cumulated into the standard of 30 inputs set by the Central Limit Theorem, following Fisher and Yates (1953). The 0,349 correlation coefficient value threshold used for selecting variables for the Forward Stepwise Multiple Regression Analysis corresponds to 30 degrees of freedom at a 5% probability level.

Several recent comparable studies have recognized that Stepwise Multiple Regression Analysis is the best multivariate technique available for the type of computational assessment required in this study eg: Stocking (1972), Liggitt (1988), Whitlow (1988) and Liggitt and Fincham (1989). The rationale of this technique, and it's particular relevance in geographical analysis, is explained in detail by Draper and Smith (1967), and Shaw and Wheeler (1985), respectively. The main attributes of Forward Stepwise Multiple Regression Analysis that motivated it's selection for use in this study, include:-

(i) **The Multiple Regression Procedure** predicts and explains the variation of a single criterion/dependent/Y variable, from a number of predictor/explanatory/independent/X variables. While the X variables are independent of the Y variable, interdependence between the X variables may range from being completely independent, to collinearity, with one variable being either a linear or nonlinear function of the others.

(ii) **The Forward Selection Procedure** is a method of assessing the relative importance of Y variables. The test starts by regressing the variables with the highest zero-order correlation against the X variable. As each variable is entered there is an increase in the regression (explained) sum of squares. A small change in R^2 apparently incommensurate with the addition of well correlated variables, reflects the multicollinearity of the independent variables and the fact that their combined effect is partly duplicative and not separately additive. In general, multicollinearity becomes more severe as the number of variables increases.

(iii) **The Stepwise Regression Procedure** involves the re-examination at every stage of the regression of the variables incorporated into the equation/model in previous stages. A variable which may have been the best single variable to enter at an early stage may, at a later stage, be superfluous because of the relationships between it and other variables now in the regression. To check on this, the partial F criterion for each variable in the regression at any stage of calculation is evaluated and compared with a preselected percentage point of the appropriate F distribution. This provides a judgement on the contribution made by each variable as though it had been the most recent variable entered, irrespective of its actual point of entry into the equation. Any variable that provides a non-significant contribution is removed from the equation. This process is continued until no more variables will be admitted to the equation and no more are rejected.

CHAPTER EIGHT

RESULTS AND DISCUSSION

The findings of this study are discussed in three parts. The first part examines the potential influence of natural and anthropogenic factors on the study area's inherent susceptibility to erosion. The similarities in the natural parameters, and in the anthropogenic influence prior to the early 1950's, between the two components of the study area, was a key factor motivating it's use in this study. While these similarities are apparent in the description of the study area in chapter 2, some differences in characteristics that may exert a significant influence on erosion, are also indicated. The findings presented in this part give quantitative support to the predominately qualitative descriptions in chapter 2, as well as a measure of the significance of differences between the two study area components. These differences indicate that the approach described in section 1.2 of assessing the influence of traditional landuse practices on erosion by comparing the KwaZulu component's pre- and post- early 1950's erosion is sounder than that of comparing the erosion in the two components of the study area. The second part describes the temporal and spatial variations in the categories of 'erosion surfaces' included in this study, and gives an indication of the contemporary status of erosion. The third part assesses the extent to which the erosion risk factors examined in the first part, have contributed to the findings described in the second part. In doing so it identifies those factors most likely to exert a significant influence on erosion and hence management options, in the balance of the 10b bioclimatic subregion of the KwaZulu portion of the Mfolozi catchment.

8.1 POTENTIAL EROSION

8.1.1 Rainfall erosivity

The description of the potential influence of rainfall and its associated runoff on soil erosion presented in section 5.2, and of estimates of the study area's M.A.P. and rainfall erosivity presented in section 2.5.1, suggest that rainfall has the potential to remove more soil from the KwaZulu component of the study area than the Wilderness area. This suggestion is affirmed by the findings of this study. The results of the interpolation procedure described in section 7.2.2 are shown in Table 7. Their analyses show that differences between the Wilderness area and the KwaZulu component of the study area are significant ($F = 5{,}36$), and that a high and significant degree of association ($r = 0{,}74$) exists between variations in their highly variable ($V = 25{,}8$ and $25{,}2\%$, respectively) respective data sets. Their respective average M.A.P. computed from these data, of 694 and 820 mm is 65 mm less than, and 8 mm more than the respective values estimated by Pitman *et al.* (1981).

TABLE 7 : INTERPOLATED RAINFALL DATA FOR STUDY AREA.

YEAR	RAINFALL mm GAME RESERVE	% DEVIATION FROM MAR*	RAINFALL mm KWAZULU	% DEVIATION FROM MAR*	YEAR	RAINFALL mm GAME RESERVE	% DEVIATION FROM MAR*	RAINFALL mm KWAZULU	% DEVIATION FROM MAR*
1924	744	-10,4	950	+15,6	1962	583	-16,0	654	-20,2
1925	317	-54,3	605	-26,2	1963	750	+ 8,1	1141	+39,1
1926	918	+32,3	934	+13,9	1964	679	- 2,2	721	-12,1
1927	[illegible]	+24,9	889	- 8,4	1965	524	-24,5	339	[illegible]
1928	600	-13,5	677	-17,4	1966	643	- 7,3	616	-24,9
1929	[illegible]	-31,7	976	+19,0	1967	719	+ 3,6	760	- 7,3
1940	1026	+47,8	1053	+28,4	1968	521	-24,9	672	-18,0
1945	549	-20,9	604	-26,3	1969	605	-12,8	746	- 9,0
1946	685	- 1,3	574	-30,0	1970	598	-13,8	673	-17,2
1947	747	+ 7,6	879	- 7,2	1971	789	+13,7	1132	+38,0
1948	405	-41,6	576	-29,8	1972	727	+ 5,0	980	+19,5
1949	917	+32,1	947	+15,5	1973	600	-13,5	947	+15,5
1950	569	-18,0	659	-19,6	1974	531	-23,5	679	-17,2
1951	526	-24,2	649	-20,9	1975	992	+42,9	922	-12,6
1954	696	+ 0,3	968	+18,0	1976	909	+31,0	1148	+40,0
1955	713	+ 2,7	805	- 1,8	1977	950	+36,9	1141	+39,1
1956	697	+ 0,4	1240	+51,2	1978	768	+10,7	935	+14,0
1957	860	+23,9	916	+11,7	1979	478	-31,1	733	-10,6
1958	998	+43,8	775	- 5,5	1980	447	-35,6	489	-40,4
1959	544	-21,6	509	-37,9	1981	782	+12,7	1109	+35,2
1960	923	+33,0	1100	+34,1	1982	401	-42,2	548	-33,2
1961	756	+ 8,9	923	+12,6	1983	546	-21,3	601	-26,7

MAR* = mean annual rainfall.

The description of the potential influence of dry and wet cycles, and seasons on the accuracy of estimates of temporal variations in erosion obtained from sequential aerial photographs presented in section 7.1, suggests that the 1970 and 1983 sets may have overestimated erosion by about the same degree. The average deviation from M.A.P. over the three year period assumed to exert a significant influence on the tonal characteristics of aerial photographs (refer section 7.1), prior to both sets was -17%. Both sets were taken in the middle of the dry season. By the same token, the data extracted from the 1937 set are likely to have provided the most accurate estimates of erosion, as the rainfall over the three year period prior to when they were taken, did not deviate significantly from the M.A.P. If anything, erosion may have been slightly overestimated using them, as they were taken at the end of the dry season. Although erosion may have been underestimated by the use of both the 1960 and 1975 sets, the underestimation involved in the use of the 1960 set is likely to have been substantially greater because the average deviation from M.A.P over the three year period prior to when they were taken was + 18,4% whereas it was only + 1,9% over the same period prior to the 1975 set. Also the 1960 set were taken at the end of the wet season, whereas the 1975 set were taken early in the dry season.

8.1.2 Soil erodibility

On the basis of the potential influence of geology on erosion (refer section 5.3 and Table 3), it's description in section 2.3 suggests that the Wilderness area is more susceptible to erosion than the KwaZulu component. This suggestion is affirmed by the findings of this study. Tables 8 and 9 show that while erodible and moderately erodible formations are significantly better represented in the Wilderness area, the resistant and very resistant formations are significantly better represented in the KwaZulu component.

On the basis of the potential influence of soil on erosion (refer section 5.3 and Table 4), it's description in section 2.6 and figure 6, suggests that the Wilderness area is less susceptible to erosion than the KwaZulu component. Although it apparently contradicts the geologic influence noted above, this suggestion is affirmed by the findings of this study presented in Table 10. Only Valsrivier/Dundee and sandy Swartland/Mispah occur in both components. An Analysis of Variance of them (F = 1.66 and 0.02, respectively) revealed that there was no significant difference in their representation between the components. The incorporation of the alluvium represented in the game reserve, into the Valsrivier/Dundee form did not change the F ratio test finding. While the very highly erodible and moderately erodible forms are significantly better represented in the KwaZulu component, very resistant forms are only represented in the Wilderness area.

Tables 11 and 12 show that there is no significant difference in the representation of the very highly and highly erodible surfaces between the study area components. However, the moderately erodible surfaces are significantly better represented in the KwaZulu component, while the resistant and very resistant surfaces only occur in the Wilderness area. An Analysis of Variance of the K values derived for the study area components, revealed that there was no significant difference in their susceptibility to erosion (F = 0,73). This overall comparability in erodibility is no doubt primarily due to the equal

TABLE 8 : GEOLOGIC FORMATIONS AS PERCENTAGE OF 1 KM^2 GRID CELLS.

GEOLOGIC FORMATION	GAME RESERVE			KWAZULU		
	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE
Alluvium	3	9	0-48	2	6	0-22
Karoo Dolerite	30	30	0-90	5	7	0-22
Letaba Basalt	1	4	0-16	38	38	0-100
Clarens Sandstone				3	3	0-10
Nyoka Shale + Sandstone	5	9	0-34	10	11	0-37
Ntabene Sandstone	2	5	0-14	6	7	0-28
Emakwezeni Shale + Sandstone	3	9	0-36	11	14	0-42
Volksrust Shale	2	6	0-23	2	4	0-13
Vryneid Shale + Sandstone	47	33	0-97	23	32	0-100
Pietermaritzburg Shale	7	21	0-81			

Note: the mean values are equivalent to the percentage of the study area covered by the various geologic formations.

TABLE 9 : SIGNIFICANCE OF DIFFERENCES IN THE GEOLOGY OF THE STUDY AREA'S COMPONENTS.

GEOLOGIC FORMATION	F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL
Alluvium	0,86	No
Karoo Dolerite	23,59	Yes
Letaba Basalt	29,89	Yes
Clarens Sandstone	KwaZulu Only	Yes
Nyoka Shale + Sandstone	3,44	No
Ntabene Sandstone	5,79	Yes
Emakwezeni Shale + Sandstone	6,24	Yes
Volksrust Shale	0,19	No
Vryheid Shale + Sandstone	8,79	Yes
Pietermaritzburg Shale	Game Reserve Only	Yes

TABLE 10 : SOIL FORMATIONS AS PERCENTAGE OF 1 KM^2 GRID CELLS.

PEDOGENIC FORMATION	GAME RESERVE			KWAZULU		
	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE
Shortlands	25	20	0 - 76			
Rocky Shortlands	9	7	0 - 29			
Fernwood	2	3	0 - 12			
Valsrivier/Dundee	5	4	0 - 15	9	17	0 - 67
Alluvium	7	7	0 - 19			
Swartland/Sterkspruit				6	18	0 - 84
Sandy Swartland/Mispan	25	14	1 - 48	25	26	0 - 85
Mayo				20	25	0 - 72
Swartland	14	15	0 - 50			
Mayo/Mispan/Milkwood				15	22	0 - 77
Mispan	13	8	0 - 31			
Mayo/Milkwood/Shortlands/Swartland				25	21	0 - 67

Note: The mean values are equivalent to the percentage of the study area covered by the various soil formations.

weighting accorded to the geology and pedology in calculating each grid cell's K value. It may also reflect the strong influence of highly erodible materials such as alluvium, Volksrust shale and Valsrivier/Dundee soils, that are similarly represented in the study area components, as well as the predominate influence of well represented similar materials such as Karoo dolerite and Letaba basalt; Vryheid, Nyoka and Emakwezeni shales and sandstones; and various associations of Swartland, Mispah and Mayo soils.

Tables 13, 14, 15 and 16 identify the following significant associations between the topography, soils and geology within the major terrain types of the study area's components:-

i) In the game reserve's riverine terrain - very gentle and gentle short slopes with Fernwood and Valsrivier/Dundee soils and alluvium, and with Ntabene sandstone; Emakwezeni shale and sandstone; Volksrust shale and Pietermaritzburg shale.

ii) In the KwaZulu component's riverine terrain - very gentle and gentle short slopes with Valsrivier/Dundee soils and alluvium.

TABLE 11 : ERODIBILITY CLASSES AS PERCENTAGE OF 1 KM^2 GRID CELLS.

ERODIBILITY CLASS	GAME RESERVE			KWAZULU		
	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE
Very Low	34	21	2 - 85			
Low	2	3	0 - 14			
Moderate	48	17	8 - 77	85	21	0 - 100
High	5	5	0 - 18	8	16	0 - 59
Very High	11	10	0 - 26	7	18	0 - 84

Note: The mean values are equivalent to the percentage of the study area covered by the various erodibility classes.

TABLE 12 : SIGNIFICANCE OF DIFFERENCES IN THE ERODIBILITY OF THE STUDY AREA'S COMPONENTS.

ERODIBILITY CLASS	F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL
Very Low	Game Reserve Only	Yes
Low	Game Reserve Only	Yes
Moderate	53,75	Yes
High	0,86	No
Very High	2,21	No

TABLE 13 : RELATIONSHIPS BETWEEN SOIL AND GEOLOGY.

GEOLOGIC FORMATION	SOIL FORMATIONS	
	GAME RESERVE	KWAZULU
Alluvium	Fernwood (0,59)	Valsrivier/Dundee (0,84)
Karoo Dolerite	Shortlands (0,86)	Sandy Swartland/Mispan (0,81), Mayo/Mispan/Milkwood (0,[illegible])
Letaba Basalt		Mayo (0,84), Mayo/Milkwood/Shortlands/Swartland (0,77)
Clarens Sandstone		Mayo/Milkwood/Shortlands/Swartland (0,38)
Nyoka Shale + Sandstone	Swartland (0,38)	Mayo/Mispan/Milkwood (0,38)
Ntabene Sandstone	Alluvium (0,39), Swartland (0,80)	Mayo/Mispan/Milkwood (0,49)
Emakwezeni Shale + Sandstone	Alluvium (0,37), Swartland (0,57)	Sandy Swartland/Mispan (0,40)
Volksrust Shale	Valsrivier/Dundee (0,37), Alluvium (0,55), Swartland (0,77)	Sandy Swartland/Mispan (0,35), Mayo/Milkwood/Shortlands/Swartlands (0,47)
Vryheid Shale + Sandstone	Sandy Swartland/Mispan (0,40), Mispan (0,26)	Swartland/Sterkspruit (0,77), Sandy Swartland/Mispan (0,58)
Pietermaritzburg Shale	Alluvium (0,27)	

TABLE 14 : RELATIONSHIPS BETWEEN TOPOGRAPHY AND GEOLOGY.

GEOLOGIC FORMATION	TOPOGRAPHIC COMPONENT	
	GAME RESERVE	KWAZULU
Alluvium		
Karoo Dolerite	Highest Altitudes (0,76), Lowest Altitudes (0,81)	Slope Angles 10–20° (0,63)
Letaba Basalt	Slope Angles > 20° (0,44)	Slope Angles > 20° (0,47)
Clarens Sandstone		Shortest Slopes (0,40)
Nyoka Shale + Sandstone		Shortest Slopes (0,38)
Ntabene Sandstone		Shortest Slopes (0,47)
Emakwezeni Shale + Sandstone		Slope Angles > 20° (0,49)
Volksrust Shale		Slope Angles 10–20° (0,48)
Vryheid Shale + Sandstone		Highest Altitudes (0,55), Lowest Altitudes (0,79)
Pietermaritzburg Shale	Slope Angles < 2° (0,28), Shortest Slopes (0,42)	

TABLE 15 : RELATIONSHIPS BETWEEN TOPOGRAPHY AND SOIL.

SOIL FORMATION	TOPOGRAPHIC COMPONENT	
	GAME RESERVE	KWAZULU
Shortlands	Highest Altitudes (0,74), Lowest Altitudes (0,65)	
Rocky Shortlands	Slope Angles 10-20° (0,55), Altitudinal Range (0,50)	
Fernwood		
Valsrivier/Dundee		Slope Angles < 2° (0,71), Slope Angles 2-5° (0,47), Shortest Slopes (0,26)
Alluvium	Slope Angles < 2° (0,64)	
Swartland/Sterkspruit		Lowest Altitudes (0,62)
Sandy Swartland/Mispah		Slope Angle 10-20° (0,56), Lowest Altitude (0,42)
Mayo		
Swartland		
Mayo/Mispah/Milkwood		
Mispah	Slope Angles 5-10° (0,42), Shortest Slopes (0,41), Altitudinal Range (0,58)	
Mayo/Milkwood/Shortlands/Swartland		Slope Angles > 20° (0,68), Altitudinal Range (0,47)

TABLE 16 : RELATIONSHIPS BETWEEN TOPOGRAPHY AND ERODIBILITY.

ERODIBILITY CLASS	TOPOGRAPHIC COMPONENT	
	GAME RESERVE	KWAZULU
Very Low	Slope Angles 5-10° (0,51), Highest Altitudes (0,75), Lowest Altitudes (0,75), Altitudional Range (0,44)	
Low	Slope Angles 2°-5° (0,40), Highest Altitudes (0,41), Lowest Altitudes (0,50)	
Moderate		Slope Angles 10-20° (0,50), Slope Angles > 20° (0,37), Altitudinal Range (0,58)
High		Slope Angles < 2° (0,70), Slope Angles 2-5° (0,46), Shortest Slopes (0,38)
Very High	Slope Angles < 2° (0,65)	Highest Altitudes (0,35), Lowest Altitudes (0,62)

iii) In the game reserve's bottomlands - altitudinal range and moderately steep short slopes with Swartland; Mispah and sandy Swartland/Mispah soils, and with Nyoka shale and sandstone; Ntabene sandstone; Emakwezeni shale and sandstone and Vryheid shale and sandstone.

iv) In the KwaZulu component's bottomlands highest and lowest altitudes and very steep and steep slopes with Swartland and sandy Swartland/Mispah soils, and with Karoo dolerite; Emakwezeni shale and sandstone; Volksrust shale and Vryheid shale and sandstone, or lowest altitudes with Swartland/Sterkspruit soils, and with Vryheid shale and sandstone.

v) In the game reserve's uplands - very gentle and gentle short slopes with Valsrivier/Dundee soils and alluvium.

vi) In the KwaZulu component's uplands altitudinal range and very steep short slopes with Mayo; Mayo/Milkwood Shortlands/Swartland and Mayo/Mispah/Milkwood soils, and with Karoo dolerite; Letaba basalt; Clarens sandstone; Nyoka shale and sandstone and Ntabene sandstone.

8.1.3 Topographic influence

On the basis of the potential influence of topography on erosion (refer section 5.2) it's description in section 2.4, suggests that the Wilderness area is less susceptible to erosion than the KwaZulu component. This suggestion is affirmed by the findings of this study. Tables 17 and 18 show that very gentle, gentle and moderate slope angles are significantly better represented in the Wilderness area, while the steep, and very steep slope angles, and very long and very short slope lengths are significantly better represented in the KwaZulu component. The associations shown in Tables 14 and 15 reflect the much stronger stratigraphic influence in the KwaZulu component.

The overall assessment of Tables 8 to 18 inclusive, indicates that the 'erosion surfaces' identified in this study are likely to be well represented on (i) the very gentle and gentle, short slopes of the river valley plains covered by Fernwood and Valsrivier/Dundee soils developed on alluvium, (ii) the very steep and steep slopes underlain by the Volksrust shale. They outcrop east and immediately alongside of the strike traversing the study area and are covered by various associations of Swartland, Mispah and Mayo soils, and (iii) the very steep and steep slopes covered by Swartland/Mispah and Mispah soils and underlain by the Pietermaritzburg shale in the south west portion of the Wilderness area.

TABLE 17 : COMPARATIVE REPRESENTATION OF TOPOGRAPHIC VARIABLES IN STUDY AREA'S COMPONENTS.

TOPOGRAPHIC COMPONENT		GAME RESERVE			KWAZULU		
		MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE
*Slope Angles	< 2°	21	14	0 - 46	12	8	[illegible] - 32
	2-5°	44	11	19 - 60	23	[illegible]	14 - 37
	5-10°	27	13	5 - 60	19	5	12 - 30
	10-20°	5	5	0 - 18	40	11	15 - 59
	> 20°	3	2	0 - 10	6	[illegible]	1 - 31
Slope Lengths (In Metres)	Longest	798	95	588 - 1003	845	58	712 - 960
	Shortest	118	21	37 - 160	94	27	52 - 152
	Average	481	57	366 - 633	214	77	[illegible] - 425
Altitude (In Metres)	Highest	193	59	98 - 307	154	44	72 - 233
	Lowest	113	46	51 - 208	72	30	30 - 140
	Average	80	22	40 - 118	82	22	41 - 141

* slope angle class as percentage area of sampling unit.

TABLE 18 : SIGNIFICANCE OF DIFFERENCES IN THE TOPOGRAPHY OF THE STUDY AREA'S COMPONENTS.

TOPOGRAPHIC COMPONENT		F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL
Slope Angles	< 2°	9,55	Yes
	2-5°	78,59	Yes
	5-10°	6,71	Yes
	10-20°	236,80	Yes
	> 20°	5,98	Yes
Slope Lengths	Longest	5,42	Yes
	Shortest	15,15	Yes
	Average	206,19	Yes
Altitude	Highest	8,48	Yes
	Lowest	16,86	Yes
	Average	0,17	No

8.1.4 Vegetation influence

On the basis of the potential influence of vegetation on erosion (refer section 5.4), it's description in section 2.7 suggests that while the Wilderness area was less susceptible to erosion than the KwaZulu component throughout the study period. the potential for erosion progressively increased in both components. The findings of this study affirm that the Wilderness area's vegetation afforded it greater protection against erosion throughout the study period (Table 19). However, a progressive dimunition in this protection is not indicated in either component. In spite of significant changes in the proportions of both components covered by the textural classes during the intervals between the study years (Table 20), the Wilderness area's vegetation cover consistently afforded the soil about 15% more protection than the KwaZulu component's vegetation cover. Overall the vegetation in both components afforded moderate protection to the soil throughout the study period (Table 21).

The changes in the proportions of the Wilderness area covered by the vegetation textural classes during the intervals between the study years (Table 19), reflect the interrelationships between variations in rainfall, veld burning and herbivore utilization as described in section 2.7. The following significant correlations between changes in grassland and burning factor -0,47; -0,43; -0,39; and -0,68, for the intervals between 1937 and 1960; 1960 and 1970; 1970 and 1975; and 1975 and 1983 respectively, affirm that it's stability increases as the intensity of burning increases. The significant decrease in the hemicryptophyte classes and corresponding significant increase in the phanerophyte classes over the period from 1937 to 1960 (Figures 8 and 9) reflects the substantial bush encroachment that occurred during the 'nagana' campaign encouraged by the dramatically reduced herbivore stocking rates and the virtual exclusion of fire. The -0,44 and +0,48 significant correlation between changes in wooded grassland and open woodland over the same period, and the burning factor respectively, reflects the latter influence. The decrease in the hemicryptophyte classes over the period from 1960 to 1970 (Figures 9 and 10) reflects the continued bush encroachment facilitated by the ineffectiveness of fire on overgrazed veld. The increase in grassland over the period from 1970 to 1975 (Figures 10 and 11), and the inconspicuousness of woody elements in it in 1975, reflects fuel loads enhanced by above average rainfall and the increased game removal programme, and the consequent increased effectiveness of fire. The decrease in grassland and increase in wooded grassland over the period from 1975 to 1983 (Figures 11 and 12) reflects the competitive advantage gained by shrubs when drought causes grass mortality.

Throughout the study period short term reciprocal variations in open woodland and closed woodland/forest (Table 19) have been superimposed on the general trend in seral development towards the phanerophyte climatic climax. The significant increase in open woodland and

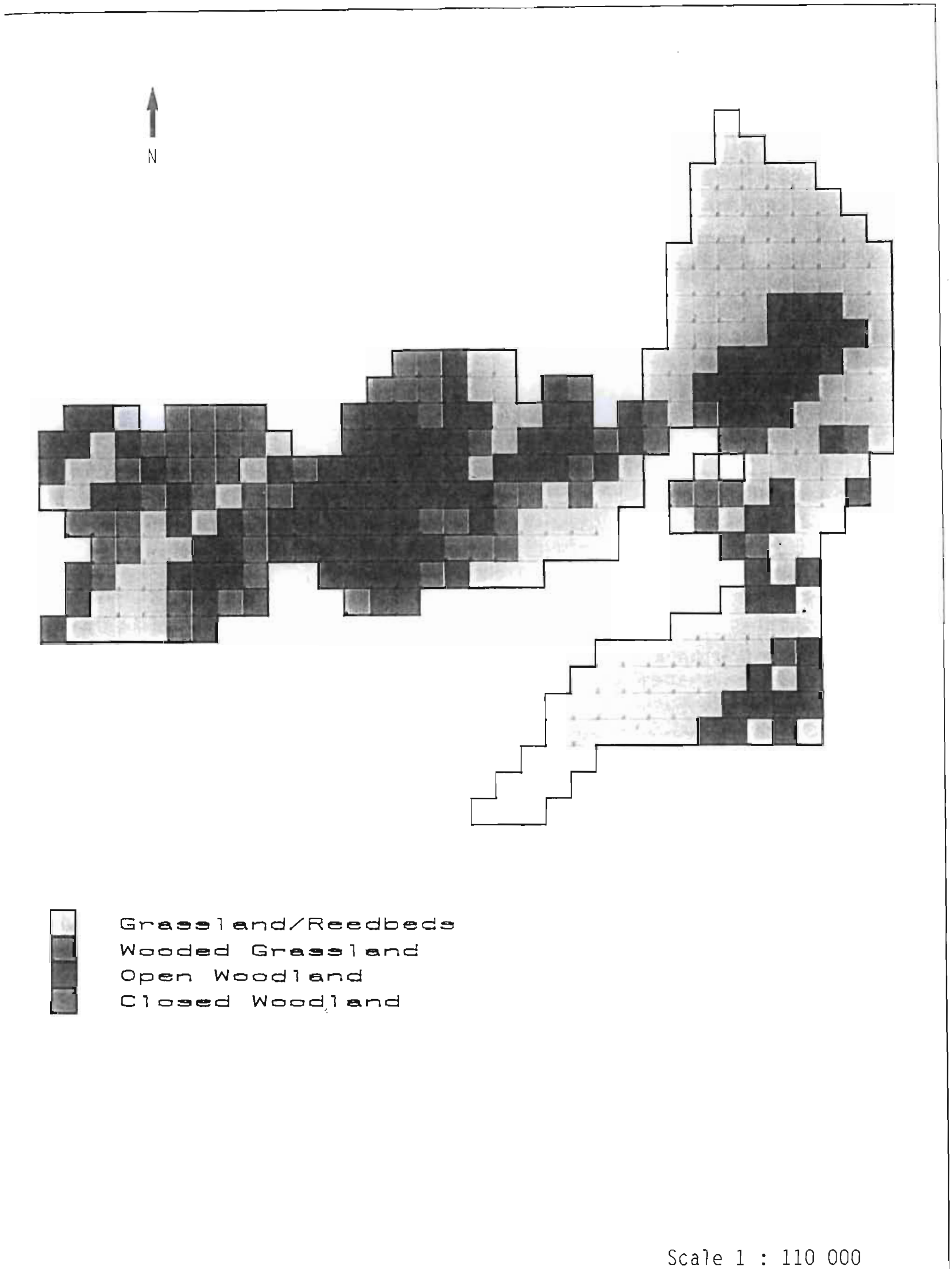


Figure 8. Dominant vegetation communities in 1937.

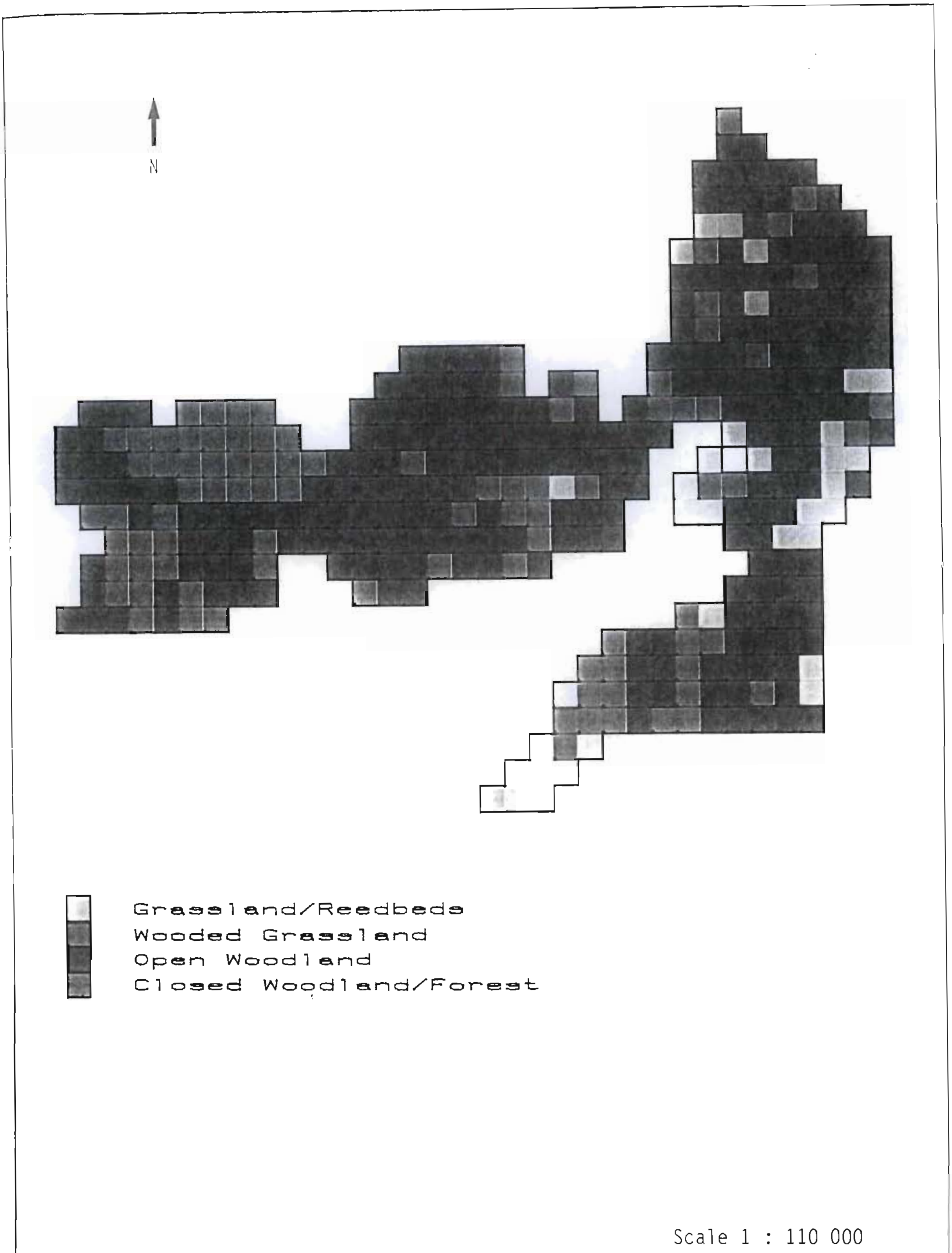


Figure 9. Dominant vegetation communities in 1960.

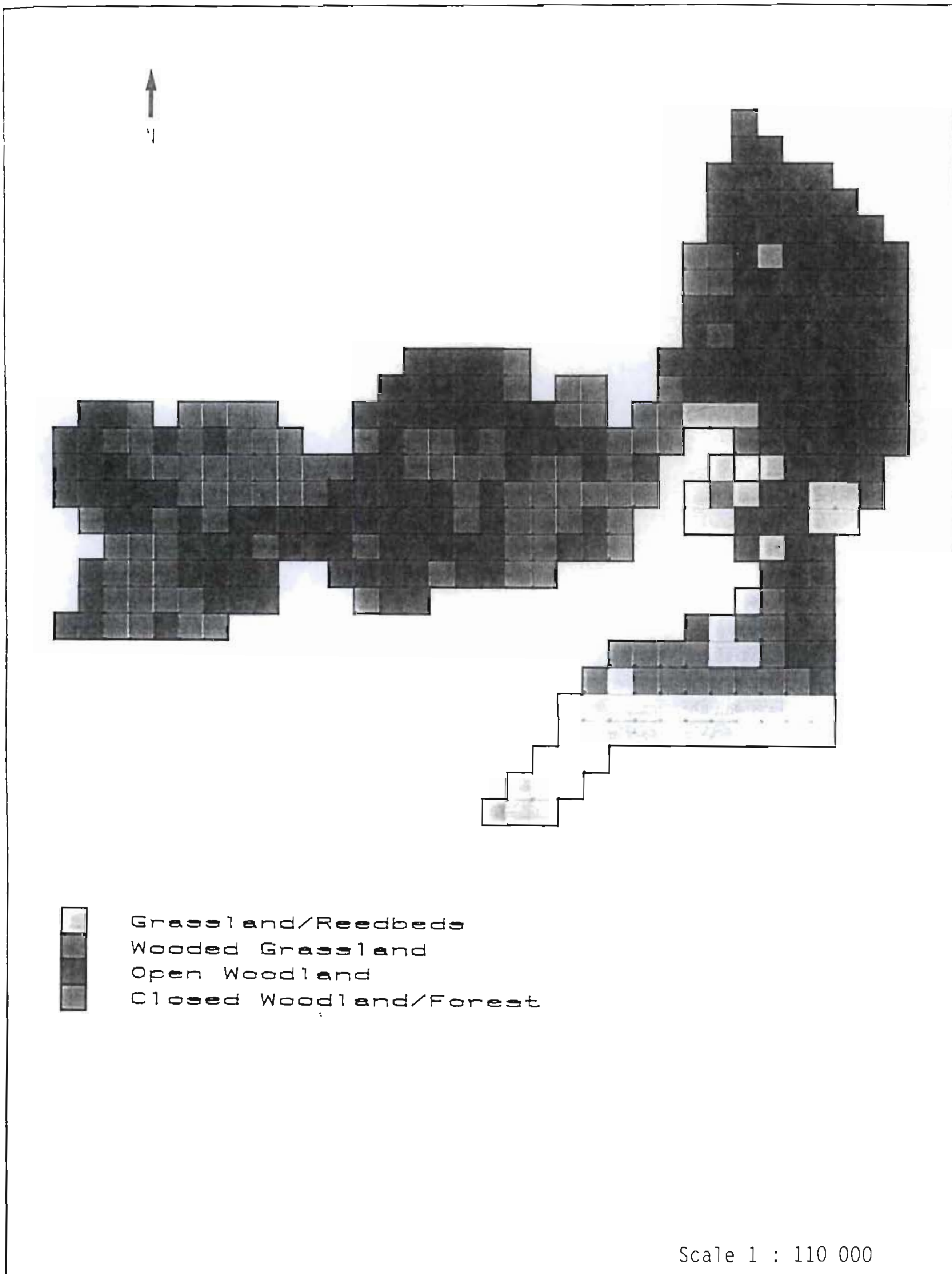


Figure 10. Dominant vegetation communities in 1970.

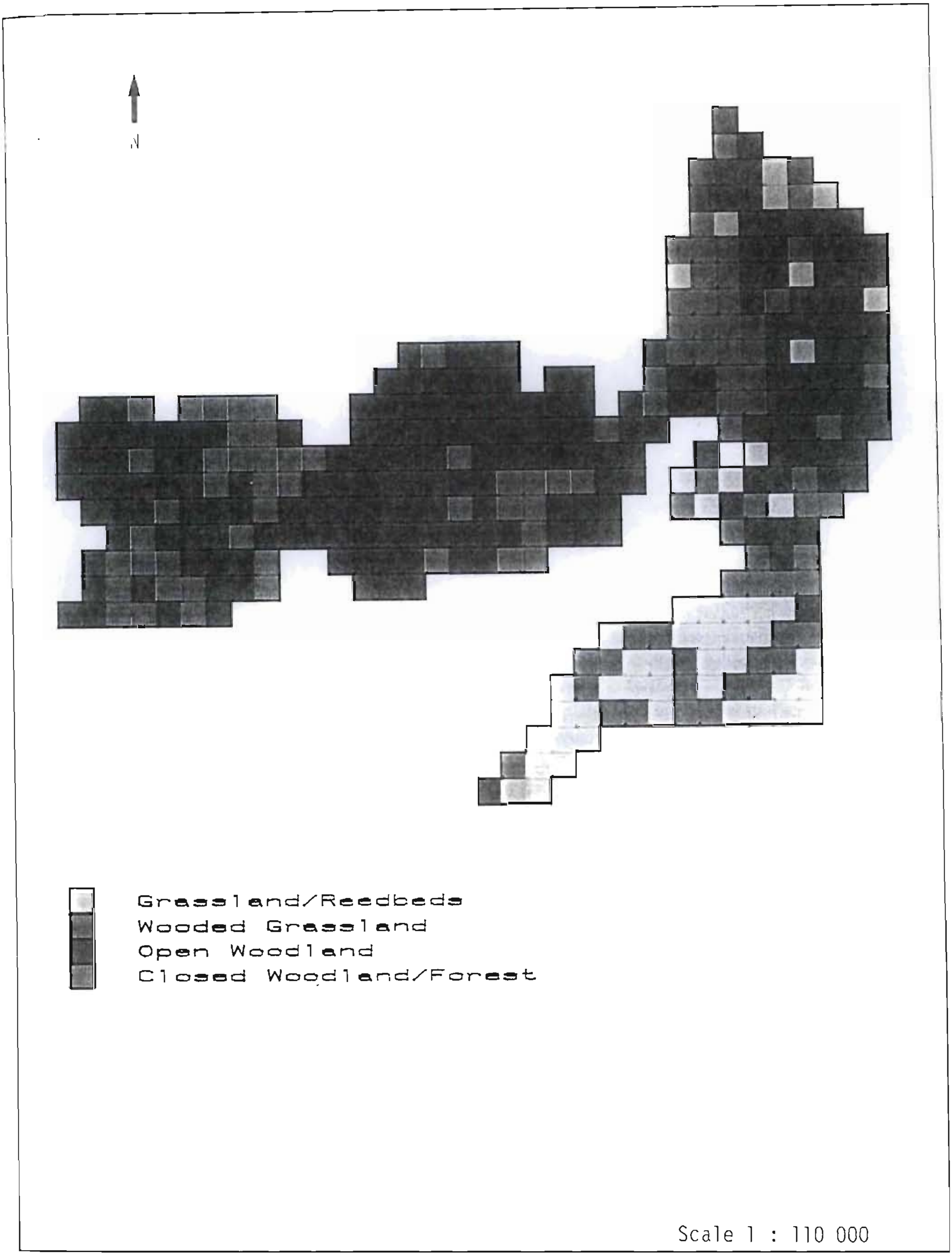


Figure 11. Dominant vegetation communities in 1975.

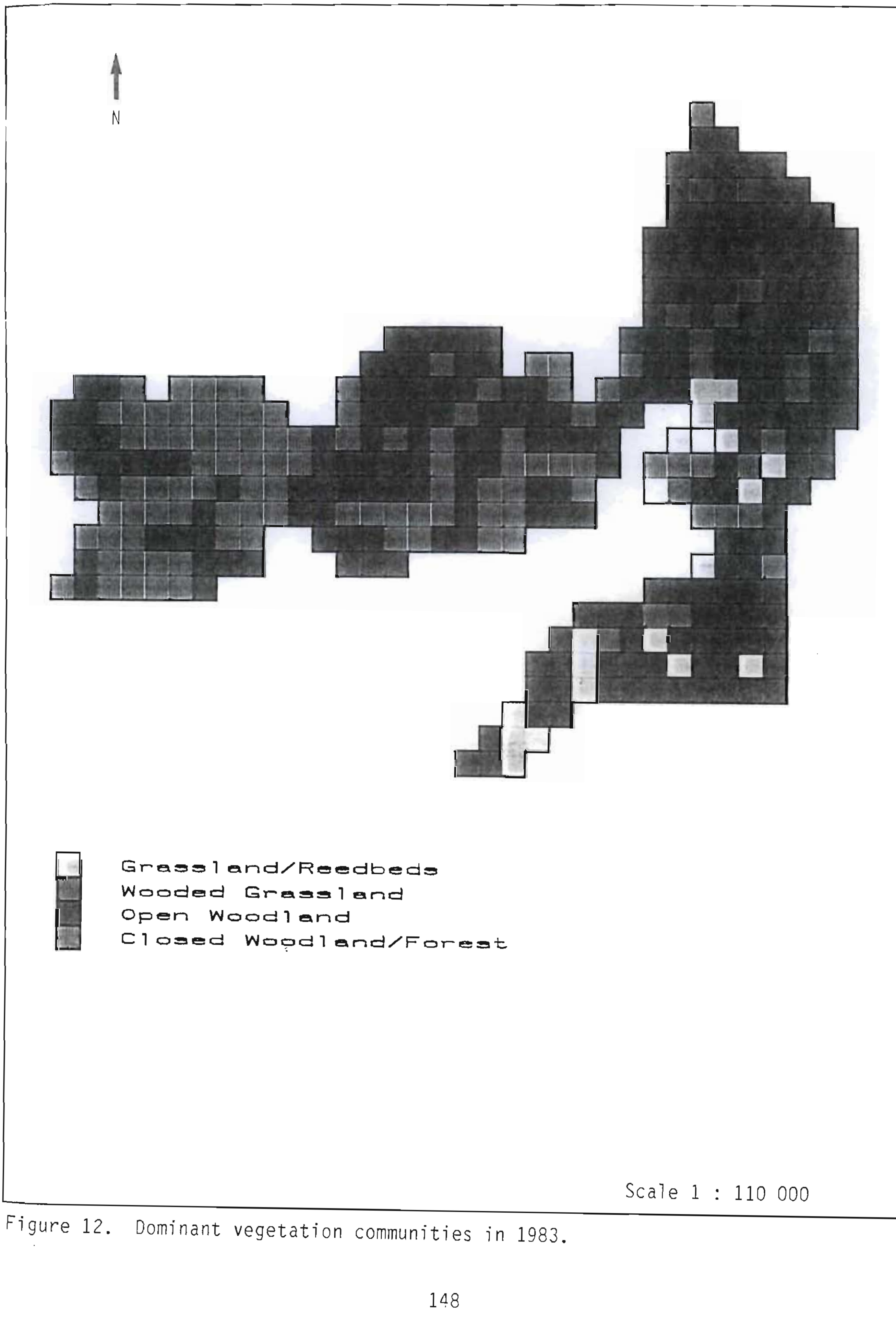


Figure 12. Dominant vegetation communities in 1983.

TABLE 19 : VEGETATION CLASSES AS PERCENTAGE OF 1 KM^2 GRID CELLS.

		GRASSLAND/REEDBEDS		WOODED GRASSLAND		OPEN WOODLAND		CLOSED WOODLAND/FOREST		VEGETATION COVER FACTOR	
	YEAR	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU
MEAN	1937	[illegible]	[illegible]	10,7	6,0	[illegible]	[illegible]	[illegible]	3,7	[illegible]	0,83
	1960	1,5	14,0	7,3	9,4	51,7	33,2	27,2	5,0	0,69	0,83
	1970	1,0	16,4	7,0	9,1	49,2	25,7	20,8	4,3	0,68	0,83
	1975	2,0	16,2	0	22,3	58,0	23,8	27,8	5,0	0,69	0,84
	1983	1,0	7,1	2,8	3,5	47,1	40,2	47,3	3,4	0,67	0,87
STANDARD DEVIATION	1937	6,5	15,4	11,2	9,6	18,1	25,1	16,2	3,8	0,04	0,04
	1960	2,8	15,1	9,8	8,5	17,4	16,2	15,3	5,4	0,03	0,03
	1970	1,5	17,9	7,9	13,9	20,1	22,3	13,4	4,7	0,04	0,03
	1975	2,7	18,4	0	12,1	17,0	18,5	15,2	5,0	0,03	0,02
	1983	1,9	3,3	4,3	4,0	18,5	11,4	13,5	7,8	0,03	0,03
RANGE	1937	0-26	0-51	0-59	0-39	13-78	4-100	5-68	0-43	0,53-0,73	0,70-0,87
	1960	0-11	1-77	0-31	0-33	25-92	2-68	5-61	0-24	0,61-0,73	0,77-0,88
	1970	0-6	0-59	0-32	0-57	6-64	3-73	3-76	0-22	0,61-0,73	0,76-0,88
	1975	0-9	0-58	0	1-50	35-95	0-50	5-65	0-25	0,63-0,73	0,80-0,88
	1983	0-6	0-26	0-18	0-16	11-82	13-63	18-78	0-27	0,62-0,72	0,76-0,86

TABLE 20 : SIGNIFICANCE OF DIFFERENCES IN THE VEGETATION OF THE STUDY AREA'S COMPONENTS.

YEAR	F VALUE	SIGNIFICANT AT A 95% CONFIDENCE LEVEL
1937	246,65	Yes
1960	354,89	Yes
1970	346,64	Yes
1975	416,51	Yes
1983	428,30	Yes

TABLE 21 : SIGNIFICANCE OF DIFFERENCES IN THE VEGETATION CLASSES AND COVER FACTOR BETWEEN THE STUDY YEARS.

		GRASSLAND/REEDBEDS		WOODED GRASSLAND		OPEN WOODLAND		CLOSED WOODLAND/FOREST		VEGETATION COVER FACTOR	
		F VALUE	SIGNIFICANT*	F VALUE	SIGNIFICANT*	F VALUE	SIGNIFICANT*	F VALUE	SIGNIFICANT*	F VALUE	SIGNIFICANT*
GAME RESERVE	1937-1960	[illegible]	Yes	[illegible]	No	[illegible]	Yes	0,61	No	[illegible]	No
	1960-1970	0,71	No	0,02	No	5,65	Yes	8,27	Yes	[illegible]	No
	1970-1975	3,04	No	24,06	Yes	15,26	Yes	7,54	Yes	[illegible]	No
	1975-1983	2,38	No	12,63	Yes	20,62	Yes	30,15	Yes	[illegible]	No
KWAZULU	1937-1960	1,43	No	1,08	No	10,90	Yes	0,79	No	[illegible]	No
	1960-1970	0,23	No	0,01	No	2,32	No	3,28	No	0,22	No
	1970-1975	0,00	No	15,42	Yes	4,99	Yes	0,26	No	0,51	No
	1975-1983	6,17	Yes	65,49	Yes	17,05	Yes	3,59	No	5,20	Yes

* significant at a 95% confidence level

corresponding significant decrease in closed woodland/forest in 1960 and 1975, reflects the effect of above average rainfall on the increased fuel load of the herbaceous ground layer in the closed woodland/forest, and consequent increased effectiveness of fire in penetrating it's communities and reverting them to less mature open woodland sere. The significant decrease in open woodland and corresponding significant increase in closed woodland/forest in 1970 and 1983, reflects the seral development of open woodland communities into closed woodland communities facilitated by the below average rainfall conditions reducing the vigour of herbaceous species, and rendering fire ineffective. The +0,47 and +0,47 significant correlation between changes in open woodland, and -0,54 and -0,39 significant correlation between changes in closed woodland/forest, over the study period between 1960 and 1970, and 1970 and 1975, and the burning factor respectively, reflects the differential effect of fire in these two phanerophyte textural classes.

The smaller proportion of the KwaZulu component of the study area covered by grassland in 1960 compared to 1937 reflects it's conversion to cultivated plots when the area was settled in the late 1950's. The larger proportions of grassland in 1970 and 1975 compared to 1960 reflects arable land left fallow over the dry season and invaded by herbaceous species. The substantial decrease in grassland evident on the 1983 aerial photographs reflects arable land abandoned during the severe drought and invaded by woody species. The variations in wooded grassland (Table 19) reflect the overall trend in seral development towards the phanerophyte climatic climax. The growth of woody species was rapidly and substantially stimulated during the above average rainfall conditions that prevailed during the mid-1970's. Such conditions simultaneously stimulated the stocking rate of domestic animals ensuring that fuel loads in the herbaceous layer remained inadequate to support the intensity of fires necessary to destroy the woody invaders. By 1983 succession in most of the areas identified as wooded grassland on the earlier sets of aerial photographs, had progressed to the extent that these areas were identified as open woodland.

The decrease in the KwaZulu component's open woodland over the period from 1937 to 1975 (Table 19) reflects it's degradation to sparsely covered surfaces. These light toned surfaces were categorized separately as 'susceptible to erosion' (refer section 7.2.1). Their corresponding increases are shown in Table 30, which is discussed in section 8.2. In 1937 open woodland was significantly better represented in the KwaZulu component than in the Wilderness area. During the early 1950's it's representation in the KwaZulu component was apparently comparable to the Wilderness area (refer section 2.7.3). Most of the degradation of almost a third of the open woodland in the KwaZulu component between 1937 and 1960 (Figures 8 and 9) must have therefore occurred following settlement in the late 1950's and reflects the major impact of deforestation associated with hut and fence construction. In addition to deforestation, the further degradation of almost a fifth of the remaining open woodland between 1960 and 1970 (Figures 9 and 10) reflects the resumption of annual early dry season veld burning, and overgrazing. Overgrazing is likely to have been more important than the effects of other poor landuse practices in accounting for the further degradation of a third of the remaining open woodland between 1970 and 1975 (Figures 10 and 11) when above average rainfall conditions stimulated the stocking rate of domestic animals. The reversal of the diminishing trend in open woodland in 1983 (Figure 12), is due to the bush encroachment of areas previously identified as wooded grassland, qualifying them for identification as open woodland, as noted above.

The decrease in the proportion of the KwaZulu component covered by closed woodland/forest between 1937 and 1970 (Table 19) reflects the influence of deforestation and the increased frequency with which fire penetrated their peripheral fringes, following settlement in the area. The increase in closed woodland/forest between 1970 and 1983 reflects a decrease in the frequency with which the margins were burnt due to the ineffectiveness of fire on overgrazed veld. It also reflects the effectiveness of the prohibition on wood harvesting (refer section 2.10.2) instituted by the local chiefs in 1974, and followed by four consecutive years of above average rainfall conditions which were condusive to the successional advancement and spatial expansion of the communities associated with these physiognomic types.

In addition to quantifying physiographic associations described in section 2.7.3, Table 22 affirms that riverine grasses and reeds predominately occur on very gentle slopes covered by very highly and highly erodible unconsolidated alluvial deposits and Valsrivier/Dundee soils underlain by Ntabene sandstone, Emakwezeni shale and sandstone, and Volksrust shale, and that the bottomland grasses predominately

TABLE 22 : RELATIONSHIPS BETWEEN VEGETATION CLASSES AND PHYSIOGRAPHIC VARIABLES IN THE STUDY AREA'S GAME RESERVE COMPONENT.

PHYSIOGRAPHIC CATEGORIES	VARIABLES	GRASSLAND/REEDBEDS					WOODED GRASSLAND					OPEN WOODLAND					CLOSED WOODLAND/FOREST				
		37	50	70	75	83	37	60	70	75	83	37	60	70	75	83	37	50	70	75	83
Topographic Components	Slope Angles <2°	0,36	0,36	0,50	0,37	0,54											0,37	0,69	0,73	0,79	0,59
	Slope Angles 5-10°						0,40						0,39	0,58	0,58	0,47					
	Slope Angles 10-20°						0,57						0,41	0,52	0,46	0,53					
	Shortest Slope Lengths																0,37	0,44		0,35	0,48
	Highest Altitudes						0,38							0,50							
	Lowest Altitudes													0,42							
	Altitudinal Range													0,47	0,48						
Erodibility Classes	Very High	0,42	0,51	0,49	0,71	0,64												0,47	0,52	0,42	
	High		0,38																		
	Low							0,50													
	Very Low													0,55	0,37						
Geologic Formations	Karoo Dolerite							0,43													
	Nyoka Sandstone & Shale	0,37	0,56			0,43			0,54												
	Ntabene Sandstone	0,42	0,66	0,46		0,40			0,37												
	Emakwezeni Shale & Sandstone	0,66	0,66	0,75	0,44	0,45					0,45										
	Volksrust Shale	0,62	0,88	0,65	0,61	0,64			0,36												
	Pietermaritzburg Shale																	0,36			
Soil Formations	Shortlands																0,42				
	Shortlands Rocky						0,58						0,49		0,42	0,43					
	Fernwood													0,39							
	Valsrivier/Dundee	0,56	0,53	0,40	0,43	0,44															
	Alluvium	0,40	0,59	0,54	0,71	0,65												0,37	0,44	0,33	
	Sandy Swartland/Mispah																				
	Swartland	0,42	0,68	0,61		0,37															
Hydrology	Proximity to River	0,54	0,62	0,45	0,77	0,48															

occur on Swartland soils underlain by Nyoka shale and sandstone. The decrease in the proportion of the variability in the grassland/reedbeds textural class explained by Nyoka shale and sandstone from a third in 1937 to zero in 1970 and 1975 reflects the progressive degradation of the bottomland grassland communities caused by herbivore overutilization and the consequent selective advantage gained by woody species. The increase in this proportion in 1983 reflects the encroachment of the bottomland

TABLE 23 : ANALYSIS OF VARIABLES INFLUENCING THE DISTRIBUTION OF VEGETATION CLASSES IN THE STUDY AREA'S GAME RESERVE COMPONENT.

VEGETATION COMMUNITY	YEAR	VARIABLES OF INFLUENCE - THEIR MULTIPLES ARE GIVEN IN BRACKETS	R^2
Grassland/Reedbeds	1937	Nyoka Sandstone & Shale (0,34), Valsrivier/Dundee (0,38), Emakwezeni Shale & Sandstone (0,66)	0,61
	1960	Nyoka Sandstone & Shale (0,26), Emakwezeni Sandstone & Shale (0,35), Volksrust Shale (0,94)	0,91
	1970	Slope Angles < 2° (0,34), Volksrust Shale (0,53), Emakwezeni Shale & Sandstone (0,75)	0,67
	1975	Valsrivier/Dundee (0,27), Alluvium (0,38), Proximity to River (0,77)	0,61
	1983	Nyoka Sandstone & Shale (0,40), Alluvium (0,65), Volksrust Shale (0,89)	0,68
Wooded Grassland	1937	Slope Angles 5-10° (0,34), Slope Angles 10-20° (0,36), Rocky Shortlands (0,58)	0,41
	1960	Karoo Dolerite (0,43)	0,16
	1970	Nyoka Sandstone & Shale (0,55)	0,21
	1983	Emakwezeni Shale & Sandstone (0,45)	0,21
Open Woodland	1960	Slope Angles 5-10° (0,26), Rocky Shortlands (0,49)	0,24
	1970	Highest Altitudes (0,19), Slope Angles 10-20° (0,28), Fernwood (0,37), Slope Angles 5-10° (0,58)	0,43
	1975	Rocky Shortlands (0,27), Slope Angles 5-10° (0,58)	0,33
	1983	Rocky Shortlands (0,21), Slope Angles 5-10° (0,28), Slope Angles 10-20° (0,53)	0,29
Closed Woodland/Forest	1937	Shortest Slope Lengths (0,25), Shortlands (0,36)	0,34
	1960	Alluvium (0,12), Shortest Slope Lengths (0,44)	0,34
	1970	Alluvium (0,9)	0,37
	1975	Shortest Slope Lengths (0,34)	0,36
	1983	Shortest Slope Lengths (0,35)	0,25

grassland communities into the riverine grassland communities facilitated by the severe drought conditions reducing the vigour of the hygrophilous species. Tables 22 and 23 show that wooded grassland predominately occurred on the upper portion of slope profiles with moderately steep and steep gradients covered by shallow soils underlain by resistant parent material, and affirm that this vegetation textural class represented a very dynamic seral stage intermediate between the more stable grassland plagiosere and equally dynamic open woodland sere.

Tables 22 and 23 affirm that as the general trend in seral development towards the phanerophyte climatic climax progressed, the open woodland sere became progressively better represented on shallow resistant soils covering moderately steep and steep gradients throughout the profile of slopes. These tables also affirm that throughout the study period the closed woodland/forest communities predominately occurred on very gentle slopes covered by very highly erodible alluvium. The proportion of the variability in the vegetation textural classes not accounted for by the physiographic parameters considered in this study reflects the influence of (i) other physiographic parameters such as rainfall erosivity, antecedent soil moisture and slope aspect; (ii) biotic factors such as seral development, consumption by insects and ungulates; and (iii) management influences such as veld burning and stocking rates. Succession towards the woody climatic climax appears to have been the most significant of these influences as while the physiographic parameters considered account for an average of 70% of the variability in the grassland/reedbeds class over the study period, they accounted for much less of the variability of the more dynamic phanerophyte classes viz:- only a third, a quarter, and a fifth of the closed woodland/forest, open woodland, and wooded grassland, respectively.

Tables 24 and 25 show that prior to the KwaZulu component of the study area becoming settled in the late 1950's, the grassland/reedbeds textural class was best represented by the riverine grasses and reeds that occurred on the very gentle slopes of the broad valley of the Mfolozi river covered by highly erodible Valsrivier/Dundee soils. And that after settlement, this class was best represented by the upland grassland communities that occurred on the short gentle slopes of hilltops and the steep gradients of the upper portion of slope profiles on the resistant predominantly sandstone and basalt parent material. These tables also show that the wooded grassland, and closed woodland/forest in this component of the study area throughout the study period, predominately occurred on upland areas covered by Shortlands/Swartland soils and underlain by Letaba basalt, and on very gentle riverside slopes covered by Valsrivier/Dundee soils underlain by alluvium, Emakwezeni shale and sandstone and Volksrust shale, respectively. The fact the deforestation associated with settlement in this component of the study area was predominately restricted to the hilltops and upper and middle slope profile positions, is also apparent from these tables. Whereas prior to settlement the open woodland communities occurred throughout slope profiles on very steep and steep gradients, after settlement they were restricted to long steep slopes covered by sandy Swartland/Mispah underlain by Karoo dolerite, Emakwezeni shale and sandstone, and Volksrust shale.

The variability not accounted for in Table 25, in addition to reflecting the same range of other influences operant in the Wilderness area (refer to discussion on Table 23), reflects the influence of clearing; abandoning; and leaving cultivated plots fallow, and deforestation. Of all these influences, cultivation appears to have exerted the most significant effect on the grassland/reedbeds class, as the average of 47% of the variability in this class over the study period accounted for by the physiographic parameters considered, was substantially lower than the proportion of the variability in this class accounted for by these parameters in the Wilderness area, in which cultivation influences were absent. The KwaZulu component's wooded grassland communities were evidently not significantly influenced by wood harvesting activities, as the average proportion of the variability in these communities accounted for by the physiographic parameters considered is equivalent to that of the Wilderness area. These activities evidently exerted a much greater influence in the KwaZulu component's open woodland and closed woodland/forest communities where the effort expended in harvesting a unit of wood is substantially less, as the proportion of the variability in them accounted for by the physiographic parameters considered, was 1,3 and 1,5 times greater on average than the comparable

TABLE 24 : RELATIONSHIPS BETWEEN VEGETATION CLASSES AND PHYSIOGRAPHIC VARIABLES IN THE STUDY AREA'S KWAZULU COMPONENT.

		GRASSLAND/REEDBEDS					WOODED GRASSLAND					OPEN WOODLAND					CLOSED WOODLAND/FOREST				
PHYSIOGRAPHIC CATEGORIES	VARIABLES	37	60	70	75	83	37	60	70	75	83	37	60	70	75	83	37	60	70	75	83
Topographic Components	Slope Angles < 2°	0,40															0,58	0,57	0,52		0,54
	2-5°		0,47			0,45															
	10-20°											0,44	0,45			0,41					
	> 20°			0,74	0,49	0,65						0,50									
	Longest Slope Lengths												0,56	0,38							
	Shortest Slope Lengths		0,68			0,46															
	Highest Altitudes											0,59									
	Lowest Altitudes											0,30									
	Altitudinal Range			0,47				0,35				0,63									
Erodibility Classes	Moderate				0,41			0,43				0,43				0,41					
	High	0,47								0,43								0,68	0,52		0,50
	Very High																0,72				
Geologic Formations	Alluvium																0,41	0,39			0,30
	Karoo Dolerite												0,38	0,50						0,48	
	Letaba Basalt			0,64	0,66	0,61		0,52	0,41	0,51											
	Clarens Sandstone		0,39							0,36											
	Nyoka Sandstone & Shale		0,37																		
	Ntabene Sandstone		0,49																		
	Emakwezeni Shale & Sandstone													0,41	0,38		0,48	0,56	0,69	0,56	0,47
	Volksrust Shale												0,38	0,47				0,40	0,40	0,59	
Soil Formations	Valsrivier/Dundee	0,51								0,41							0,67	0,67	0,51		0,58
	Sandy Swartland/Mispan													0,44	0,45					0,45	
	Mayo			0,57	0,53	0,50		0,46													
	Mayo/Milkwood/ Shortlands/Swartland			0,54	0,61	0,52			0,37	0,41	0,58	0,38									
Hydrology	Proximity to Water	0,65													0,41		0,46	0,49	0,39		0,67

values in the Wilderness area, respectively. The significant decrease in the proportion of the variability in the open woodland communities in 1983 accounted for by the physiographic parameters considered, may reflect the influence of the very severe drought, and the associated ineffectiveness of veld burning and overgrazing.

TABLE 25 : ANALYSIS OF VARIABLES INFLUENCING THE DISTRIBUTION OF VEGETATION CLASSES IN THE STUDY AREA'S KWAZULU COMPONENT.

VEGETATION COMMUNITY	YEAR	VARIABLES OF INFLUENCE - THEIR MULTIPLES ARE GIVEN IN BRACKETS	R^2
Grassland/Reedbeds	1937	Slope Angles < 2° (0,05), Valsrivier/Dundee (0,06), Proximity to River (0,65)	0,39
	1960	Clarens Sandstone (0,15), Slope Angles 2-5° (0,18), Ntabene Sandstone (0,26), Shortest Slope Lengths (0,68)	0,44
	1970	Letaba Basalt (0,15), Mayo (0,43), Slope Angles 20° (0,90)	0,69
	1975	Slope Angles >= 20° (0,13), Mayo (0,45), Mayo/Milkwood/Shortlands/Swartland (0,48), Letaba Basalt (0,66)	0,42
	1983	Letaba Basalt (0,12), Shortest Slope Lengths (0,22), Mayo (0,32), Slope Angles 2-5° (0,42), Slope Angles >= 20° (0,65)	0,40
Wooded Grassland	1960	Mayo (0,17), Altitudinal Range (0,24), Letaba Basalt (0,52)	0,24
	1970	Mayo/Milkwood/Shortlands/Swartland (0,13), Letaba Basalt (0,41)	0,14
	1975	Valsrivier/Dundee (0,47), Mayo/Milkwood/Shortlands/Swartland (0,49)	0,33
	1983	Mayo/Milkwood/Shortlands/Swartland (0,58)	0,32
Open Woodland	1937	Slope Angles 720° (0,16), Slope Angles 10-20° (0,38), Altitudinal Range (0,63)	0,45
	1960	Slope Angles 10-20° (0,17), Volksrust Shale (0,40), Longest Slope Lengths (0,57)	0,43
	1970	Emakwezeni Shale & Sandstone (0,16), Volksrust Shale (0,33), Karoo Dolerite (0,50)	0,33
	1975	Proximity to River (0,51), Sandy Swartland/Misoan (0,54)	0,42
	1983	Slope Angles 10-20° (0,41)	0,14
Closed Woodland/Forest	1937	Emakwezeni Shale & Sandstone (0,17), Valsrivier/Dundee (0,85)	0,47
	1960	Volksrust Shale (0,45), Proximity to River (0,50), Valrivier/Dundee (0,76)	0,69
	1970	Volksrust Shale (0,29), Valsrivier/Dundee (0,36), Emakwezeni Shale & Sandstone (0,69)	0,55
	1975	Sandy Swartland/Misoan (0,27), Emakwezeni Shale & Sandstone (0,40), Volksrust Shale (0,59)	0,44
	1983	Emakwezeni Shale & Sandstone (0,31), Proximity to River (0,90)	0,49

8.1.5 Landuse influence

The distribution of the Iron Age sites in the Wilderness area is shown in Figure 13. The total of twenty one 1 km^2 grid cells containing an average of one and up to four sites, indicate that their distribution is restricted to the riverine area. The following significant correlations affirm this distribution pattern:- very gentle slopes (0,39) covered by very highly erodible (0,72) unconsolidated alluvial deposits (0,70), Swartland (0,47) and Valsrivier/Dundee (0,41) soils underlain by Volksrust shale (0,69), Ntabene sandstone (0,54), Emakwezeni shale and sandstone (0,35) and Nyoka shale and sandstone (0,35). Although Hall (1981) noted a strong association between Iron Age sites and *Acacia nilotica*, *A. nigrescens*, and *Urochloa mossambicensis* communities (refer section 2.7.3), this study did not find any significant correlation between them and the four vegetation textural classes in the five study years.

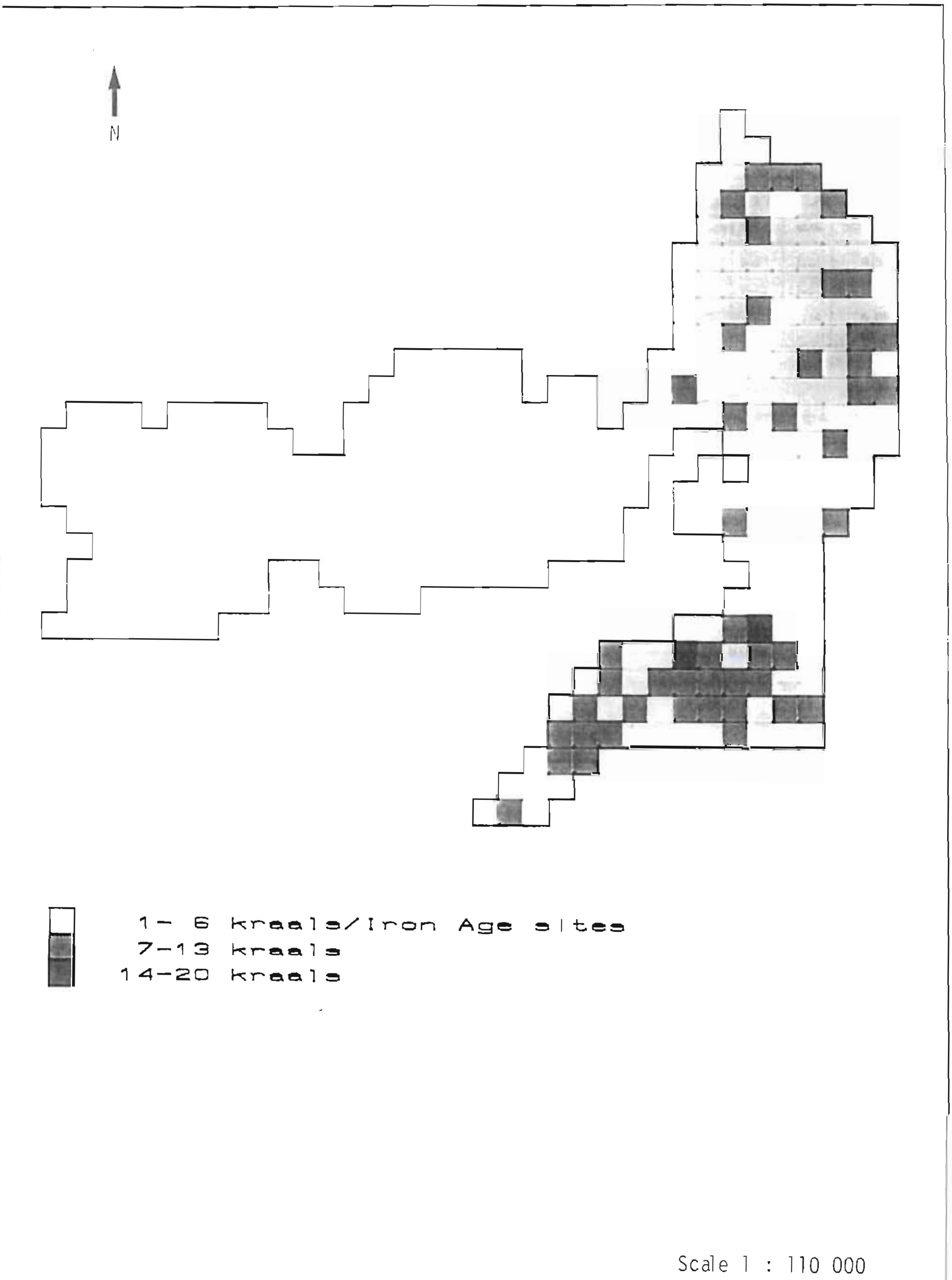


Figure 13. The location of Iron Age sites in the game reserve area and the density of kraals in the traditional landuse area in 1960.

TABLE 26 : VEGETAL BURNING IN GAME RESERVE FROM 1937 TO 1983.

	PERIOD 1: 1955-1959			PERIOD 2: 1960-1969			PERIOD 3: 1970-1974			PERIOD 4: 1975-1983		
	MEAN	DEVIATION	RANGE	MEAN	DEVIATION	RANGE	MEAN	DEVIATION	RANGE	MEAN	DEVIATION	RANGE
NUMBER OF BURNS	2,8	1,2	0-5	1,0	0,6	0-2	0,3	0,5	0-1	2,2	0,5	1-3
PERCENTAGE OF AREA BURNT	11,2	2,3	8-15	8,1	4,7	0-17	3,3	3,8	0-13	12,6	2,1	8-16
BURNING FACTOR	1,45	0,61	0,05-2,53	1,05	0,85	0-2,88	0,47	0,75	0-2,73	3,14	0,86	1,39-4,00

The 4,51; 7,67; and 164,47 F values respectively obtained when the variance in the Wilderness area's veld burning between periods 1 and 2; 2 and 3; and 3 and 4, as specified in Table 26 was analyzed, indicates that differences between these periods were significant. In addition to reflecting variations in veld burning management policy, Table 26 and the significant correlations between the burning factors and the various vegetation textural classes in the various study period intervals presented in section 8.1.4, affirm the assertion made in section 2.9.1, that it was the excessive ungulate utilization pressure described in section 2.8.1, coupled with the exceptionally dry years, that resulted in burning frequencies and intensities that were too low to stem the successional advancement towards the woody climatic climax. The vegetal burning data presented in Table 26 assessed in combination with the rainfall data presented in Table 7, shows that the number of burns and percentage area burnt was highest over the 1955 to 1959 period when above average rainfall occurred during four of the five years. The frequency and extent of vegetal burning decreased progressively from 1960 to 1974 over which period above average rainfall was received during 40% of the years, and increased again during the last study period interval, when five years of above average rainfall preceded the severe drought.

Table 27 shows that when veld burning was initially applied in the late 1950's to promote rotational grazing, its influence was not manifested in any particular vegetation textural class. Over most of the balance of the study period veld burning was principally applied to control bush encroachment, its influence was therefore predominately manifested in the open woodland communities. As the vegetal burning between 1960 and 1969, and 1975 and 1983 was significantly correlated with moderately steep and steep gradients on the lower portion of slope profiles covered by highly erodible alluvial soils, the control treatments during these periods appear to have been predominately applied to the bottomland open woodland communities. Similarly, the significant correlations between burning from 1970 to 1975, and moderately steep and steep slope gradients on middle and upper slope profiles covered by

TABLE 27 : RELATIONSHIPS BETWEEN LANDUSE AND BIOPHYSIOGRAPHIC VARIABLES.

		GAME RESERVE								KWAZULU				
		BURNING FACTOR				ROADS					KRAALS			
BIOPHYSIOGRAPHIC CATEGORIES	VARIABLES	37-59	60-69	70-74	75-83	37	60	70	75	83	60	70	75	83
Vegetation Communities	Wooded Grassland						0,37				0,41			
	Open Woodland		0,47	0,47										
Topographic Components	Slope Angles 2-5°										0,47	0,40		
	5-10°		0,52	0,63	0,41		0,45							
	10-20°		0,56	0,81										
	Highest Altitudes			0,51										0,33
	Lowest Altitudes			0,39				0,40					[illegible]	[illegible]
	Altitudinal Range		0,46	0,55										
Erodibility Classes	Very High		0,40					0,36				0,59	0,65	0,53
	Very Low			0,39										
Geologic Formations	Karoo Dolerite							0,45	0,45					
	Letaba Basalt										0,50			
	Vryheid Shale & Sandstone							0,56	0,40				0,39	0,43
Soil Formations	Rocky Shortlands			0,45										
	Fernwood		0,40		0,39									
	Swartland/Sterkspruit							0,36				0,59	0,65	0,33
	Sandy Swartland/Mispah							0,62	0,56	0,35				
	Mayo					0,40								
	Mayo/Mispah/Milkwood								0,35					
	Mayo/Milkwood/Shortlands/ Swartland										0,46			

average the physiographic parameters considered in this study, accounted for less than a third of the variability in roads indicating that their distribution was influenced to a greater extent by other considerations such as: the relationships between homesteads and cultivated plots; preferred grazing areas; livestock bomas; cattle dips; shops; schools; mobile clinic stations; and feeder routes to the shallow resistant soils, suggests that the control treatments during this period were predominately directed at the upland open woodland communities.

Irrespective of whether they occurred on the more erodible Swartland and associated soils in the bottomland areas of the KwaZulu component of the study area, or on the less erodible Mayo and associated soils on it's upland areas, the roads, vehicular and animal tracks, and footpaths all categorized as roads in Tables 27, 28 and 29, were best represented on moderately steep slopes. On

TABLE 28 : THE ROAD RANKING AND NUMBER OF KRAALS IN THE STUDY AREA'S KWAZULU COMPONENT.

	1937			1960			1970			1975			1983		
	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE	MEAN	STANDARD DEVIATION	RANGE
ROADS	1,0	1,2	0 - 3	3,6	0,9	2 - 5	4,6	1,4	2 - 7	4,3	1,1	2 - 5	4,7	1,0	2 - 7
KRAALS	0	0	0	4,3	1,8	2 - 8	7,0	3,0	2 - 18	7,6	3,2	2 - 20	9,2	3,7	3 - 2[illegible]

primary road system through the area, as well as to the main road between Mtubatuba and Nongoma. Table 28 shows that settlement in the late 1950's resulted in a dramatic increase in the number and width of roads, tracks and paths present by 1960. The density of this transport network continued to increase at a substantially lower rate through until 1970. The decrease in 1975 reflects the spread of pioneer grass species onto tracks and paths that were either seldom used or had been abandoned, facilitated by the good rainfall conditions. The increase in 1983 reflects the extension of the network associated with the increased settlement in the north east section as described below.

Data on kraals presented in Tables 27, 28 and 29 affirm that the KwaZulu component of the study area was uninhabited in 1937 when it was deployed as a buffer zone during the 'nagana campaign'. Settlement in the area in the late 1950's resulted in a dramatic increase in population. Most of this initial settlement was concentrated on gentle slopes of hilltops covered by moderately erodible Mayo and associated soils underlain by Letaba basalt. The population continued to increase rapidly during the 1960's decade when settlement on the gentle slopes of the bottomland areas' very highly erodible Swartland and associated soils underlain by Vryheid shale and sandstone predominated, (Figure 13). This rate of population increase declined during the early 1970's as the availability of suitable land in the bottomland areas became limiting, and increased again in the late 1970's and early 1980's when the upland area in the vicinity of Mdlambila, and parallel to the main road between Mtubatuba and Nongoma became settled, (Figure 14). This latter settlement in the north east section was coincident with the emergence of Mtubatuba as a 'growth point'. The systematic sample of 100 kraals traversing the central portion of the KwaZulu component of the study area as described in section 7.2.6, showed that the average; standard deviation; and range in the number of huts per kraal was 4; 1,87; and 1 to 13, respectively.

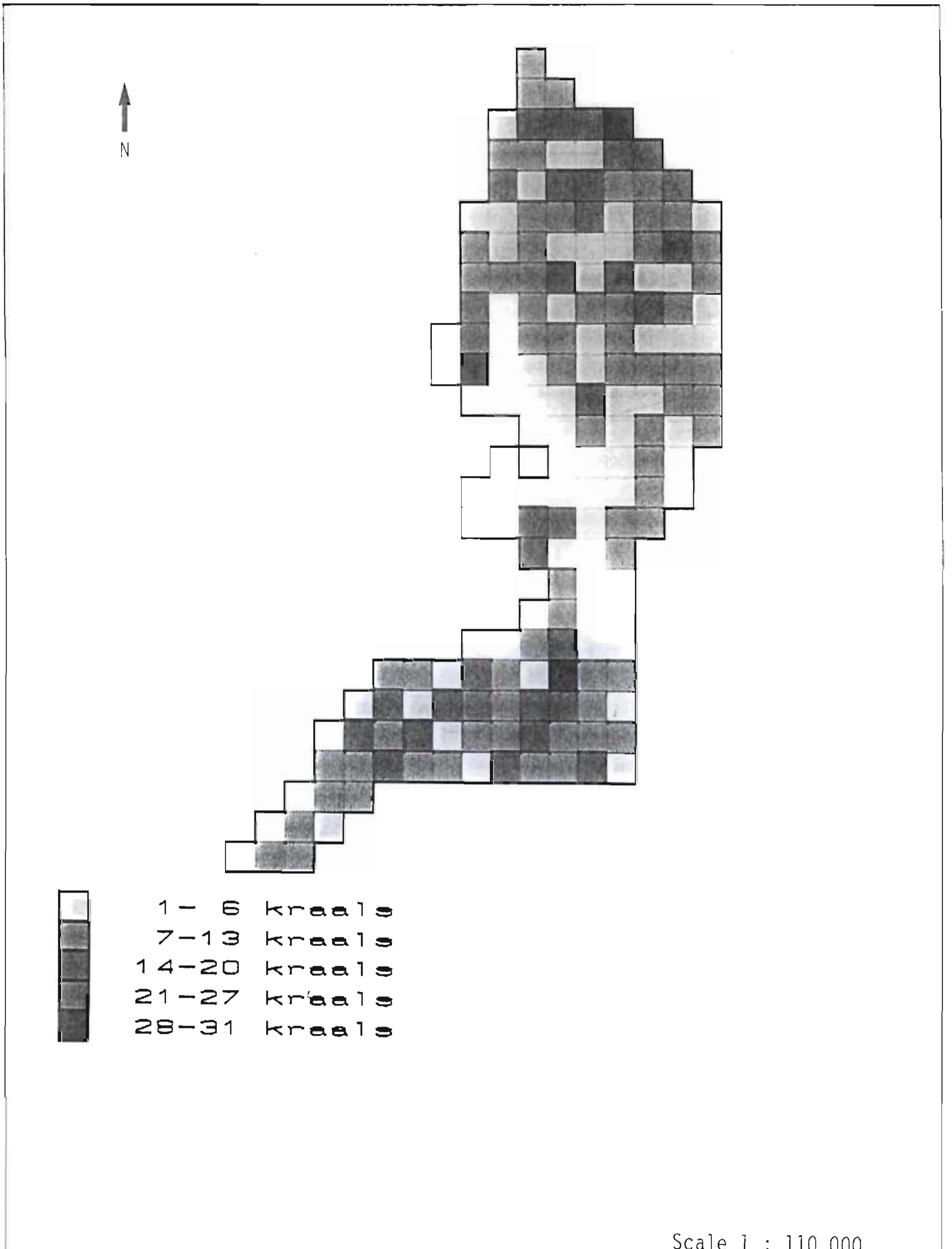


Figure 14. The density of kraals in the traditional landuse area in 1983.

TABLE 29 : ANALYSIS OF VARIABLES INFLUENCING THE DISTRIBUTION OF ROADS AND KRAALS IN THE STUDY AREA'S KWAZULU COMPONENT.

LANDUSE CATEGORY	YEAR	VARIABLES OF INFLUENCE - THEIR MULTIPLES ARE GIVEN IN BRACKETS	R^2
Roads	1937	Slope Angles 5-10° (0,44), Mayo (0,48)	0,20
	1960	Slope Angles 5-10° (0,45)	0,23
	1970	Swartland/Sterkspruit (0,32), Sandy Swartland/Mispah (0,63)	0,43
	1975	Mayo/Mispah/Milkwood (0,36), Sandy Swartland/Mispah (0,59)	0,37
	1983	Sandy Swartland/Mispah (0,35)	0,09
Kraals	1960	Mayo/Milkwood/Shortlands/Swartland (0,17), Slope Angles 2-5° (0,37), Letaba Basalt (0,50)	0,33
	1970	Slope Angles 2-5° (0,31), Swartland/Sterkspruit (0,59)	0,40
	1975	Lowest Altitudes (0,33), Swartland/Sterkspruit (0,87)	0,44
	1983	Lowest Altitudes (0,04), Highest Altitudes (0,27), Swartland/Sterkspruit	0,31

8.2 ACTUAL EROSION

At the commencement of the study period in 1937 when the study area was deployed by the Division of Veterinary Services in the 'nagana campaign', eroded surfaces in both components were very localized (Tables 30, 31 and 32; Figure 15). In the Wilderness area they predominated in both riverine and bottomland grassland communities. These communities occur on very gentle and gentle slopes covered by unconsolidated alluvium or Valsrivier/Dundee soils underlain by Ntabene sandstone or Volksrust shale, and on the gentler gradients covered by Swartland soils underlain by Nyoka sandstone and shale, respectively (Tables 33 and 34). In the KwaZulu component they predominated on the moderately steep slopes of upland areas. These slopes are covered by Mayo and associated soils underlain by Clarens sandstone. The sparsely vegetated surfaces were also very localized throughout the study area in 1937 (Figure 20). In the Wilderness area they predominated throughout the bottomland slopes covered by shallow Mispah soils underlain by Vryheid shale and sandstone. They were significantly better represented in the KwaZulu component where they were mainly associated with the primary road system through the upland areas covered by Mayo soils underlain by Letaba basalt.

Eroded surfaces in the Wilderness area remained very localized throughout the study period (Tables 30, 31, 32; Figures 16, 17, 18 and 19). Although they occupied the same proportion of the Wilderness area in 1960 as they did in 1937, their distribution changed, such that they additionally occurred in the riverine areas underlain by Pietermaritzburg shale, and were less common in the bottomland areas. While the substantial bush encroachment during the 'nagana campaign', and the overutilization of bottomland and riverine areas by grazers in the late 1950's, did not increase the density of eroded

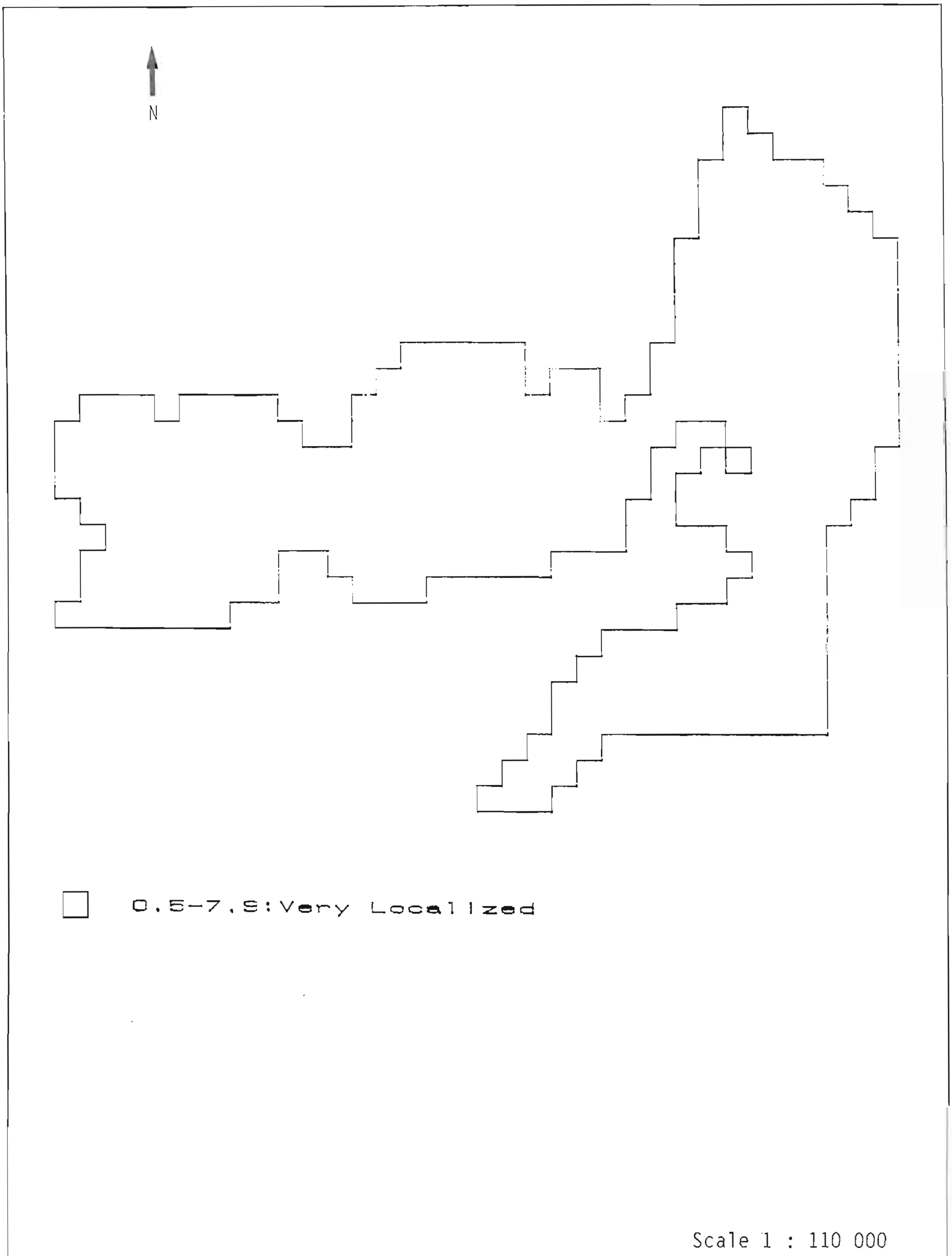


Figure 15. Percentage of non vegetated surfaces subjected to active erosion processes in 1937.

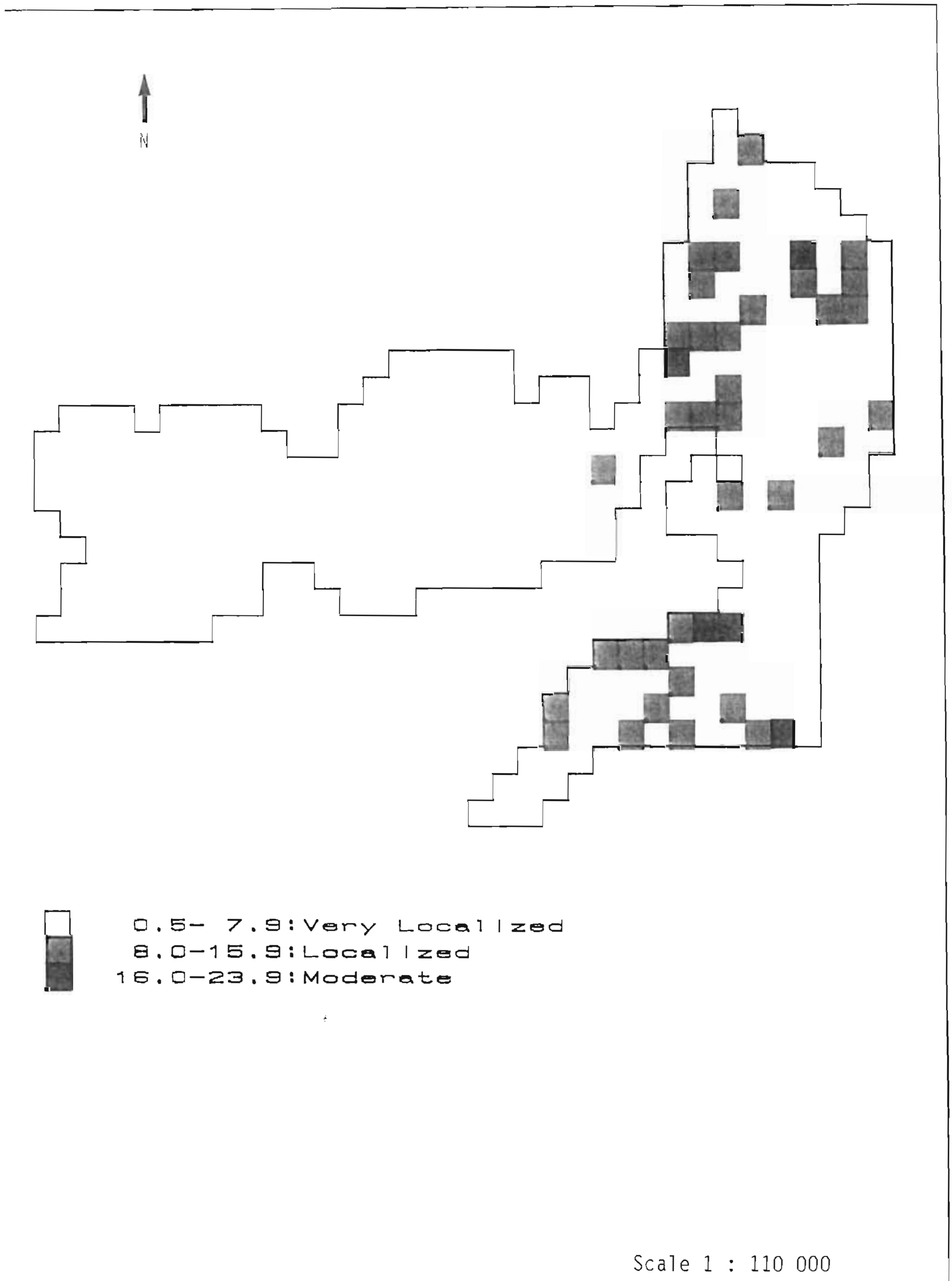


Figure 16. Percentage of non vegetated surfaces subjected to active erosion processes in 1960.

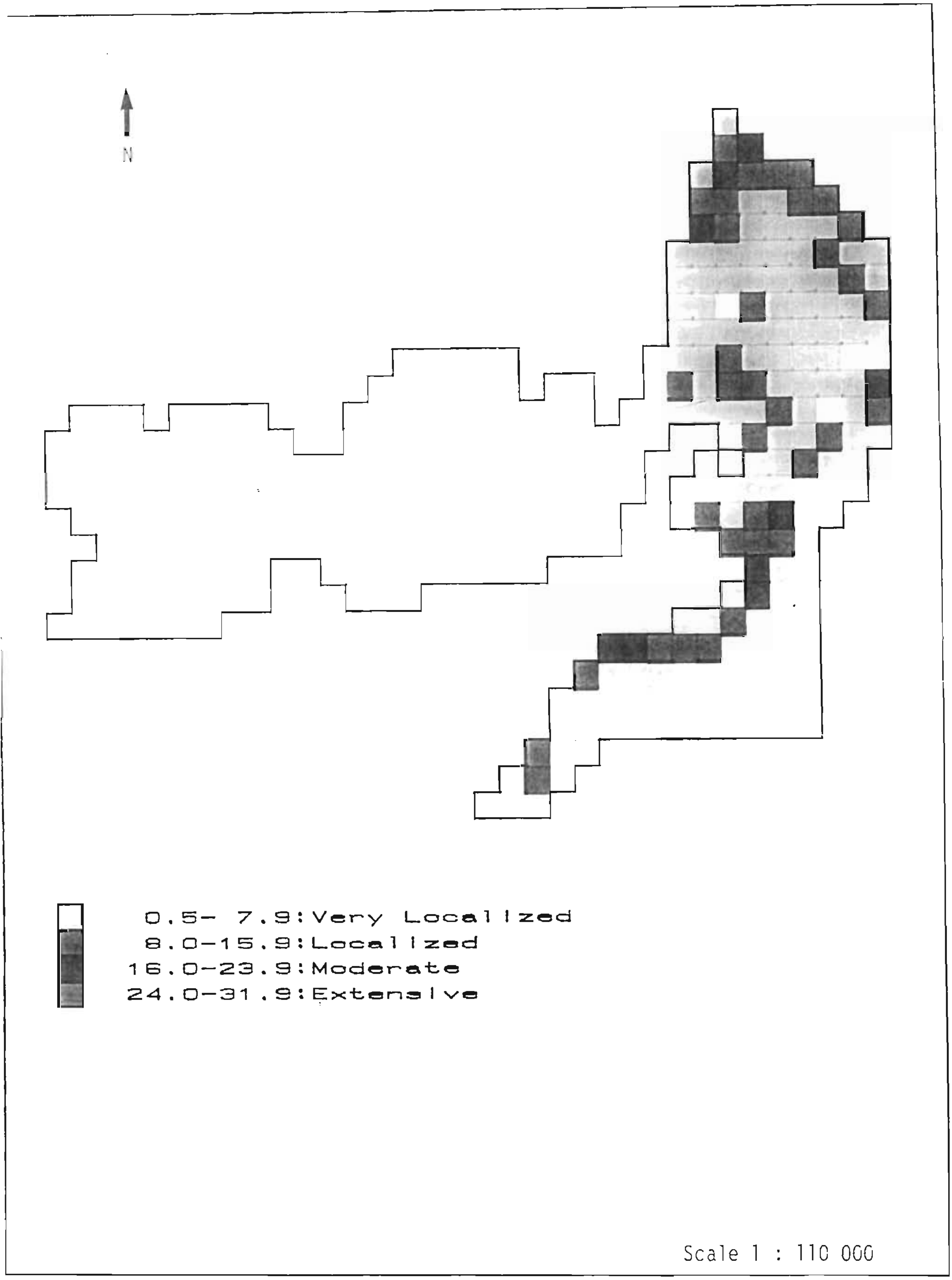


Figure 17. Percentage of non vegetated surfaces subjected to active erosion processes in 1970.

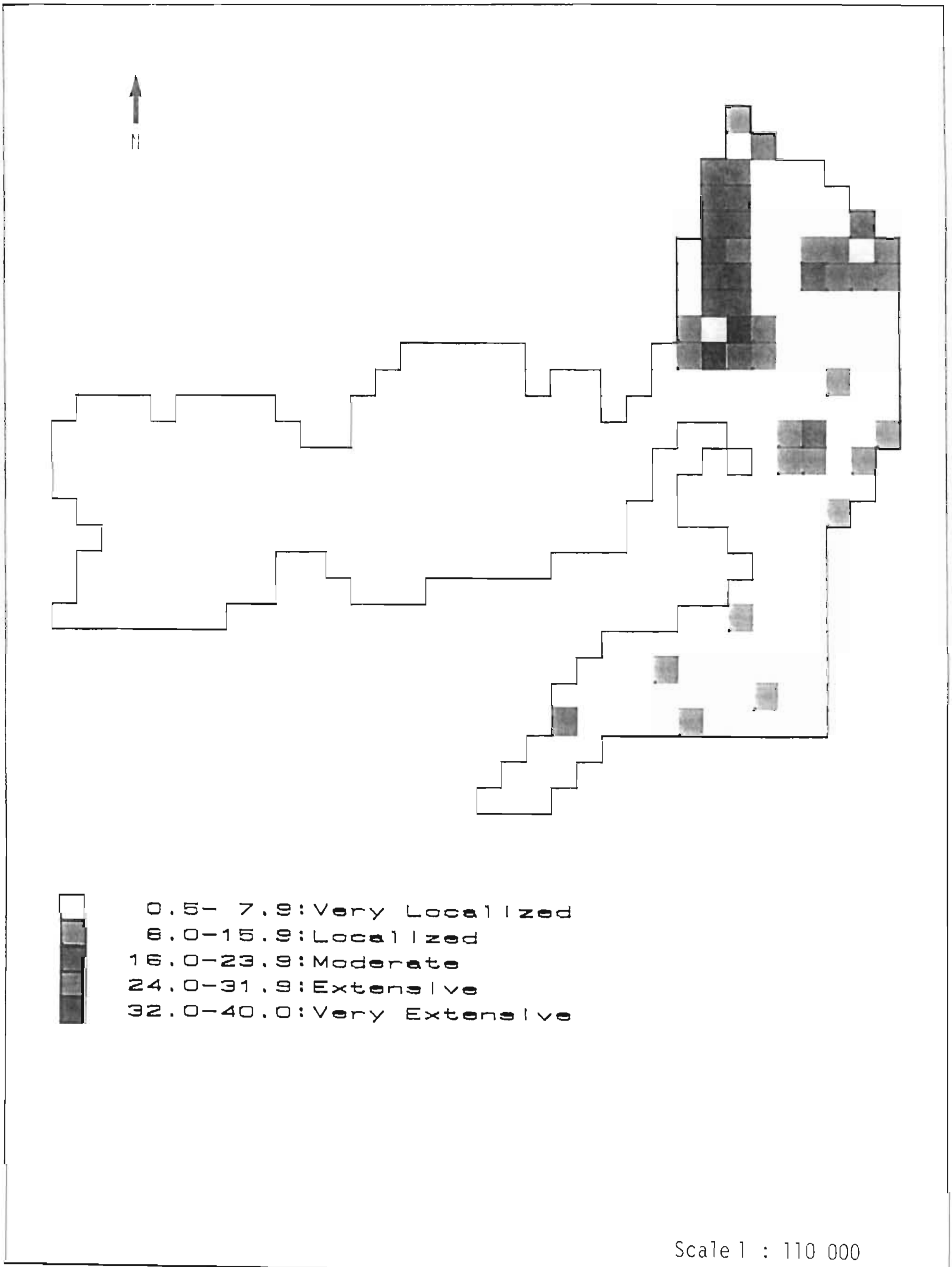


Figure 18. Percentage of non vegetated surfaces subjected to active erosion processes in 1975.

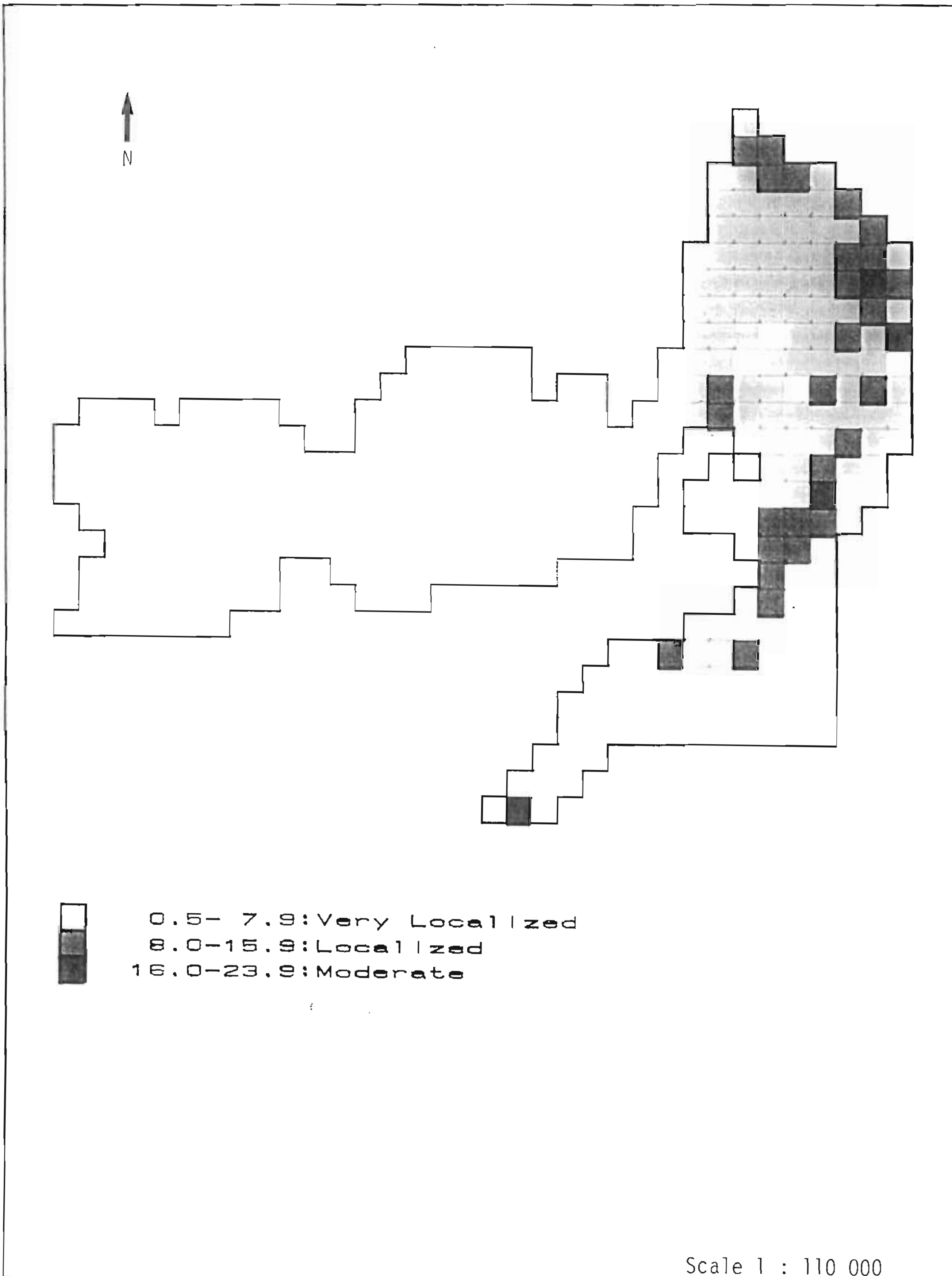


Figure 15. Percentage of non vegetated surfaces subjected to active erosion processes in 1983.

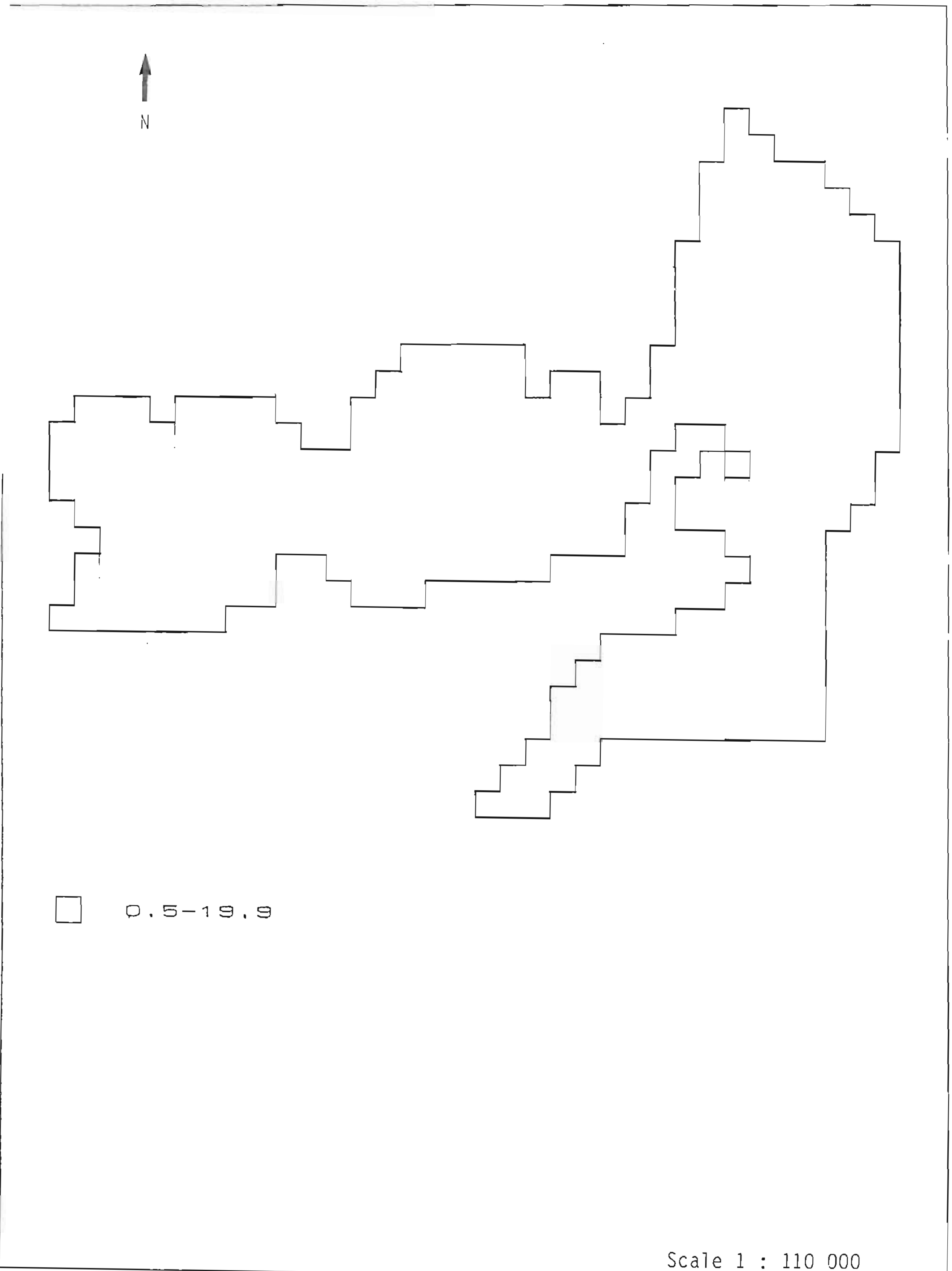


Figure 20. Percentage of sparsely vegetated surfaces susceptible to erosion processes in 1937.

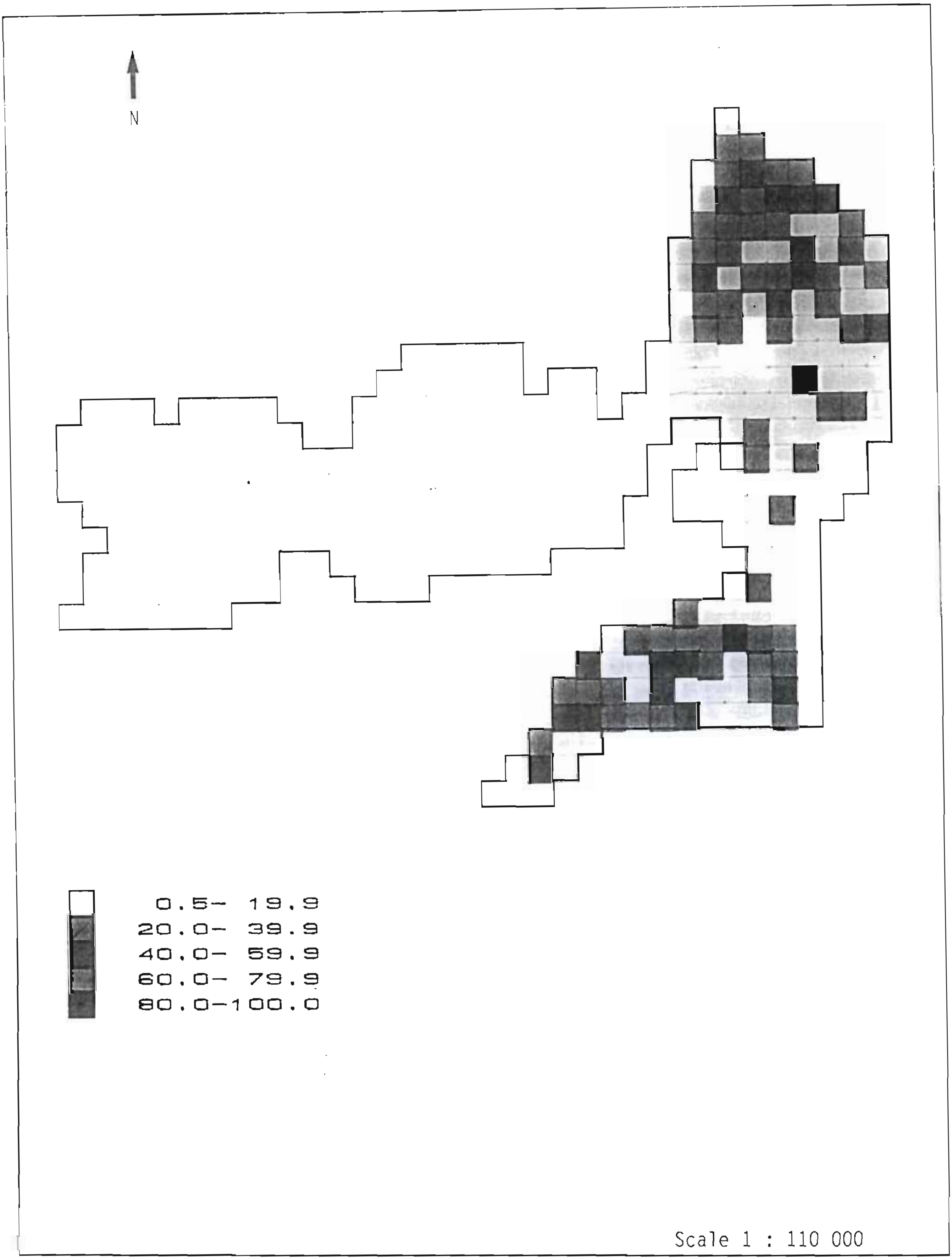


Figure 21. Percentage of sparsely vegetated surfaces susceptible to erosion processes in 1960.

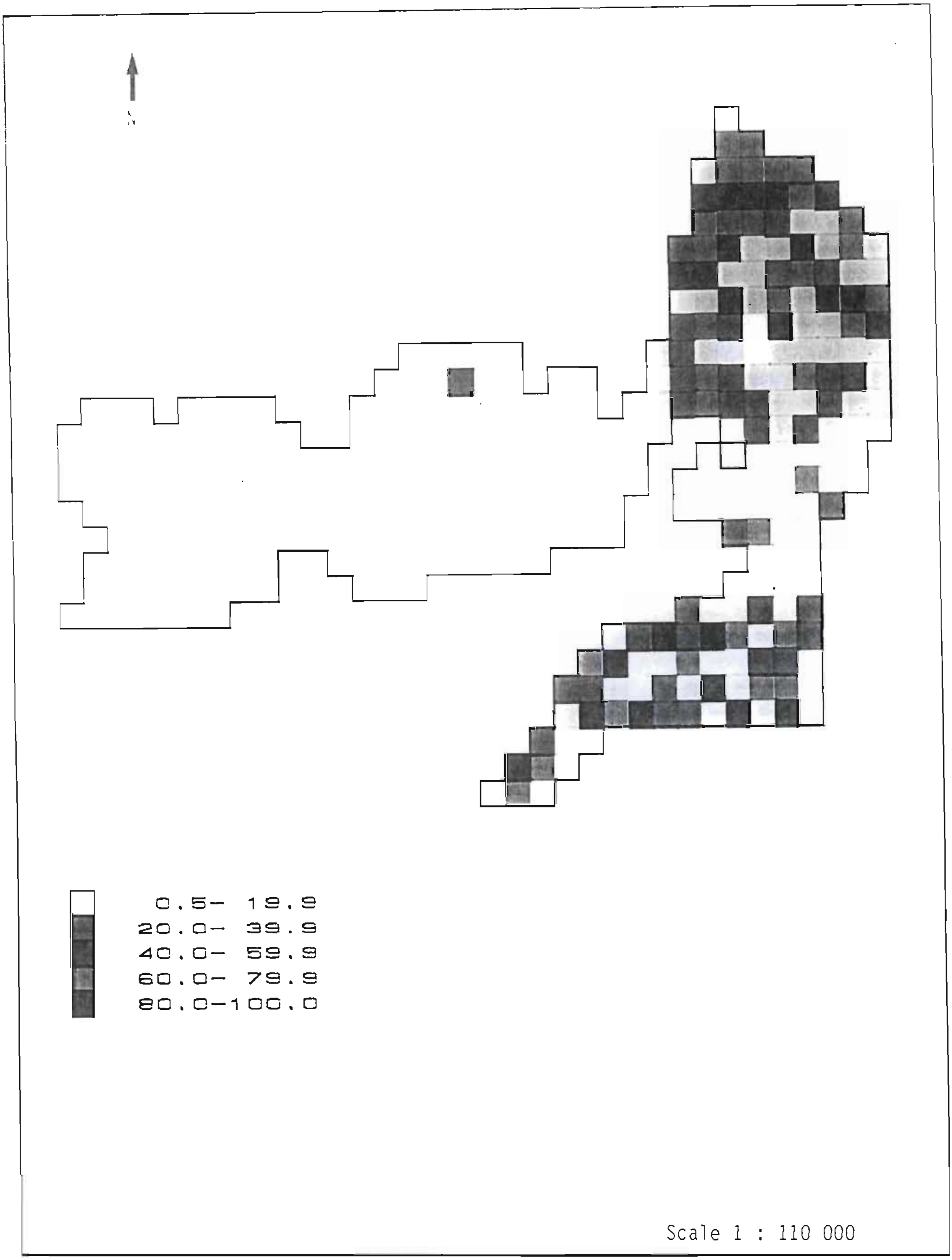


Figure 22. Percentage of sparsely vegetated surfaces susceptible to erosion processes in 1970.

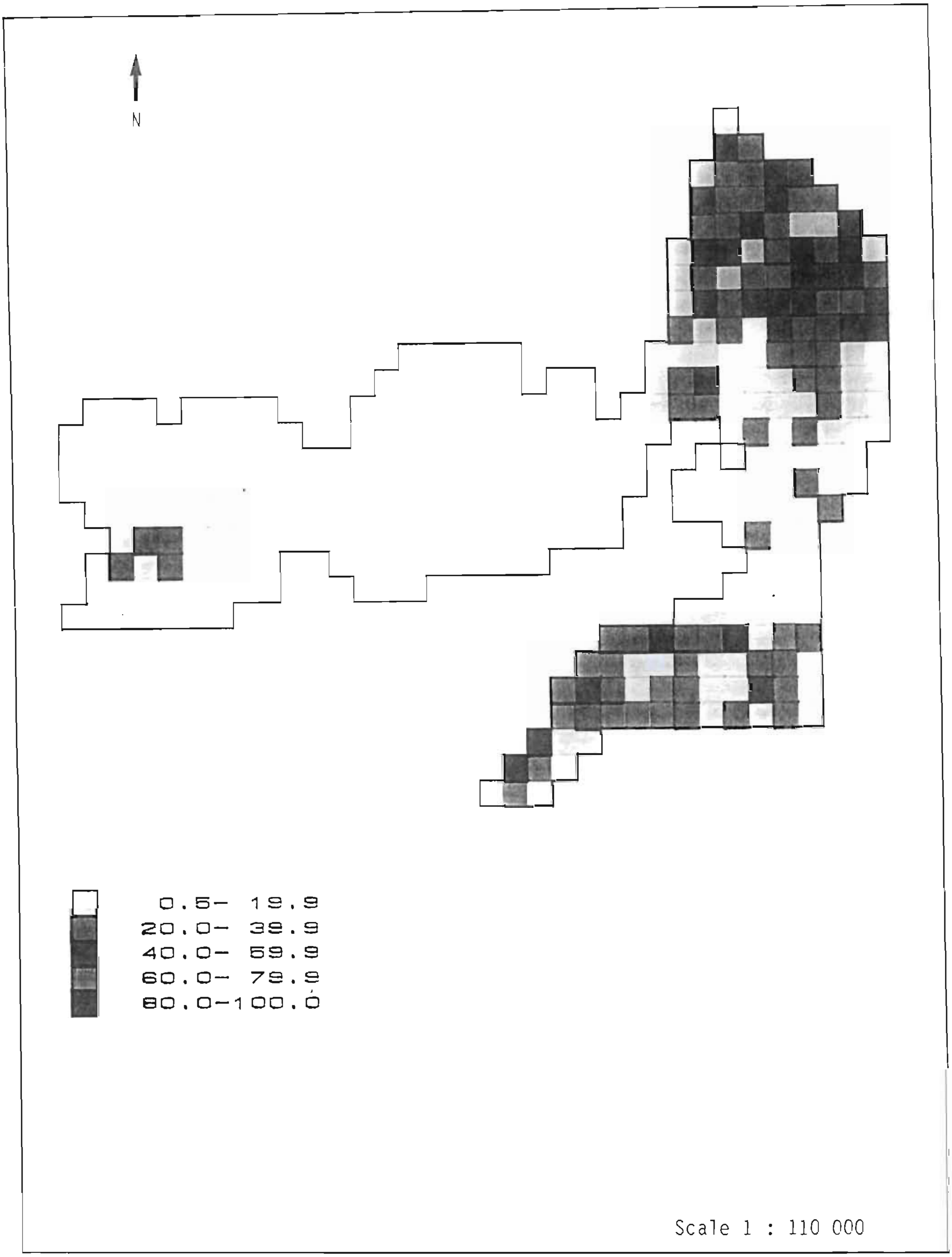


Figure 23. Percentage of sparsely vegetated surfaces susceptible to erosion processes in 1975.

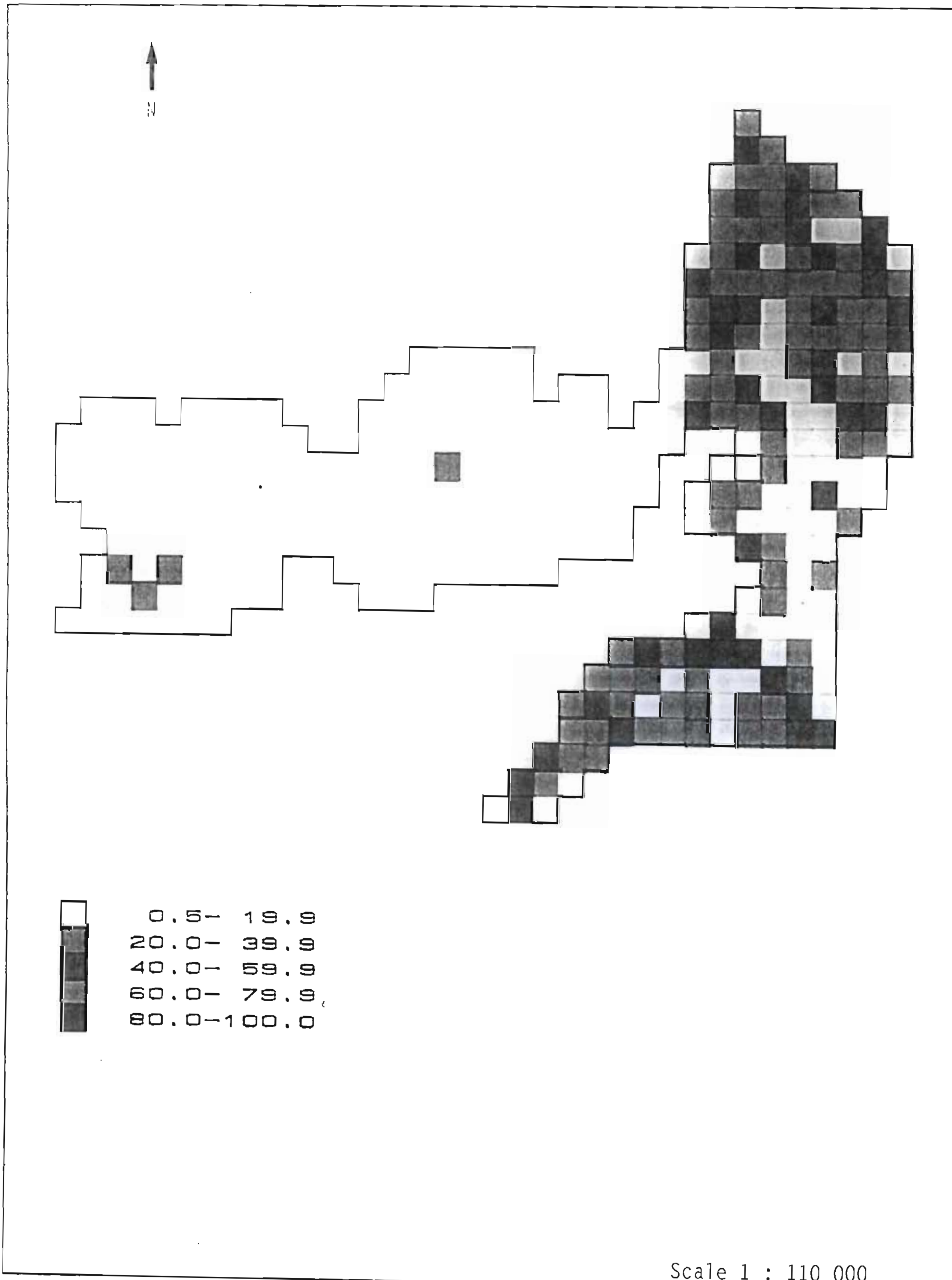


Figure 24. Percentage of sparsely vegetated surfaces susceptible to erosion processes in 1983.

TABLE 30 : ERODED SURFACES AND SURFACES SUSCEPTIBLE TO EROSION AS PERCENTAGE OF 1 KM^2 GRID CELLS.

	YEAR	NON-VEGETATED ERODED SURFACES		SPARSELY VEGETATED SURFACES SUSCEPTIBLE TO EROSION	
		GAME RESERVE	KWAZULU	GAME RESERVE	KWAZULU
MEAN	1937	0,3	0,2	0,7	2,8
	1960	0,3	5,0	1,8	25,0
	1970	0,4	6,1	1,6	31,8
	1975	0,1	5,5	5,0	30,9
	1983	0,1	4,6	4,8	39,4
STANDARD DEVIATION	1937	0,5	0,8	1,0	2,4
	1960	0,5	2,8	1,8	13,6
	1970	0,4	3,0	2,3	16,6
	1975	0,1	4,4	3,4	19,1
	1983	0,3	2,0	3,9	15,1
RANGE	1937	0-1,8	0-4,3	0-4,0	0-8,5
	1960	0-2,1	1,3-15,5	0-6,4	4,8-57,1
	1970	0-1,3	1,2-15,1	0-8,8	7,5-78,2
	1975	0-0,6	0-17,7	0,2-16,0	5,7-75,7
	1983	0-1,3	0,8-9,0	0,1-15,4	11,7-81,6

Note: the mean values are equivalent to the percentage of the study area subjected to and susceptible to erosion processes.

surfaces, it did contribute to the fourfold increase in sparsely vegetated surfaces. This increase did not only reflect their expansion in the bottomland areas, but their emergence on the unconsolidated alluvial deposits of the riverine areas as well (Tables 33 and 34). The 1,3 times increase in both the eroded surfaces and those susceptible to erosion between 1960 and 1970 (Figures 21 and 22), reflects the progressive overutilization of the gentle bottomland slopes covered by sandy Swartland/Mispah underlain by Vryheid shale and sandstone, by grazers throughout the decade, and by browzers during the second half of it.

The shift to a burning policy aimed at attracting game to underutilized areas and greater flexibility in the season and frequency of burning, coincident with the above average rainfall conditions, and the intensification of the culling programme from the early 1970's, contributed to a decrease in both the

TABLE 31 : SIGNIFICANCE OF DIFFERENCES IN THE EROSION SURFACES OF THE STUDY AREA'S COMPONENTS.

YEAR	NON-VEGETATED ERODED SURFACE		SPARSELY VEGETATED SURFACES SUSCEPTIBLE TO EROSION	
	F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL	F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL
1937	0,10	No	9,34	Yes
1960	33,62	Yes	78,38	Yes
1970	90,32	Yes	84,74	Yes
1975	45,77	Yes	53,73	Yes
1983	110,96	Yes	141,05	Yes

eroded surfaces and those susceptible to erosion. While the non-vegetated surfaces decreased significantly between 1970 and 1975, the sparsely vegetated surfaces continued to increase at their 1970's rate and became better represented in the upland areas (Tables 30 to 34 inclusive, Figures 23 and 24). The difference in the response of these surfaces indicates that the invasion of pioneer species onto patches of bare ground, was more rapid than the re-establishment and thickening of the cover of the more mature sere associated with the sparsely vegetated more localized surfaces. Table 33 additionally indicates that the eroded surfaces in the more palatable, heavier utilized bottomland grassland communities were covered less rapidly than those in the riverine grassland communities.

Contrary to the general perception based on field assessment, held by NPB management officials (Venter, 1988), erosion did not increase dramatically during the severe drought of the early 1980's. The overall proportion of eroded surfaces in 1983 was equivalent to that of 1975 when good rainfall conditions prevailed, while the overall proportion of sparsely vegetated surfaces in 1983 was marginally less than it was in 1975. A factor that may have influenced this perception of the effects of drought on erosion, is that the eroded surfaces became substantially better represented in the riverine areas, particularly on the unconsolidated alluvial deposits underlain by Pietermaritzburg shale. Their increase

TABLE 32 : SIGNIFICANCE OF DIFFERENCES IN THE EROSION SURFACES BETWEEN THE STUDY YEARS.

		NON-VEGETATED ERODED SURFACES		SPARSELY VEGETATED SURFACES SUSCEPTIBLE TO EROSION	
		F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL	F VALUE	SIGNIFICANT AT 95% CONFIDENCE LEVEL
Game Reserve	1937-1960	0,0	No	32,45	Yes
	1960-1970	0,49	No	2,74	No
	1970-1975	17,03	Yes	3,37	No
	1975-1983	1,09	No	0,05	No
KwaZulu	1937-1960	81,39	Yes	82,38	Yes
	1960-1970	1,34	No	2,98	No
	1970-1975	0,35	No	0,04	No
	1975-1983	0,35	No	3,62	No

reflected the increase in surface scuffing and track formation facilitated by the drought mortality of the hygrophilous herbaceous communities, and caused by the greater traffic as game searched for water. Their increase also reflected the exposure and consequent drying out of river bed deposits normally either saturated or covered by water during average rainfall conditions. In common with 1975 the sparsely vegetated surfaces in 1983 were best represented on both the steep slopes of the upland areas covered by associations of Swartland or Mispah soils predominately underlain by Vryheid shale and sandstone, and in riverine areas underlain by Pietermaritzburg shale. Another factor that may account for the discrepancy between the field assessment of erosion during the early eighties drought, and that gained in this study from the 1983 aerial photographs, is that very light and light toned areas less than the equivalence of 0,5 ha on the ground, were excluded from measurement. Such small areas appear to be cognized cumulatively when viewed laterally from the ground. Watson (1981) found that this cumulative affect resulted in basal cover estimates on burnt veld derived subjectively being consistently lower than those derived objectively using scientific apparatus.

TABLE 33 : RELATIONSHIPS BETWEEN THE EROSION SURFACES AND BIOPHYSIOGRAPHIC VARIABLES.

		GAME RESERVE										KWAZULU AREA														
BIOPHYSIOGRAPHIC CATEGORIES	VARIABLES	ERODED					SUSCEPTIBLE TO EROSION					ERODED					SUSCEPTIBLE TO EROSION					GULLIES				
		37	60	70	75	83	37	60	70	75	83	37	60	70	75	83	37	60	70	75	83	37	60	70	75	83
Vegetation Communities	Grassland/Reedbeds	0,38																						0,65	0,83	0,64
	Wooded Grassland																						0,41	0,39		
	Open Woodland																					0,40				
	Closed Woodland Forest									0,36	0,37				0,49											
Topographic Components	Slope Angles <2°		0,45							0,63				0,41		0,39										
	2-5°			0,40										0,44												
	5-10°											0,44														
	10-20°														0,36											
	>20°										0,49											0,59	0,59	0,59	0,59	0,59
	Highest Altitudes														0,36			0,53	0,59	0,72	0,63					
	Lowest Altitudes														0,54			0,56	0,76	0,82	0,80					
	Altitudinal Range						0,49															0,43	0,43	0,43	0,43	0,43
	Average Slope Lengths									0,38																
Erodibility Classes	Moderate				[illegible]			0,48			0,44											0,35	0,35	0,35	0,35	0,35
	Very High	0,36	0,57					0,42		0,38				0,62	0,50	0,55		0,52	0,65	0,63	0,68					
Geologic Formations	Karoo Dolerite														0,53											
	Letaba Basalt									0,50	0,51						0,62					0,49	0,49	0,49	0,49	0,49
	Clarens Sandstone											0,34														
	Nyoka Sandstone & Shale	0,61																								
	Ntabene Sandstone	0,38	0,37																							
	Volksrust Shale	0,54	0,39												0,61											
	Vryheid Shale & Sandstone				[illegible]			0,57						0,39	0,71	0,51		0,41	0,62	0,66	0,68					
	Pietermaritzburg Shale		0,60			0,45					0,36															
Soil Formations	Alluvium		0,59					0,42		[illegible]																
	Swartland/Sterkspruit													0,63	0,50	0,55		0,52	0,66	0,62	0,68					
	Sandy Swartland/Mispah				0,38				0,36	0,35	0,66				0,57											
	Mayo																0,60					0,35	0,35	0,35	0,35	0,35
	Mayo/Mispah/Millwood															0,35										
	Mispah						0,36				0,40															
	Mayo/Milkwood/Shortlands/Swartland																					0,55	0,55	0,55	0,55	0,55
Hydrology	Proximity to River	0,42																								
Landuse Components	Roads																0,38	0,39	0,50							
	Kraals													0,37				0,45	0,46	0,52	0,55		0,66			

TABLE 34 : ANALYSIS OF VARIABLES INFLUENCING THE DISTRIBUTION OF THE EROSION SURFACES.

STUDY AREA	SURFACE CATEGORIZATION	YEAR	VARIABLES OF INFLUENCE - THEIR MULTIPLES ARE GIVEN IN BRACKETS	NUMBER*	R^2
Game Reserve	Eroded	1937	Volksrust Shale (0,56), Nyoka Sandstone & Shale (0,61)	5	0,42
		1960	Volksrust Shale (0,50), Pietermaritzburg Shale (0,68)	7	0,57
		1970	Slope Angles 2-5° (0,40)	[illegible]	0,13
		1975	Swartland/Mispah (0,30)	[illegible]	0,13
		1983	Pietermaritzburg Shale (0,45)	[illegible]	0,17
KwaZulu	Eroded	1937	Clarens Sandstone (0,23), Slope Angles 5-10° (0,44)	[illegible]	0,19
		1960			
		1970	Kraals (0,03), Slope Angles < 2° (0,24), Slope Angles 2-5° (0,35), Swartland/Sterkspruit (0,63)	7	0,55
		1975	Slope Angles 10-20° (0,40), Closed Woodland/Forest (0,42), Volksrust Shale (0,57), Vryheid Shale & Sandstone (0,77)	11	0,66
		1983	Slope Angles < 2° (0,33), Mayo/Mispah/Milkwood (0,45), Swartland/Sterkspruit (0,62)	5	0,55
Game Reserve	Susceptible to Erosion	1937	Altitudinal Range (0,49)	[illegible]	0,21
		1960	Alluvium (0,53), Vryheid Shale & Sandstone (0,66)	5	0,57
		1970	Swartland/Mispah (0,25)	[illegible]	0,09
		1975	Swartland/Mispah (0,21), Letaba Basalt (0,38), Slope Angles < 2° (0,63)	7	0,58
		1983	Pietermaritzburg Shale (0,24), Mispah (0,29), Slope Angles > 20 (0,49), Swartland/Mispah (0,66)	[illegible]	0,65
KwaZulu	Susceptible to Erosion	1937	Roads (0,17), Letaba Basalt (0,62)	[illegible]	0,47
		1960	Roads (0,22), Kraals (0,28), Highest Altitudes (0,55), Swartland/Sterkspruit (0,62), Lowest Altitudes (0,76)	8	0,63
		1970	Kraals (0,03), Highest Altitudes (0,05), Roads (0,32), Swartland/Sterkspruit (0,37), Lowest Altitudes (0,95)	[illegible]	0,59
		1975	Kraals (0,12), Highest Altitudes (0,28), Swartland/Sterkspruit (0,31), Lowest Altitudes (0,98)	5	0,70
		1983	Kraals (0,10), Swartland/Sterkspruit (0,32), Lowest Altitudes (0,80)	7	0,62
KwaZulu	Gullied	1937	Open Woodland (0,10), Mayo/Milkwood/Shortlands/Swartland (0,81), Slope Angles > 20° (0,66)	9	0,37
		1960	Wooded Grassland (0,08), Slope Angles > 20° (0,48), Kraals (0,67), Mayo/Milkwood/Shortlands/Swartland (0,72), Mayo (0,97)	10	0,60
		1970	Mayo (0,14), Altitudinal Range (0,24), Mayo/Milkwood/Shortlands/Swartland (0,33), Wooded Grassland (0,51), Grassland (0,78)	9	0,52
		1975	Mayo/Milkwood/Shortlands/Swartland (0,14), Mayo (0,19), Altitudinal Range (0,22), Slope Angles > 20° (0,30), Grassland (0,83)	8 8	0,68 0,68
		1983	Altitudinal Range (0,25), Slope Angles > 20° (0,31), Grassland (0,63), Mayo (0,83), Mayo/Milkwood/Shortlands/Swartland (1,00)	8	0,46

Note * the total number of variables that were significantly correlated with the dependent variable and entered into the regression analysis.

Settlement in the KwaZulu component of the study area in the late 1950's caused a significant 25 and 9 fold increase in eroded surfaces and surfaces susceptible to erosion (Tables 30, 31 and 32, Figures 16 and 21), respectively. The concept introduced in section 3.4.6 that soil erosion processes are more sensitive to a *change* in landuse than to an intensification of them, is supported by the fact that eroded surfaces in 1960 were not significantly associated with any of the biophysiographic parameters considered in this study (Tables 33 and 34). The significant association of the 1960 sparsely vegetated surfaces with roads and kraals, and their predominate occurrence throughout the profile of bottomland slopes covered by very highly erodible Swartland/ Sterkspruit soils underlain by Vryheid shale and sandstone, indicates that they were predominately caused by the deforestation of open woodland communities associated with hut and fence construction, as noted in section 8.1.5. During the sixties non- and sparsely vegetated surfaces continued to expand to the same extent, but at rates substantially lower than those that prevailed during the first few years after settlement. The localized bare ground areas in 1970 were significantly associated with kraals. Their prevalence on very gentle and gentle gradients of the bottomland slopes described above however, indicates that cultivation exerted the major influence on their development. While roads and kraals exerted a marginally greater influence on the distribution of sparsely vegetated surfaces in 1970 than in 1960, their very extensive occurrence throughout the profile of these bottomland slopes indicates that their development was regulated more by spatially extensive activities such as deforestation, annual early dry season veld burning and overgrazing, as noted in section 8.5.1.

Although compared to 1970 localized eroded surfaces in 1975 were better represented on upland areas covered by Mayo and associated soils underlain by Karoo dolerite, and on the steeper gradients of the bottomland slopes covered by sandy Swartland/Mispah underlain by Volksrust shale, overall they contracted to the same extent as the sparsely vegetated surfaces during the mid seventies wet spell. The use of steep slopes for cultivation reflects the shortage of land on the more suitable gentler slopes. While the association between the sparsely vegetated surfaces and kraals increased, their association with roads decreased. Their improved representation throughout the profile of bottomland slopes reflects the intensification of the extensive landuse influences. As noted in section 8.1.5, the good rainfall conditions would have stimulated the domestic stocking rate, making overgrazing the most intensive of these influences. Despite the severe drought of the early eighties, eroded surfaces continued to decrease. As these surfaces remained significantly associated with both the upland areas and the gentle slopes of bottomland areas detailed above, this contraction predominately reflects the abandonment of the plots on the steeper gradients of bottomland slopes that were cleared for cultivation during the mid seventies wet spell. Yields on the shallow soils of these plots would have responded to the drought earlier and to a greater extent than those on gentler gradients and deeper soils within the river's contributing area. The overall 8,5 percent expansion of sparsely vegetated surfaces between 1975 and 1983, contrasts with the contraction of the non-vegetated surfaces described above. Although the drought induced mortality of domestic animals reduced the stocking rate to a level more compatible with the carrying capacity (refer section 2.10.4), the continued extensive representation of sparsely vegetated surfaces on bottomland slopes indicates that overgrazing continued to exert a major influence. As noted in section 1.1 and 2.11.2, Looser (1984; cited in Kovacs *et al.* 1985) designated most of the spectral signature of the 1:250 000 LANDSAT image corresponding to the KwaZulu component of the study area as representing overgrazed veld. The aerial photographs used in this study which were taken almost exactly a month before this satellite image however, showed that overall sparsely vegetated surfaces predominately caused by overgrazing comprised less than two fifths of the area. This discrepancy is due to the fact that the light toned areas on the aerial photographs less than the equivalence of 0,5 ha on the ground, excluded from measurement in this study, produce the same spectral signature as more extensive sparsely vegetated surfaces when they occur in high densities.

None of the very few gullies larger than 0,5 ha in extent present in the Wilderness area showed any evidence of activity on the five sets of aerial photographs examined in this study. While most of the gullies larger than this threshold size in the KwaZulu component were active, their dimensions did not change significantly during the study period, and overall they covered on insignificant 0,03% of this component of the study area. Field surveys revealed that most of these gullies occurred parallel to primary roads on long slopes, and traversed the roads at the base of the slopes. Their predominate occurrence in hemicryptophyte communities on very steep slopes covered by moderately erodible Mayo soils underlain by Letaba basalt, shown in Table 33, indicates that most of them originated in these upland areas prior to settlement, when the primary roads through them were developed.

8.3 POTENTIAL VERSUS ACTUAL SOIL EROSION

The extent to which the biophysiographic variables examined in section 8.1, have actually contributed to the soil erosion in the study area described in section 8.2, is apparent from Table 34. These variables accounted for between 13 and 67% of the variability in the Wilderness area's eroded surfaces, and for between 9 and 65% of the variability in it's sparsely vegetated surfaces. As noted in section 2.11.1, Venter (1988) used runoff plots to monitor soil loss in the Umfolozi Reserve over a four year period. He concluded that the variability in soil loss was primarily determined by the large year to year fluctuations in rainfall rather than by the manipulations of the large ungulate stocking rates. While his conclusion may be valid over short term periods, the findings of this study suggest that over long term periods, variations in stocking rate exert a greater affect on soil erosion than rainfall variability. Above average rainfall conditions occurred during both 1960 and 1975, yet the corresponding R^2 values for eroded surfaces are at opposite extremes of their range. Similarly, the R^2 value for sparsely vegetated surfaces in the severe 1983 drought was more equivalent to the corresponding 1960 and 1975 values, than those corresponding to the below average rainfall conditions in 1937 and 1970. The relationship between the proportion of the variability in these surfaces accounted for by biophysiographic variables, and the intensity of large ungulate population control, contrasts with the discrepancies between R^2 and rainfall noted above. In the case of the eroded surfaces this relationship is a simple reciprocal one such that; the R^2 value was highest when the large ungulate populations were not actively managed, and lowest when the culling programme was most intense (refer section 2.9). In the case of sparsely vegetated surfaces the R^2 values are related to the intensity of large ungulate population control via the affect of this control on biotic influences. That is, the R^2 values were low when the biotic influences associated with the exceptionally low and excessively high stocking rates in 1937 and 1970 respectively, were very high.

Because of the high degree of multicollinearity between the biophysiographic variables (Tables 10, 11, 13 and 25), most of the variability in both the eroded surfaces and those susceptible to erosion in the following landtypes of the Wilderness area was explained by the following variables:-

i) riverine - gentle slopes, Volksrust shale, Pietermaritzburg shale
ii) bottomlands - Swartland/Mispah soils
iii) uplands - very steep slopes, Letaba basalt

Although the distribution of the Iron Age sites is restricted to the riverine area (refer section 8.1.5) they did not exert a significant influence on the variability in the Wilderness area's 'erosion' surfaces, as the only significant correlation between them and these surfaces was a weak negative one ($r = -0,37$) with the sparsely vegetated surfaces in 1937.

The biophysiographic variables examined in this study accounted for between 0 and 66, 47 and 70, and 37 and 68 percent of the variability in the KwaZulu components' eroded, susceptible to erosion, and gullied surfaces, respectively. The low 1937 R^2 values for each of these surfaces reflects the affect that the activities associated with the development of the primary roads through the area had on both sheet/rill and gully erosional processes. As noted in section 8.3, settlement in the area in the late 1950's had a dramatic effect on eroded surfaces. The fact that the biophysiographic variables examined were unable to explain any of their variability in 1960, but accounted for an average of 59% of it once settlement had stabilized reaffirms this, and supports the concept introduced in section 3.4.6 that soil erosion processes are more sensitive to a *change* in landuse than to an intensification in them. Averaged over the study period, roads and kraals accounted for about one fifth of the variability in the sparsely vegetated surfaces and an insignificant proportion of that of the non-vegetated surfaces, reflecting the fact that more extensive landuse activities predominately deforestation, annual early dry season veld burning and overgrazing exert a greater influence on the former surfaces, while the latter surfaces are predominately influenced by cultivation. Because of the high degree of multicollinearity

TABLE 35 : EFFICIENCY OF EROSION POTENTIAL FACTORS IN ACCOUNTING EROSION SURFACES.

			FACTORS					
			ERODIBILITY		TOPOGRAPHY		COVER	
STUDY AREA	SURFACE CATEGORIZATION	YEAR	MULTIPLE	R^2	MULTIPLE	R^2	MULTIPLE	R^2
Game Reserve	Eroded	1937	0,61	0,42				
		1960	0,59	0,32				
		1975	0,35	0,09				
KwaZulu	Eroded	1970	0,69	0,49				
		1975	0,71	0,53				
		1983	0,66	0,40				
Game Reserve	Susceptible to Erosion	1937			0,39	0,31		
		1960	0,79	0,31				
		1983	0,39	0,35				
KwaZulu	Susceptible to Erosion	1960	0,50	0,63				
		1975	0,11	0,92				
		1983	0,30	0,67				
KwaZulu	Gullied	1937	0,19	0,37	0,75	0,37	0,14	0,37
		1960	0,17	0,60	0,12	0,60	0,20	0,60
		1970			0,10	0,52		
		1975			0,22	0,68		
		1983	0,25	0,46	0,65	0,46		

Note: The multiple is the proportion of R^2 accounted for by using the erosion potential factors in the forward stepwise multiple regression analysis, in place of the component variables that each is a composite measure of.

between the biophysiographic variables (Tables 10, 11, 13, 25 and 29), most of the variability in the surfaces affected by sheet/rill erosional processes in the following landtypes of the KwaZulu component of the study area was explained by the following variables:-

i) riverine/arable land - lowest altitudes, very gentle slopes
ii) bottomlands/arable lands - Swartland/Sterkspruit soils
iii) bottomlands/rangelands - Swartland/Mispah soils, Vryheid shale and sandstone
iv) uplands/settlements - highest altitudes, very steep slopes, Letaba basalt

As the gullies were best represented in the upland areas most the the variability in them was explained by very steep slopes and Mayo and associated soils.

Table 35 shows that overall the erodibility factor was unable to account for about two fifths of the variability in the 'erosion' surfaces. With few exceptions lower R^2 values were obtained when the K index values were substituted for the data on the individual parent material and soil formations in the forward stepwise multiple regression procedure. The greater efficiency of the latter data in explaining the variability in the 'erosion' surfaces is due to the fact that in the bottomland and upland areas, they were often best represented on moderately erodible and resistant substrates respectively, due to the stronger influence of other erosion risk factors, whereas the erodibility index is weighted in favour of the erodible substrates. Due to the co-variation of the study area's topography with it's geology and it's pedology (Tables 11 and 13), with the exception of the sparsely vegetated surfaces in the Wilderness area in 1937, the factor describing the influence of topography on erosion, was unable to account for any of the variability in the surfaces effected by sheet/rill erosional processes. Ironically, although the LS factor was developed to explain erosion caused predominately by unconfined surface flow processes (refer section 5.4) in this study, it was found to be more efficient in accounting for the variability in the gullies. As noted in section 8.2 they were best represented on the very steep, long slopes of the KwaZulu components' upland areas. The vegetation cover factor generally did not account for a separate portion of the variability in the 'erosion' surfaces, reflecting the fact that it's effect on erosion is almost totally duplicated by the combined effect of the other multicollinear biophysiographic variables examined in this study (Tables 22, 23 and 25).

CHAPTER NINE

CONCLUSION

9.1 INTRODUCTION

This chapter assesses the major conclusions drawn from this study in terms of (i) the general perception of soil erosion on traditional communal lands, (ii) the aims of the study, and (iii) the weaknesses of the research design employed in this study, and consequent possible sources of data error, misinterpretation and inconclusiveness. This assessment yields a perspective on the past, present and future status of soil erosion in the Mfolozi catchment. The recommendations eminating from it note the constraints on management and development options in the 10b bioclimatic subregion of the Mfolozi catchment, imposed by the findings of this study. They also identify the topics that would need to be more thoroughly researched in order to substantiate the perspective on soil erosion presented, and its country-wide implications. Other findings of this study that are of special interest either because they challenge or confirm previously reported findings, or because they are not known to have been previously reported are also highlighted in this chapter.

9.2 PERCEPTION OF SOIL EROSION

The major conclusions drawn from the review of South African literature on soil erosion presented in chapter three, as well as those derived from the results of this study presented in chapter eight, indicate that a substantial revision of the general perception of soil erosion in this country is long overdue. This perception is epitomised by the assertions about erosion in the Mfolozi catchment noted in section 1.1 which originally motivated this study, viz:- (i) that both sheet and gully erosion are very severe, (ii) that erosion is prevalent in the areas administered by KwaZulu, (iii) that erosion is primarily caused by overstocking and poor cultivation practices, (iv) that the progressive increase in erosion throughout this century is directly associated with similar trends in human and livestock populations, (v) that erosion is likely to become more intensive and extensive in the traditional communal lands in the future and (vi) that the erosion scenario depicted above is the primary cause of the increased incidence and severity of flooding of the Mfolozi rivers.

Schulze's (1981) study suggesting very severe sheet erosion in the Mfuyeni and Biyela catchments contrasts with Liggit's (1988) and Liggitt and Fincham's (1989) assessment of sheet erosion in a physiographically comparable area that has been subjected to an anthropogenic influence of comparable duration and intensity. As noted in section 2.11.2 these researchers found that sheet erosion was absent from 60% of the area surrounding Ulundi that they examined, and only rated 2% of the sheet erosion present as severe. While Looser's (1984; cited in Kovacs *et al.* 1985) designation of most of the spectral signature of LANDSAT images of KwaZulu, as representing overgrazed veld, suggests extensive sheet erosion, it does not necessarily imply that the associated soil loss rates are very severe. On the contrary, Venter's (1988) report of weak soil loss rates in the non-cull management area of the Umfolozi Game Reserve during the height of the 1983 drought, suggests that the average rates are more likely to be insignificant. The findings of this study suggest that sheet erosion processes only remove significant quantities of soil from very localized areas in the Wilderness area, and from localized areas in the KwaZulu component of the study area.

Although the Mfolozi Catchment Planning Committee's foundation report described large gullies as being well represented throughout the KwaZulu area (Anon, 1985a), Liggitt (1988), and Liggitt and Fincham (1989) found that only 15% of the area surrounding Ulundi that they examined, contained gullies. They rated 7% of the gullies present as moderate and the balance as slight. Discrepancies in the estimation of the severity of gully erosion may arise from the failure to exclude stable systems. This study which considered only active gullies, found that they covered an insignificant 0,03% of the KwaZulu component of the study area. Literature reviewed in section 3.4 suggests that most gullies in the 10b bioclimatic subregion's riverine and interior lowland occur in highly erodible stratified deposits that owe their origin to the Quaternary glacial eustacy, and that the gullies' incision, consequent growth and even possibly their degree of stability evident today, occurred in advance of any significant anthropogenic influence. The views of Stewart (1965), Porter (1972) and Brooks *et al* (1980) cited in section 2.11, and those of Beckedahl and Dardis (1988) cited in section 4.11, that most gullies that owe their origin and development to anthropogenic influences are caused by poorly sited, built and maintained roads, are supported by the findings of this study. This in turn suggests that the exaggerated perception of the severity of gully erosion evident in reports by Anon (1984, 1985), Combrie Greig (1984) and Compton (1984) cited in section 1.1, may be due to inadvertent cognition stemming from the fact that a large proportion of these gullies occur in very close proximity to the roads used in travelling through the area. The above contradictions in the perception of the status of erosion in physiographically comparable parts of KwaZulu, suggests that the conclusion reached regarding the status of soil erosion in the country as a whole presented in section 3.6, is equally valid in the Mfolozi catchment. That is, very severe erosion rates are generally localized and associated with poor vegetation cover, broad scale rates are weak, and rates in good cover areas are insignificant.

The general consensus in the literature cited in sections 3.4, 3.6 and 3.7 that greater soil erosion rates occur on communal peasant lands as compared to commercial farmland, or land under conservation management, supports the assertion that erosion is more prevalent in the areas administered by KwaZulu. However, the recognition in an increasing proportion of the more recent of this literature that (i) much of the land designated for tribal use by the colonial government already contained much of the gully erosion evident today, (ii) many of these gullies are natural and predate any anthropogenic influence, (iii) the physiographic characteristics of much of the traditional communal lands are marginal even in terms of the requirements of subsistence agriculture, and are therefore more susceptible to erosion, suggests that the more common occurrence of erosion on the communal lands may not be an exclusive reflection of the traditional landuse practices. Notwithstanding the fact that the characteristics of the rainfall, soil, topography and vegetation were found to render the KwaZulu component of the study area more susceptible to erosion than the Wilderness area, this study found that the traditional landuse practices did exert a significant influence. Prior to their commencement in the KwaZulu component, eroded and sparsely vegetated surfaces were very localized throughout the study area. These practices increased the status of these surfaces to localized and very extensive, respectively.

This study found that the localized non-vegetated surfaces exhibiting evidence of active sheet/rill erosion processes mainly occurred on cultivated lands in the riverine and bottomland areas. Their existence elsewhere was associated with roads, paths, tracks and kraals. Extensive sparsely vegetated surfaces evidently susceptible to erosion processes, occurred throughout the bottomland and upland areas. In addition to overgrazing, they were attributed to deforestation and poor veld burning practices.

There is no consensus or conclusive evidence available in the literature reviewed in section 3.4, for South African erosional activity over this century having increased, decreased or stabilized. In this study, eroded and sparsely vegetated surfaces increased dramatically during the first few years after settlement in the KwaZulu component in the late 1950's. While these surfaces continued to expand to the same extent over the following two decades, they did so at substantially lower rates. The increasing trend in the eroded surfaces was reversed by the mid seventies wet spell. While the sparsely vegetated surfaces also contracted during this wet spell, the overstocking encouraged by it, caused them to subsequently increase. Although evidently initiated by road construction activities, the mechanism regulating gullying appeared to be intrinsic, as their dimensions did not change substantially over the study period. The above findings support several very important concepts introduced in section 3.4, viz:- (i) that soil erosion processes are more sensitive to a change in landuse than an intensification in them, (ii) that the soil system has a certain resilience and self regulatory capacity, so that a rapid increase in erosion initiated by a change in landuse, stabilises at decreased rates once adjustment to the new landuse has taken place, and (iii) erosional responses in the summer rainfall region of north eastern South Africa reflect rainfall oscillations.

Predictions of soil erosion becoming more intensive and extensive on the traditional lands in future are largely dependent on the assumption that human and livestock populations will continue to increase. Two factors have become apparent recently that may nullify this assumption. The first, is the new political dispensation in the post apartheid South Africa. The economic rationality of overstocking and the traditional land tenure system are likely to remain major obstacles to rural development in common with virtually all independent African countries. Ironically, should the current general aspirations for rural development succeed, erosional processes triggered by the communications infrastructure and intensive market based agriculture, unless actively controlled, are likely to attain unprecedented levels. Given the re-evaluation of tribal lands, homelands and national states that this new dispensation demands, there can be little justification for the existing soil conservation legislation not becoming mandatory throughout South Africa. The second, relates to be significant dampening effect that Aids is projected to have on such rural populations.

Given the fact that there is no conclusive evidence that erosion in the Mfolozi catchment has increased progressively throughout this century, the assertion that it is the primary cause of the increased incidence and severity of flooding requires critical evaluation. The table of the Mfolozi river's flood peaks from 1880 to 1984 presented by Anon (1984) and Combrie Grieg (1984), do suggest an increase in the frequency and severity of flooding. Phillips' (1983), and Fleming and Hay's (1983) estimates of the Mfolozi river's mean annual sediment load, are comparatively high. However, the suggestion that many of the gullies in the catchment are natural and predate any significant anthropogenic influence, and that the response of erosion to such an influence has most probably stabilized as most of the contemporary settlement pattern was established in the first few decades of this century, implicates a more dramatic and consistent causative factor. This researcher is of the opinion that the destruction of wetlands is most likely the primary causative factor. As noted in sections 2.7.3 and 3.8.3, Begg (1983) found that most of the Mfolozi catchment's former wetland resource had been destroyed this century. This destruction has meant that sediment eroded from the catchment and accreted in the wetlands over aeons has been rapidly liberated into the river channels, where it's temporary storage has reduced the channel's ability to accomodate peak flows, and consequently increased the incidence and severity of bank scouring and flooding.

9.3 AIMS OF STUDY

The aims of this study as listed in section 1.3, were achieved. The major conclusions reached regarding the influence of traditional landuse practices on erosion, and the contemporary status of soil erosion in the KwaZulu component of the study area, have been noted in section 9.2 above, and will not be repeated in this section. The influence of each of the physiographic parameters examined on the study area's soil erosion potential, and on it's temporal variations in actual erosion, was found to be appreciably influenced by the levels at which the other erosion risk factors were present. As the topography of the riverine terrain is characterized by very gentle and gentle short slopes, the susceptibility of the substrate exerted the dominant influence on erosion, such that, it was best represented on highly erodible unconsolidated alluvial deposits, and on the most erodible soil formations - Fernwood, Valsrivier/Dundee, and geologic formations - Emakwezeni shale and sandstone, Volksrust shale and Pietermaritzburg shale. Erosion in the bottomland terrain was largely influenced by topography and pedology. It was best represented on long steep and very steep slopes covered by various combinations of shallow Sterkspruit, Swartland and Mispah soils. As the upland areas are underlain by resistant rocks and covered by resistant soils, the erosion on them is primarily influenced by the steep and very steep short slopes.

Erosion in the bottomland grasslands was additionally significantly influenced by the high palatability and consequent herbivore overutilization of the *Panicum coloratum* communities. Likewise the high erosion potential rating of the *Acacia karoo, A. tortilis, A. caffra* and *Combretum apiculatum* accounted for the eroded surfaces' better representation in the more serally dynamic wooded grassland and open woodland textural classes, as compared to grassland/reedbeds and closed woodland/forest. Despite significant changes in the vegetation in both components of the study area caused by rainfall oscillations, variations in veld burning and herbivore utilization; the clearance and abandonment of arable land; and deforestation, and by the general trend in seral development towards the woody climatic climax, neither component experienced an overall progressive dimunition in the protection afforded to the soil by it's cover.

The eroded surfaces in the Wilderness area remained very localized and restricted to the riverine area throughout the study period. Prior to 1970 the surfaces susceptible to erosion were very localized and predominated in the riverine and bottomland areas. After 1970 they became localized and also occurred on the upland areas. While the expansion of both these surfaces reflects the progressive bush encroachment particularly during the "nagana campaign", and the herbivore overutilization during the sixties and early seventies, their contraction in the late seventies reflects the shift to a burning policy aimed at attracting game to underutilized areas coincident with above average rainfall conditions, and the intensification of the culling programme. The fact that their contraction was not reversed by the severe drought of the early eighties, indicates that the Natal Parks Board is to be commended for it's management approach.

The biophysiographic variables examined in this study accounted for up to two thirds, of the variability in the erosion surfaces in the study area. The dramatic effect of settlement in the KwaZulu component was affirmed by the fact that these variables were unable to explain any of the bare soil surfaces on the set of aerial photographs taken a few years after settlement. With few exceptions data on the individual parent material and soil formations, topographic parameters and vegetation classes entered into the forward stepwise regression procedure, proved more efficient in accounting for the variability in the erosion surfaces than the K, LS and C erosion risk factors. Roads and kraals which as noted in section 7.2.6 have been found in other studies to be fairly reliable indices of the anthropogenic influence, explained only an average of 15% of the non-vegetated surfaces in the KwaZulu component, and were totally inefficient in accounting for the sparsely vegetated surfaces caused by more extensive activities.

9.4 WEAKNESSES OF RESEARCH DESIGN

The increase in erosion in theWilderness area in the sixties and seventies, it's increase in the KwaZulu component of the study area throughout the study period, and it's overall status, were very much lower than that anticipated from the discussion presented in sections 1.1 and 2.11. It is possible that the difficulties associated with identifying erosion in bush encroached areas, and the exclusion of 'erosion' surfaces smaller than 0,5ha explained in section 7.1, resulted in an underestimation of the erosion present. Notwithstanding this potential source of error, this researcher is of the opinion that it is unlikely to have seriously jeopardised the major conclusions reached in this study.

9.5 OTHER NOTEWORTHY FINDINGS

The following findings of this study are highlighted either because they challenge or confirm previously reported findings, or because they are not known to have been previously reported.

i) During wet spells the increased fuel loads and consequent increased effectiveness of fire in penetrating closed woodland/forest communities, causes them to revert to less mature open woodland sere. During dry spells the reduced vigour of herbaceous species renders fire ineffective consequently encouraging the seral development of open woodland communities into closed woodland communities.

ii) The contrast of the expansion of the grassland communities in the Wilderness area with their contraction in the KwaZulu component of the study area during the mid seventies wet spell, illustrates the effectiveness of the Natal Parks Board's ungulate population control policy. Whereas the level of herbivore utilization in the Wilderness area permitted fuel loads capable of supporting effective fires, the livestock density inflated by the more favourable conditions in the KwaZulu component, caused overgrazed veld which was ineffective in stemming the accelerated advance of woody invaders.

iii) The Natal Park Board's veld burning policy has failed to arrest seral development. Bush encroachment evidently has no significant effect on non-vegetated surfaces on which soil loss rates are significant. While it does cause substantial increases in sparsely vegetated surfaces, their soil loss rates are unlikely to be of concern.

iv) Non-vegetated surfaces responded quicker than sparsely vegetated surfaces to improved moisture conditions indicating that the invasion of pioneer species onto patches of bare ground, was more rapid than the re-establishment and thickening of the more mature sere associated with the poorly covered surfaces.

v) Although Venter (1988) recorded the highest soil loss rates during the peak of the early eighties drought, and the general perception by Natal Parks Board officials based on field assessment, was of increased erosion severity, this study found that the overall proportion of eroded surfaces in 1983 was equivalent to that of 1975 when good rainfall conditions prevailed, while the overall proportion of sparsely vegetated surfaces in 1983 was marginally less than it was in 1975.

vi) Venter's (1988) conclusion that the variability in soil loss was primarily determined by the large year to year fluctuations in rainfall rather than by the manipulations of the large ungulate stocking rates, may be valid over short term periods. However, the findings of this study detailed in section 8.3, suggest that over long term periods variations in stocking rate exert a greater effect on soil erosion than rainfall variability.

vii) The distribution of the Iron Age sites did not exert a significant influence on the variability in the Wilderness area's erosion surfaces.

9.6 RECOMMENDATIONS

The following research should be carried out in order to substantiate the perspective on soil erosion obtained from this study, and it's country-wide implications.

i) Verification of van Wyk's (1963, cited by Kent, 1980) assertion that more than 60% of the gullies in Natal occur in the Masotcheni formation. As noted in section 3.4.2 this formation owes it's origin to the Quaternary glacial eustacy, and it's profile and physiochemical properties contribute to it's high erodibility and account for the gullying that subsequently took place in it. Such a verification would therefore confirm that natural rather than anthropogenic factors have regulated the origin and development of most of Natal's gullies.

ii) Conduct field surveys of gullies in the geologic formations in which they are best represented to obtain sedimentological and stratigraphic evidence to indicate (a) the date of initial incision and influence of rainfall oscillations on their subsequent activity, and (b) their contemporary activity status.

iii) As noted in section 3.4.5, Broderick (1985, 1987) examined a wide range of possible sources of reference to the soil erosion scenario in Natal prior to the availability of aerial photographs shortly before the Second World War. She cautioned that the perception she found of the scale and magnitude of the erosion may have been exaggerated as large gully systems and silt laden rivers were not characteristic features of the countries of origin of most settlers. An equivalent study should be conducted on a possible source of reference on the African perception of Natal's pre World War II soil erosion scenario which has recently become accessible in the form of James Stuart's (1868-1942) original notes. Stuart was fluent in Zulu by the age of twenty and served as an interpreter before holding various posts in the Natal, Swaziland and Zululand administrations. He was magistrate in several divisions before being appointed Assistant Secretary for Native Affairs in Natal in 1909. His notes reflect the systematic collection of information about the Zulu people from an early stage in his career.

iv) Conduct comparative studies of the temporal and spatial variations in soil erosion on traditional communal lands and commercial agricultural lands in physiographically equivalent areas.

v) Obtain estimates of soil loss rates from non-, sparsely and well vegetated surfaces in grassland, open woodland, closed woodland and forest in the bioclimatic regions in which erosion is well represented, using experimental runoff plots and simulated rainfall.

Equivalent studies carried out in the future should designate the predominate landuse attribute of the traditional land surface on which the erosion occurs as cultivated land, abandoned arable land, rangeland, roads, paths or tracks, or kraals. Such a designation will yield a more accurate indication of the influence on erosion of each. More work needs to be carried out on the calibration of the K, LS and C factors before they can be effectively employed as indices of erosion in simiiar studies.

In future, when a rapid assessment of land suitability for rural development from an erosion risk perspective is required in the 10b bioclimatic subregion of the Mfolozi catchment the first step should be to assess whether the target area is affected by a limited or stable landuse influence, or by a very recent or dynamic landuse influence. In the case of the former, about two thirds of the highest risk areas can be identified by demarcating the most susceptible parent material and the steepest terrain as unsuitable, using the readily available 1:50 000 geology and topocadastal maps. In the case of the latter, areas actually affected by erosion are best delimited on the readily available 1:10 000 orthophoto maps, and designated as unsuitable.

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