AN INVESTIGATION INTO THE NATURE AND EXTENT OF EROSION AND SEDIMENTATION IN THE MAQALIKA DAM CATCHMENT, MASERU.

THESIS

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ABSTRACT

The study investigates the nature and extent of erosion and deposition in the Maqalika catchment, Maseru. Components of the study include (i) the re-construction of erosion and land use history in the catchment from 1961 to 1985, (ii) determination of dominant factors or combinations of factors responsible for the observed erosion distribution at each date, (iii) the identification and evaluation of erosion and deposition features, and their spatial and temporal variations, and (iv) identification of socio-economic problems associated with observed erosion and deposition.

Methods employed for the re-construction of erosion and land use history include the use of sequential aerial photography of 1961, 1979 and 1985, orthophoto maps and review of literature from past studies. It has been possible to map erosion and land use for the three time periods pin-pointing areas of major change. Results are presented in map form showing the spatial distribution of each erosion class and each land use category. It was however not possible to derive any meaningful relationship between erosion distribution and land use, on the aforementioned maps. The only observation made from the comparison of the maps is that erosion degree and distribution sometimes changes with land use, while land use sometimes changes in response to erosion. Major land use changes are the conversion of agricultural land to urban land use, and grazing land.

Due to the multi-dimensional nature of soil erosion, hand factor analysis was employed to determine which factors or combinations of factors were dominant at each date. Despite the extensive research on the various factors affecting erosion such as those used for the USLE and SLEMSA there is a growing uncertainty as to which factors are more important to erosion. Soil erodibility has been found to be a component of the major controlling factor combinations in all three periods under study. At each date erodibility combined with a number of other factors determined the observed erosion distribution.

As suggested by Mosley (1980), Cambell (1985) and Coleman and Scatena (1986) sediment from a catchment is derived principally from spatially limited portions of the catchment. Likewise eroded sediment becomes deposited in spatially limited areas with special characteristics which encourage deposition. Aerial photographic survey aided by ground survey and oblique photographs were employed to identify sediment sources and sinks within the catchment. Some sediment sources are fixed such as gully floors and sides, while some change location from time to time such as construction sites. An evaluation of portions of the catchment for their ability to supply and deliver sediment has shown that the most eroded areas are not the most active sediment sources. Sediment yield is limited by either supply or transport.

Sediment yield was estimated using reservoir survey data which indicate that there is a high rate of soil loss from the catchment. One flaw of this method as a measure of soil loss is that it treats the measured sediment yield as if it were contributed uniformly from the basin. This method however affords the researcher to estimate minimum erosion rates, taking into account that large amounts of sediment are stored at various places within the catchment.

The possible socio-economic consequences of erosion and deposition have been identified. These include loss of cropland, destruction of roads and building sites which require methods of reclamation, sedimentation of small reservoirs and ponds, and the formation of gully bottom fills which are potential sediment sources. Conservation measures presently applied in the catchment are assessed and found to be irrelavant to the present erosion problem. Data from the reservoir survey revealed that the estimated rate of soil loss is more important to on-site erosion damage than to off-site damage in the form of the sedimentation of Maqalika reservoir. Appropriate conservation measures such as those suggested by Amimoto (1981) would be relevant to the study area, however the main constraint in their implementation would be lack of legislation and the absence of a sound land use policy. It is therefore concluded that the present land use situation which does not take into consideration the physical constraints of the catchment is partly responsible for accelarated erosion in the catchment.

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CHAPTER ONE

INTRODUCTION

The Problem

There is growing concern in Lesotho about the widespread, and increasing rates of soil erosion and sedimentation which have been identified as serious problems hindering development and threatening the country's natural resources. These problems were first reported by Pim (1935), and since then a number of publications reviewed elsewhere in the text have further supported Pim's findings. Research papers presented at the International Conference on Development and Environment held in Maseru in 1988 re-emphasized the severity of the soil erosion problem in Lesotho. Most of these papers indicate that the observed erosion problems require attention in the form of measures promoting control or prevention of erosion.

Research framework

There have been extensive publications on research concerning erosion and sediment transport. Methods of research differ in scale and detail depending on its purpose. The major aim of erosion research is to understand processes at work in order to be able to apply suitable control measures (Morgan, 1980a). The success of any erosion control programme is determined by the ability of the control personnel to select strategies appropriate to specific problems.

A variety of techniques exists for measuring or predicting sediment production and sediment yield. These techniques do not always provide relevant information required for developing and managing control programmes (Coleman and Scatena, 1986). The measurement of on-site erosion does not provide information on sediment yield, and likewise sediment yield measurements at the catchment outlet or any other control point do not identify specific areas of considerable sediment supply that would require control measures. Furthermore the development of a control programme requires knowledge of the distribution of erosion promoting factors and how they influence the distribution and severity of erosion.

Various researchers have carried out integrated studies on both on-site erosion and drainage basin sediment yield. Studies such as those by Rapp (1972), Chakela (1981), and Christianson (1981) stress the importance of evaluating and analyzing data and observations in order to document and discuss types, extent and rates of erosion and sedimentation. Rapp *et al.* (1972) note that "much of the debates on the subject (*erosion*) have been carried out with only superficial specific information on the types of processes at work, their relative importance and their rates of operation" (Rapp *et al.*, 1972, p105). Understanding of processes and their rate of operation forms an integral part of soil erosion research which is intended to provide a basis for conservation strategies. This also affords the researcher an opportunity to test some selected methods for collection and analysis of indicators of land degradation. Among these methods Garland (1982) discusses the mapping and classification of eroded areas so that follow up maps can be used to indicate the rate of land degradation and the efficiency of conservation measures.

A number of studies such as those by Stocking (1987), and Chakela and Stocking (1988) have included the mapping of the spatial variability of erosion promoting factors and the resultant combinations and interactions. The purpose of such studies is to pinpoint "black spots" that have an erosion potential. In most studies dealing with the analysis of erosion promoting factors parameters describing human influence are lacking, probably because they are many and difficult to measure. Moreover the final choice of parameters considered important involves a great deal of subjectivity. Population density has been used extensively as a measure of human influence (Nir, 1983), however Blaikie and Brookfield (1987) note that different sectors of the population are involved in a variety of activities which have a wide range of effects on erosion. Understanding the effects of human activities and their relative magnitudes forms another part of soil erosion research which is very important in disturbed areas that are exposed to human occupation.

It has been mentioned that the main purpose of soil erosion research is to be able to apply appropriate conservation measures. These measures are sometimes costly and therefore require justification, particularly if scarce resources are to be used. Swanson (1979) notes that the determination of socio-economic loss due to erosion and deposition should be included in research in order to provide a perspective regarding the seriousness of the erosion-sedimentation problem. Such a perspective would provide a justification for conservation and improve the basis for selection and emphasis of policy instruments.

The present study

The present study is defined as an anthropogeomorphological study, which examines geomorphological forms and processes in relation to man's activities (Nir, 1983). The study deals with the examination of erosion and deposition in the Maqalika dam catchment and subsequent sedimentation of Maqalika reservoir, which supplies the town of Maseru with water. The study examines water erosion, which is more important in Lesotho than wind erosion (Makhanya, 1979).

Water erosion includes raindrop splash, surface runoff and channel erosion. The main thrust of the study is on the effect of human land use in the form of residential urban development on sediment production and transport. Studies such as the present one serve a number of purposes which include:-

(i) to provide an inventory of erosion and sedimentation information that may be used as a base line for future studies or for comparison with other studies.

(ii) to elucidate the erosion problem, identifying processes, sub-processes, resultant forms, and probable causes, thus discounting theories that are not supported by any scientific research.

(iii) to provide data that form a scientific framework for the practical implementation of conservation measures, for the design of structures, for the development of legislation and for rational decision making.

(iv) to draw attention to the changing nature of erosion as society changes. The present study in particular is intended to draw attention to the increasing importance of urban development and settlement evolution as factors influencing erosion.

It has been shown that catchment erosion varies in both space and time (Morgan, 1986), with variability being a function of rainfall and catchment characteristics. Urban development is one component of the catchment which may alter characteristics of the catchment resulting in increased erosion. The present study describes processes of erosion and deposition in a catchment experiencing rapid and ill-planned urban residential development. In order to gain a clearer perspective of the data and results obtained from the study, catchment characteristics which are known to influence erosion are described before any inferences are made about the effect of urban development.

Although many studies have examined the effect of catchment characteristics on erosion, their relative importance to long term erosion rates is not clear. It is for this reason that the current study incorporates both the studies of present erosion conditions, and past historical trends. Beckedahl, *et al.* (1988) note that contemporary erosion rates may not necessarily reflect longer term catchment behavior because of the dynamic nature of the landscape. In order to place contemporary erosion rates into perspective, it is sometimes necessary to examine previous catchment behavior. Weaver (1988a) notes that the determination of rates of land degradation in Southern Africa by sequential mapping and classification of soil erosion is a neglected area of research. Most studies concentrate on the areal distribution of erosion, factors affecting erosion, resultant forms and rates of soil loss. The current study attempts to monitor erosion changes at one site over a longer time period. Similar studies have been carried out by Lunden *et al.* (1986), Marker (1988), and Weaver (1988a) who showed that the analysis of sequential aerial photographs is a valid approach to the reconstruction of erosion history.

The current study also examines the movement of sediment from sources to sinks, identifying temporary storages which are potential sediment sources. The examination of the movement of sediment has inherent problems, especially when control measures are to be applied. The main problem is that what could have been major controlling factors in historical time may no longer be important at the time the study is undertaken, or may not be important in the near future. A similar problem was reported by Meade (1982) whose study in a number of basins in the Atlantic drainage basin of the U.S.A. revealed that soil erosion was accelerated by a factor of at least 10 when European settlers cleared forests and planted crops. The major problem was identified and proper control measures were applied. It was later realized that large quantities of eroded material were still stored on hillslopes, and continued to augment the sediment load of rivers. Sediment control measures in this case should have been extended to temporary storages on hillslopes. On a catchment scale, Chakela, *et al.* (1986) analysed sediment sources, storage, residence time and transfer in the lowlands of Lesotho. Studies similar to that by Chakela *et al.* (1986) describe the movement of sediment from sources to the catchment outlet, identifying areas which require most attention, and stressing the importance of the time lag between sediment production, transport and deposition.

General methodology

The general methodology employed is that recommended by Nir (1983) for an anthropogeomorphological study. The method has the following four components:-

(i) An historic approach which investigates man's intervention on landforms, land use and geomorphological processes and resultant forms, this is accomplished through the sequential analysis of aerial photographs.

(ii) A socio-economic approach which investigates the dynamics of man's economic and cultural activities. Aerial photography, field investigations, and retrieval of information from past studies were employed to determine man's activities in the area.

(iii) A geomorphological approach which investigates the rate and extent of processes and resultant forms. The processes in question are erosion and deposition, which were studied through catchment and reservoir surveys.

(iv) A planners approach which attempts to define relationships between the physical and human components of the study area, in order to make suggestions and recommendations that could form a basis for planning and decision making.

The need for the present study.

Although there are extensive publications on erosion research in Lesotho, one recognizes some gaps in the literature. For instance, most research has been carried out in lowland regions because of accessibility, availability of background information, and hydrometeorological data. Most research is undertaken in rural catchments used for cultivation, grazing and scattered traditional settlements. Trends in erosion research show a bias towards problems related to the extensive exploitation of land for agricultural purposes. The bias towards agricultural erosion problems is probably due to the fact that, throughout the history of Lesotho, agriculture has been the most extensive and dominant land use (Makhanya, 1979). Molapo (1986) and Mateka (1987) report that the exploitation of land for agricultural purposes has decreased, with a subsequent increase in urban residential land use. More research is therefore needed on erosion problems related to urban land use.

There is at present very little information on the effect of urban development and settlement evolution on soil erosion in Lesotho. Rapid urbanization has been unknown in Lesotho until the period 1976 to 1986 when Maseru, the Capital town, doubled in population and in physical terms (Mateka, 1987). Problems associated with urban development and population growth have therefore been relatively infrequent (Makatjane and Lesaoana, 1988), and as a result were often poorly perceived as environmental problems. Although there have been reports of rapid urbanization such as those by Mateka (1987) and Mosaase (1988) the situation is still poorly perceived, probably due to the absence or scarcity of data.

There are a number of reasons or factors which have led to the initiation of the current study. These factors are listed below:-

(i) There are visible signs of erosion and general land degradation in the Maqalika and similar catchments of the lowland areas of Lesotho. The Maqalika catchment drains into an important water supply reservoir.

(ii) High rates of reservoir sedimentation (Chakela, 1981) and suspended sediment loads (Jacobi, 1977; Makhoalibe, 1984) have been observed in Lesotho. These observations have been related to high rates of erosion in upland catchments.

(iii) Conservation measures have been applied to many parts of Lesotho in a bid to control or prevent erosion. Chakela and Cantor (1987) report that measures have not been successful because of poor implementation attributed to a lack of understanding of erosion processes and causes.

(iv) Erosion data may not be extrapolated from one problem area to another, since erosion problems differ from place to place. On-site data collection is encouraged so that specific problem areas may be identified and evaluated for purposes of conservation.

Research aims

The overall purpose of the study is to identify the nature and extent of erosion and sedimentation in the Maqalika dam catchment. The specific aims of the study are as follows:-

(i) To reconstruct the history of erosion and land use in the Maqalika catchment.

To achieve this aim sequential aerial photographs of 1961, 1979 and 1985 will be analysed in order to map erosion and land use features.

(ii) To determine and evaluate probable causes of erosion.

This part of the study investigates the effects of catchment characteristics including land use on erosion. Areal extent and intensity of erosion are monitored over three time periods and related to catchment characteristics using statistical techniques.

(iii) To identify, map and evaluate areas that actively supply, transport and store sediment.

Erosion and deposition features are mapped since they represent sediment sources and sinks respectively. The sources and sinks are then classified according to type, position on the landscape, and degree of activity. Sediment transport routes are also identified in order to trace sediment movement from sources to sinks. Mosley (1980) and Coleman and Scatena (1986) have shown with case studies that the recorded degree of erosion is not necessarily equal to or proportional to the quantity of sediment supplied by a particular land surface. For the current study a procedure is formulated to assess the catchment in terms of its ability to produce and transport sediment. Results from the sediment assessment procedure are then used to derive a qualitative sediment routing description.

(iv) To estimate the rate of soil loss from the catchment and the useful life of the reservoir.

Sediment yield determined through a reservoir sedimentation survey is used to compute the average rate of soil loss. From the computed soil loss value, the rate of surface lowering is estimated using bulk density figures. The useful life of the reservoir is estimated from sediment yield data.

(v) To describe qualitatively the possible socio-economic implications of erosion and sedimentation in the study area.

A number of general (possible) socio-economic consequences of erosion and deposition reported in the literature are listed in Table 4 (Chapter 4). From this list, problems which also occur in the Maqalika catchment are noted and reported. Some of these problems are determined through techniques described for Aims 1, 2 and 3.

Structure of thesis

The introductory chapter summarises erosion and sedimentation problems and introduces the present study, putting it into a conceptual framework of geographical research. The aims of the study are outlined in order to form a scientific framework within which the study may be carried out. The second chapter presents the review of literature on erosion and sedimentation. A theoretical model of geomorphological processes at a catchment scale is presented, including factors which are known to influence erosion and deposition. Chapter 3 discusses catchment characteristics in relation to their ability to enhance or suppress erosion. Chapter 4 discusses the general methodology and techniques applicable to the stated aims of the study. Chapter 5 presents the analysis of results which are then interpreted and discussed in Chapter 6. Chapter 7 presents conclusions from the study, recommendations and the need for future research. At the end of the thesis a number of appendices are presented describing some of the techniques employed. Although there is a section on relevance and limitations of techniques, a number of problems are discussed as they occur throughout the text.

Summary of conclusions

It has been possible to re-construct the history of erosion and land use using sequential aerial photography. However no meaningful relationship could be attained using a direct comparison between the distribution of erosion and land use alone. Hand factor analysis performed on the data shows that the observed degree and distribution of erosion are influenced by various combinations of factors, some of which are anthropogenic while some are natural catchment characteristics. Soil erodibility has been found to be a component of all major controlling combinations at each date. The study further shows that whereas the highly erodible duplex soils contribute to erosion, certain forms of land use aggravate the problem. Road and housing densities were found to be important land use components determining erosion distribution and degree. Sediment sources, sinks and transport features were identified and were found to be limited to certain portions of the catchment. An assessment of sediment sources shows that the most eroded areas are not necessarily the most active sediment sources. Sediment yield from any part of the catchment is limited by either supply or transport. Most sediment is stored in the lower reaches of the gully system and does not reach the catchment outlet, thus the Maqalika catchment has a low sediment delivery ratio at present. The estimated soil loss value of $18{,}29t.ha^{-1}.yr^{-1}$ is way above the catchment soil loss tolerance range of 2 to $9t.ha^{-1}.yr^{-1}$, and approaching the maximum tolerable soil loss figure of $25{,}0t.ha^{-1}.yr^{-1}$ for construction sites. The recorded rate of soil loss is more important to on-site than off-site damage. The estimated useful life of 100,9 years does not pose any threat to the proper functioning of the reservoir. Erosion control measures directed at sediment transport such as gully check dams are irrelevant to the present erosion problems which are related to soil disturbance. Control measures should be directed to areas of maximum sediment production (detachment) rather than attempting to trap sediment which is already entrained.

CHAPTER TWO

THEORETICAL BACKGROUND

In the first section of this chapter the theoretical geomorphological model on which this study is based is presented. The model describes processes of detachment, transportation and deposition as part of the debris cascade described by Paterson (1984). The second section discusses factors affecting erosion. Anthropogenic factors are discussed in detail, with a special emphasis on urban development which forms the main focus of the study. The third section discusses the economic consequences of erosion and deposition.

THE GEOMORPHOLOGICAL MODEL

The model consists of three components. (i) Sediment supply from sources, (ii) sediment deposition and storage in sinks, and (iii) transport mechanisms from sources to sinks. The concept of sediment delivery ratio (SDR) is discussed to show the relationships between sediment sources, temporary catchment storages and sediment yield at the catchment outlet.

SEDIMENT SOURCES

Sediment sources refer to specific areas that actively contribute sediment to the stream or reservoir (Coleman and Scatena, 1986). Actively eroding land may thus be regarded as a source since it provides sediment to the drainage system. Sediment sources are many and varied, and their distribution changes both spatially and temporally (Morgan, 1986). Various forms of erosion which throughout this study are considered as sediment sources are discussed in the sections that follow.

Sheet erosion

Sheet erosion is characterized by the more or less uniform detachment of soil over a whole surface of land (Holy, 1980; SARCCUS, 1981; Zachar, 1982). Sheet erosion occurs in a sequence of stages that may not be readily observable unless certain soil tests are made (Holy, 1980). These stages are outlined by Morgan (1986) who proposes a model in which the first stage is raindrop splash resulting in the disaggregation of soil, with or without displacement. In the second stage the resultant runoff water displaces some of the finer particles and chemical substances resulting in selective erosion (Holy, 1980).

Morgan (1986) notes that sheet erosion is important as a contributor of sediment, especially where downstream effects like reservoir sedimentation are considered. The sub-process of selective erosion which is more pronounced in non-cohesive soils, picks up finer particles and chemicals which form the suspended and solute load respectively (Novotny, 1980). Both suspended and solute loads will more often than not reach the stream or reservoir.

Rill erosion

Rill erosion is the removal of soil through the accumulation of sheet runoff, and the concentration of overland flow into numerous small rivulets and grooves (SARCCUS, 1981). These rivulets are a few centimetres wide, and their depth does not exceed that of the arable layer (Morgan, 1986). According to SARCCUS (1981) rill erosion is associated with severe sheet erosion, to an extent that rilling is sometimes interpreted as an advanced stage of sheet erosion.

Rills may sometimes deepen to form gullies (Morgan, 1986), or change location (Carson and Kirkby, 1972), or become completely obliterated (Selby, 1982). Change of location follows infilling of original rills by sediment coming from upslope or from interill areas (Meyer, 1986). Dunne and Aubry (1986) showed with laboratory and field experiments that during overland flow the drainage system shifts from a state of stability to that of instability, resulting in incision and rill formation. However if rain occurs simultaneously with sheetwash, raindrop impact diffuses sediment from interill protuberances and fills depressions, eradicating original rills. The movement of material into rills is effected by trampling and other forms of surface disturbance. Selby (1982) notes that the infilling material is usually more permeable than the original soil, therefore, new rills will preferentially form elsewhere. Rills also get obliterated through the processes of micropiracy or cross-grading (Selby, 1982), or through ploughing (Morgan, 1986).

All the above-mentioned processes of rill obliteration tend to produce a more or less even lowering of the hillslope, giving an impression that sheet erosion is dominant on the particular hillslope. This observation is important to mapping and measuring the areal extent of the different forms of erosion.

Gully erosion

A gully is generally described as a steep channel over 0,5m deep, which may not be destroyed between flows or storm events, and which conducts ephemeral flow (SARCCUS, 1981; Morgan, 1986). Gully erosion being an energy related process is determined by changes in stability (Harvey, 1974). Under natural undisturbed conditions, the drainage system attains a state of metastable equilibrium through the balance between all components of the landscape (Schumm and Hadley, 1957). Slight changes in any one component tend to displace the drainage system from its stable state resulting in gully initiation (Hudson, 1971). Vegetation is one component of the landscape which controls basin equilibrium. This fact was stressed by Rowntree (1988) who showed that vegetation changes play an important role in determining the erosion and deposition phases of the landscape. Rowntree's study also shows that semi-arid areas such as the Karoo are more sensitive to such changes.

According to Schumm and Hadley (1957) a gully may shift from a state of instability to that of stability when the gully floor is covered with deposited sediment coming from eroded areas upslope. The deposited sediment is subsequently colonized by vegetation and no further incision takes place (Hudson, 1971). This state may not be maintained for long, as is the case in the formation of inset gullies (Brice, 1966), where a new incision is initiated on the floor of the original gully. The afore-mentioned shifts in stability explain the cut and fill, or erosion and deposition cycle of semi-arid areas (Schumm and Hadley, 1957). The same concept was used by Gryta (1986) to explain variations in sediment movement and storage in a gully system between individual storms, and between seasons.

Gullies are important sources and transporters of sediment. Gully floor incision and bed scour (Morgan, 1986), headscarp retreat (Selby, 1982), bank under-cutting and slumping (Chakela, 1981), all result in the production of relatively loose sediment which is more readily entrained by gully flow.

Although gullies are usually given one general description there are certain features and processes by which they differ from one another (Selby, 1982), and these features form the basis for classification (Dardis, *et al.*, 1988). A distinction is generally made between continuous and discontinuous gullies, where the former consist of channels directly connected to the drainage network, and in the latter the channels do not have a direct link with the stream or drainage network (Carson and Kirkby, 1972; Selby, 1982). This feature of gullies is important to sediment transport because it determines whether sediment is delivered to the drainage system or not.

Rooyani (1982a) distinguishes two gully types in Lesotho, according to the resistance of soils on which they occur. On the one hand there are narrow, shallow, v-shaped gullies which form on relatively erosion resistant soil. The formation of such gullies seems to be due to improper land use (Chakela, 1981). On the other hand there are deep, wide, u-shaped gullies which form on erosion susceptible soils. Chakela (1981) made an attempt to relate the development of such gullies to physiographic components of the landscape, and concluded that u-shaped gullies develop mainly where there is a concentration of overland flow, such as in concave depressions, and where slopes change abruptly.

Piping

Pipes are open passage ways within the soil, ranging in size from one centimetre to several metres in diameter (Atkinson, 1978). Pipes have ephemeral flow with hydrological properties of gullies, such as flash floods during or immediately after rainfall.

Pipes can be major problems and contributors to soil loss, sediment production and sediment transport (Morgan, 1986). The pipe floor, sides and roof are actively eroding resulting in roof collapse which deposits large amounts of sediment on the pipe floor (Drew, 1982; Slaymaker, 1982). Dardis and Beckedahl (1988a) observe that though there may be quite an extensive documentation of pipes and piping problems, many aspects of pipe formation and development are poorly understood. This is probably because pipes generally escape observation due to their situation below the earth's surface.

Principles of pipe initiation and development will not be discussed here since they are well reviewed in a number of studies, examples of which are listed in Table 1. Most literature indicates that there are numerous factors and conditions determining pipe initiation and development. There is also an indication that these factors interact to form new conditions which may not be readily observable and understood.

Table 1 Factors determining pipe initiation and development.

Factor	Relevant study
1. General soil properties	
(a) Duplex soils	Schmitz (1980), Rooyani (1981), Faber and Imeson (1982), Humphrey (1982).
(b) Sodium content	Rooyani (1982a)
2. Steep hydraulic gradient	Atkinson (1978), Thornes (1980), Selby (1982), Jones (1987).
3. Surface conditions	Drew 1982), Beckedahl and Dardis (1988)
4. Temperature and rainfall characteristics	Drew (1982), Slaymaker (1982), Dardis and Beckedahl (1988a).

Reservoir bank erosion

A reservoir bank consists of various forms of rocks and soils which formed part of the landscape before inundation. The reservoir bank may not be stable due to the constant exposure to waves caused by wind action (Hakanson and Janson, 1983). Surface movement of water due to wind action is well documented by Sly (1978), Sheng and Lick (1979) and Langmuir (1983), who among other things noted that wind action generates enough wave energy to resuspend sediment from the bottom of the reservoir.

Rooseboom (1985) explains reservoir bank erosion in terms of collapsing slopes, whereby the bank wall slips into the reservoir. According to Rooseboom (1985), wave action causes undercutting of the reservoir's bank along the waterline, resulting in hanging wedges of the upper (above water line) part of the bank. Further wetting of the water line causes instability and subsequent slumping of the bank wall. The reservoir bank recedes and a new bank is exposed.

SEDIMENT SINKS

Sediment sinks refer to those parts of the catchment which receive and store sediment. Storage may be temporary as in the deposition of sediment on slope breaks, in small hillside depressions, and in channels (Morgan, 1986), or may be permanent as in the deposition of sediment on the bottom of a reservoir or pond, assuming that no resuspension occurs (Hakanson and Janson, 1983). This implies that all areas of deposition may be considered as sediment sinks.

Within the broader context of sediment deposition, two classes are identifiable. On the one hand there is local sedimentation in which deposition of sediment occurs at relatively short distances from source areas. On the other hand there is downstream sedimentation in which sediment is deposited after having moved relatively long distances on the earths surface.

Chakela (1981) classifies the manifestations of sedimentation in Lesotho into three categories.

(i) Valley or river plain sedimentation,

(ii) Channel sedimentation,

(iii) Reservoir sedimentation.

Valley sedimentation

Most studies of sediment deposition focus on sediment associated with channels and reservoirs, for instance those by Twenhofel (1939) and Happ and Dobson (1940). This bias is still present even in more recent studies such as Wilkin and Hebel (1982), Lambert and Walling (1986), Miller and Shoemaker (1986). Studies on the deposition of sediment in intergully areas and slope breaks seem to be a neglected area of research, yet it has been shown (Trimble, 1981) that these areas accumulate large quantities of sediment. This is probably because processes taking place in channels and reservoirs are more readily observable since they occur within defined boundaries.

Processes of sedimentation range in scale from the deposition of soil particles which have been displaced by raindrop splash, through to the delivery of sediment to the channel, after travelling long distances through the catchment. Morisawa (1980) notes that after entrainment deposition occurs anywhere along the slope where runoff is no longer competent to carry the load. Processes of rill obliteration described earlier, are confirmation that sediment does get entrained by off-channel runoff, and does get deposited along the slope. Rill deposition is common where the rills are situated immediately downslope of relatively steep eroding surfaces.

Channel sedimentation

Channel sedimentation refers to the deposition of sediment within the stream and its tributary gullies (Gottschalk, 1964). The stream provides the main means of transportation for sediment load, and its ability to work depends on its energy (Morisawa, 1980); thus decreasing the stream's energy results in deposition. As the stream flows through its basin it is exposed to a wide variety of conditions, some of which encourage deposition (Hey, 1987), for instance the type and quantity of load, the hydraulic properties of the stream, and the general properties of the drainage area. These conditions and their effects on deposition are discussed in detail by Gottschalk (1964) and Morisawa (1980). Deposition also occurs when the load supplied to the stream exceeds the streams competency (Schumm, 1972). Assuming that the volume and velocity of flow are held constant while excessive load is provided by tributaries, deposition will occur on gully junctions (Heede, 1976). Chakela (1981) reported thick gully bottom fills in gullies draining extensively eroded cropland in the lowlands of Lesotho.

Reservoir sedimentation

All reservoirs formed by dams on sediment laden water courses are subject to sediment accumulation (Gottschalk, 1964). This is confirmed by the current voluminous literature on reservoir sedimentation ranging in scale from the small sediment storage impoundments in the peri-urban areas of Maseru (Ntsiki and Mokone, 1986), through small water supply and livestock watering reservoirs in Ciskei (Weaver, 1988b), to large multipurpose reservoirs and lakes in North America (Pharo and Carmack, 1979).

Studies on reservoir sediment distribution, such as those by Weaver and Stone (1980) have shown that sedimentation occurs in all parts of the reservoir, from the point of inflow to the point of outflow. The final distribution of sediment on the reservoir floor is determined by settling rates (Ackers and Thompson, 1987), shear stresses on the reservoir floor (Hakanson and Janson (1983) and the morphology of the reservoir (Rooseboom, 1985). When a sediment laden stream enters a reservoir, its velocity decreases because its cross-sectional area has increased (Borland, 1971), and because it meets the quiet waters of the reservoir (Witzig, 1943). Once velocity has decreased, the stream's kinetic energy also decreases, resulting in loss of capacity (Chen, *et al.*, 1978). The physical changes which occur at the stream reservoir confluence are well documented by Morisawa (1980), and will not be discussed here.

The movement of sediment into a reservoir is governed by two forces, the horizontal force in the direction of flow and vertical forces due to gravity and water turbulence (Borland, 1971; Strand, 1974). On entering a reservoir, a particle remains in suspension for as long as the upward turbulent force equals or exceeds the force of gravity. Annandale (1983) identifies three mechanisms by which sediment can be transported in a reservoir, namely colloidal suspension, turbulent suspension and density currents. Density currents described by Borland (1971) are considered special cases occurring in a small number of reservoirs with particular characteristics (Rooseboom, 1975; Annandale, 1983). Deposition of colloidal material occurs only when the physical or chemical properties of water change (Annandale, 1983). From the afore-mentioned observations it should be expected that the most common means of transport in a reservoir is turbulent suspension.

Deposition of sediment is determined by the settling velocity of particles, which is in turn determined by factors such as grain size (Weaver and Stone, 1980), flow velocity (Chen *et al.*, 1978), reservoir inflow relations and operation (Strand, 1974), temperature and pressure changes (Annandale, 1983) and the size and shape of the reservoir (Borland, 1971). During deposition, suspended sediment is sorted so that coarse particles settle at or near the point of inflow, while the finer particles are carried into the reservoir and spread on the reservoir floor.

While being deposited particles may settle down as individuals or as flocs (Ackers and Thompson, 1987). Settling properties of particles are important since they determine consolidation and final distribution on the reservoir floor. Settling properties of flocs differ from those of individual particles due to differences in density. Flocculation is more pronounced in fine cohesive sediments with a high colloidal content (Partheniades, 1972). With increasing concentration flocs eventually interact hydrodynamically (Been and Sills, 1981), and their settling causes an upward flow of water (Hakanson and Janson, 1983). Friction between the settling flocs and the resultant upward movement of water reduces the rate of settling. It should be expected that coarse non-cohesive particles will settle much faster as suggested by Been and Sills (1981), since most particles settle as individuals. Due to their quick settling rates, coarse particles settle before being incorporated into flocs.

Sediment distribution on the reservoir floor is also determined by characteristics of the load, and the source of a large percentage of sediment. A common feature of reservoir sedimentation is the delta (Borland, 1971), the apex of which consists of coarse particles, while the periphery consists of finer particles. Witzig (1943) suggests that sediment lacking coarse particles may not form a delta, since fine particles tend to move further into the reservoir and get deposited away from the point of inflow, or never get deposited at all. On the effect of the source of material, Hakanson and Janson (1983) suggest that allochthonous material becomes deposited close to the point of inflow, while autochthonous material becomes deposited near its origin on the reservoir floor. Dyer (1986) draws attention to sediment dynamics on the reservoir floor, noting that sediment may move from one part of the reservoir floor to another, altering the original distribution.

Trap efficiency

Trap efficiency is the proportion of incoming sediment that is deposited or trapped in the reservoir, usually expressed as a percentage (Heinemann, 1981). A trap efficiency value of a reservoir is important to sediment yield computations since it can be applied to volume of deposited sediment to determine the total incoming sediment and vice versa. Methods for estimating trap efficiency are based on empirical relationships based on a large number of field measurements. Brune (1953) and Heinemann (1981) developed means of computing trap efficiency based on the relationship between annual inflow and the remaining capacity.

Studies on reservoir trap efficiency on different sized reservoirs are in agreement that values of trap efficiency vary from one reservoir to another due to certain features of the reservoirs. Gottschalk (1964) presents a summary of the factors describing how each factor influences trap efficiency. Some of these factors are: reservoir operation, nature, location, and size of outlet, and the detention storage time.

SEDIMENT TRANSPORT

Paterson (1984) notes that sediment movement forms an integral part of any drainage system, and it is partly through this movement that the present landscapes have evolved. The importance of sediment movement has long been realized, as evidenced by the extensive world wide research on many aspects of erosion and sediment yield. Studies on sediment movement from sources to sinks focus on transportational losses on slopes and headwater channels (Piest *et al.*, 1975), on losses of suspended load within the main channel (Walling *et al.*, 1986), or on a combined investigation of channel storage and sediment supply from outside the channel (Bathurst *et al.*, 1986). All these studies are in agreement that sediment movement is dependent on the efficiency of the transporting agent. Transporting agents are overland flow and channelized flow, both of which are determined by a complex array of factors listed in Table 2. From this table a theoretical model of sediment transport is developed and presented in Figure 1.

Table 2 Factors determining sediment transport.

Factor	Source
1. Storm timing and intensity.	Gryta (1986)
2. Type of discharge output.	Bathurst *et al.* (1986)
3. General catchment characteristics.	Walling (1983)
4. Sediment availability and size.	Gryta (1986)
5. Overland flow characteristics.	Novotny (1980)
6. Surface conditions	Gryta (1986)
7. Gully processes	Piest *et al.* (1973)
8. Rill processes	Merritt (1984)
9. Soil erodibility	Meyer (1986)
10. Man made channels.	Nicklin *et al.* (1986)

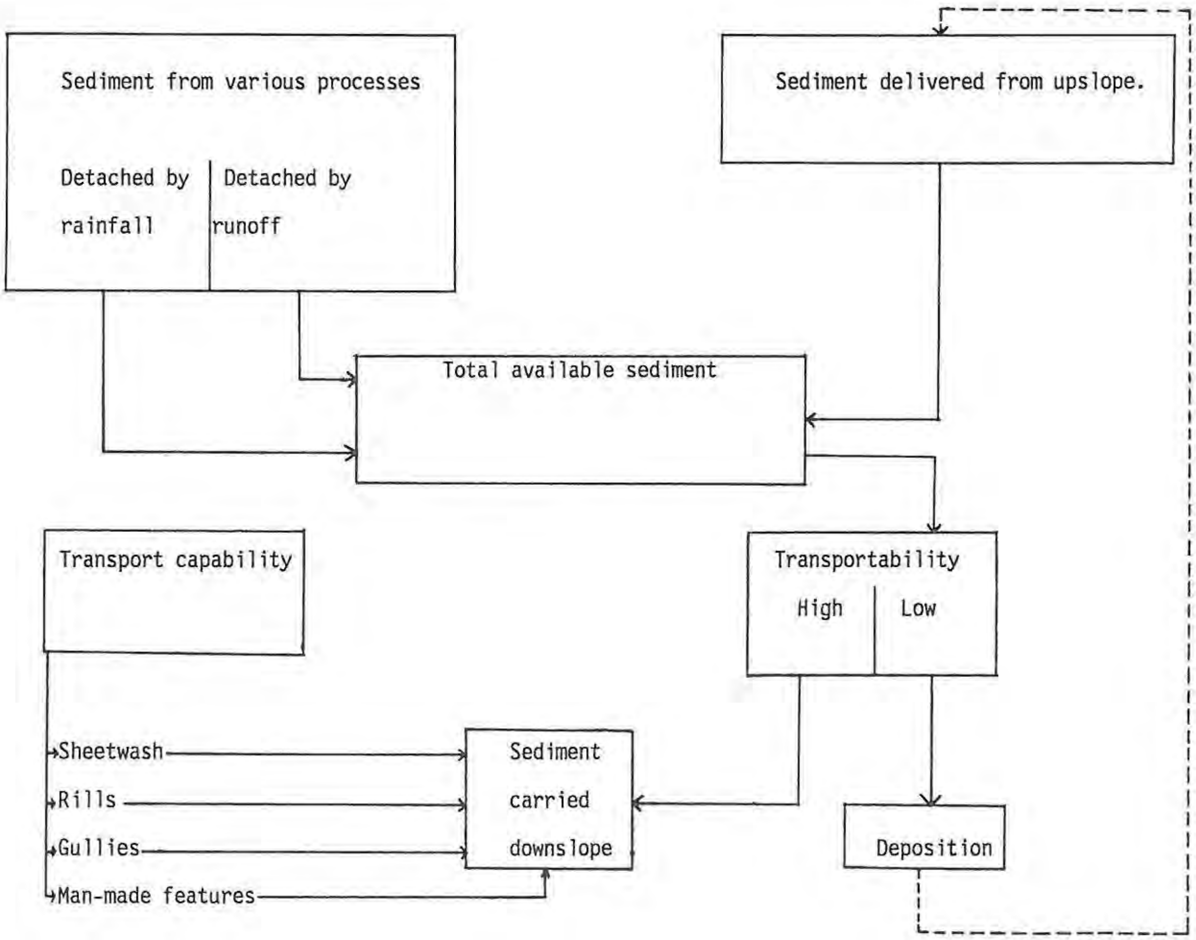

Figure 1 A theoretical model of sediment transport. Adopted and modified from Meyer (1986).

Sediment delivery ratio

Sediment delivery ratio is closely linked with sediment transport as discussed earlier. The ability of a catchment to transport sediment to the outlet is known as the sediment delivery of that catchment. The property determines the quantity of sediment that would leave the catchment. Gottchalk (1964) draws attention to the differences between sediment yield and gross erosion. Gross erosion will always be greater than sediment yield. The ratio between gross erosion and sediment yield is the sediment delivery ratio (SDR) expressed as a percentage.

The concept of SDR has been used in many studies attempting to explain processes of sediment transport, for instance Boyce (1975), Mutchler and Bowie (1976), Dickinson and Wall (1977). Factors affecting sediment transport (Table 2) always affect the sediment delivery ratio of a catchment. There have been numerous attempts to produce equations and models quantifying SDR, based on catchment characteristics. Of all these factors, drainage area has been dominant in quantification as shown by Roehl (1962), Gottchalk (1964), Mutchler and Bowie (1976) and Williams (1977). Other workers, while concentrating on basin area, have included variables like basin relief and length (Roehl, 1962; Renfro, 1975), annual runoff (Mutchler and Bowie, 1976), and gully density (Mou and Meng, 1980). This attempt at including factors other than drainage area was due to the realization that relationships between SDR and drainage area vary from place to place (Walling, 1983). Furthermore Cambell (1985) points to some of the flaws of using drainage area to quantify SDR. Cambell's argument is based on the partial areas concept which relates to "effective" drainage area. The effective drainage area is usually less than the total catchment area.

The use of SDR to relate sediment yield to gross erosion, and vice versa is limited by problems of spatial and temporal lumping (Walling, 1983; Cambell, 1985) in which sediment yields are calculated for total basin area as opposed to effective drainage area. Yields are calculated assuming constant rates and ignoring the concept of sediment attenuation. In an attempt to overcome these problems, the sediment budget concept was introduced (Leopold *et al.*, 1966; Dietrich and Dunne, 1978; Trimble, 1981 and Lehre, 1982). The sediment budget approach involves the identification and quantification of sediment sources and processes responsible for the generation of sediment transport (Dietrich and Dunne, 1978). When using the sediment budget approach, one is able to overcome to a certain extent problems of spatial lumping, indicating that sediment delivery corresponds to the potential ability of each sediment source to produce and deliver sediment (Mosley, 1980).

Although the sediment budget approach gives a clearer explanation of sediment delivery, this method also has inherent problems. Dietrich and Dunne (1978) note that quantification of processes is very difficult because processes are often slow and variable over space and time. Another problem identified by Dietrich and Dunne (1978) was that data from short term monitoring at few localities are not easily extrapolated. In the present study where quantification of processes is limited, sediment routing (Meade, 1982; Strömquist *et al.*, 1985) seems to be the most effective approach to explaining the transfer of sediment from one area to another.

A sediment routing model gives a qualitative description of observed sediment sources, transport mechanisms and deposition. The first stage in sediment routing is the identification of sediment sources (Mosley, 1980; Chakela *et al.*, 1986). Coleman and Scatena (1986) identify sediment sources and assess each source in terms of its ability to supply and deliver sediment. Strömquist *et al.* (1985) identify processes of sediment transport and also identify catchment attributes that enhance the efficiency of transport.

FACTORS AFFECTING EROSION

The rate, severity and spatial distribution of erosion processes are determined by various factors, some of which are part of the physical environment, referred to in this text as general erosion factors. Some factors are related to man's use of land and are referred to as anthropogenic factors. Some of these factors are presented in Figure 2 which has been modified from Morgan (1986) to include factors affecting water erosion only.

GENERAL EROSION FACTORS

This group of factors comprises components of the physical environment. The current voluminous literature on factors affecting erosion shows that these are numerous. Morgan (1986) notes that there are a number of researchers studying the relationship between erosion and controlling factors, and hence a multiplicity of factors that are recognized as being important. There are, however some factors which appear to be persistent, and which are commonly accepted as important (Morgan, 1986) and only these are discussed here.

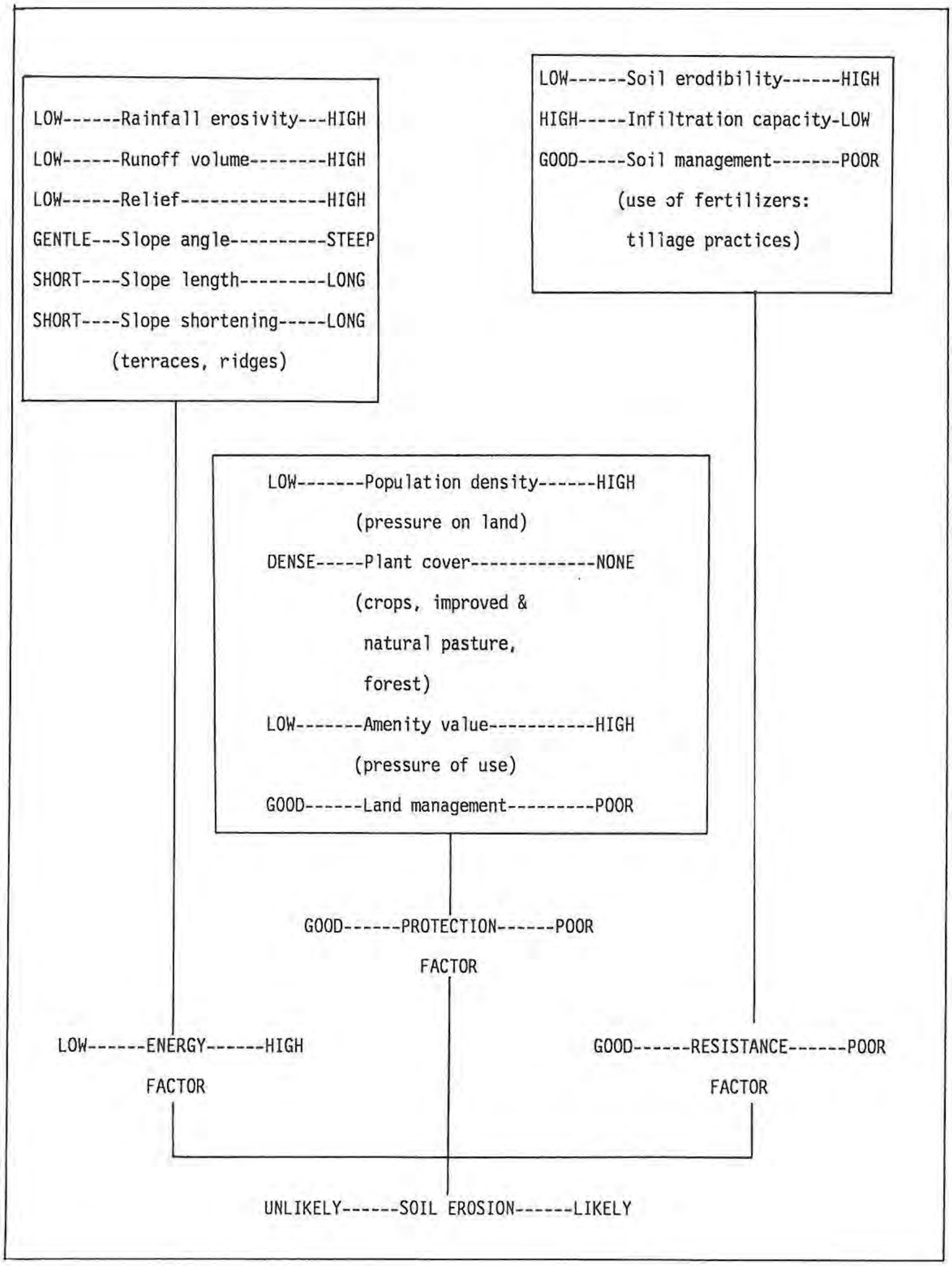

Figure 2 Factors affecting erosion (adapted from Morgan, 1986).

Erosivity

Rainfall characteristics which have the greatest effect on erosion are amount and drop size (Morgan, 1986). Runoff volume and rate have been shown to increase directly with rainfall amount and intensity (Meyer, 1986). Intensity also controls drops since most intense rains fall as large drops while low intensity rains fall as small drops. Bigger drops tend to initiate runoff and erosion more readily than smaller drops (Hudson, 1971). Effects of drop size on erosion are well documented by Hudson (1971) and will not be reviewed here.

Regional rainfall erosivity studies such as those by Wischemier and Smith (1965) usually assess erosivity on a spatial basis, omitting the temporal variations from season to season and thus overlooking vegetation effects. Rainfall amount in the present study area is not evenly distributed throughout the year and throughout the period of record. Chakela (1981) suggests that the alternating dry and wet periods are significant to vegetation changes and the initiation of erosion. Rowntree (1983) suggests a programme for assessing regional variations in erosion risk in Kenya, relating to both rainfall erosivity and vegetal cover. Rowntree's study stresses the significance of seasonal changes in erosivity relative to changes in crop cover.

Erodibility

Soil erodibility expresses the ability of the soil to resist erosion (Stocking, 1987). This ability is determined by the soil's physical and chemical properties, organic matter and many other complex and interdependent variables. A number of field and laboratory studies have been carried out to derive indices of erodibility based on soil properties. Examples of such indices are the k-factor used extensively for the USLE (Wischemier and Smith, 1965) and the Fb rating used in SLEMSA (Stocking, 1987). Erodibility characteristics may change within and between seasons and these changes are related to surface crusting and loss of organic matter (Stocking, 1987).

Some soils such as the duplex soils of the lowlands of Lesotho are inherently erodible (Rooyani, 1981). Erodibility in duplex soils is determined by their profile formation which comprises horizons that differ sharply in both structure and permeability. Similar soils have been reported in Natal (Roberts, 1964) and in Zimbabwe (Stocking, 1976).

Slope of the land

The morphological characteristics of slope such as gradient, length, profile, micro-relief and configuration are among the major factors affecting processes of water erosion (Stocking, 1976). These characteristics may affect erosion individually or in combinations (Holy, 1980). It is difficult to study and describe the effect of each characteristic individually because in nature these characteristics occur in various combinations. Laboratory studies such as those by Zingg (1940), D'Souza and Morgan (1976) affords one the opportunity to study the effects of one characteristic while others are held constant. Among all slope morphological characteristics Holy (1980) describes slope gradient as the most important erosion factor. Slope steepness combined with slope length have been used extensively in soil erosion prediction techniques based on erosion plot experiments.

Slope aspect

The effect of slope aspect is through the different degrees of insolation occurring on sunny versus shaded slopes (Zachar, 1982). Sunny slopes are more vulnerable to erosion than the shaded slopes because of their higher rate of organic matter decomposition, evapotranspiration, thawing rate of snow and soil salt concentration (Zachar, 1982). Cuff (1985) noted that aspect also influences exposure to storms, mean temperature and freeze-thaw patterns. All these influences have an effect on soils and vegetation. It should therefore be expected that slope aspect will influence, though indirectly, variations in erodibility and soil cover. The effect of slope aspect is more pronounced in the higher latitudes than the lower latitudes which are exposed to the overhead sun for longer time periods.

Vegetation cover

Vegetal cover plays a role in protecting the soil against rainfall and runoff. Vegetation intercepts raindrops so that their kinetic energy is dissipated by the plants rather than being imparted to the soil (Morgan, 1986). Vegetation also enhances the infiltration of rainfall into the soil thereby slowing down surface runoff (Hudson, 1971). The root system of vegetation, especially trees, creates a binding effect on soil particles (Morgan, 1986), resulting in improved structure (Meyer, 1986).

The degree of protection provided by vegetation differs according to the type of vegetation, its condition and its stage. Holy (1980) ranks forest highest in erosion resistance effectiveness, followed by grass and row crops. In Lesotho there is no natural tree growth because of the harsh climatic conditions (Acocks, 1953), therefore grass cover is the only means of natural protection. Grass cover with a well developed turf may provide as much protection provided as by forests (Holy, 1980).

However if the turf is not well developed, or if the turf has been disturbed the degree of protection is reduced. A change from natural vegetation to cultivated land or to urban development results in increased runoff (Wolman, 1967: Gregory and Walling, 1973). These changes and their effects on erosion are discussed in the section on anthropogenic factors.

Underlying material

Underlying geology can affect erosion in two ways. Firstly, directly by resistance of bedrock exposed to runoff, and indirectly by giving the parent material properties which make it resistant to erosion or vulnerable to erosion (Holy, 1980). Soils formed on limestone and dolomite are resistant to erosion. The less resistant soils are formed from sediments such as loam clay and chalk. Soils may not necessarily be formed out of the underlying geological formations, but may also be formed from erosional mantles such as colluvium filling valley branches (Bawden and Carroll, 1968). Rooyani (1982a) and Schmitz (1984) noted that such colluvium is susceptible to erosion.

ANTHROPOGENIC FACTORS

While it has been shown that the entire surface of the earth is affected by geological and to some extent accelerated erosion (Hudson, 1971), in most cases erosion is intensified by man (Mirtskhovlava, 1974). Man's use of land ranges from his insidious presence on the land, grazing by his domesticated animals, cultivation and the development of the built up areas. These activities individually or in combinations exert hydrological and geomorphological influences on the environment by changing surface conditions.

Anthropogenic factors can be divided into two classes, those related to rural land use, and those related to urban land use. Any assessment of the influence of man on the landscape must consider population densities (FAO, 1977). Population densities are important in both rural and urban land uses since the effect of any one land use will be intensified by increasing population numbers. Problems of population pressure have been reported on agricultural land (Rapp *et al.*, 1972; Mirtskhovlava, 1974; FAO, 1977; Brown, 1978), on grazing land (Chakela, 1981; Christianson, 1981), and on settled urban areas (Douglas, 1983; Nir, 1983; Goudie, 1986).

Rural land use

Rural land use has a number of components each of which has differing effects on the surface and on erosion. Accelerated erosion of land in rural areas is a result of badly organized intensification of agriculture (Fournier, 1974). Agriculture is not the only component of the rural environment. Grazing and the development of traditional settlements are rural land uses which are inclined to increase erosion potential under population pressure.

Agriculture

Erosion related to agriculture as mentioned earlier is influenced by bad ploughing methods, such as ploughing up and down the slope (Nir, 1983). This form of erosion is exacerbated by poor land use planning which includes the extension of cultivation to marginal land, and the misuse and improper choice of machinery. Lal and Banerji (1974) reported shifting cultivation as one of the factors determining erosion in Indian rural catchments. While mechanical conservation structures are employed to abate erosion, they sometimes serve as causal factors. Failure of conservation measures such as bench terraces creates more erosion problems than the total absence of such measures (Rooyani, 1982a).

Grazing

Goudie (1986) notes that the soil erosion problem is not confined to cultivated land only, but extends to grazing lands which get exposed to overgrazing and trampling by livestock. Erosion problems related to grazing include compaction of soil at gathering places (Christianson, 1981), destruction or modification of vegetation (Schmitz-Ruch, 1984) and the formation of gullies on animal tracks.

Urban land use

Inhabitants of urban settlements are involved in numerous activities that have differing effects on the landscape (Nir, 1983). Douglas (1983) recognizes four stages of urban development which are; (i) transition from pre-urban to early urban, (ii) transition from early urban to middle urban, (iii) transition from middle urban to late urban and (iv) transition from late urban to urban renewal. The onset of each stage brings about certain changes in runoff and sediment yield of a catchment. Stages of urban development and their associated effects are listed in Table 3. This table, based on a description by Douglas (1983), has been modified to include only those stages observed in the Maqalika area.

Table 3 Summary of hydrological and geomorphological effects caused by changes in land use (Douglas, 1983).

Changes in land use	Possible hydrological effect
Transition from pre-urban to early urban stage, occurs on the rural urban fringe.	
(i) Removal of natural vegetation	Decrease in transpiration and increase in peak storm runoff.
(ii) Fields abandoned where present farmland left fallow.	Increased raindrop splash, deposition at slope breaks.
(iii) Construction of scattered type houses.	Increased sedimentation of streams and reservoirs.
(iv) Drilling of wells.	Some lowering of the water table.
Transition from early urban to middle urban stage.	
(i) Bulldozing of land for mass housing. Topsoil removed.	Accelerated land erosion, stream and reservoir sedimentation and aggradation, elimination of smallest streams.
(ii) Mass construction of houses, paving of streets, construction of new roads, building of culverts.	Decreased infiltration, increased runoff and peak flows. Lowered ground water levels, occasional flooding of culverts, undermining of channel banks.

Erosion associated with building construction.

Development of new construction sites allows rapid erosion of soil. This is because construction activity is often preceded by vegetation removal (Douglas, 1983), and soil excavations for foundations (Goudie, 1986). Implications for soil erosion in urbanizing catchments have been discussed by Walling and Gregory (1970), Gregory and Walling (1973), Hannam (1979), Leigh (1982b) and Johnston (1986). All these studies are in agreement that the conversion of land from rural to urban use modifies the land surface and hydrological characteristics.

Walling and Gregory (1970) showed with a case study from Exmouth, Devon, England that suspended sediment concentrations from a catchment may increase by between 2 and 100 times as a result of building activity. Similar studies (Wolman, 1967; Wolman and Schick, 1967; Walling, 1974) presented variable results on sediment yields in different areas, but are all in agreement that building activity results in a higher production of sediment than other land uses.

Erosion problems in urban areas are exacerbated by the rapid and often ill-planned urban expansion (Fournier, 1974; Hannam, 1979; Leigh, 1982b), or what Omuta (1986) describes as the "urban sprawl". Lack of physical planning and its effects on the physical environment were highlighted in a case study by Leigh (1982b) working in Kuala Lumpur, Peninsular Malaysia. A whole hillside on deeply weathered material was stripped of vegetation in preparation for a big housing development scheme. The hillside was never developed for a period of ten years. A dense gully network developed on the hillside following years of heavy rainfall.

Erosion associated with roads and footpaths.

Footpaths, tracks, dirtroads and tarred roads differ in size, construction management, maintenance and surface conditions. Their effects on erosion are expected to vary accordingly. Roads and tracks on the one hand are subject to vehicular compaction resulting in surface sealing, while footpaths on the other hand are subject to human trampling (Quin *et al.*, 1980). Paved roads normally do note erode on the surface since the paving acts as an armour protecting the soil against ordinary agents of erosion. However, Nir (1983) notes that due to the impervious surfaces roads start new processes by concentrating rainfall into runoff.

Construction of a road plays a role in determining runoff from the surface. Paved roads are often inclined towards the sides to effect disposal of water from the surface. Nir (1983) suggests that erosion from roads stems from the co-existence of the paved inclined surfaces with the surrounding loose soil which may or may not be covered with vegetation. Rill development is initiated on the roadside, usually in the direction of road surface inclination. Nir (1983) reported undermining of a road surface and subsequent collapse of the paving due to runoff generated by the impervious road surface.

The surface of a dirt road is not covered with any paving and is therefore not armoured. Under heavy traffic stresses caused by vehicle movement detach some surface particles which are readily entrained by runoff (Garland, 1983). Surface modification resulting in accelerated erosion was reported by Iverson (1980) who noted that off-road vehicle traffic smoothes the microtopography roughness and loosens surficial soil.

Footpaths are important agents of erosion since they are void of vegetation and organic matter due to human trampling (Garland, 1983). This is specially so in semi-arid areas where footpaths have a high probability of deflation in the dry season (Nir, 1983). Garland (1983) contends that most footpath erosion is attributable to the action of walking. This suggestion had been put forward by Quin *et al.* (1980) whose study showed that the shearing action of the toe initiates soil detachment. The initiation of erosion due to walking follows a series of stages shown in Figure 3.

On the effect of trampling on vegetation, Quin *et al.* (1980) concluded that the breakdown of soil occurs whilst wear of vegetation is still in progress as opposed to an earlier belief that the breakdown of soil due to trampling occurs only after vegetation cover has disappeared.

Effects of culverts and stormwater drains.

Culverts like bridges are constructed in order to connect parts of a road on one side of a stream, gully or drain to the other side. Usually the culvert is never as big as the stream or gully itself (Nir, 1983). Due to this restricted size, flow through the culvert is reduced causing a temporary impoundment that may overflow (Whipple and Dilouie, 1981). Due to through flow and flow over the culvert, erosion progressing upstream is halted and gets concentrated just below the culvert resulting in a deep pool (Whipple and Dilouie, 1981). This erosion downstream is also related to flow restriction and increased flow velocity in the downstream area. These effects are shown in Figure 4.

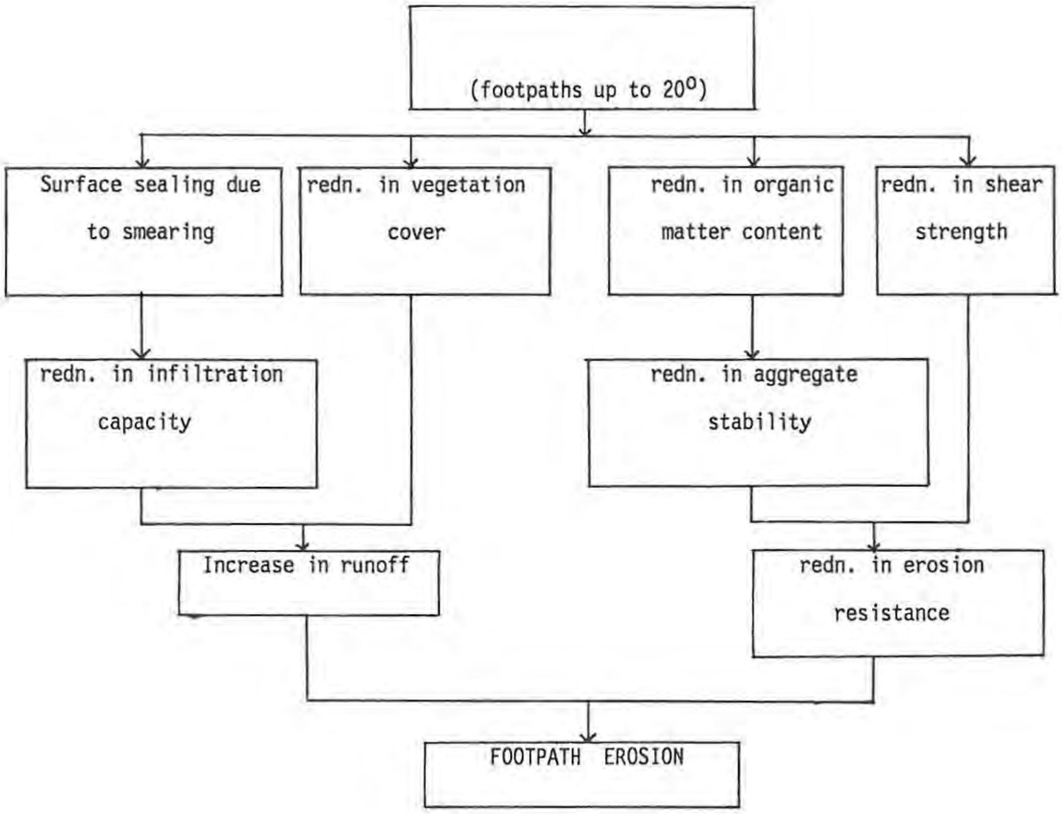

Figure 3 Stages leading to footpath erosion (Garland, 1983).

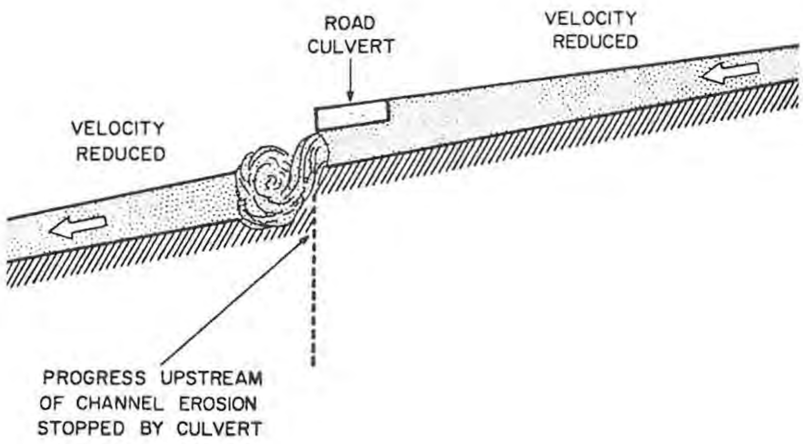

Figure 4 Local effects of culvert during floods (Whipple and Dilouie, 1981).

It should be expected that where the road network is unplanned ditches, and stormwater drains are also unplanned and poorly constructed. Road ditches receive concentrated runoff from roads (Nir, 1983) and deliver to natural water courses which hardly ever have the capacity for that type of flow (Gregory and Walling, 1973). Odemerho and Sada (1984) working in Auchi, Bendel State, Nigeria found that gullying was a result of poorly planned drains discharging into natural water courses. Hudson (1971) considers erosion of natural water courses due to this form of flow as one of the causes of gully initiation.

ECONOMIC CONSEQUENCES OF EROSION AND SEDIMENTATION.

Practical problems of erosion and subsequent deposition are many and varied and the importance of each is dependent on what function of the catchment or reservoir is affected. Common design functions of reservoirs include flood control, navigation, water supply, recreation and hydroelectric power generation, while catchment functions are the various land uses practiced by man, such as cultivation grazing and housing.

Problems which affect the afore-mentioned functions are well documented in literature and shall not be discussed in detail here. However some examples of the socio-economic consequences of soil erosion and sedimentation are listed in Table 4, which is divided into three sections. (i) Erosion problems in the catchment, (ii) deposition problems in streams and the valley, (iii) deposition in reservoirs and ponds.

From the afore-mentioned problems one can infer that all processes of erosion and sedimentation, from the initial displacement to the final deposition on a reservoir floor, undermine economic development and the social and cultural structures of societies or of whole countries. All soil and water conservation strategies require justification if the country's resources are going to be used in the strategy, hence the identification of socio-economic consequences form an integral part of erosion and sedimentation research.

Table 4 Summary of socio-economic consequences of erosion and deposition.

CATCHMENT EROSION PROBLEMS.	Relevant sources
Loss of topsoil, exposure of infertile sub-soil.	Rooyani (1981)
Loss of productivity due to leaching of nutrients.	Stocking (1986), Mokhothu (1988)
Loss of arable land due to sheet, rill and gully erosion (cropland abandoned).	Brown (1978), Rooyani (1982a), Nkalai (1988)
Loss of grazing land due to systems of gullies.	Stocking (1972), Christianson (1981)
Destruction of settlements due to systems of gullies (people resettled).	Ekboka, Orajaka and Nwosu (1986)
Destruction of roads and highways.	Nir (1983), Sundborg and Rapp (1986)
Potential downstream sediment input.	Rapp (1975)
Transport of pollutants.	Lee and Guntermann (1976), Novotny *et al.* (1986), Nkalai (1988).
STREAM AND VALLEY SEDIMENTATION PROBLEMS.	
Deposition of infertile sediments on arable land.	Stocking (1987), Mokhothu (1988)
Deposition of pollutants in streams.	Hudson (1971)
Damage of buildings and urban property such as sewers and other engineering structures.	Happ and Dobson (1940)
Temporary storage creating potential reservoir inputs.	Happ and Dobson (1940)
Cutoff channels creating potential flooding.	Christianson (1981)
Changes in bed elevation, reduced discharge capacity leading to drainage problems.	Dangroup (1980), Morisawa (1980), Sundborg (1983).

RESERVOIR SEDIMENTATION PROBLEMS.	
Loss of storage for water supply.	Rapp *et al.* (1972), West (1975), Chakela (1981), Strömquist (1986), Weaver (1988b)
Loss of storage for irrigation.	Bowonder, Ramanana and Haumantha (1987)
Loss of storage for hydropower.	Paskett (1982)
Loss of storage for sediment control.	Ntsiki and Mokone (1986)
Damages to reservoir structures.	Bhargava, *et al.* (1987)
Changes in upstream flow characteristics.	Gregory and Park (1974)
Increased turbidity.	Bondurant (1970)
Influence on algal production.	Bruwer and Grobler (1979)

CHAPTER THREE

THE MAQALIKA CATCHMENT

The purpose of this chapter is to describe catchment characteristics which probably play a part in determining the geomorphological model described earlier. Each of the catchment characteristics is described with reference to its effect on the processes of erosion and deposition. Both the natural and human characteristics of the catchment are described. Knowledge of background information on the characteristics of the natural environment is necessary for understanding the effect of the human environment.

LOCATION OF THE STUDY AREA.

The Maqalika dam catchment (Plate 1) is located in the western lowlands of Lesotho, approximately 5km from Maseru, the capital town (Figure 5). The dam has been constructed on a second order tributary of the Caledon River which forms a boundary between Lesotho and the Republic of South Africa. The dam is situated 250m from the Caledon River as shown in Figure 5.

Plate 1 The catchment observed from the top of the escarpment.

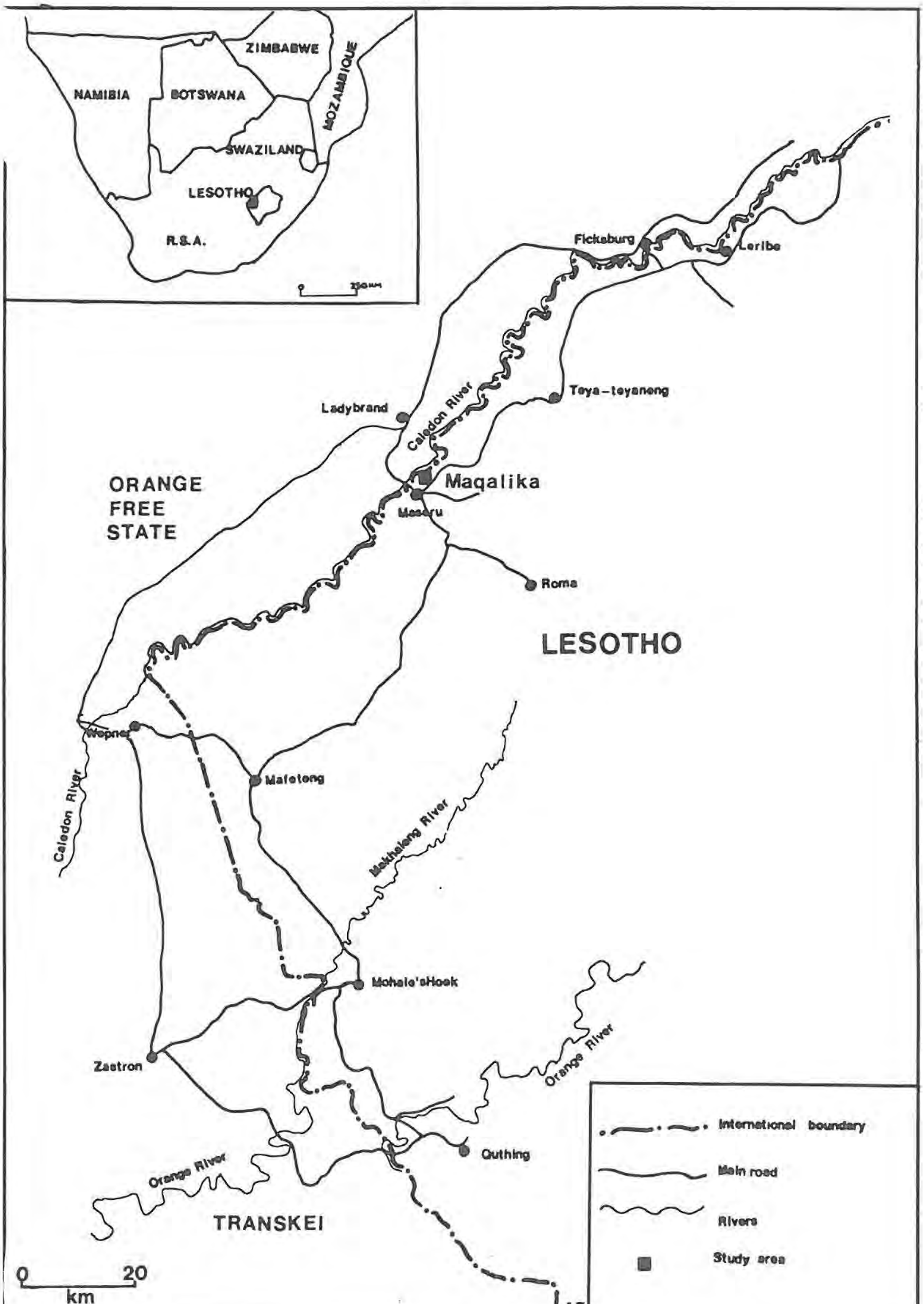

Figure 5 Location of study area.

PHYSIOGRAPHY

The altitude of the catchment ranges from 1500m above mean sea level near the Caledon floodplains, to 1820m above m.s.l. on the Berea Plateau shown in Figure 6. The hypsographic curve of the catchment, Figure 7 shows that a large percentage of the area lies below 1600m. There is a sharp rise in elevation to about 1750m and then the land rises steadily to 1820m. The sharp rise in elevation is explained by the occurrence of sandstone scarps which are sometimes over 20m high.

THE RESERVOIR

Features of the reservoir are listed in Table 5 while the pre-construction floor topography is presented in Figure 8.

Table 5 Salient features of reservoir (Binnie and Partners, 1983).

Feature	Dimension
Surface area	0,5 km^2
Maximum length	1,7 km
Maximum width	0,36 km
Active stored volume	3 700 000 m^3
Dam height	18 m
Dam length	200 m
Crest elevation	15 003 m
Initial dead storage	350 000m^3

From the listed features, one can describe the reservoir as being long and narrow, as shown in Plate 2. The reservoir is expected to have a relatively long retentiou time and a high trap efficiency because it has a large capacity and a relatively low inflow.

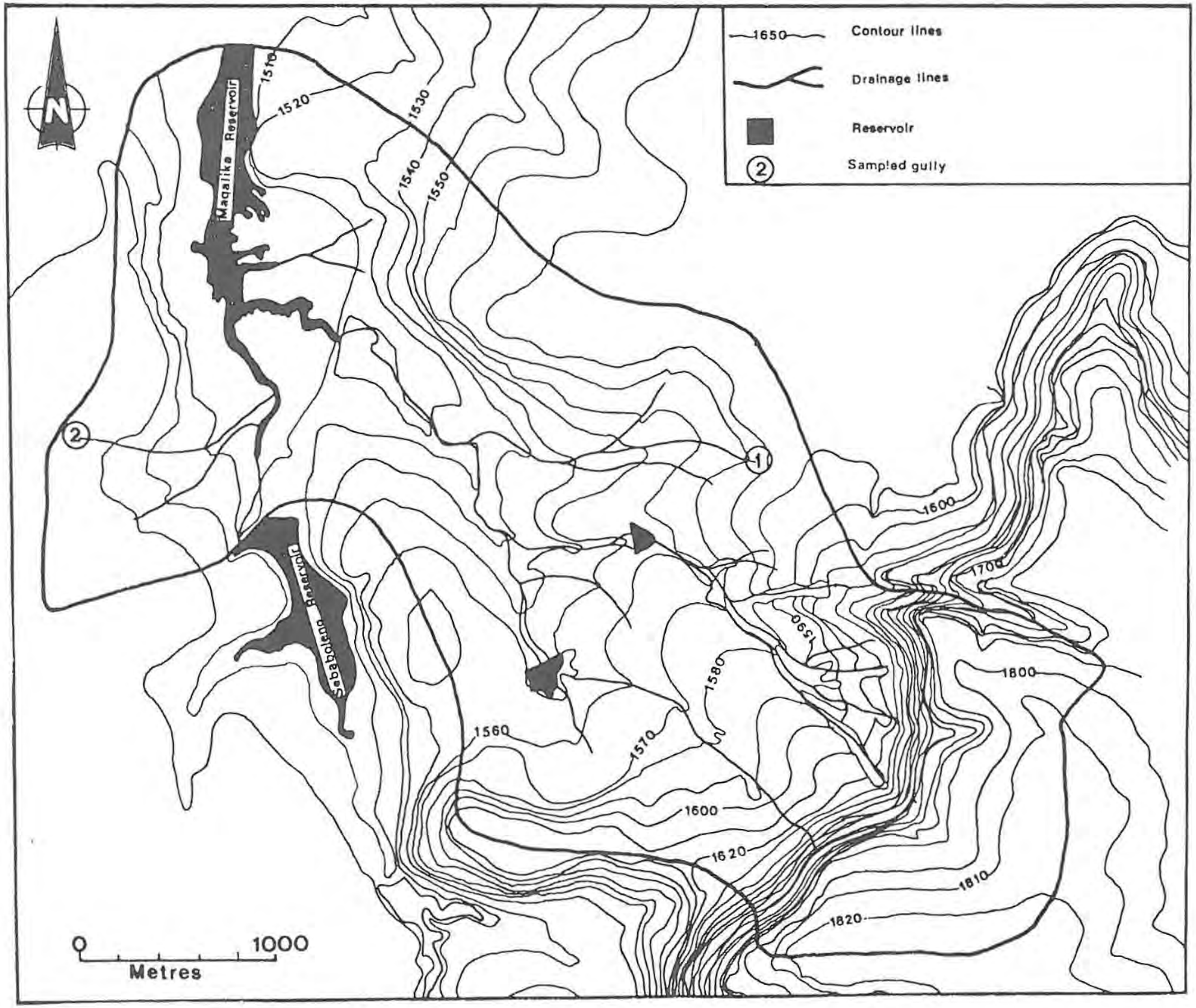

Figure 6 Maqalika catchment : Topography and Drainage.

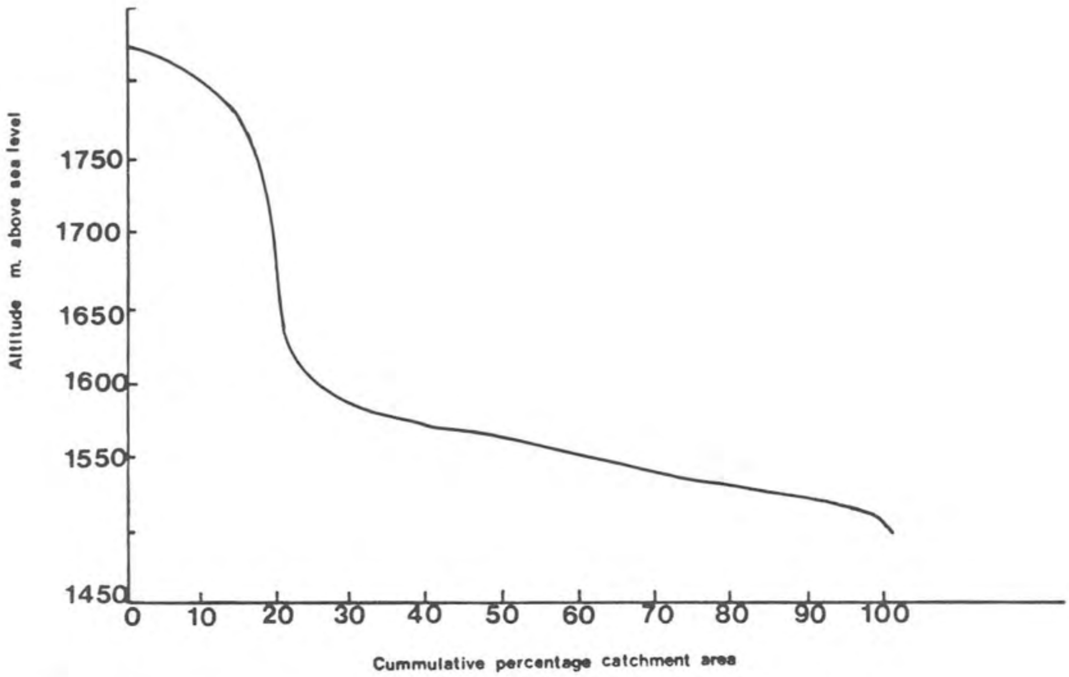

Figure 7 Hypsographic curve of Maqalika dam catchment.

Plate 2 Maqalika reservoir observed from the south.

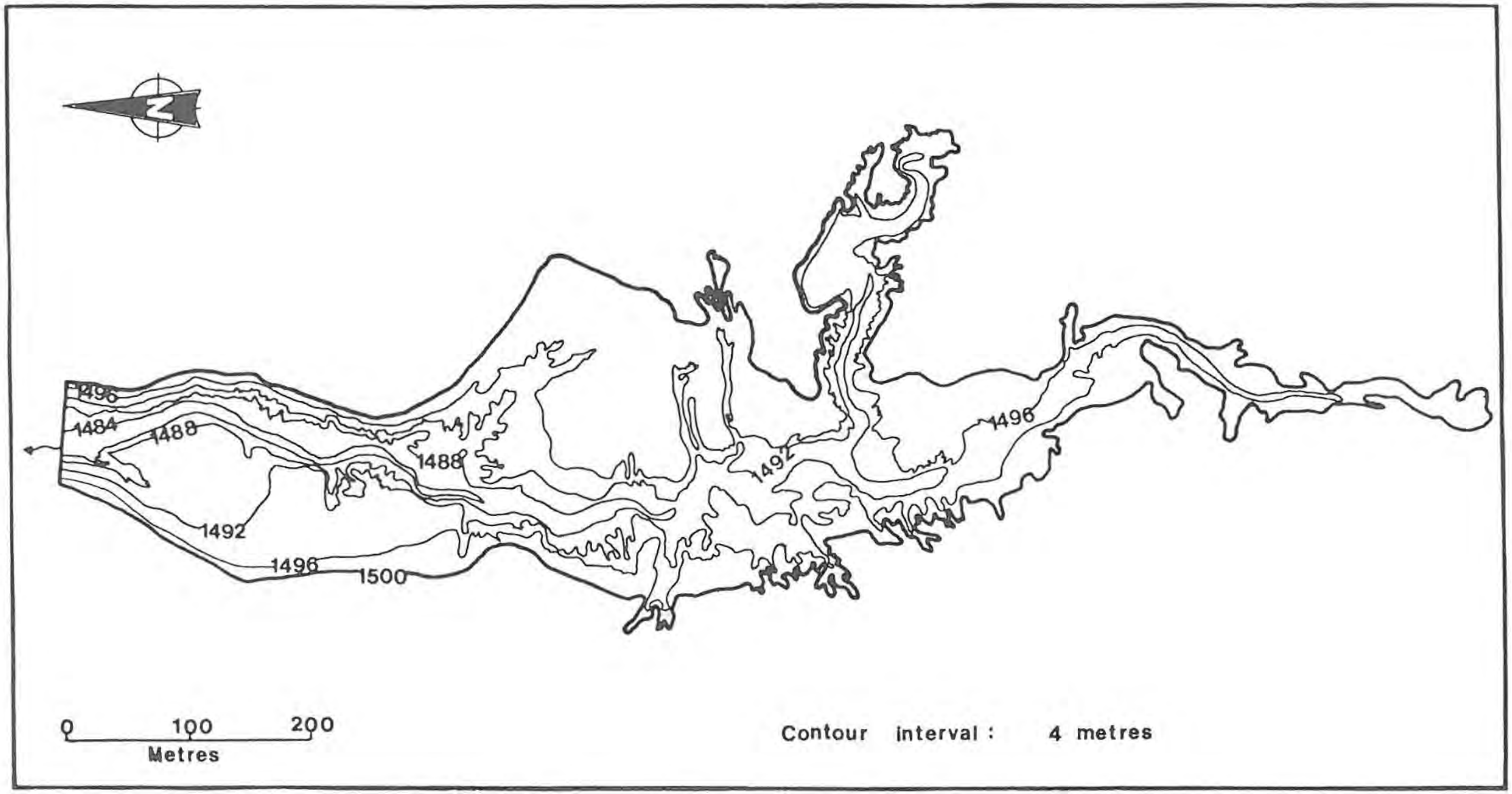

Figure 8 Pre-construction reservoir floor topography of Maqalika reservoir.

THE CATCHMENT

Bedrock geology

Bedrock geology of the study area comprises sedimentary rocks of the Molteno, Elliott and Clarens formations of the Stormberg series. There are also igneous rocks in the form of Dolerite dykes and intrusions. The distribution of these rock types is shown in Figure 9, while the types of sedimentary rocks are listed in Table 6.

Table 6 The geological succession of sedimentary rocks in the study area (Stockley, 1947).

Series	Formation	Lithology	Age
Stormberg	Clarens	Sandstones, mudstones and shales	Lower Jurassic
Stormberg	Elliot (Red Beds)	Mudstones, sandstones with grits	Triassic - Rhaeltic
Stormberg	Molteno beds	Sandstone, grits mudstones and shale	Rhaeltic + Lower Jurassic

Dolerite dykes and intrusions.

Dolerite dykes formed in this region are less resistant to weathering than the surrounding sedimentary rock which comprises cave sandstone (Dangroup, 1980). Dolerite dykes weather much faster than the cave sandstone leaving visible depressions on the surface. These features of contrasted susceptibility to decomposition are developed exclusively in regions where cave sandstone appears at the surface (Meijs, no date). In the study area one can easily trace the depressions or gaps in the yellow cliffs of the sandstone beds. After a period of selective weathering, the relatively resistant sandstone walls stand out as ridges with a gap in between them. An example of this feature is the Lancer's gap dyke which forms a distinct valley in the escarpment bordering the Berea Plateau, shown in Plate 3. Where dolerite dykes occur through Red beds the opposite is observed. The surrounding rocks weather much faster than the dolerite dykes, leaving visible ridges and spurs along the landscape.

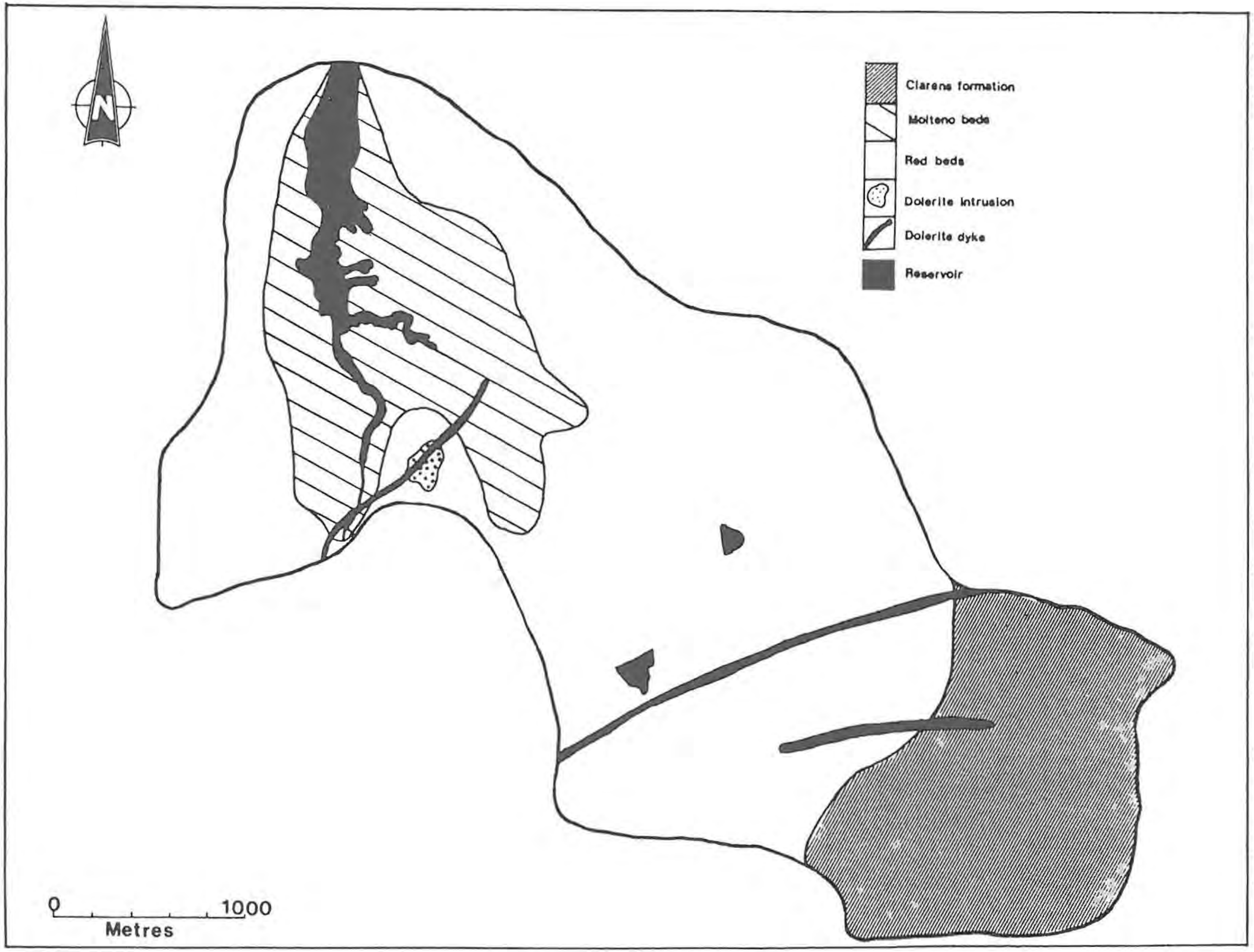

Figure 9 Geology map of Maqalika catchment.

Plate 3 The Lancer's gap dolerite dyke.

A dyke that forms a gap in the landscape provides cheap and easy means of constructing a road to the top of the escarpment. The Lancer's gap dyke has been quarried for road surfacing material and is thus a potential source and conduit of sediment. The dyke is also expected to act as a conduit for water coming from the top of the escarpment to lower parts of the catchment.

General geomorphology

This section describes landforms and surficial deposits of a rather longer term and more permanent nature. The method of mapping used here is that recommended by Schmitz and Verstappen (1978), and later used for erosion and land resources studies by Schmitz (1980 and 1984). Descriptions are adopted from the works of Bawden and Carroll (1968) and Schmitz (1980). The distribution of landforms on the three land systems identified by Bawden and Carroll (1968) is shown in Figure 10.

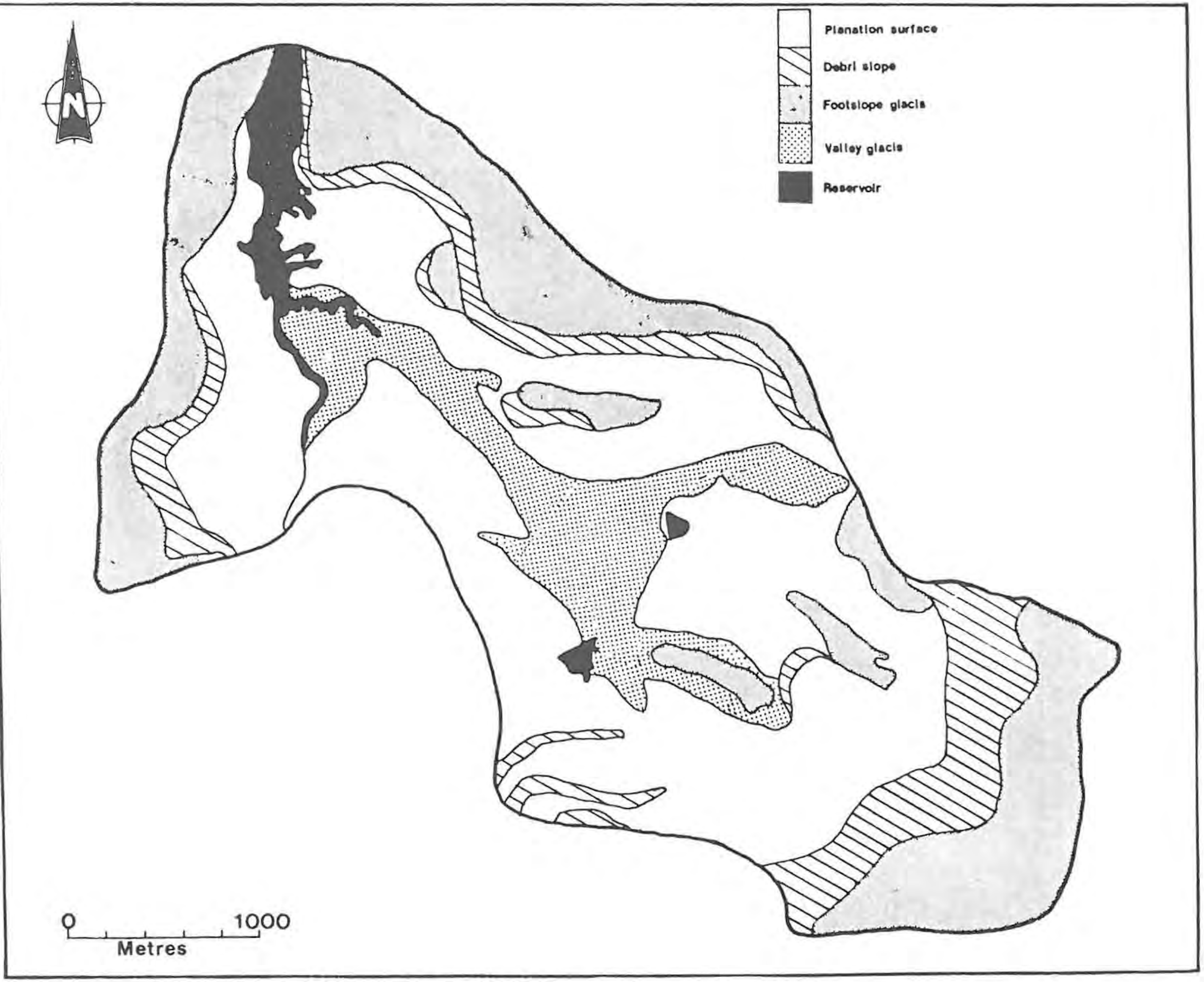

Figure 10 Landform units of Maqalika catchment.

Caledon lowlands

Predominant landforms on this land system are alluvial flats which consist of an alluvial plain along the Caledon River, and the tributary channel flats or valley glacis. The valley glacis occur where valley branches are filled with colluvium covering original bedrock (Schmitz, 1984). This area is cut by branched deep gullies characterized by incision of the upper reaches, and deposition in the low reaches.

The valley glacis merges into a relatively steeper footslope glacis which marks the boundary between the Caledon lowlands and the lowlands escarpment. Colluviation follows the same pattern as in the formation of valley glacis, except that the resultant material is deposited on the lower edges of a rather steep debris slope which is part of the lowland escarpment. Colluvium in the lowlands of Lesotho has been observed to be highly susceptible to erosion (Bawden and Carrol, 1968; Schmitz, 1980; Chakela, 1981).

Lowland escarpment

The lowland escarpment comprises both the cave sandstone escarpment and the steep sided plateau of sedimentary rocks (Bawden and Carroll, 1968). The sandstone scarps consist of vertical cliffs surrounding the plateau. The scarps result from weathering and mass wasting leading to the retreat of the cave sandstone. In areas where soft mudstones or clay shales occur at the base of the scarps, rapid weathering of these soft rocks leads to undermining and collapse of the sandstone above (Schmitz, 1980). The resultant debris is deposited further down the slope forming the debris slope which represents the downslope section of the lowland escarpment.

Debris slopes are formed below scarps due to accumulated weathering products consisting of pebbles and large boulders derived from the scarp above (Schmitz, 1980). The boulders may be embedded in a sandy matrix or left standing out on the surface, as shown in Plate 4. Some areas of the debris slope are partly covered by colluvium deposits which may be gullied. Schmitz (1984) noted that debris slopes reach a gradient of 34^{o} throughout Lesotho. Due to their steep gradient, debris slopes are exposed to torrential runoff which may have a bearing on downslope erosion.

Plate 4 Debris slope with boulders standing out.

Sandstone foothills

This land system consists of relatively undissected sandstone plateau on a planation surface with broad gentle slopes (Bawden and Carroll, 1968). The surfaces slope gently towards the valley axes at angles of 1^{0} to 4^{0} and sometimes 5^{0}, forming spurs which may be strongly denuded. Rockstripping is widespread on the lower edges of the plateau.

Soils

There have been a number of soil surveys in Lesotho, for instance Carroll and Bascombe (1967), Binnie and Partners (1972) and Carroll, *et al.* (1976). These works were reconnaissance surveys lacking the detail required for conservation and planning (Conservation Division Team (CDT), 1979). A detailed soil survey of Lesotho was carried out by the CDT for the Ministry of Agriculture (1979), and from this survey an expanded and more detailed classification of soils was adopted. Throughout the present study, soils are classified according to the CDT (1979) at the level of soil series. Other commonly used classifications corresponding to each series are given in Appendix 1. The distribution of soils of the Maqalika catchment is shown in Figure 11. The CDT

(1979) survey is relevant and may be relied on for the present study since the survey was specially for soil conservation purposes. Descriptions of the physical and chemical properties of the soils relate mainly to their resistance or susceptibility to erosion. These properties are summarized in Table 7.

Climate and hydrology

Climatological and meteorological data referred to in this study are obtained from the Agricultural research station and Maseru Airport station, both of which are situated less than 500m from the catchment boundary.

Rainfall

The study area has a mean annual rainfall of 682mm as shown in Figure 12. Most of this rainfall occurs as high intensity, short duration thunderstorms. A large proportion of the yearly rainfall occurs in summer, with maximum values shifting between January and February (Figure 13).

There are marked variations from year to year (Figure 12), however there is a recurring pattern of extremely low values being followed by extremely high values such as 1933/34, 1941,42 and 1949/50. The dry periods are significant for vegetation cover and its ability to counter erosion (Chakela, 1981). Further analysis of the rainfall data shows that in each year a large proportion of rainfall occurs between November and March (Figure 13). This concentration of rainfall within short periods is significant to runoff and the initiation of erosion (Chapter 2).

Temperature

There is a marked difference between winter and summer temperatures. Summer temperatures in the lowlands normally range from a minimum of 1^{o} C to a maximum of $28,7^{o}C$. January is the hottest month with a mean of $21^{o}C$. Winter temperatures range from $-1,5^{o}C$ to $21^{o}C$. June is the coldest month with a mean of about $7^{o}C$ (Bureau of Statistics, 1982). Frost occurs during the winter months and hail occurs in both summer and winter. Carroll and Bascombe (1967) suggest that the dry cold winter months do not favour rapid weathering, but instead inhibit soil development.

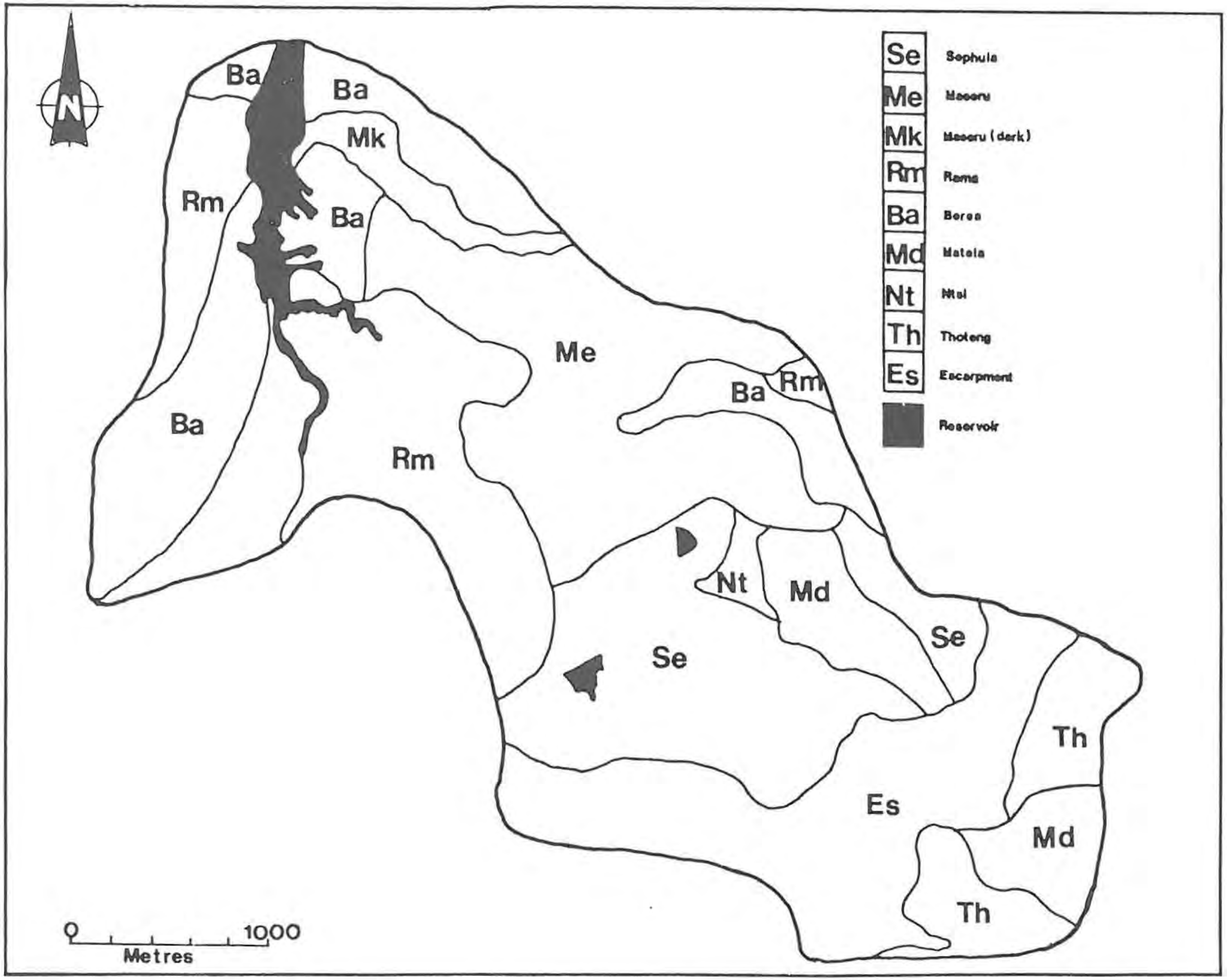

Figure 11 Maqalika Catchment soils map.

Table 7 Soil characteristics of the Maqalika catchment, CDT(1979).

SOIL SERIES	SYMBOL	TEXTURE	K-FACTOR	PERMEABILITY 25 - 100cm	PERMEABILITY 100 - 150cm	BULK DENSITY $g.cm^3$	PROFILE FORMATION	SOIL DEPTH	T-FACTOR $(t.h^{-1})$	AWHC
Berea	Ba	LFS	0,40	moderate	moderate to slow	1,7	Normal Profile	Deep	7	L
Maseru	Me	L	0,79	very slow		1,8	Duplex	Mod. Deep	2	L
Maseru Dark variant	Mk	L(dark)	0,60	slow	v. slow	1,9	Semi-Duplex	Deep	2	M
Matela	Md	FSL,LFS	0,33	moderate	moderate	1,6	Normal	Deep	9	L
Ntsi	Nt	FSL	0,55	moderate to rapid	moderate	1,4	Semi-Duplex	Shallow	2	VL
Rama	Rm	L,FSL	0,24	moderate to slow	slow	1,5	Semi-Duplex	Deep	5	M
Sephula	Se	L,vFSL	0,76	moderate		1,9	Duplex	Deep	2	VL
Thoteng	Th	LFS	0,24	rapid	rapid	1,6	Normal	Deep	9	VL

LEGEND

LFS - Loamy fine sand
L - Loam
FSL - Fine sandy loam
vFSL - very fine sandy loam

K-factor - Erodibility factor
T-factor - Soil loss tolerance
AWHC - Available water holding capacity.

L - Low
M - Medium
VL - very low

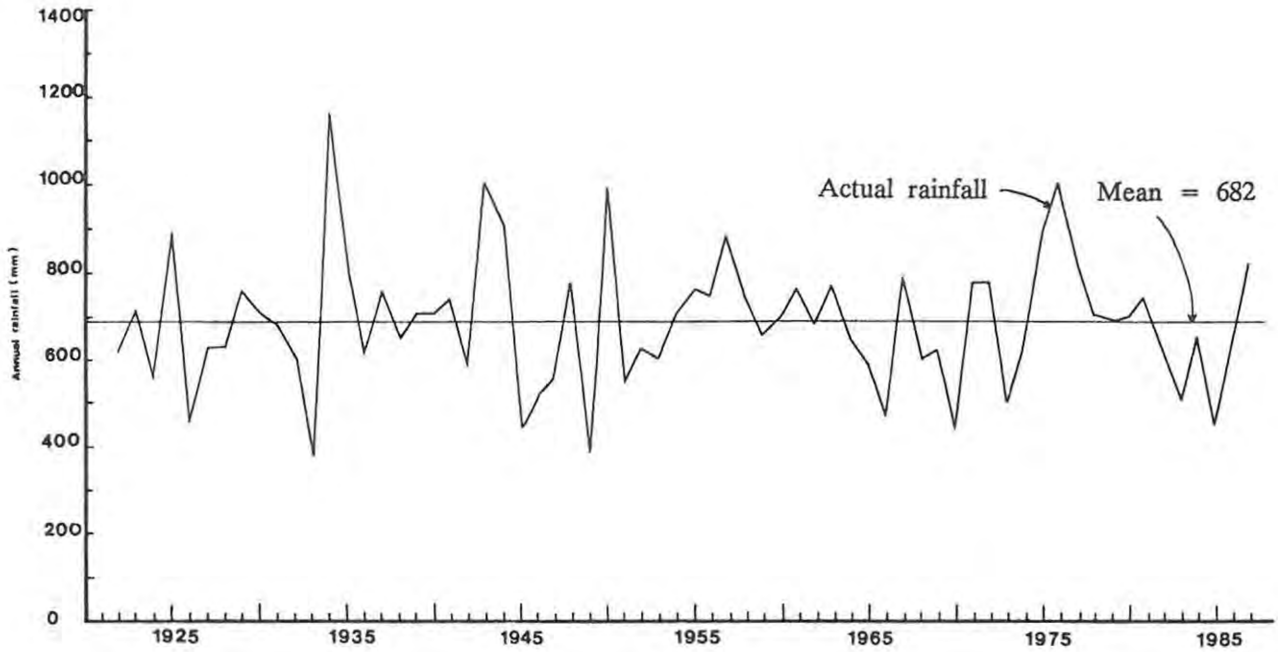

Figure 12 Mean annual rainfall at Maseru, 1921/22 to 1986/87.

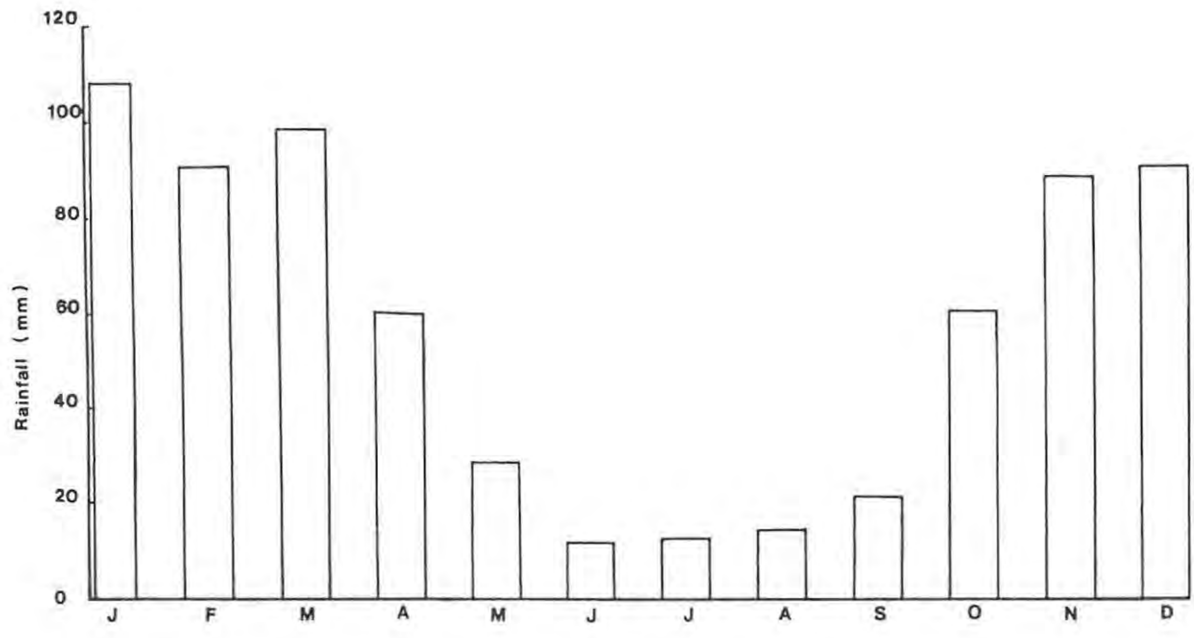

Figure 13 Mean monthly rainfall at Maseru.

Streamflow

There is no stream gauging in the catchment however mean annual runoff has been estimated as 600 000 m^3yr^{-1} (Binnie and Partners, 1979). The area is drained by ephemeral streams, whose flow occurs during or immediately after rainfall. A large part of the drainage network consists of gullies whose flow is made of flash floods of short duration resulting from short duration, high intensity thunderstorms.

Vegetation

Lesotho in general is a grassland country with almost complete absence of natural tree growth (Carroll and Bascombe, 1967; Bawden and Carroll, 1968). Acocks (1953) suggests that conditions are too dry and frosty to permit natural tree development, which is significant to surface protection. Most of the natural grassland vegetation has been destroyed through years of overpopulation, overgrazing and veld fires (Bawden and Carroll, 1968; Schmitz-Ruch, 1984).

In the present study area, natural vegetation was originally dominated by *Themeda* grasses, especially *Themeda trianda*, most of which has been removed for purposes of cultivation and urban development. *Themeda trianda* has been exposed to heavy overgrazing due to overpopulation, and has been replaced by *Eragrostic chloromelas* and other xyrophytic *Eragrostis* (Bawden and Carroll, 1968).

There has been a drastic change in the vegetation of Lesotho in general, due to population pressure and mismanagement of the land. Schmitz-Ruch (1984) notes that there has been a general impoverishment of flora and physiological changes which diminish the role of vegetation as a soil cover. Bawden and Carroll (1968) suggest that mismanagement of the land has encouraged invasion of grassland by plant species which are unpalatabie to stock. Two such species *Chrysocoma tenuifolia* and *Aster fillifolius* are extensive on the sandstone escarpment and the Berea Plateau.

There are a number of land and vegetation uses listed in Table 8 which have played a direct role in changing vegetation in the present study area and similar areas in Lesotho.

Table 8 Land and vegetation uses (after Schmitz-Ruch, 1984).

Vegetation type	Extensive use
Hyparrhenia hirta	Thatching
Aristida congesta	Broom making
Themeda trianda (grass)	Grazing
Themeda trianda (land)	Cultivation
Aloe polyphylla	Decorations and hedgings

Schmitz-Ruch (1984) noted that the disappearance of native species around settlements has been followed by the development of anthropophilous species. Most of these species are common weeds which do not provide any protection since they are removed for aesthetic and other purposes. A few such plants present in the study area are *Chenopodium album*, *Homenia-pallida*, and *Tagentes minuta*.

The area around the north east and the north west of the reservoir consists of rocky outcrops. Vegetation in this region consists of *Rosa rubiginosa* growing below and between rock overhangs. Woodlot plantations were introduced to provide wood fuel and to provide surface cover. There is a notable woodlot planation downslope of Maseru Airport extending to the western shore of Maqalika reservoir. The woodlot consists of *Pinus* and *Eucalyptus* species. Throughout the present study vegetation types are referred to using scientific terminology. Other common (English) and Sesotho names are given in Appendix 2.

Land use

Land use in the study area consists of residential development, cropland, grazing and the Airport grounds. Most of the area bordering the reservoir comprises abandoned fields which are truncated by gully systems.

The residential area

Residential development and growth are unplanned (Mateka, 1987). Planned development is hindered by the unauthorized and arbitrary building in the area (Mosaase, 1988). The residential area is described in terms of its components which are: (i) housing developments, (ii) infrastructure and (iii) the extraction and use of raw materials.

Housing

Housing comprises a greater part of any city (Drakakis-Smith, 1980), in terms of physical dominance over other components, and in terms of relative need. Housing development in the Maqalika catchment is unplanned and uncontrolled leading to shortages or absence of infrastructure in the form of roads, water supply and sewerage. This has led to the present situation of vast areas of unserviced urban sprawl (Land Survey and Physical Planning (LSPPa, no date).

Within the housing component of the residential area, three sub-components were identified in terms of density; these are low, medium and high density housing. The low density area consists of scattered dwellings with an approximated density of 1 - 30 houses per square km, while medium density housing consists of about 30 - 100 houses per square km, and high density housing over 100 houses per square km. The residential area consists of fenced and unfenced sites of different sizes. Some of the fenced sites have gardens producing fruit and vegetables. This kind of cultivation makes up a large percentage of urban agriculture (Mosaase, 1988). This form of cultivation is not always successful because some plots are developed on marginal lands whose cultivation leads to erosion.

Most houses in the high density area are fenced, with well kept gardens, running water and sewerage. Low density housing occurs close to the cultivated land towards the steep slopes. In this area former field boundaries can be identified while some fields are still cultivated. In the low and medium density areas pit latrines are common since there are usually no services in the form of reticulated water or water borne sewerage. Communal taps and boreholes are common forms of water supply.

Infrastructure

Communication is by way of tarred and earth roads, tracks and footpaths (Figure 14). The main Northern Highway from Maseru to Teya-teyaneng runs through the study area. This tarred road is heavily trafficked (Linström, 1986) and requires careful maintenance. Another tarred road branches off the highway to the top of the escarpment through Lancer's gap. The road sides are eroded and sometimes potholes occur on the surface.

There are a number of earth roads running in different directions through the area. Most of these roads are unplanned, emerging between sites and on former field boundaries and on tracks that were formerly used for agricultural appliances. These roads are also heavily trafficked as they serve some of the most highly populated settlements in Lesotho. The distribution of roads and settlements is shown in Figure 14.

Stormwater drains and road ditches are not lined in large parts of the catchment. There are only two paved drains in the whole catchment. One runs along the Main North Highway and the other runs along the road leading to the drawoff works on the reservoir. Paving has been attempted on some roads but was very poor and has since collapsed in some areas, causing serious erosion problems. Most of the culverts are badly designed, allowing water to over flow, causing erosion of the road surface.

Footpaths are common along roads, through unfenced sites, through open areas between settlements and around public amenities like communal taps and boreholes. Footpaths are also heavily trafficked and severely eroded. Some footpaths have developed into rills and gullies.

Extraction of raw materials

Raw materials are required for the construction of the physical structures of the city, such as buildings, roads, airports and other infrastructure (Douglas, 1983). Due to transportation costs, sources of raw materials are usually derived locally, especially when required in bulk. Activities related to the extraction of raw materials in the study area are quarrying, sandstone crushing and brick making.

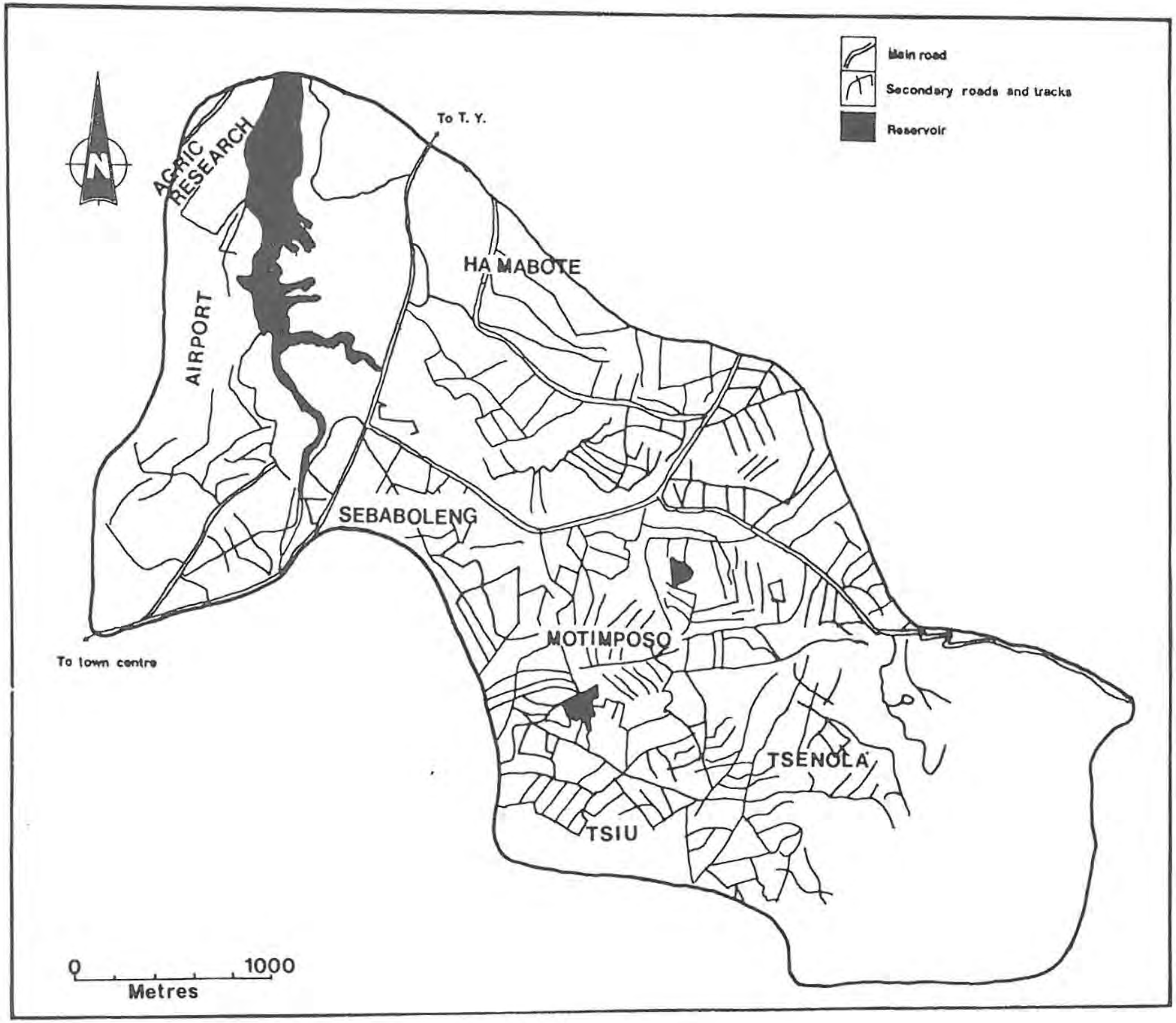

Figure 14 Distribution of roads and settlements in the Maqalika catchment.

The dolerite dyke situated at Lancer's gap was quarried for pavement material and concrete aggregates. This quarry consists of a large pit about 5 m deep, 150 m long and 50 m wide. The aggregates are worked by mechanical appliances. The quarry is presently not in use, but its floor and walls have not been protected. The near vertical walls are unstable and constantly eroding.

Sandstone crushing is common around the scarps and debris slopes where large boulders of sandstone stand out on the surface. The sandstone provides facing stone for housing. Unlike quarrying, sandstone crushing is not limited to one specific point. Each point is situated as close as possible to the site to be developed.

Another common activity in the catchment is brick making, which is concentrated around Maqalika reservoir and other smaller reservoirs and ponds. Brickmakers use local material (clay) to manufacture bricks. This is obtained by digging several pits, each of which may be 2 to 3 m in diameter and 1 to 2 m deep. These pits are not protected or restored after use.

Agricultural land use

Agricultural land use consists of cultivation and stock rearing. Most of the livestock is kept on small farms on the top of the escarpment, while some of the livestock is kept within the residential sites. Common livestock consists of cows, sheep, goats and pigs. Cultivation is limited to some planation surfaces both on the top of the escarpment and below. Due to a high demand for land, urban encroachment is pushing cultivation to steep slopes, leading to erosion of the land. Maize is the main crop being planted, together with a few vegetables for rotation. Cultivation is however being abandoned because of the opportunity of gaining more money through the illegal sale of land and because of vandalism on the cultivated land (LSPP, no date a). The northern part of the catchment is occupied by the Agricultural College and Research Station, large parts of which are cultivated and used for experimental crops. The western part of the catchment is occupied by the airport and sports ground. In this region there are no signs of erosion, but it is likely that runoff is high due to the impermeable nature of the surface.

Population

The population of Lesotho is not evenly distributed. The Bureau of Statistics (1986) reports that 75% of the 1 577 million inhabitants live in the lowlands. Maseru, being the largest town and urban centre, doubled its population from 55 031 in 1976 to 109 382 in 1986 (Mateka, 1987). Although there are no exact figures for the present study area, population densities in the Maseru urban area are estimated at 451 persons per km^2 and above (Central Planning Division (CPD), 1976). The sub-urban areas of Motimposo, Sebaboleng, Tsiu and Mabote (Figure 14) which are part of the study area are among the most densely populated areas in Lesotho. Mateka (1987) reports figures of 2,1 persons per room, which create pressure on the land, and the subsequent conversion of agricultural land to residential land.

Land Policy

Any study concerned with the evaluation of land and water resources should include the description and interpretation of policy measures in existence in the area in question. The following section describes the past and present policy measures, their successes and failures and amendments that were intended to create land reform. It has been noted by a number of investigators such as LSPP (no date b), Mosaase (1988) and Mateka (1987) that the present unplanned and uncontrolled land development has been due to lack of, or poor implementation of sound land policy.

Throughout the history of Lesotho up to independence in 1966, land policy measures were based on the land tenure system described by Sheddick (1954). This system of land allocation presented problems since development of the land was the obligation of the holder only. Outsiders and donor agencies were reluctant to invest capital in such development which lacked security (LSPP, no date b). Ownership of land was vested in the King, while land allocation was at the discretion of local chiefs.

Evolution of land policy from 1967 to the present time includes the Land procedure Act of 1967 and the Deeds registry Act of 1967, which did not have any impact on land reform since land allocating power was still vested in local chiefs (LSPP, no date b). The Land Act of 1973 among other things transferred land allocation powers from chieftainship to local government. The 1973 Act was passed as a measure of land reform but was openly opposed by chiefs.

The 1979 Land Act was enacted in order to bring about land reform. According to the Act, power to grant land is still vested in the King and exercised by land committees. Unlike previous Acts, the 1979 Act defined urban areas and growth, and included the selection of development areas, housing schemes and infrastructure provisions. The Act also indicated areas considered as prime agricultural land. It was hoped that the implementation of the Act would create orderly urbanization, preserving agriculture and grazing lands accordingly. Implementation of the Act was not successful because it included dramatic alterations to the traditional land tenure system, taking away land powers from chieftainship which in turn opposed the law and refused to apply it.

Mateka (1987) reports that failure of the implementation of the 1979 Land Act became evident in the urban areas where land demand was high. It is alleged that local chiefs in collaboration with field owners started to convert agricultural land into residential sites using back dated documents (LSPP, no date b).

The 1980 Town and Country planning Act was inacted to provide for orderly development of land and improvement of amenities. This Act took years to be implemented due to lack of resources, skilled manpower, finance, and the absence of local authorities who would prepare and enforce the plans.

Lack or poor implementation of land use policy manifests itself in the growing urban sprawl. Site development which often escapes observation by authorities involves haphazard excavations for buildings, leading to soil erosion. The badly sited roads which are a result of unplanned sites also contribute to erosion.

CHAPTER FOUR

METHODOLOGY

The study has been divided into two parts for convenience, (i) the assessment of the past and present condition of the catchment, and (ii) the measurement of sediment yield at the catchment outlet.

THE CATCHMENT SURVEY

The purpose of the catchment survey was to identify specific areas that produce, transport and store sediment in the catchment and to identify catchment attributes which affect production and movement of sediment. The study combines surveys of past historical trends, the present state of erosion and deposition, the apparent processes and the causal factors. In order to work within the structural framework of the study, techniques are applied in relation to each of the specific aims. The description of the technique used is preceded by a statement of the relevant aim.

AIM 1

To reconstruct the history of erosion and land use in the Maqalika dam catchment.

Technique 1: Aerial photo interpretation.

The whole catchment was surveyed using black and white panchromatic aerial photographs of 1961, 1979 and 1985, with scales of 1:9 000, 1:11 000 and 1:11 000 respectively. Photographs were analysed using a mirror stereoscope with power magnification of X3. Erosion was mapped at each date using the classification system of the Southern African Regional Commission for the Conservation and Utilization of Soil (SARCCUS) (1981) which indicates types and intensities of erosion. The SARCCUS (1981) system allows for the classification of either each type of erosion separately, or a combination of types. A guide to the use of the system is presented in Table 9. The original guide has been modified to include water erosion only.

Table 9 Summary of the types and classes of soil erosion (SARCCUS, 1981).

TYPE OF EROSION	CLASS OF EROSION	SYMBOL	DESCRIPTION AND REMARKS
EROSION CAUSED BY WATER			
SHEET (SURFACE) Uniform removal of surface soil	None apparent	S1	No visible signs of erosion on air-photo. Level of management appears to be high.
	Slight	S2	Areas of light-tone observed on air-photos. Erosion deduced from poor cover, sediments deposits and plant pedestals.
	Moderate	S3	Eroded areas obvious on air-photos. Plant cover very poor and sediment deposits extensive. Associated with small rills.
	Severe	S4	Sheet erosion of such severity always associated with rills and gullies. Much or all of the A-horizon has been removed.
	V. Severe	S5	As for S4.
RILL Removal of soil in small channels or rivulets, mainly on arable land	None apparent	R1	As for sheet erosion.
	Slight	R2	Small, shallow (mainly < 0,1m) rills present but not readily observed on air-photos.
	Moderate	R3	Rills of considerable depth (mainly 0,1 to 0,3m) and intensity usually observed on air-photos.
	Severe	R4	An abundance of deep rills (less than 0,5m) easily observed on air-photos. Subsoil may be exposed.
	V. Severe	R5	Large well defined rills but may be crossed by farm machinery. Associated with gully erosion.
GULLY (DONGA) Removal of soil in large channels or gullies by concentrating runoff from large catchment areas	None apparent	G1	As for sheet erosion.
	Slight	G2	Clearly observed on air-photos and usually up to 1m deep. Cannot be crossed by farm machinery.
	Moderate	G3	Intricate pattern of deep gullies (mainly 1 to 3m) exposing entire soil profile in places. Many 'islands' of topsoil removed.
	Severe	G4	Landscape dissected and truncated by large (3 to 5m deep) gullies. 25% - 50% of area unproductive.
	V. Severe	G5	Large and deep (often > 5m) gullies have totally denuded over 50% of the area.

The purpose of the aerial photo analysis was to prepare erosion maps, showing the spatial distribution of erosion at each date, giving sub-divisions of the terrain as erosion units, each of which is characterised by a well defined degree of erosion of specified types. The erosion unit is used as the basic sampling unit throughout the study. It must be noted that erosion units change from time to time in relation to changing erosion intensity and distribution. At each date the observed erosion units were grouped into six classes listed and described in Table 10. The original erosion maps based on the SARCCUS (1981) classification were transformed into new maps according to Table 10. Although the initial aerial photo analysis was carried out at varying scales, all erosion information was plotted on 1:20 000 base maps. The areal extent of each erosion class was determined and recorded. Increases in extent were recorded as positive change while decreases were recorded as negative change. The 1:20 000 base maps were used throughout the study for purposes of data extraction. For presentation in the text, the maps were further reduced to 1 : 30 000 for graphical reasons.

Table 10 Erosion classes obtained as a simplification and grouping of SARCCUS (1981) classes.

EROSION CLASS	DESCRIPTION	SARCCUS (1981) CLASS
1	No erosion	S1
2	Slight sheet erosion without rilling.	S2
3	Severe sheet erosion with slight rill erosion.	S2R2, S3R2
4	Severe sheet and rill erosion with-out gullying.	S3R3, S4R3, R4R4
5	Sheet and rill erosion with low density first order gullying (extension of gully network).	S2R2G2, S3R2G2, S3R3G2 S3R4G2, S4R2G2, S4R3G2 S4R4G2
6	Sheet and rill erosion with high density second order (and above) gullying. Incision of gully network.	S3R2G3, S3R3G3, S4R2G3 S4R3G3, S4R4G3, S4R3G4 S4R4G4

It has been noted that the total surface area of the catchment was decreased by about 0,6km^2 after dam construction. To reduce chances of errors in computations, the area presently occupied by the impoundment, together with the area excluded from the original catchment due to the position of the dam wall were excluded from all areal measurements and computations. This area is shown as dotted lines in all catchment maps.

Land use was mapped using the aerial photographs described earlier. Six land use categories were identified; (1) cropland (C), grazing land (G), low density housing (LDH), medium density housing (MDH), high density housing (HDH) and the airport and sports grounds (AS). A few scattered woodlots were also identified. These woodlots cover very small areas, some of which could not be measured on maps. All woodlots were therefore included within grazing land. The areal extent of each land use was determined and changes recorded at each date.

Technique 2: Groundtruthing

Field studies were carried out to groundtruth aerial photographs. The whole catchment was surveyed through the inspection of each erosion unit identified from the aerial photographs. Examination of each erosion unit was undertaken in two stages as follows: firstly larger features were observed throughout the catchment from a relatively high point on the plateau. This gave a clearer view of the gullies and built up areas. Secondly examination of smaller features, vegetation, gully floors and sides was carried out by walking and driving through the catchment, from one erosion unit to another. Groundtruthing was also aided by a series of oblique photographs taken during the field study.

There were no major changes made to the erosion classification as a result of groundtruthing. A few changes were made to erosion unit boundaries. Changes to the mapping accounted for about 8.6% of the total survey. This implies that there could be an error of 8.6% on the analyses of earlier photographs. It was noted that the 1985 photographs were the most difficult to analyse because of the extensive built up area obstructing view of the surface conditions. It could therefore be assumed that the error in the 1961 and 1979 analyses is less than 8.6%.

AIM 2

To determine and evaluate erosion factors.

Technique 1: Selection and mapping of erosion factors.

Factors considered for evaluation were selected on the basis of literature, availability and reliability of data. These factors are listed in Table 11. Because no measure of its spatial variability was available, rainfall erosivity was not included. Catchment characteristics which are closely related to rainfall, and which could be used as surrogates for erosivity such as slope angle, slope aspect and altitude were considered. These characteristics were however not used as surrogates for erosivity for a number of reasons; (i) the effect of slope angle on erosivity has been covered by the measurements of the spatial variability of slopes (ii) the effect of slope aspect is mainly through soil type and soil moisture distribution, and is therefore covered by the measurement of the spatial distribution of erodibility and (iii) a large percentage (80%) (Figure 7) of the catchment lies between 1500 and 1600m above mean sea level, and this is the area where erosion is most widespread. A very small percentage lies between 1600 and 1820m therefore there is very limited spatial variability in altitude.

Table 11 Factors considered.

Factor	Source
1. Land use	Mapped from 1:11 000 aerial photographs.
2. Road density	Computed from 1:9 000 and 1:11 000 aerial photographs.
3. Erodibility	CDT (1979) K - factors (nomograph).
4. Slope class	Computed from 1:20 000 topographic map.
5. Geology	Extract from 1:50 000 geology map of Roma and Thaba-Bosiu. Government of Lesotho.

The catchment physiography was mapped mainly using pre-existing data in the form of maps and tables. The bulk of information has been presented in Chapter 3. Some of the data were obtained in a form not readily usable for the present study. It was necessary to transform some of the original maps into forms usable for the study. The maps were obtained at varying scales and were either reduced or increased to 1:20 000 for data extraction. The maps are however presented at a scale of 1:30 000 in the text.

Geology

Information of the geology of Maqalika dam catchment was extracted from the 1:50 000 map of the Geology of Lesotho (Department of Mines and Geology, 1981). The map was enlarged to 1:30 000 for use in the present study (Figure 9).

General geomorphology

The geomorphological mapping of the landscape was carried out using aerial photographs. Boundaries were drawn around major landforms (Figure 10) using methods described by Schmitz (1980) who showed with a case study from Lesotho that geomorphological analysis of the terrain is a valid approach to the study of water erosion. Landform units were not included in the final analysis of erosion factors since they are included within the slope classes discussed below.

Slope

A slope map shown in Figure 15 was prepared using a topographic map. The technique based on Olofin (1974) involves the determination of slope values within grid squares of 0,1 * 0,1 km. Gradient was estimated by the absolute height method in which the maximum slope is determined from the distance apart of contours. Olofin (1974) suggests that to make the determined slope values data manageable, the computed values should be grouped into classes according to boundaries formed by morphological, technical-economic, and farming requirements. Schmitz (1980) noted that in Lesotho landform units occur within certain defined slope ranges. These slope ranges of landform units were used to group the recorded slope values within geomorphological boundaries.

Soils

Due to time and resources limitations, field checking of some of the pre-existing soils data was not carried out. Soils information obtained from CDT (1979) was assumed to be correct since the CDT survey was carried out for purposes of soil conservation and land use planning. It may be assumed that the degree of detail required for the present study was covered by the CDT (1979) survey. The only change made to the soils map is that where CDT (1979) classified escarpment and rockland sandstone as separate units, in the present study the two were classified as one since the whole escarpment consists of bedrock outcrops (Figure 11).

Land use

Land use was mapped at each date using aerial photographs as described earlier. Six land use categories were identified and used in the analysis.

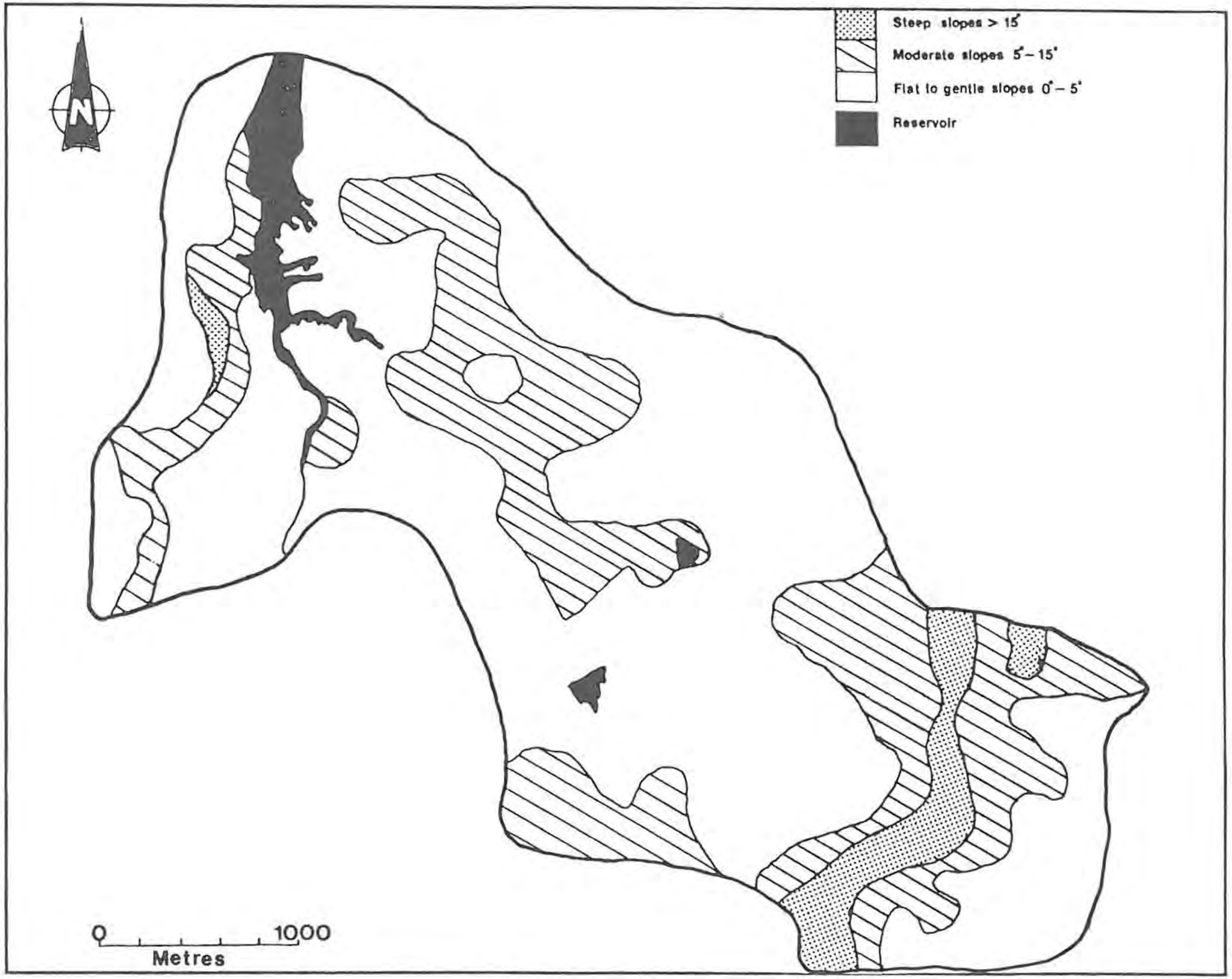

Figure 15 Slope map of the Maqalika catchment.

Road density

Road density was determined using grid squares superimposed on aerial photographs. Density values were determined by measuring the total length of roads within each grid square and dividing by the area of the square. Road density was expressed as metres per km^2.

Technique 2: Sampling procedure

The basic sampling unit is the erosion unit as mapped in Figures 16, 17 and 18. At each date the areal extent of each erosion unit was determined. The erosion unit maps were superimposed on erosion distribution maps (Figures 19, 20 and 21), land use maps (Figures 22, 23 and 24), Geology map (Figure 9), Soils map (Figure 11), Slope map (Figure 15) and road distribution map (Figure 14). Data on erosion degree and erosion promoting factors were extracted from relevant maps and recorded in Appendix 3. In some cases, the basic erosion unit exhibited more than one catchment characteristic such as geology or soil type. Under these circumstances the unit was divided into two or three sub-units in order to accommodate the observed catchment characteristics.

Technique 3: Non parametric hand factor analysis

A non-parametric hand factor analysis (Potter and Coshall, 1986) was applied at each date to determine the relationship between erosion distribution and factors listed in Table 11. It has been shown that erosion factors have certain common characteristics which result in inter-correlation. Moreover erosion is not necessarily influenced by individual factors but may be influenced by a combination of factors (Stocking, 1972). Hand factor analysis (Appendix 4) was carried out to distinguish characteristics resulting from inter-correlations, and to relate erosion to those non-observed characteristics.

One advantage of factor analysis is that many variables may be reduced to a few factors providing a simplified version of original data (Doornkamp and King, 1971). Conventionally factor analysis has been undertaken using a computer to handle the complex mathematical functions involved (Doornkamp and King, 1971), but a technique has been developed and applied by Potter and Coshall (1984) to carry out factor analysis using a non-parametric, non-computer dependent approach.

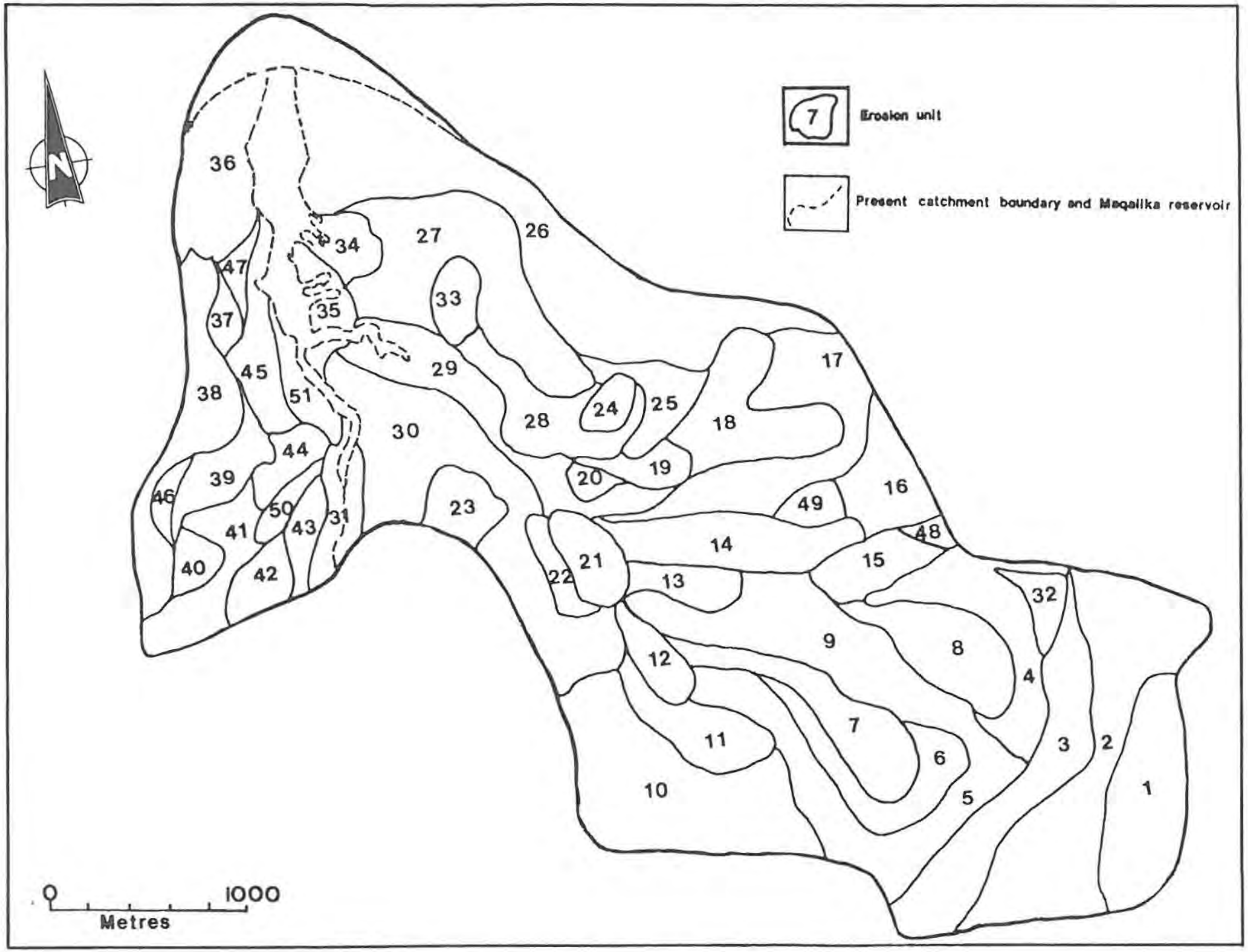

Figure 16 Erosion units map - 1961 (N.B an erosion unit is a sub-division of the terrain which is characterised by a well defined degree of erosion of specified types).

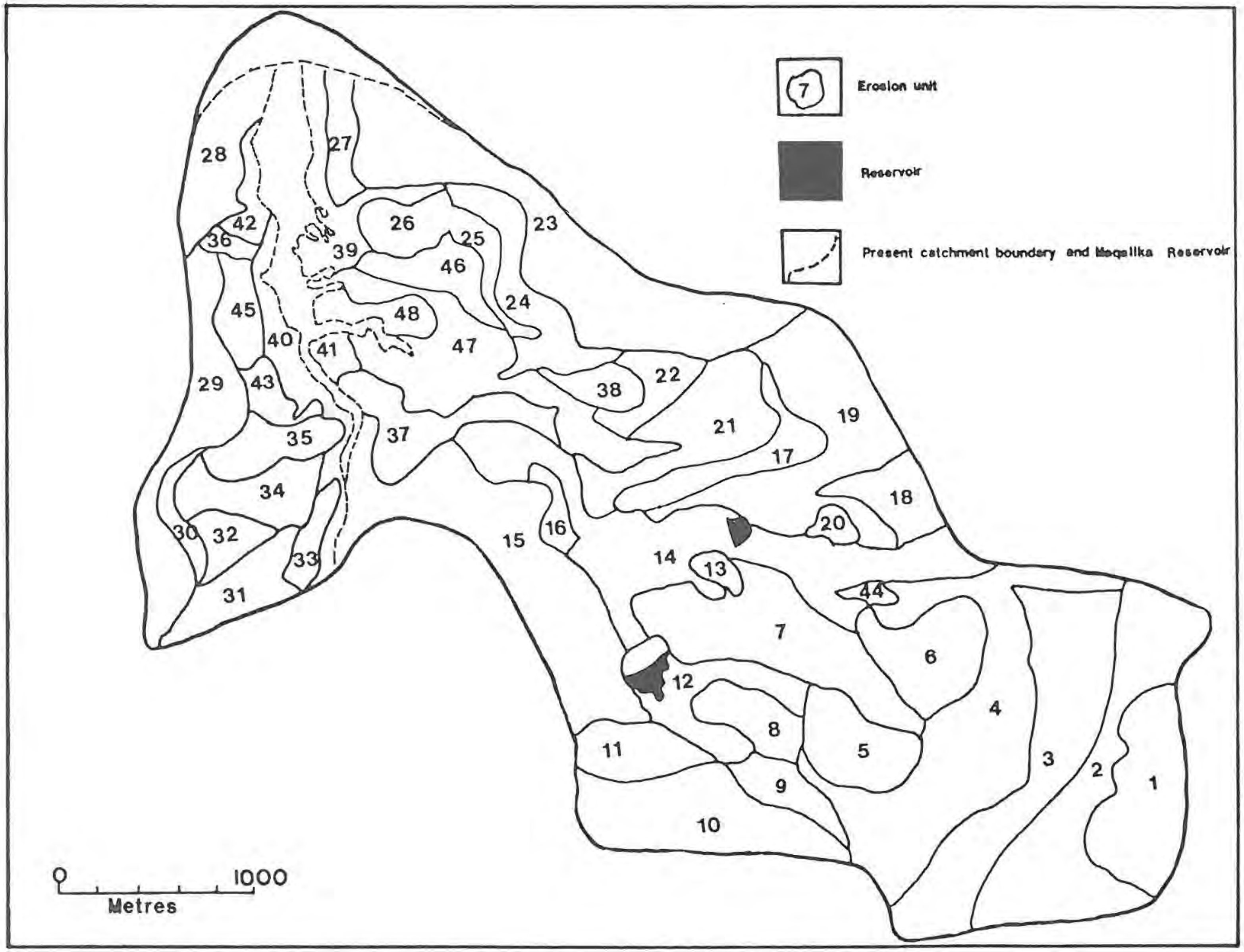

Figure 17 Erosion units map - 1979. (N.B an erosion unit is a sub-division of the terrain which is characterised by a well defined degree of erosion of specified types).

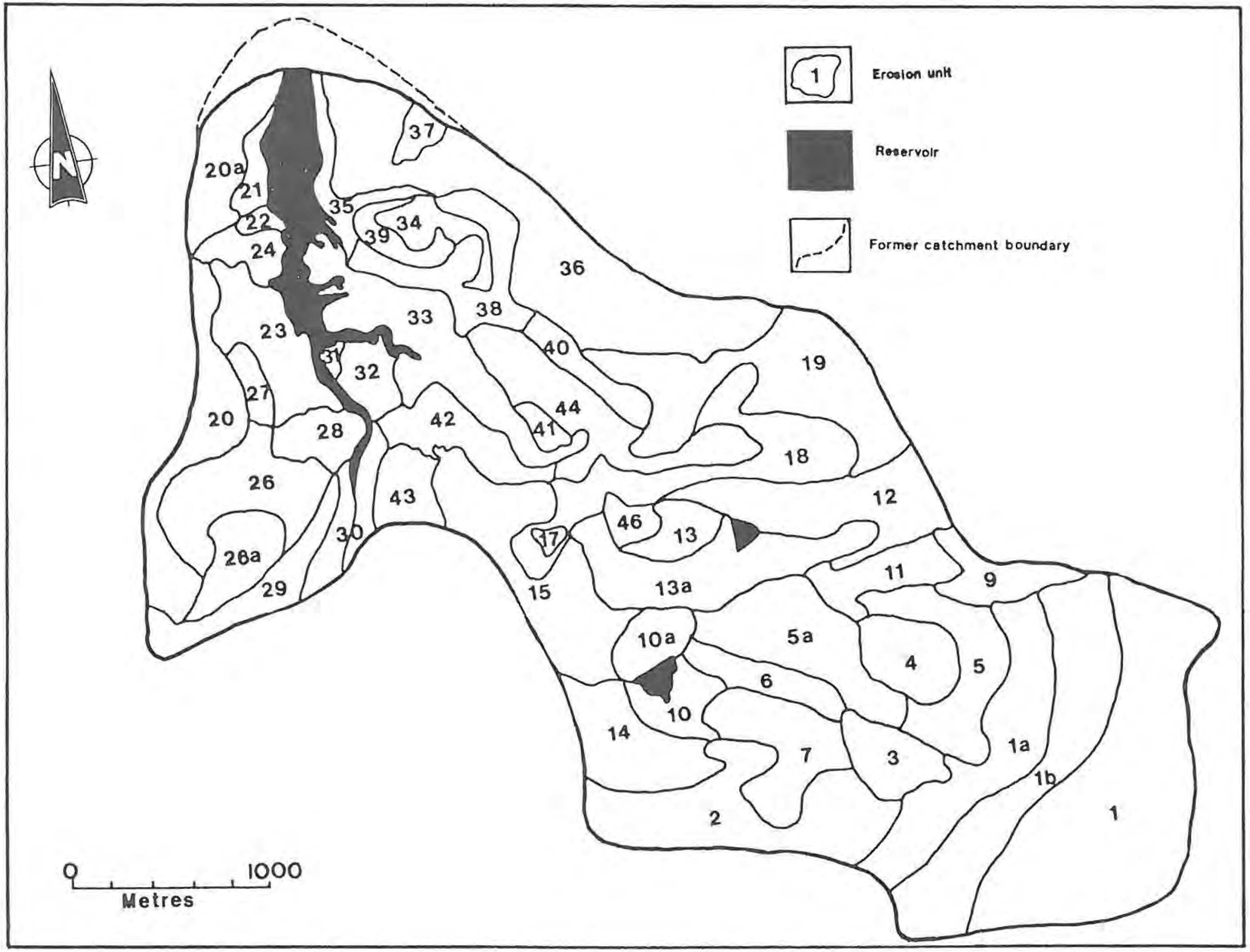

Figure 18 Erosion units map - 1985. (N.B an erosion unit is a sub-division of the terrain which is characterised by a well defined degree of erosion of specified types).

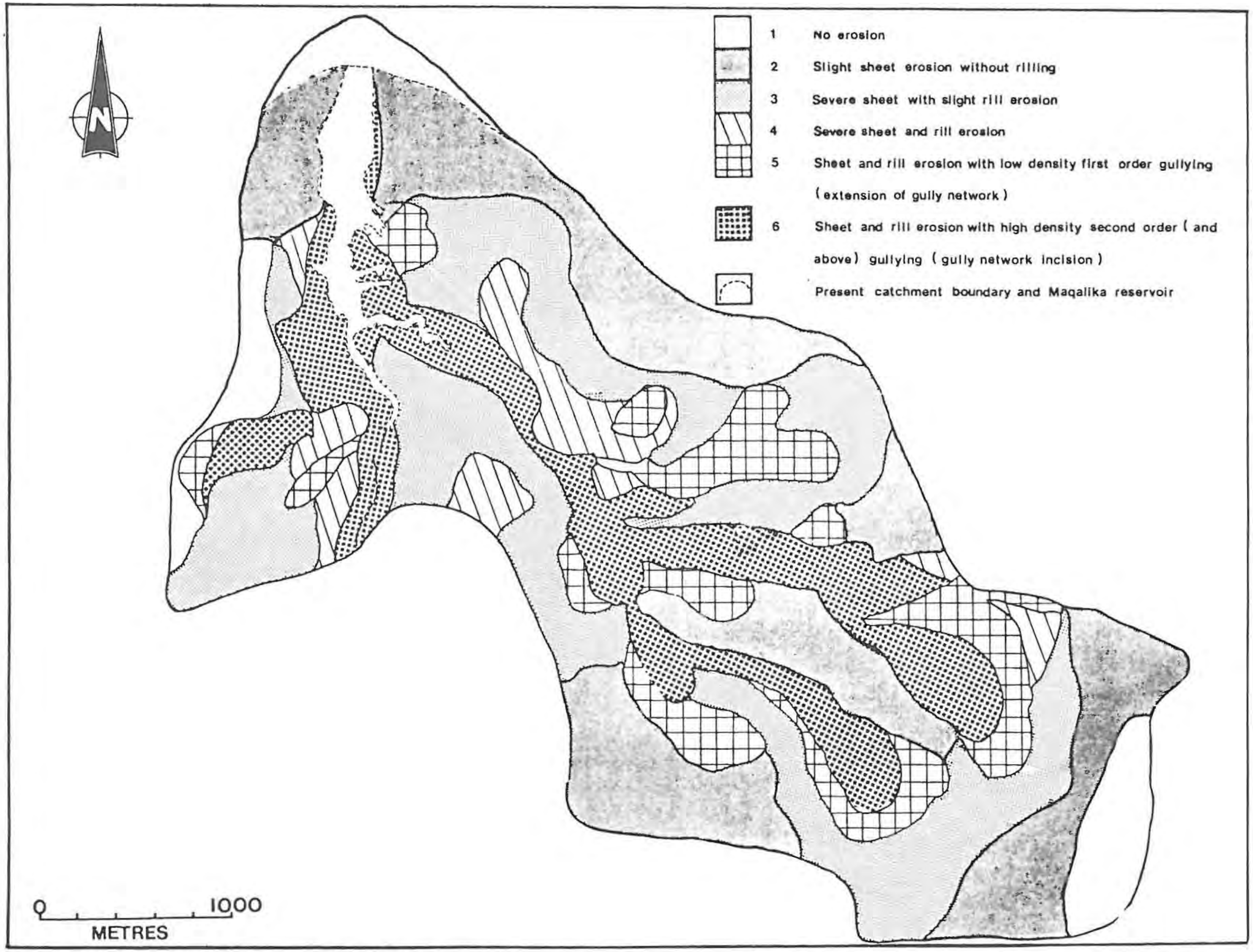

Figure 19 Maqalika catchment : Erosion distribution - 1961.

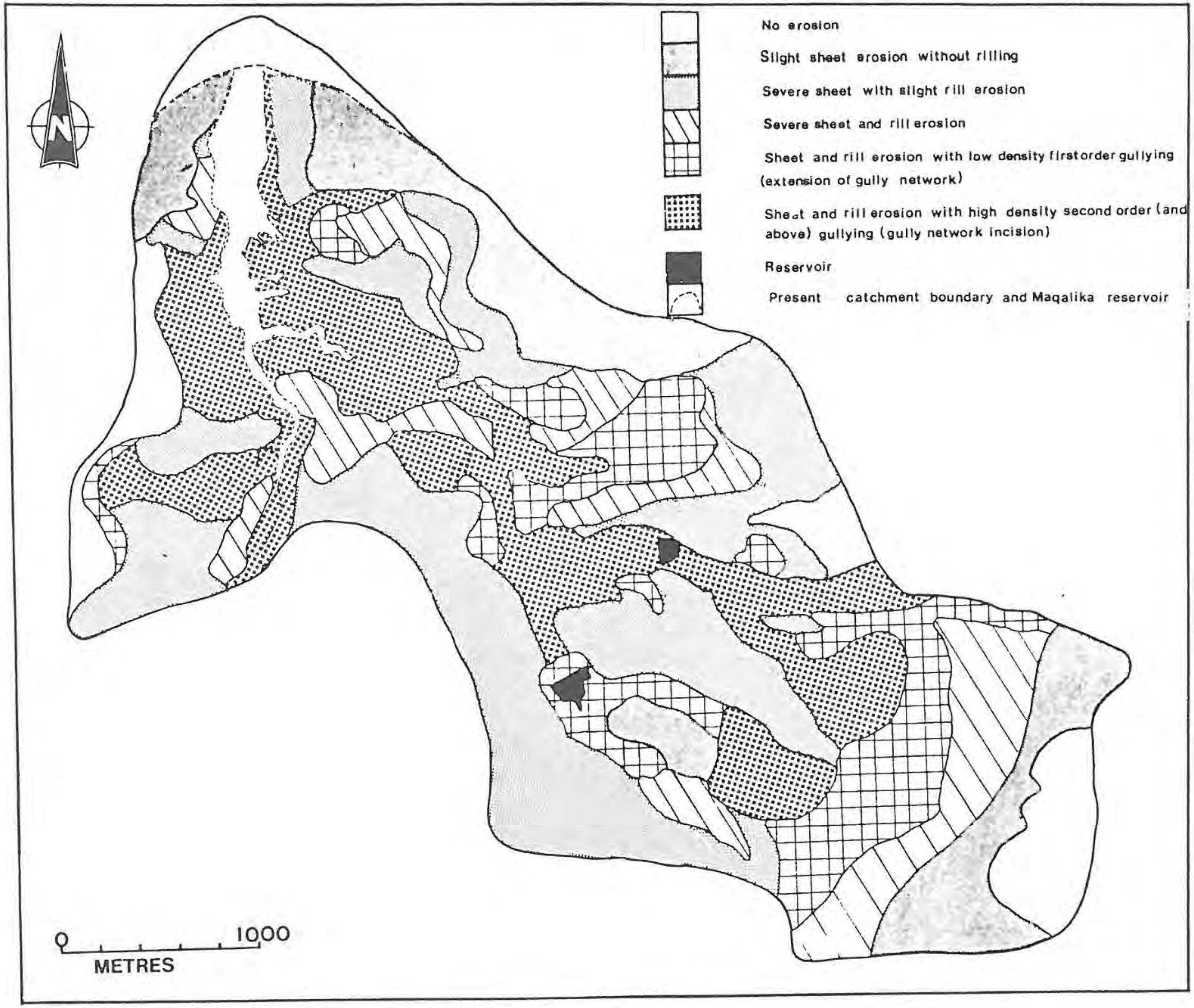

Figure 20 Maqalika catchment : Erosion distribution - 1979.

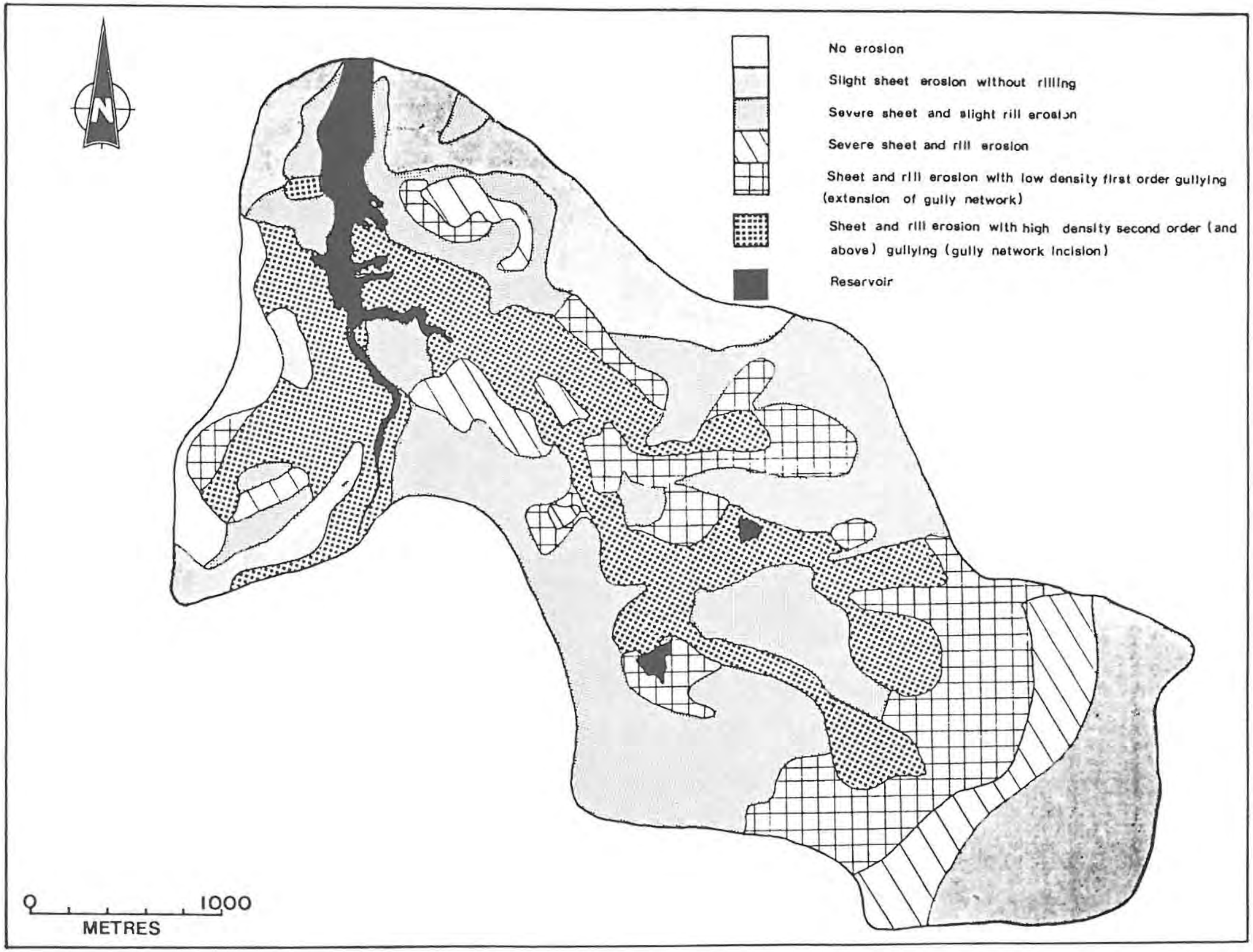

Figure 21 Maqalika catchment : Erosion distribution - 1985.

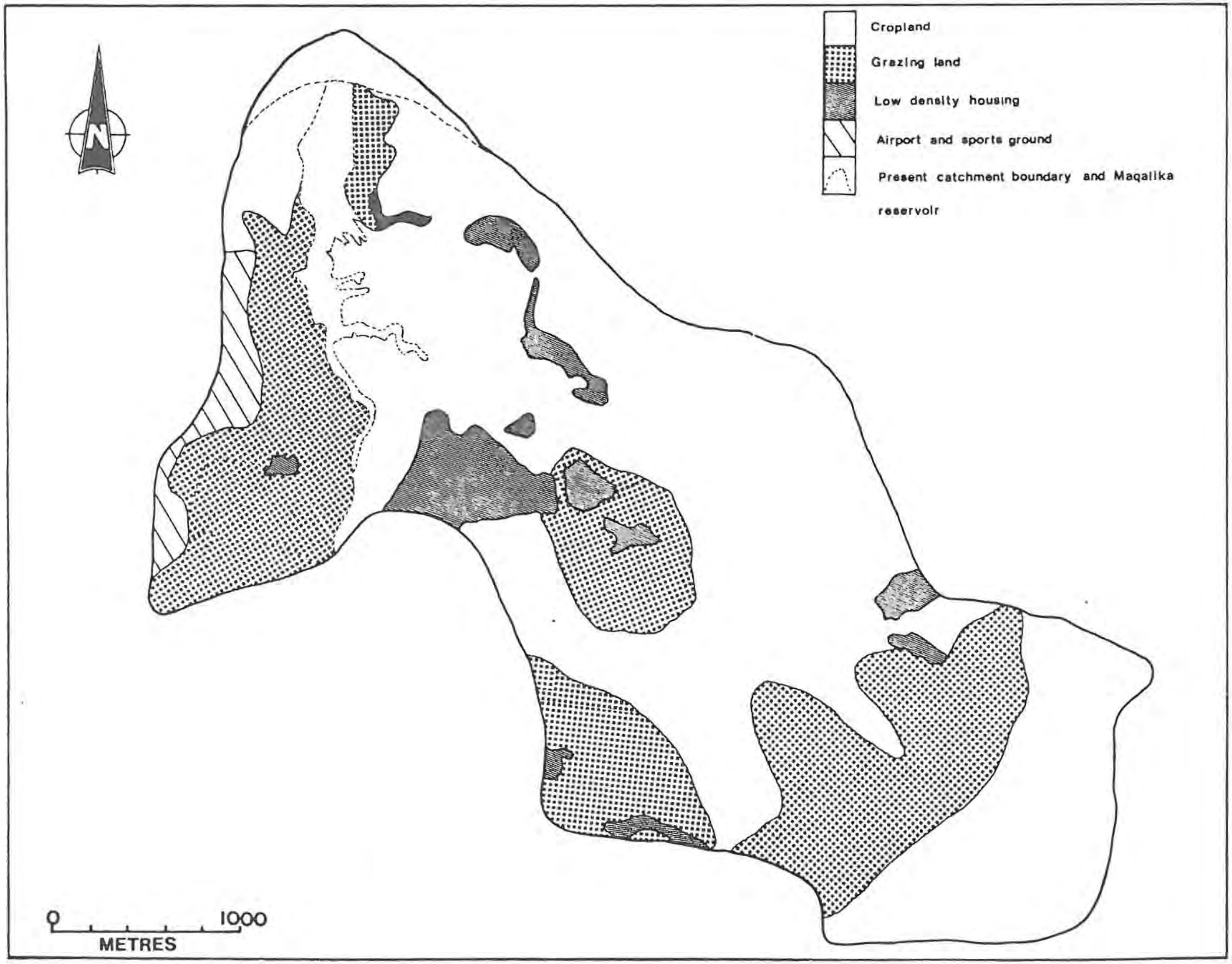

Figure 22 Maqalika catchment : Land use map - 1961.

Figure 23 Maqalika catchment : Land use map - 1979.

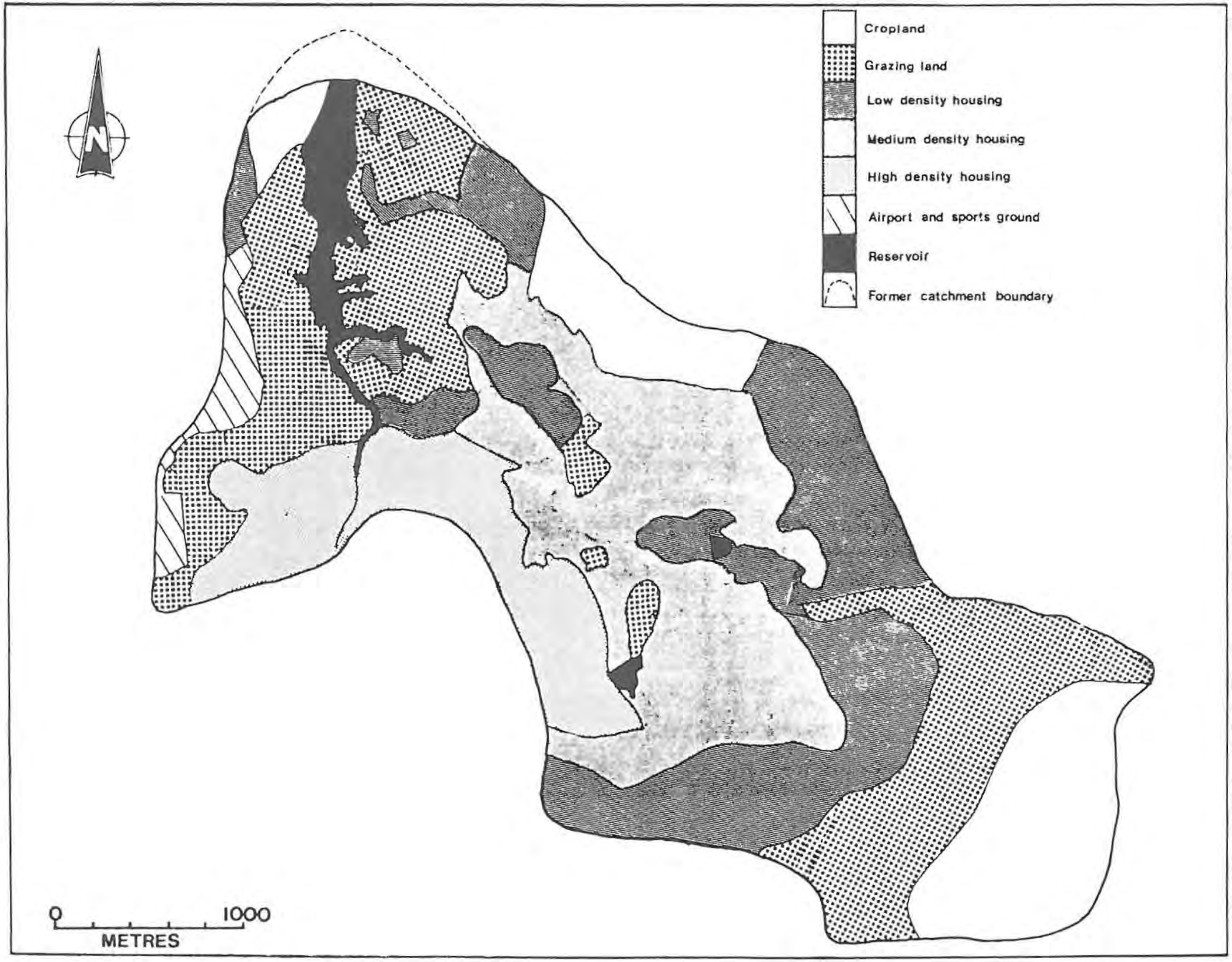

Figure 24 Maqalika catchment : Land use map - 1985.

The non-parametric hand factor analysis is recommended for Third world countries where computers are not always available, or where field personnel are not well acquainted with computers (Potter and Coshall, 1984). The method is also excellent as an exploratory procedure where large inventories of data are to be analysed. The method was carried out step by step as described in Appendix 4 and thus enables the researcher to retain feel for data and remain in direct contact with data, rather than loosing feel and working with the final output only. A cursory examination of data can be made at all stages of the procedure, to make quick field based interpretations. Ilbery and Hornby (1983) and Potter and Coshall (1984) have shown with case studies that the non-parametric hand factor analysis produces essentially the same results as conventional multivariate analyses such as cluster analysis and principal components analysis. The nonparametric hand factor analysis was applied to data given in Appendix 5 which is a summary of the raw data given in Appendix 3.

AIM 3

To identify and map areas that actively supply, transport and store sediment.

Technique 1: Air photo interpretation

The whole catchment was surveyed using the 1985 aerial photographs and orthophoto maps plotting present day erosion and deposition features. Various types of erosion and deposition features were identified and distinguished according to forms and positions on the landscape. This form of mapping does not distinguish various degrees of erosion as in the SARCCUS (1981) mapping. No suitable existing classification was found in the literature to distinguish deposition processes and features according to their relative intensities.

Technique 2: Groundtruthing

The whole catchment was field surveyed as described under Aim 1, Technique 2, to groundtruth aerial photographs.

Technique 3: Ground surveying

Some erosion and deposition features were measured at sampled areas using stratified sampling. De Ploey and Gabriels (1980), Ebdon (1985) and Morgan (1986) outline the advantages and disadvantages of sampling, and suggest sampling procedures appropriate to certain forms of investigation. Stratified sampling was preferred because it emphasizes the inclusion of places where the specific process seems to be active in its clearest and most varied forms.

Sample sites were selected on the basis of the distribution of erosion and depositional features, relief features and land use. In view of the distribution of the afore-mentioned features, slope transect and gully profile surveys were found to be the most feasible considering the degree of detail to be obtained from each sample site, and the time available for the study. Slope transects were difficult to measure because of obstructions such as buildings and fences. The slope transect surveys were ultimately abandoned. Oblique photographs were taken throughout the survey in order to record information not depicted on aerial photographs.

Gully profile surveys

The longitudinal gully profile surveys were measured on gullies numbered 1, and 2 in Figure 6, selected as being representative. On each gully the following investigation was carried out.

(i) The measurement of slope gradient at 50m intervals using a clinometer.
(ii) The measurement of sediment depth using an auger and tape.
(iii) Sampling of sediment for particle size analysis.
(iv) Examination of side walls for piping and tunnelling.
(v) Examination of gully head for headscarp activity.
(vi) Examination of gully floor for vegetation colonization, and new incisions.
(vii) Examination of gully micro-catchments for sheet and rill erosion.

Although sediment samples were collected during field work, results of particle size analysis were inconclusive as an indicator of erosion and deposition. The technique shows different degrees of erosion on similar soils and moreover was found to be inappropriate in the catchment where there is a high degree of surface disturbances in the form of excavations for roads and buildings. The results from particle size analysis will therefore not be discussed further.

Technique 4: Final mapping of erosion and deposition.

Information from the 1985 aerial photographs and from gully profile surveys was used to plot erosion and deposition in the form of symbols, so that their exact position on the landscape could be ascertained. This method of mapping has been used in erosion studies such as those by Christianson (1981), Bergsma (1983), and Thwaites (1986). A resultant map is what is described as a morpho-conservation map (Rao, 1975; Morgan, 1980; Proffit, 1983). Morpho-conservation maps are used mainly for identifying problem areas in order to formulate a soil conservation strategy (Verstappen, 1983; Morgan, 1986). One advantage of this form of mapping is that the completed map shows all geomorphological forms in one diagram. The map shows (i) degradation features such as gullies, pipes, scarps and slump scars, (ii) aggradation features such as gully bottom fills, alluvial fans and terraces, and (iii) the hydrography of the catchment which includes the watershed, the drainage network, rills and flow lines. Morpho-conservation maps for 1961 and 1979 were drawn from the analysis of aerial photographs. These maps were drawn for purposes of comparison to the 1985 map, to show changes in erosion and deposition, indicating that problem areas identified for one time period may not necessarily be the same for another.

Technique 5: Sediment routing

Information from the 1985 erosion and deposition map, gully profile surveys and the geomorphological map was used to derive a qualitative sediment routing procedure. This was achieved by dividing the catchment into landform units as shown in Figure 10. Sediment sources, sinks and transport mechanisms were identified and described on each landform unit, starting from the watershed and progressing to Maqalika reservoir.

Technique 6: Sediment yield capability assessment

Based on the assumption that the recorded degree of erosion is not always equal, or directly proportional to the quantity of sediment supplied by a particular land surface, a procedure was formulated to assess each erosion unit in terms of its ability to produce, transport and deliver sediment to the reservoir. The procedure, adopted and modified from Coleman and Scatena (1986), Quantitatively evaluates and ranks the sediment yield capability of each erosion unit, indicating relative magnitudes but not the actual yield.

From the theory on sediment production and delivery discussed in Chapter 2, and observations made during the catchment survey, factors which probably affect sediment production and delivery are identified and listed in Table 12. These factors are used in the sediment yield capability assessment.

Data on some of the factors listed in Table 12 were obtained as readily available maps and tables, while some data were obtained from field observations and measurements. Catchment characteristics listed in Table 12 were identified on each erosion unit and recorded in catchment data forms (Appendix 6). These data were used in the sediment yield capability rating of each erosion unit. The influence of each of these factors shall not be reiterated here, however a brief explanation and justification follows as to why and how the factors were used in the assessment.

Table 12 Assessment factors used in the sediment yield capability rating.

Production factors	Transport factors
1. Soil erodibility	1. Topography
2. Vegetation	2. Transport capability
3. Construction level	3. Control measures
	4. Distance from reservoir

Erodibility in the present procedure is represented by factor - K (Wischemeir and Smith, 1978). Each soil series has been assigned a K value after detailed soil analyses by CDT (1979). The K values are listed in Table 7. From the assigned K values, the soils have further been grouped according to their relative erodibilities as follows; (i) highly erodible, (ii) slightly erodible, and (iii) relatively resistant (CDT, 1979; Rooyani, 1981).

Vegetation acts as a soil cover, therefore the type and areal extent determine the degree of protection. Areal extent is usually expressed as a percentage of the total area under study (Stocking, 1987). Percentage cover was very difficult to determine since large parts of the catchment comprise patchy vegetation due construction activity. Vegetation type which also influences erosion (Holy, 1980) was used as a surrogate for cover. It has been shown (Leopold, *et al.*, 1964) that erosion rates change drastically when forests and grasslands are changed into cropland. For the present procedure, the following vegetation categories were used; (i) woodlot and grassland with a well developed turf, (ii) cropland and grassland without a turf, and (iii) common weeds, or the complete absence of vegetation.

Construction level is used as a surrogate for the degree of surface disturbance. Land disturbance has a variety of components which range from the insidious presence of man on land, through grazing and cultivation, to large scale urban construction (Blaikie and Brookfield, 1987). Among the afore-mentioned activities, construction activity provides the greatest disturbance (Wolman, 1967; Walling and Gregory, 1970). In the present study area construction activity ranges from (i) no activity, (ii) on-going construction accompanied by vegetation removal, excavations and the exposure of sub-soil, and (iii) completion and stabilization of activity, followed by vegetation re-establishment.

Slope steepness has been used as a surrogate for topography. It has been shown (Holy, 1980; Morgan, 1986) that slope steepness is an important factor determining runoff and erosion. Moreover slope steepness and length have been used extensively in soil erosion prediction techniques such as the USLE and SLEMSA. Analysis of relief in this study area indicates abrupt changes in slope within short distances, implying discontinuous slopes and irregular topography. This form of relief coupled with the presence of buildings limit the effect of slope length, therefore slope steepness may be considered representative of topography. According to Schmitz (1984) slope values from 1^{o} to 4^{o}, and sometimes 5^{o} are persistent on planation surfaces. Slopes of 5^{o} to 10^{o} are dominant on accumulation glacis, with values of 10^{o} merging onto the foot of the debris slope which may be up to 34^{o}. These three slope classes were used in the assessment.

Transport capability is determined by the efficiency of the transporting agent which may be overland or channelized flow. Transport capability increases with the size of the channel and the degree of channelization (Leopold *et al.*, 1964; Morgan, 1986). Overland flow without any form of channelization is expected to provide a relatively low degree of transport when compared to flow within defined channels. The differences in channel size were used as surrogates for transport capability.

Control measures present in the study area are directed mainly to sediment transport rather than production. Common control measures include the construction of barriers within gullies in the form of stone-earth and loose-stone check dams, both of which are ineffective since they tend to collapse due to poor construction and lack of maintenance. Other methods of control include the dumping of old car bodies and other urban trash into gullies. This seems to be relatively efficient since it does not require any maintenance. The filling of gullies with loose sediment from construction sites is also ineffective since the sediment is readily entrained by flow.

Distance from reservoir is important to sediment delivery since the longer the distance of travel, the higher the probability that sediment will be deposited before reaching the reservoir (Walling,1983). Breaks in slope along the path of sediment encourage deposition and impede transport. The hypsographic curve of the study area shows a general break in slope along the 1600m contour, where general deposition is expected. Erosion units which lie between the reservoir and the 1600m contour were given a high rating, and those situated beyond the 1600m contour were given a lower rating.

Distance from mainstream determines whether the eroded sediment will be transported from its source to the channel network. Although this factor was considered in the initial stages of the assessment, it has been excluded in the final procedure because there are some sediment sources which deliver directly into the reservoir, or through gullies as opposed to the main channel. For instance part of the catchment which lies on the west of the reservoir is not drained by the main channel.

Each of the aforementioned factors was assigned three ratings depending on whether its effect was considered low, medium or high and each rating assigned a score of 0, 1 and 2 respectively as shown in Table 13.

AIM 4

To estimate sediment yield from the catchment, reservoir useful life and rate of surface lowering.

Technique 1: Reservoir sedimentation survey.

Sediment yield was determined from reservoir sedimentation survey data. Ritchie and McHenry (1985) suggest a number of possible survey methods. The present study employs a bathymmetric survey based on the methods described by Rausch and Heinemann (1968).

Table 13 Sediment source capability rating; assessment factors and rating procedure.

Factor	Rating and score High (2)	 Medium (1)	 Low (0)
Soil erodibility	Highly erodible K > 0,41	Slightly erodible 0,41 > K > 0,32	Relatively resistant K < 0,32
Vegetation	(i) No vegetation (ii) Common weeds	(i) Scrub (ii) Cropland (iii) Grassland with no turf.	(i) Woodlot (ii) Grassland with good turf. (iii) rockland
Construction level	(i) Ongoing construction of buildings and roads. (ii) Vegetation removal	Recent settlement but construction complete. Gardens not fenced, limited vegetation re-established.	Older settlement with no construction activity, or where construction has stabilized. Fenced gardens with vegetation re-established.
Topography	Steep 15^{o} and above	Undulating to rolling 5 - 15^{o}	Flat to gentle 0 - 5^{o}
Transport capability	Presence of (i) Stream (ii) Continuous gully (iii) Road running downslope with road drain.	(i) Road across slope (ii) road drain across slope (iii) Rills.	(i) Dam wall (ii) Discontinuous gully (iii) no channels
Control measures	Do not exist	Exist but relatively inefficient.	Appear to be effective
Distance from reservoir	Up to the 1600m contour	From the 1600m contour to watershed	Watershed

To evaluate each sediment source, the sum of scores on production is multiplied by the sum of scores on transportation. The resultant value is the magnitude of sediment capability. Possible capability ratings range from 0 to 48, and these have arbitrarily been grouped into four classes as follows.

0 - 10 Low
11 - 19 Moderate
20 - 29 High
30 - 48 Very high

Maqalika reservoir has not been surveyed since construction, hence all survey beacons were new. A survey baseline was located along the western bank and beacons were sighted and fixed using a theodolite. The extreme ends of the baseline were marked with waterproof paint. The northern end was designated as zero point and was in line with the dam wall. The reference distance points were located by theodolite and marked with steel pegs. A gauge board on the drawoff tower within the reservoir was used as a reference point so that fluctuations in water levels could be monitored and depth readings be adjusted accordingly throughout the survey.

In order to locate points for bottom sounding, a thin nylon rope graduated at 10m intervals was winched across each range between the end points until fully taut. Depth readings were taken from a boat moving along the rope from one embankment ot the other, and at right angles to the baseline. Depth was determined at 10 metre intervals using an aluminium cable marked for length and fixed with a weight at the end. The water level remained constant throughout the survey. A new contour map of the reservoir was constructed from the survey data. One limitation of the survey which could affect the results is that the nylon rope used in locating soundings was possibly stretchable. It was noted during the survey that the stretch problem was more pronounced when the range was long, about 300m or more. Since the reference distance points were located by theodolite, it was realized that distance (widths) obtained using the nylon rope fell slightly shorter than the actual distances due to rope stretch. This occurred mainly on the widest section of the reservoir which had a maximum stretch of 1,5%. It was assumed that stretch occurred equally along the full length of the rope, and hence stretch factor was calculated using the equation:-

$$S = \frac{AD * NRD}{AD} * 100 \qquad \text{Eq. 1}$$

where S = Rope Stretch (%)

AD = Actual distance (m)

NRD = Nylon rope distance (m).

Therefore the actual mapped interval is not exactly 10m but 10m X S. Other limitations of the survey are discussed in the section on relevance and limitations of the methods used.

There is another sediment input into the Maqalika reservoir through Sebaboleng dam (Figure 6). The quantity of sediment input entering Maqalika reservoir through this route has been estimated through the use of sediment and water discharge at Sebaboleng overflow. Overflow occurs during the summer months only, and on a few days of the month. The yearly totals of estimated sediment yield were summed to give a value for five years. The estimation of sediment from Sebaboleng reservoir also has some limitations. The estimated yield value assumes that sediment concentrations at the time of sampling are representative of the day each sample was taken, and that the observed overflow at the time of measurement was representative of the whole day.

Technique 2: Computation of capacity

The present capacity of the reservoir was computed using the area depth integration method described by Linsley and Franzini (1972). The volume of the reservoir was computed as the summation of storages at different elevations. Storage between two elevations is determined by multiplying the average of two consecutive areas by the elevation difference. The area between each pair of contours is determined by counting squares of known area within the contours. The area depth integration method is summarised in Equation 2 (Chakela, 1981).

$$V = \sum_{n}^{n-1} 0.5h\,[Ai + A(i+1)] + (AL * DL) \qquad \text{Eq. 2}$$

where V = Total volume of reservoir (m^3)

Ai = Surface area of reservoir enclosed by contour 1 (m^2)

h = Contour interval (m)

AL = Area of reservoir at lowest contour (m^2)

DL = Mean depth below lowest contour (m).

Capacity loss was determined as the difference between original capacity and present capacity. The capacity loss value is equal to the volume of sediment deposited in the reservoir.

To determine the volume of sediment coming from the study catchment, the volume coming from Sebaboleng was subtracted from the total deposited volume. The resultant value was then used to compute total sediment yield from the catchment using the trap efficiency value of 99.9% obtained from Heinemann's (1981) trap efficiency curve, Figure 25.

Computation of reservoir lifespan was carried out using the capacity loss value which combines all sediment inputs into Maqalika reservoir since all inputs contribute to the general loss of capacity.

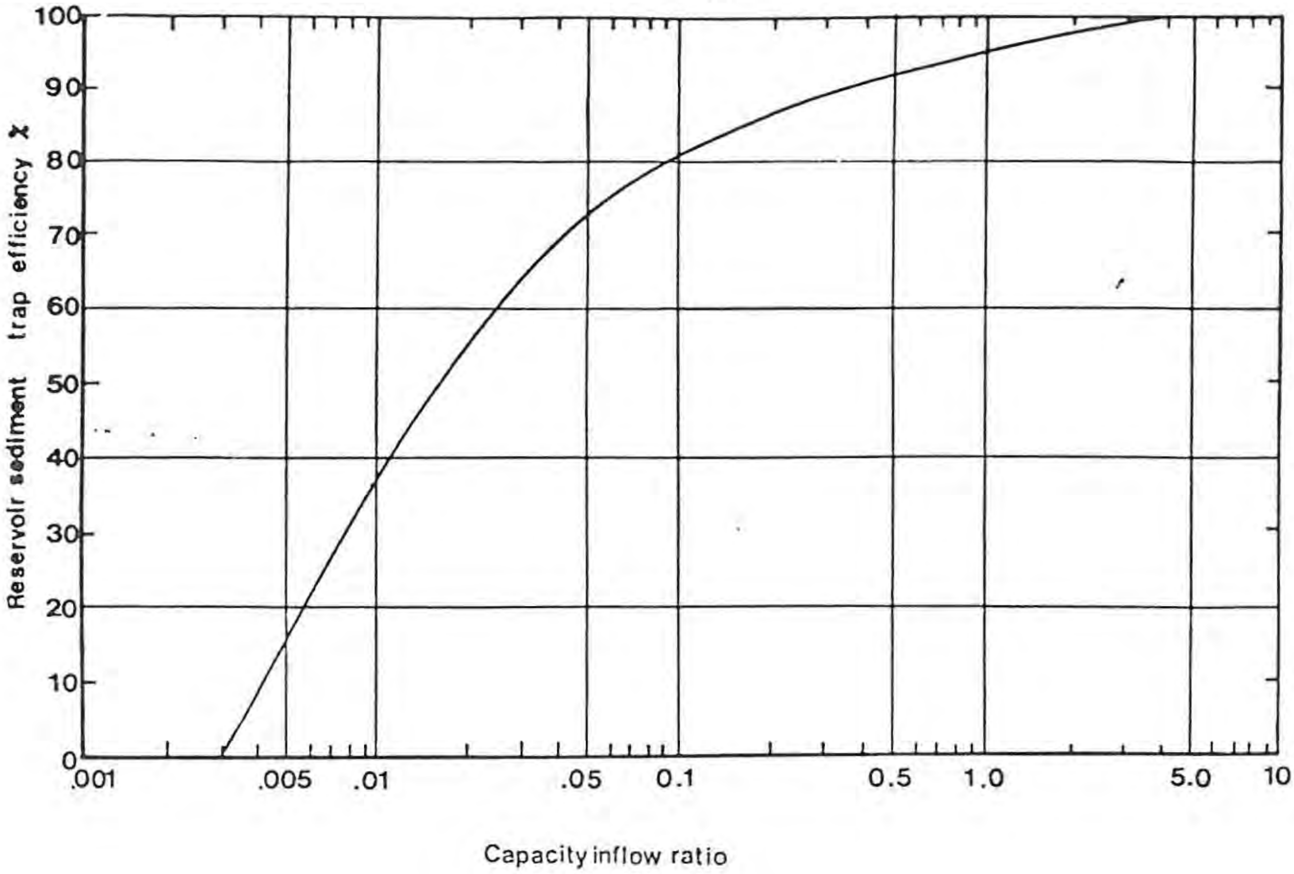

Figure 25 Heinemanns (1981) trap efficiency curve.

Technique 3: Computation of sediment bulk density.

To express sediment volume as sediment mass, the bulk density of sediment must be known. Two methods are available for determining bulk density. The first is by direct sampling of sediments, the second is an estimation from particle size distribution and reservoir operation factors. Due to sampling problems associated with the first method this study used an estimate following the second method as described below. The method employs the Lane and Koelzer (1953) equation modified according to Miller (1953).

$$W = W1 + 0,4343\,K\left[\left(\frac{T}{T-1}\right)\ln T - 1\right] \qquad \text{Eq. 3}$$

where W - Average bulk density

W1 - Initial bulk density

T - Time elapsed since initial deposition

K - Constant (Compaction factor).

Values of W1 and K are given for sand, silt and clay under different conditions of reservoir operation in Table 14. This method of bulk density determination has been successfully used by researchers such as Gill (1979), Ward (1980) and Braune (1983). In order to be able to use Equation 3 the particle size distribution of sediment must be known. Sediment samples were collected from the reservoir floor using a gravity corer (Axelsson and Hakanson, 1972). Particle size distribution was determined in the laboratory using the pipette method (British Standards Institution, 1978) described in Appendix 7.

Table 14 Values W1 and K used for bulk density determination (Strand, 1974).

	Clay		Silt		Sand	
Reservoir operation	Wc	Kc	Wz	Kz	Ws	Ks
1. Reservoir always submerged or nearly submerged.	26	16,0	70	5,7	97	0
2. Normal or moderate drawdown.	35	8,4	71	1,8	97	0
3. Reservoir normally empty.	40	0	72	0	97	0

With the computed bulk density value, sediment volume was converted to sediment mass and expressed as sediment yield in tons per hectare per year ($t.h^{-1}.yr^{-1}$) by dividing by the catchment area and the age of the reservoir.

Technique 3: Determination of reservoir lifespan.

The reservoir lifespan was determined by computing the time required to fill the reservoir, while the useful life was determined by computing the total time required to fill the critical storage. According to Brown (1950), the critical storage is equal to half the original capacity since most reservoirs have to be supplemented or replaced by the time they have lost about 50% of their storage. The lifespan of the reservoir was determined by dividing initial capacity by the computed volume of sediment trapped in the reservoir.

Construction of a water supply reservoir is a response to a certain need of the society, such as the need for reticulated water, or increases in water demand due to population increases and urbanization. During reservoir construction money and labour are vested in the project with the ultimate goals being some social and economic benefits. The proper functioning of the reservoir determines the socio-economic benefits provided by the reservoir, hence capacity loss must be checked in order to maintain the function of the reservoir.

Technique 4: To determine the rate of surface lowering.

To estimate the rate of catchment surface lowering, the computed sediment yield value was expressed as soil loss using bulk density of catchment soils which differs from that of reservoir sediment. The catchment bulk density was estimated by determining the average bulk density of different soils present in the catchment. Bulk density values of each soil series are given in Table 7 (CDT, 1979). A weighted average value of 1,7g.cm^3 was obtained, taking into consideration the fact that the soils are not uniformly distributed. The rate of surface lowering in the catchment is closely related to the rate of loss of top soil, which affects soil productivity. Kirkby (1980a) identifies loss of soil productivity as one component of socio-economic loss.

AIM 5

To describe the socio-economic implications of erosion and sedimentation in the Maqalika catchment.

Although a number of methods exist for measuring and determining social and economic costs of soil erosion and deposition (Swanson, 1979; Bojo, 1986; Stocking, 1987), these techniques were not applied in the present study due to time and resource limitations. Thus a quantitative description of socio-economic consequences of erosion and deposition in the Maqalika catchment was not obtained. A qualitative description may be given based on the observations made during field work. Some of the erosion and deposition problems listed in Chapter 2 (Table 4) do occur in the Maqalika catchment and were noted during the field study.

RELEVANCE AND LIMITATION OF METHODS EMPLOYED.

In the present study a catchment was used as a study area. Catchments are suitable as study units with readily identifiable physical boundaries that offer an opportunity for quantification (Irwin and Williams, 1986). Moreover catchments are easily identifiable on maps and aerial photographs. Processes like erosion and deposition are easier to record in well defined boundaries (Christianson, 1981). Inputs and outputs can be measured. In the present study the output of interest, sediment yield was measured at the catchment outlet. Computation of minimum (conservative) rates of erosion was possible. Computed rates of erosion are considered minimum because there are large quantities of eroded soil that do not reach the catchment outlet.

A problem of quantification arises when there is a second source of sediment (input) as is the case in Maqalika reservoir. This input was found to be minor, 1% of the total volume of sediment deposited in the reservoir. Quantification of sediment input from Sebaboleng reservoir was a limitation to the survey because the determined value is obtained from sample data at the point of outflow. The reliability and representativeness of these data are debatable. The estimated value of sediment assumes that measurements recorded at the time of sampling are representative of the day the sample was taken.

The concept of trap efficiency is based on the assumption that not all sediment delivered to the reservoir is trapped. The trap efficiency value (Heinemann, 1981) described earlier and used in this project does not take into account sediment lost through drawoff and consumption water. The rate of drawoff differs from one reservoir to another, and so does the concentration of dissolved and suspended loads. As is common to many other studies their quantity of sediment is omitted in sediment yield computations. The estimated values of sediment yield is therefore somehow lower than the true value.

The presence of a reservoir in a catchment provides an invaluable tool for estimating long term sediment yield. There is no need to take sediment samples at the catchment outlet. Bathymmetric surveys are recommended by the U.S. soil conservation service since the surveys require only sample measuring equipment. This method has been used in Lesotho by Chakela (1980 and 1981), and Ntsiki and Mokone (1986).

The relevance of the catchment survey is highlighted by the concept of sediment delivery ratio, which reveals that sediment yield is only a portion of total erosion. Christianson (1981) notes that the measurement of sediment yield is not sufficient for understanding the significance of erosion. Knowing where the sediment comes from is just as important as knowing the quantity that comes out of the catchment.

Aerial photo interpretation has been found to be an invaluable tool for reconstructing past activity, and observing present activity and conditions. Areal photo interpretation covers large areas within a short period of time, and within reasonable financial resources (Morgan, 1986). Field observation as a method of groundtruthing is an integral part of erosion research hence it was necessary to include some field investigations in this study. A possible limitation of sequential aerial photo interpretation as a technique for the reconstruction of past erosion history is due to the effect of seasonal vegetation changes. Aerial photography of 1979 and 1985 was taken in summer while that of 1961 was taken in winter. It should be expected that summer photography should show more vegetation and hence less erosion than the winter photography. If there is any error in interpretation, it should be an underestimation of the degree and extent of erosion on the 1979 and 1985 photography.

On the question of representativeness, the description of catchment characteristics and urban land use given earlier is probably applicable to large parts of the residential urban areas of Maseru. Although there are certain minor differences in soils, the present catchment may be viewed as representative of large residential areas growing on the peri-urban areas of Maseru.

CHAPTER FIVE

RESULTS

This chapter presents results obtained from field and laboratory data analysis. The chapter has been divided into four sections, each relating to one of the study aims outlined in Chapters 1 and 4.

EROSION AND LAND USE HISTORY.

EROSION CHANGES 1961 TO 1979 AND 1979 TO 1985.

Figures 19, 20 and 21 are erosion maps for 1961, 1979 and 1985 respectively. The areal extent of each erosion class at each date is presented in Table 15 and Figure 26. Changes in extent are presented in Table 16 and Figure 27.

Table 15 The areal extent of each erosion class at each date.

	Date and areal extent					
	1961		1979		1985	
Erosion class	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
1	0,60	5,4	0,66	6,0	0,32	2,9
2	3,55	32,2	1,78	16,1	1,92	17,4
3	3,00	27,2	3,20	29,0	3,12	28,3
4	0,70	6,3	1,74	15,8	0,93	8,4
5	1,31	11,9	1,26	11,4	1,60	14,5
6	1,88	17,0	2,40	21,7	3,15	28.5

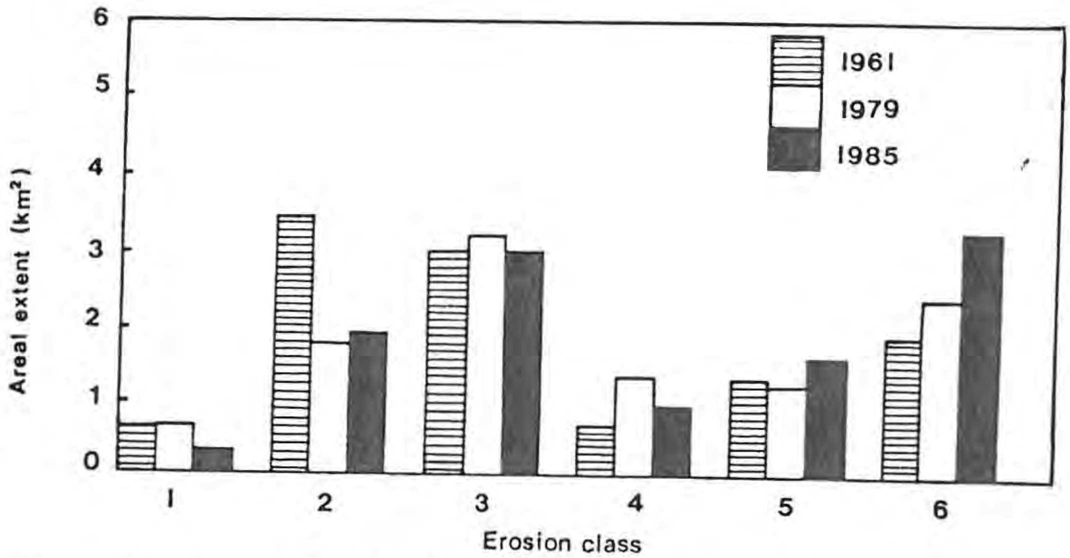

Figure 26 Areal extent of each erosion class at each date.

There has been a general change in erosion status throughout the period of study, however, the pattern of change varies between the two periods 1961 to 1979 (period A), and 1979 to 1985 (period B). During period A the most notable changes were the decrease in erosion class 2 (sheet erosion without rilling) and an increase in erosion class 4 (severe sheet and rill erosion). During period B significant changes were decreases in erosion class 1 (no erosion) and class 4 (severe sheet and rill erosion without gullying), and increases in both class 5 (gully network extension) and class 6 (gully network incision).

Table 16 Erosion changes in period A (1961-1979) and period B (1979-1985).

	A		B	
Erosion class	Area km^2	%	Area km^2	%
1	+0,06	+0,5	-0,34	-3,1
2	-1,77	-16,1	+0,14	+1,3
3	+0,10	+1,5	-0,08	-0,7
4	+1,04	+9,5	-0,81	-7,4
5	-0,05	-0,5	+0,34	+3,1
6	+0,52	+4,7	+0,75	+6,8

The positive and negative signs indicate increases and decreases respectively.

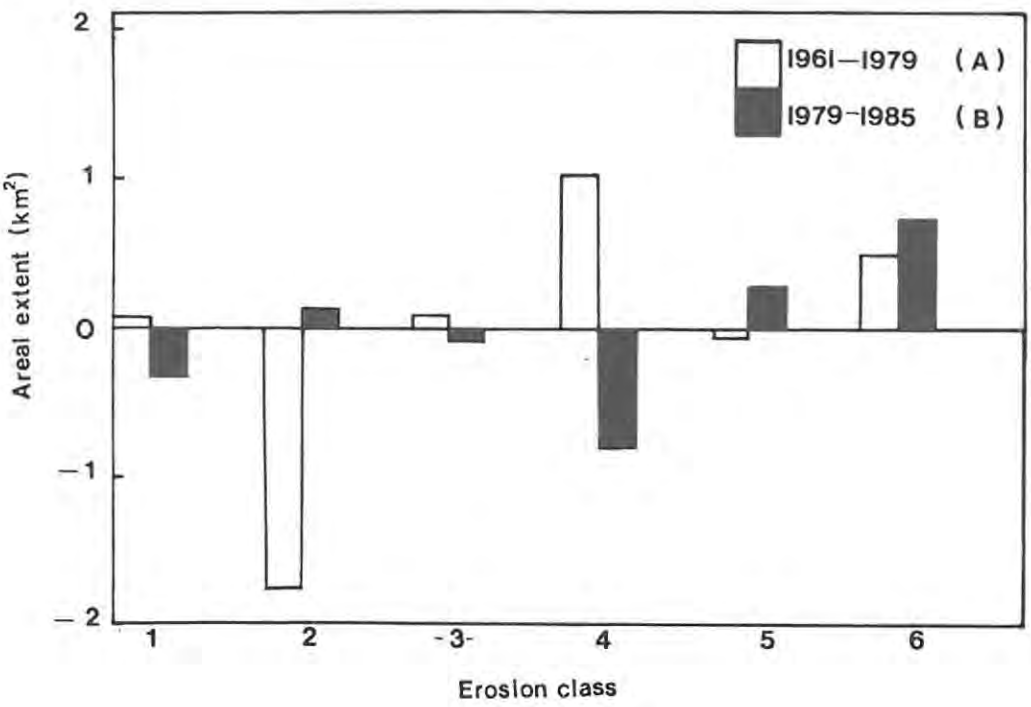

Figure 27 Changes in erosion status, period A amd period B.

Absolute changes in the areal extent of each erosion class do not mean much if they are not interpreted in terms of where they occur on the landscape. During period A, major changes occurred in the valley bottom where intergully areas changed from erosion class 2, (slight sheet erosion), to classes 3 and 4 (severe sheet and rill erosion). Other changes were in the valley branches where the gully network became progressively incised. During period B major changes were also in the valley branches where there were increases in both gully network extension and incision and a subsequent decrease in severe sheet and rill erosion. This implies that due to the progress of erosion, land areas which exhibited severe sheet and rill erosion became gradually incised to the point of being classified as gully erosion.

LAND USE CHANGES 1961 TO 1979, AND BETWEEN 1979 TO 1985.

Figures 22, 23 and 24 are land use maps of 1961, 1979 and 1985 respectively. The areal distribution of each land use category is presented in Table 17 and Figure 28. Abbreviations for land use categories listed in Table 17 and are explained in Chapter 4.

Table 17 Areal extent of each land use category in each year of study.

	1961		1979		1985	
Land use	Area (km^2)	%	Area (km^2)	%	Area (km^2)	%
C	5,04	45,7	4,70	42,6	1,80	16,3
G	3,37	30,5	2,10	19,0	2,82	25,6
LDH	2,31	20,9	1,80	16,3	2,50	22,6
MDH	0,0	0,0	1,42	12,9	2,40	21,7
HDH	0,0	0,0	0,70	6,3	1,20	10,9
A/s	0,32	2,9	0,32	2,9	0,32	2,9

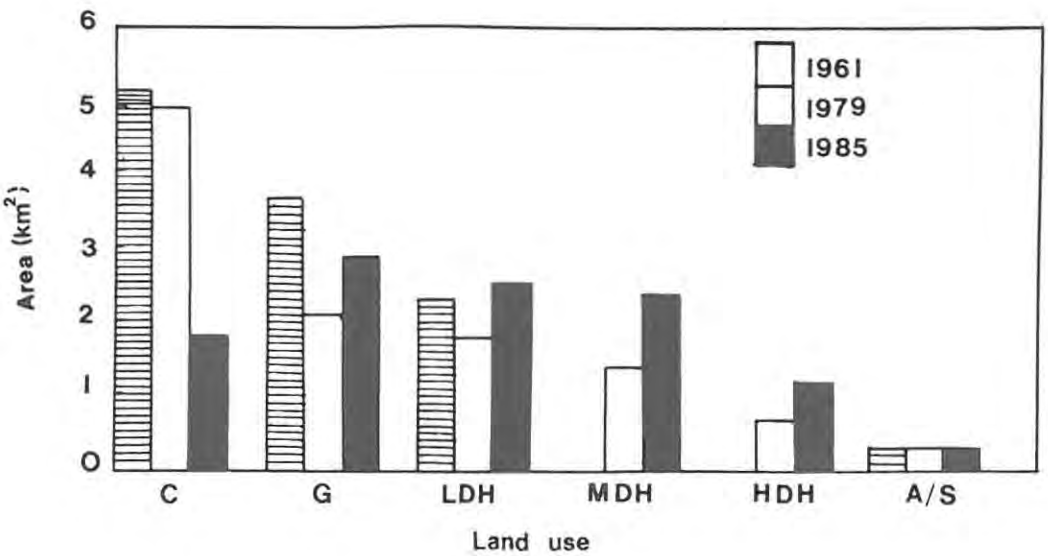

Figure 28 The areal extent of each land use category, at each date.

Table 18 Changes in land use.

Land use	Period A Area	Period A %	Period B Area	Period B %
C	-0,34	-3,0	-2,90	-26,1
G	-1,27	-11,5	+0,72	+6,4
LDH	-0,51	-4,6	+0,70	+6,3
MDH	+1,42	+12,9	+0,98	+8,9
HDH	+0,70	+6,3	+0,50	+4,5
A/s	0,0	0,0	0,0	0,0

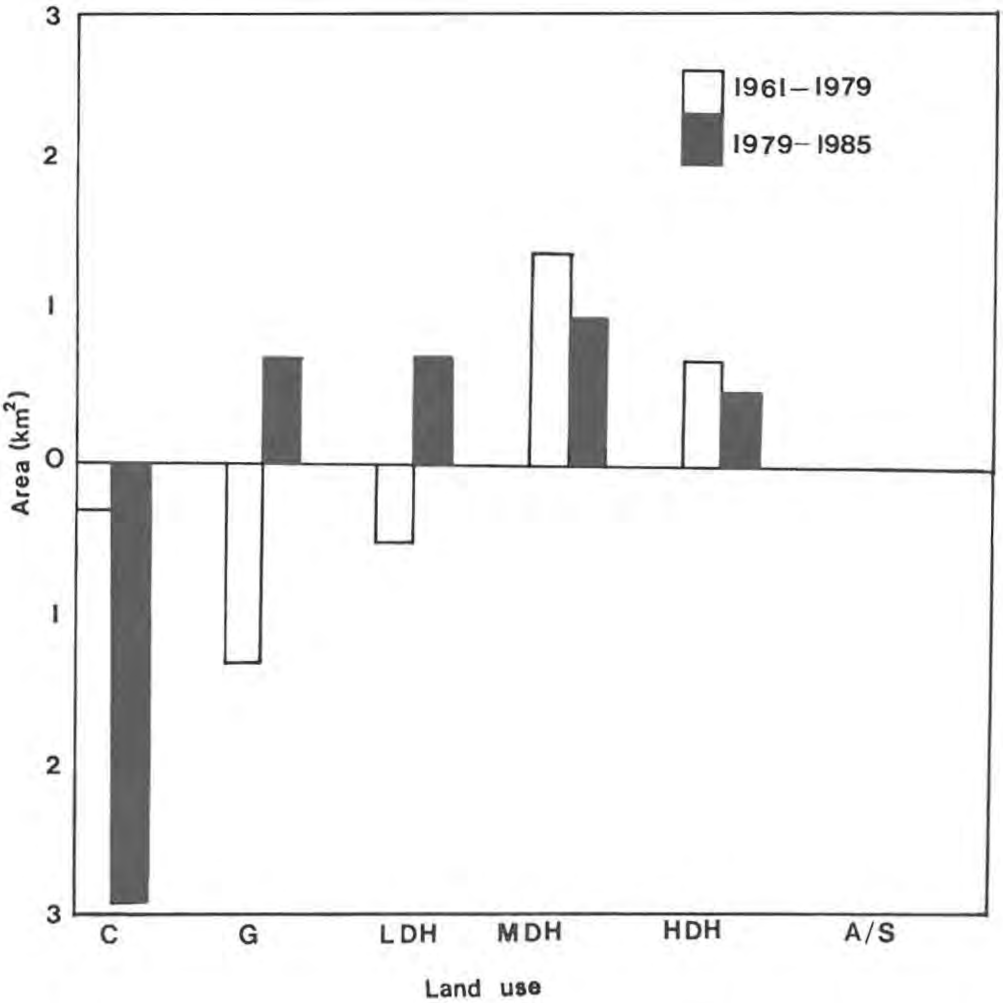

Figure 29 Changes in land use, period A and period B.

Major changes recorded during period A include the establishment of medium and high density settlement and decreases in grazing land and low density housing. Most of these changes occurred in the valley bottom which was hardly settled in 1961. Cropland on the planation surfaces and on top of the escarpment had changed little. There were no changes to the airport and sports grounds. Major changes in period B were the decrease in cropland from 4,7 km^2 to 1,8 km^2. There have been increases in all other forms of land use save for cropland, the airport and sports ground. As in period A these changes also occurred in the valley bottom where some of the former cropland was converted to housing land and some was abandoned. Former traditional settlements did not change much during this period, but remained as low density housing. Grazing land increased as a result of abandoned cropland.

THE DISTRIBUTION OF EROSION ON EACH LAND USE CLASS.

In order to relate erosion distribution to land use, the areal extent of the observed erosion class on each land use category was determined for the dates under study. These areas are recorded in Tables 19, 20 and 21, while the distribution is shown in Figures 30 to 35.

Table 19 Distribution of erosion on each land use category (1961).

Erosion class		1	2	3	4	5	6	Total
Land use								
C	(km^2)	0,28	2,60	1,70	0,14	0,18	0,14	5,04
	%	5,5	51,6	33,7	2,8	3,6	2,8	
G	(km^2)	0,0	0,68	0,56	0,20	0,45	1,48	3,37
	%	0,0	20,2	16,6	5,9	13,4	43,9	
LDH	(km^2)	0,0	0,27	0,74	0,36	0,68	0,26	2,31
	%	0,0	11,7	32,0	15,6	29,4	11,3	
MDH	(km^2)	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	%	0,0	0,0	0,0	0,0	0,0	0,0	
HDH	(km^2)	0,0	0,0	0,0	0,0	0,0	0,0	0,0
	%	0,0	0,0	0,0	0,0	0,0	0,0	
A/s	(km^2)	0,32	0,0	0,0	0,0	0,0	0,0	0,32
	%	100,0	0,0	0,0	0,0	0,0	0,0	
								11,04

Table 20 The distribution of erosion on each land use category (1979).

Erosion class		1	2	3	4	5	6	Total
Land use								
C	(km^2)	0,34	1,59	1,31	0,88	0,44	0,14	4,70
	%	7,2	33,8	27,8	18,9	9,4	3,0	
G	(km^2)	0,0	0,04	0,57	0,27	0,41	0,81	2,10
	%	0,0	1,9	27,1	12,9	19,5	38,6	
LDH	(km^2)	0,0	0,14	0,57	0,46	0,10	0,53	1,80
	%	0,0	7,8	31,7	25,6	5,5	29,4	
MDH	(km^2)	0,0	0,01	0,10	0,13	0,31	0,87	1,42
	%	0,0	0,7	7,0	9,2	21,8	61,3	
HDH	(km^2)	0,0	0,0	0,65	0,0	0,0	0,05	0,70
	%	0,0	0,0	92,9	0,0	0,0	7,1	
A/s	(km^2)	0,32	0,0	0,0	0,0	0,0	0,0	0,32
	%	100,0	0,0	0,0	0,0	0,0	0,0	
								11,04

Table 21 The distribution of erosion on each land use category (1985).

Erosion class		1	2	3	4	5	6	Total
Land use								
C	(km^2)	0,0	1,68	0,05	0,0	0,07	0,0	1,80
	%	0,0	93,3	2,8	0,0	3,9	0,0	
G	(km^2)	0,0	0,09	0,34	0,73	0,71	0,95	2,82
	%	0,0	3,2	12,0	25,9	25,2	33,7	
LDH	(km^2)	0,0	0,02	0,92	0,05	0,41	1,1	2,50
	%	0,0	0,8	36,8	2,0	16,4	44,0	
MDH	(km^2)	0,0	0,00	1,25	0,09	0,39	0,67	2,40
	%	0,0	0,0	52,1	3,70	16,3	27,9	
HDH	(km^2)	0,0	0,13	0,56	0,06	0,02	0,43	1,20
	%	0,0	10,8	46,17	5,0	1,7	35,8	
A/s	(km^2)	0,32	0,0	0,0	0,0	0,0	0,0	0,32
	%	100,0	0,0	0,0	0,0	0,0	0,0	
								11,04

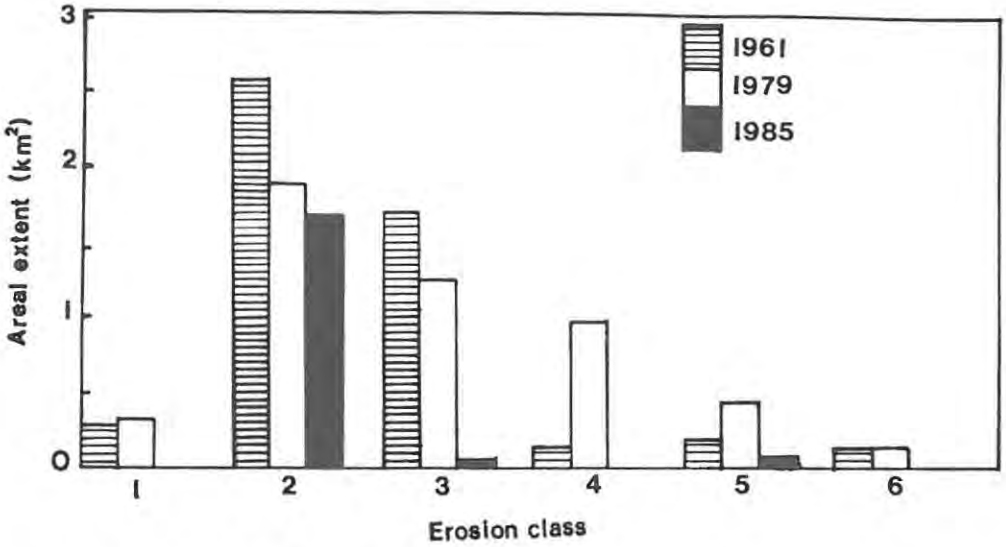

Figure 30 Distribution of erosion on cropland.

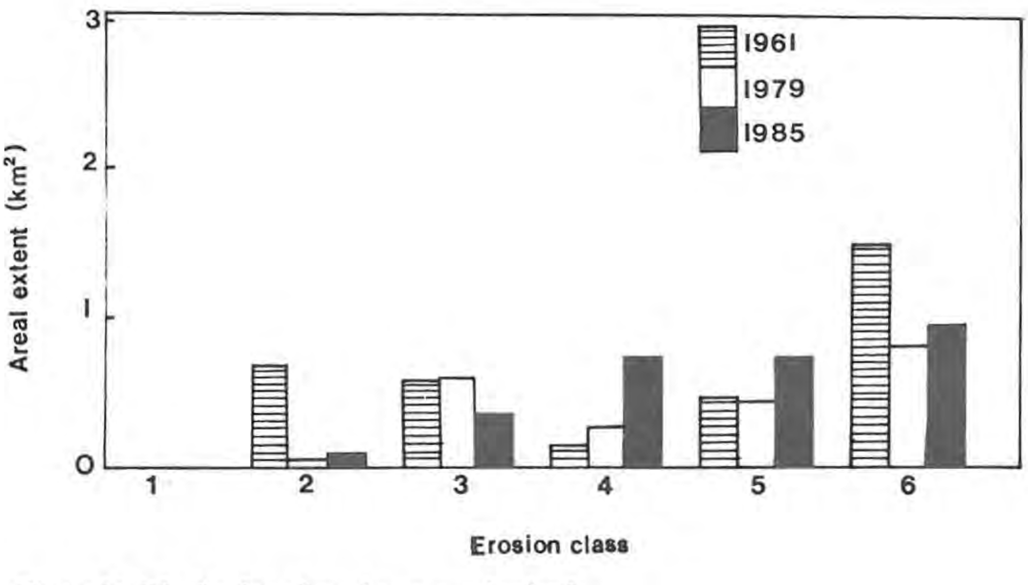

Figure 31 Distribution of erosion on grazing land.

In 1961 the most extensive form of land use was cropland which accounted for 45,6% of the catchment, or 5,04km^2. Out of the total crop land, 56,7% was subjected to slight sheet erosion and 33,5% was subjected to severe sheet erosion and slight rill erosion. Gullied cropland accounted for relatively smaller percentages. Grazing land which accounted for 3,37km^2 or 30,5% of the catchment was dominated by gully network incision, class 6 erosion, which was evident in 43,9% of total grazing land. Low density housing accounted for 2,31km^2 or 20,9% of the total catchment and was dominated by severe sheet erosion and slight rill erosion and gully network extension which are classes 3 and 5 respectively. These classes occupied 32,0% and 29,4% of the total medium density housing respectively. Medium and high density settlements were not present in 1961 and the airport and sports grounds were 100% uneroded.

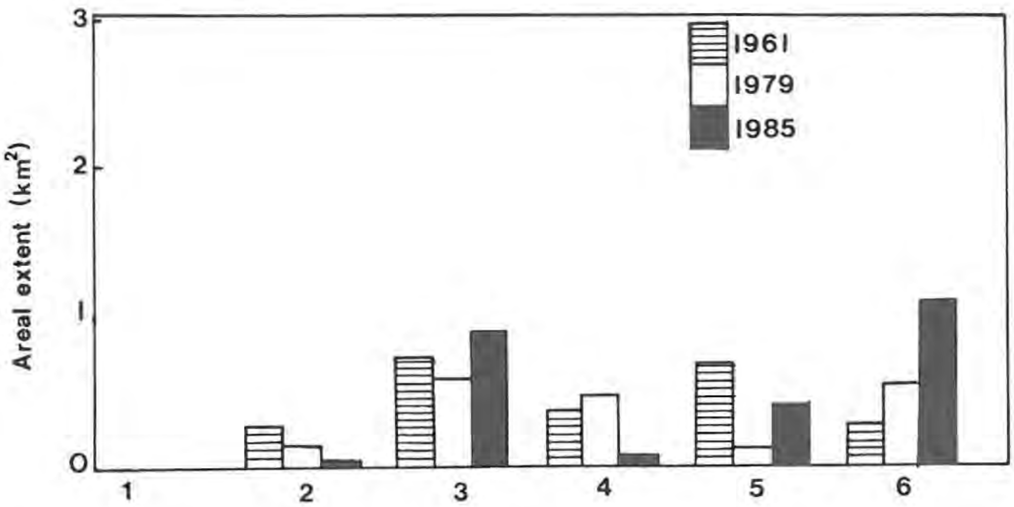

Figure 32 Distribution of erosion on low density housing areas.

In 1979 cropland still dominated and was observed on 42,6% of the total catchment. The percentage of slight rill erosion (class 2), and severe sheet erosion and slight rill erosion (class 3), classes 2 and 3 decreased with a subsequent increase in severe sheet erosion and rill erosion (class 4), and gully network extension (class 5). A major change on grazing land was the reduction of erosion class 2, and subsequent increases in classes 3, 4 and 5. A close examination and comparison of the 1961 erosion and land use maps (Figures 19 and 22), and the 1979 erosion and land use maps (Figures 20 and 23) show that class 2 grazing land was taken up by medium density housing, which did not exist in 1961. Erosion distribution on low density housing changed appreciably between 1961 and 1979. In 1961 low density housing was dominated by class 3 erosion, severe sheet erosion and slight rill erosion. Gully network extension, class 5, was also considerable. In 1979 low density housing was dominated by class 3 and class 6 erosion. Medium density housing was dominated by class 6 erosion while high density housing was dominated by class 3 erosion.

In 1985 the most extensive land use was grazing, which accounted for 25,5% of the catchment area. Grazing land was dominated by classes 4, 5 and 6. Low density housing accounted for 22,6% of the catchment and exhibited more class 6 erosion than any other land use.

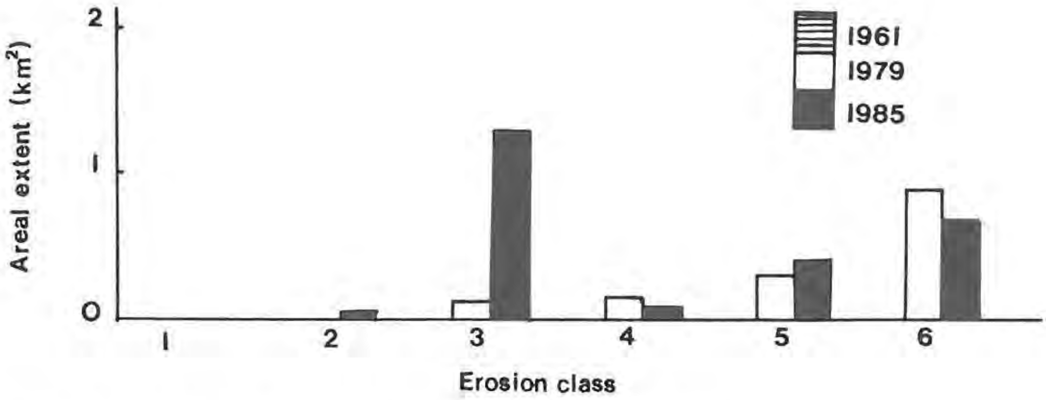

Figure 33 Distribution of erosion on medium density housing areas.

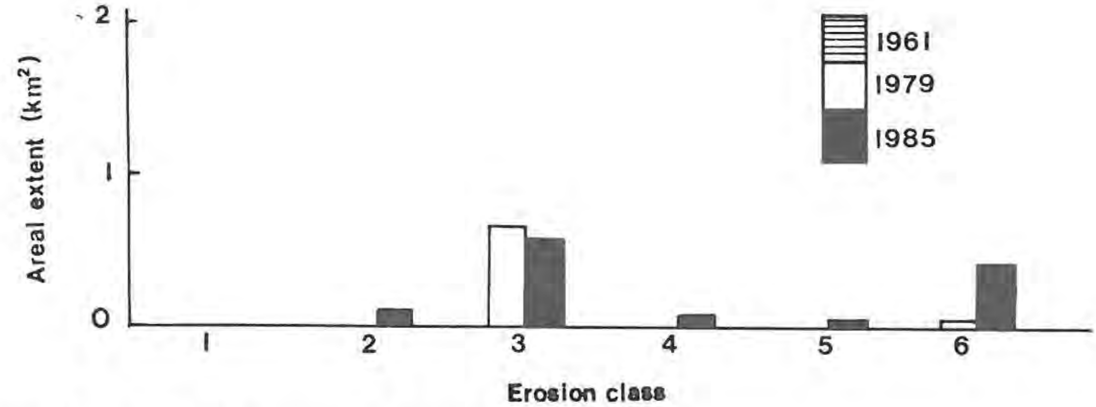

Figure 34 Distribution of erosion on high density housing areas.

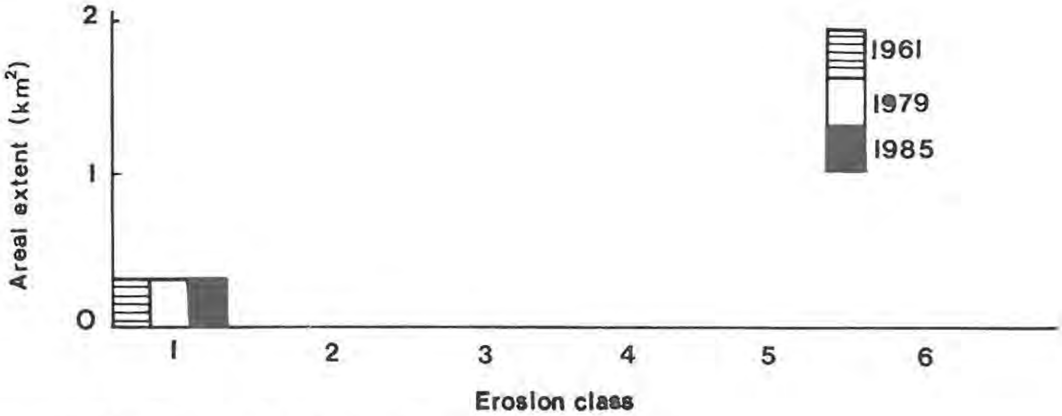

Figure 35 Distribution of erosion on airport and sports grounds.

FACTORS AFFECTING EROSION

Data matrices prepared for the non-parametric hand factor analysis are presented in Appendix 5. The present section presents results from the factor analysis for each date under study. Results for 1961, 1979 and 1985 are presented in Tables 20, 21 and 22 respectively. From the factor analysis it has been possible to determine the scores of erosion classes on each of the derived factors. These scores indicate the degree of magnitude of effect that each derived factor has on any one erosion class. This information is given in Table 23. It was also possible to determine the loadings of individual catchment characteristics on each of the derived factors. The loadings indicate the importance of each catchment characteristic on the unknown factor. These results are presented in Tables 22, 23 and 24 for the years under study. Each analysis is followed by a number of observations which are made after each unknown trial factor has been derived and isolated. From cursory examinations of all the data matrices and results, one notes several patterns of erosion distribution influenced by individual catchment characteristics. These patterns change from year to year indicating influences of those catchment characteristics subject to change.

HAND FACTOR ANALYSIS ON THE 1961 DATA: OBSERVATIONS.

The data matrix (Appendix 5) consists of 6 columns representing erosion classes and 16 rows representing catchment characteristics under study. After being subjected to the hand factor analysis (Appendix 4) the data matrix yields results which are presented in Table 22. An examination of Table 22 shows that the dominant erosion classes are 2, 3 and 6. This distribution is shown in row 1To which is considered representative of all rows 1 to 16. From the observed dominant distribution, one can describe the 1961 catchment conditions as dominated by severe sheet erosion, slight rill erosion and gully network incision. The principle of the hand factor analysis is based on the fact that the observed erosion distribution is not only the result of any one catchment characteristic individually but a combination of characteristics whose intercorrelation form an unknown factor which is the first trial factor.

The first trial factor

The first trial factor is responsible for an erosion distribution dominated by slight and severe sheet erosion, slight rill and severe gully erosion. This unknown factor is completely positively associated with the following catchment characteristics:

(i) Cropland
(ii) Low road density
(iii) High erodibility
(iv) Low slope class
(v) Moderate slope class
(vi) Red beds.

There are no apparent negative associations with any of the variables. If such an association exists, it is probably masked by other intercorrelations not yet observed. The first trial factor agrees with 69 out of a total of 96 cells.

Second trial factor

A second trial factor is responsible for the distribution presented in row 2To which is dominated by severe sheet and rill erosion without gullying, classes 3 and 4. This factor is completely positively associated with the following catchment characteristics.

(i) Low density housing
(ii) Medium road density
(iii) High road density
(iv) High slope class.

No negative associations have been observed and the factor agrees with 44 out of 60 cells.

Third trial factor

The trial factor is responsible for the distribution shown in row 3To which is dominated by slight sheet and rill erosion, or no erosion at all. This factor is completely positively associated with the following catchment characteristics.

(i) Low erodibility
(ii) Clarens geological formation.

Table 22 Factor analysis results (1961).

		EROSION CLASS FREQUENCY															
	Factor	1	2	3	4	5	6	1To	1F	2To	2F	3To	3T1	3F	4To		5To
	C	-	/	/	-	-	/	+6	F	-	-	-	-	+4	-		+4
	G	-	/	/	-	/	-	+4		3		+4	+5	-	+4	+4	
LANDUSE	LDH	-	-	/	/	-	-	3		+6	F	-	-	-	-		
	MDH	NOT APPLICABLE						-	-	-	-	-	-	-	-		
	HDH	NOT APPLICABLE						-	-	-	-	-	-	-	-		
	A/s	/	-	-	-	-	-	3		3		+4	3	-	-4		+4
ROAD	LOW	-	/	/	-	-	/	+6	F	-	-	-	-	-	-		
DENSITY	MED	-	-	/	/	-	-	3		+6	F	-	-	-	-		
	HIGH	-	-	/	/	-	-	3		+6	F	-	-	-	-		
ERODI-	LOW	/	/	/	-	-	-	+4		3		+6	+5	F	-		
BILITY	MED	-	-	/	-	/	/	3		3		-4	3	-	+6	F	-
	HIGH	-	/	/	-	-		+6	F	-	-	-	-	-	-		
SLOPE	LOW	-	/	/	-	-	/	+6	F	-	-	-	-	-	-		
CLASS	MED	-	/	/	-	-	/	+6	F	-	-	-	-	-	-		
	HIGH	-	-	/	/	-	-	3		+6	F	-	-	-	-		
	MOLTENO	-	-	/	/	-		3		+5		-5	-	-	+4		+4
GEO-	RED BEDS	-	/	/	-	-		+6	F	-	-	-	-	-	-		
OLGY	CLARENS	/	/	/	-	-	-	+4		3		+6	F	F	-		
	1To	3	9	15	5	2	8	69		44		29			18		16
	2To	3	3	9	5	2	2										
	3To	3	3	5	1	2	2										
	3T1	5	3	3	2	3	0										
	4To	1	3	3	1	2	2										
	5To	1	2	2	1	1	1										
							Total 96 cells										

Porportion of variability exlained by each trial factor.

Trial factor	1	-	69	-	39,2%
Trial factor	2	-	44	-	25,0%
Trial factor	3	-	29	-	16,5%
Trial factor	4	-	18	-	10,2%
Trial factor	5	-	16	-	9,1%

Key to Tables 22, 23 and 24.

Rows 1To to nTo = summaries of data given in rows 1 to 16, showing the erosion distribution determined by the 1st to nth trial factor respectively.

Columns 1To to nTo = summaries of the number of times each catchment characteristic agrees with the 1st to nth trial factor.

Columns 1F to NF = each determines whether the catchment characteristic under study loads significantly on the 1st to Nth trial factor.

C = Cropland
G = Grazing land
LDH = Low Density Housing
MDH = Medium Density Housing
HDH = High Density Housing
A/s = Airport and Sports field.

Fourth trial factor

The trial factor is responsible for the distribution shown in row 4To which is dominated by severe sheet erosion with slight rill erosion, gully network extensions and gully network incision. This factor is completely positively associated with moderated erodibility only.

Fifth trial factor

This factor is unexplained since it does not appear to be associated with any of the listed catchment characteristics. It is highly probable that there are other catchment characteristics which promote erosion, but which are not included in the analysis. These factors may play an important role in determining the distribution of erosion in the catchment. Factors such as footpath density which could be high on low road density areas, and stock densities could be responsible for some of the observed distributions.

Table 25 gives the percentage explanation to the observed erosion distribution that each trial factor is responsible for. As expected, the first trial factor explains a large percentage of the distribution.

Results for 1979 and 1985 were obtained in the same way as in 1961. These results are*summarised in Table 25 which lists catchment characteristics which load significantly on each trial factor at each date.

Table 23 Factor analysis results (1979).

		EROSION CLASS FREQUENCY														
	Factor	1	2	3	4	5	6	1To	1F	2To	2F	3To	3F	4To	4F	5TO
LAND USE	C	-	/	/	/	-	-	-5		+6	F	-	-	-	-	-
	G	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
	LDH	-	-	/	/	-	/	+4		+4		+6	F	-	-	-
	MDH	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
	HDH	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
	A/s	/	-	-	-	-	-	-4		+4		3		-6	F	-
ROAD DENSITY	LOW	-	/	/	-	-	/	+4		+4		+4		+4		+4
	MED	-	-	/	/		/	+4		+4		+6	F	-	-	-
	HIGH	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
ERODI-BILITY	LOW	-	/	/	/	-	-	-4		+6	F	-	-	-	-	-
	MED	-	/	/	/	-	-	-4		+6	F	-	-	-	-	-
	HIGH	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
SLOPE CLASS	LOW	-	/	/	-	-	/	+4		+4		+4		+4		
	MED	-	-	/	/	-	/	+4		+4		+6	F	-	-	-
	HIGH	-	-	-	/	/	-	+3		3		3		3		3
GEO-OLGY	MOLTENO	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
	RED BEDS	-	-	/	-	/	/	+6	F	-	-	-	-	-	-	-
	CLARENS	-	/	-	/	/	-	-4		+4		-4		+4		+4
	1To	1	6	15	8	9	12	96								
	2To	1	6	8	8	2	5		49							
	3To	1	3	5	5	2	5			36						
	4To	1	3	2	2	2	2				21					
	5To	0	3	2	2	2	2					15				
						Total 108 cells										

Proportion of variability determined by each trial factor.

Trial factor 1 - 96 - 41,5%
Trial factor 2 - 49 - 23,7%
Trial factor 3 - 36 - 17,4%
Trial factor 4 - 21 - 10,1%
Trial factor 5 - 15 - 7,2%

Table 24 Factor analysis results (1985).

EROSION CLASS FREQUENCY

	Factor	1	2	3	4	5	6	1To	1To	1F	2To	2T1	2F	3To	3T1	3F	4To	4T1	4F	5To
	C	-	/	-	-	-	-	3	-4		-4			+4			-4			-4
LAND	G	-	-	-	/	/	/	-5	+4		+4			+4			+4			+4
USE	LDH	-	-	/	-	/	/	+5	+6		+6		F - - - - - - - - - - - - - - - - -							
	MDH	-	-	/	-	/	/	+5	+6		+6		F - - - - - - - - - - - - - - - - -							
	HDH	-	-	/	/	-	/	3	+4		+4			-4			+4			+4
	A/s		-	-	-	-	-	-5	-4		-4			-4		-	-6		F	+4
ROAD	LOW	/	/	-	/	-	-	-5	-6	F -										
DENSITY	MED	-	/	-	-	/	/	+5	+4		+4			+6		F - - - - - - - - - -				
	HIGH	-	/	/	-	/	/	+6	+5	F -										
ERODI-	LOW	/	/	-	/	-	-	-5	-6	F -										
BILITY	MED	-	-	/	-	-	/	+4	+5		+5			3			3			3
	HIGH	-	-	/	-	/	/	+5	+6		+6		F - - - - - - - - - - - - - - - - -							
SLOPE	LOW	/	/	/	-	-	-	3	-4		-4			-4			-4			-4
CLASS	MED	-	-	-	/	/	/	3	+4		-4			+4			+4			+4
	HIGH	-	/	-	-	/	-	+4	3		3			+5			+4			+4
GEO-	MOLTENO	-	-	/	-	/	/	+5	+5		+6		F - - - - - - - - - - - - - - - - -							
OLOGY	RED BEDS	/	/	/	-	-	-	3	-4		-4			-4			-4			-4
	CLARENS	-		-			-	3	-4		-4			+4			+4			+4
	1To	5	9	9	7	10	10	77	84		68			46			41			
	1T1	3	9	13	5	12	12													
	2To	3	6	8	5	9	9													
	2T1	-	-	-	-	-	-													
	3To	3	6	4	4	5	5													
	3T1	-	-	-	-	-	-													
	4To	3	5	4	4	4	4													
	5To	2	5	4	4	4	4													

Total 108 cells

Proportion of variability explained by each trial factors.

Trial factor 1 - 84 - 30,6%
Trial factor 2 - 65 - 24,8%
Trial factor 3 - 46 - 16,8%
Trial factor 4 - 41 - 14,9%
Trial factor 5 - 35 - 12,8%

Table 25 Loadings on factors affecting erosion at each study period.

Derived factor	% explanation						original factors		
	Year 1961	D.E.C.	Year 1979	D.E.C.	Year 1985	D.E.C.	1961	1979	1985
1	39,2	(2,3,6)	41,5	(3,5,6)	30,6	(2,3,5,6)	C LRD HEr. L.Slope M.Slope Red beds Red beds	G MDH HDH HRD HEr. Molteno beds	HRD LRD(-) LEr.(-)
2	25,0	(3,4)	23,7	(2,3,4)	24,8	(3,5,6)	LDH MRD HRD H.Slope	C LEr. MEr.	LDH MDH HEr. Molteno beds
3	16,5	(1,2,3)	17,4	(3,4,6)	16,8	(2,5,6)	LEr. Clarens beds	LDH MRD M.Slope	MRD
4	10,2	(2)	10,1	(2)	14,9	(3,4,5,6)	MEr.	A/s(-)	A/s(-)
5	9,1	(2,3)	7,2	(2)	12,8	(2)	-	-	-

D.E.C. dominant erosion class.

Table 26 Trial factor and year in which each catchment characteristic loaded significantly.

Catchment	1			2			3			4		
Property	1961	1979	1985	1961	1979	1985	1961	1979	1985	1961	1979	1985
C	/	-	-	-	/	-	-	-	-	-	-	-
G	-	/	-	-	-	-	-	-	-	-	-	-
LDH	-	-	-	/	-	/	-	/	-	-	-	-
MDH	*	/	-	*	-	/	*	-	-	*	-	-
HDH	*	/	-	*	-	-	*	-	-	*	-	-
A/s	-	-	-	-	-	-	-	-	-	-	/(-)	/(-)
Low RD	/	-	/(-)	-	-	-	-	-	-	-	-	-
MRD	-	-	-	/	-	-	-	/	/	-	-	-
HRD	-	/	/	-	-	-	-	-	-	-	-	-
LEr.	-	-	/(-)	-	/	-	/	-	-	-	-	-
MEr.	-	-	-	-	/	-	-	-	-	/	-	-
HEr.	/	/	-	-	-	/	-	-	-	-	-	-
LSC	/	-	-	-	-	-	-	/	-	-	-	-
MSC	/	-	-	-	-	-	-	-	-	-	-	-
HSC	-	-	-	/	-	-	-	-	-	-	-	-
Molteno	-	/	-	-	-	/	-	-	-	-	-	-
Red beds	/	/	-	-	-	-	-	-	-	-	-	-
Clarens	-	-	-	-	-	-	-	-	-	-	-	-
Dominant erosion class	2,3 6	3,5 6	2,3 5,6	3,4	2,3 4	3,5 6	1,2 3	3,4 6	2,3 5,6	3,5 6	2,3 4,5 6	2,3 4,5 6

Key to Tables 25 and 26.

C	Cropland	LEr	Low erodibility
G	Grazing land	MEr	Medium erodibility
LDH	Low density housing	HEr	High erodibility
MDH	Medium density housing	LSC	Low slope class
HDH	High density housing	MSC	Medium slope class
A/s	Airport and sports field	HSC	High slope class
LRD	Low road density	*	not applicable
MRD	Medium road density	/	loads significantly (+ve)
HRD	High road density	/(-)	does load significantly (-ve)
		-	does not load significantly

IDENTIFICATION, MAPPING AND EVALUATION OF SEDIMENT SOURCES AND SINKS.

IDENTIFICATION AND MAPPING

It has been mentioned earlier that all forms of erosion are considered as sediment sources, while all depositional forms are considered as sediment sinks. Erosion features identified in the study area are sheetwash, rills, gullies and pipes. Depositional features identified in the study area are reservoir deposition, deposition in ponds, brick making pits, and discontinuous gullies, gully bottom fills, alluvial fans, and undefined deposition on slope breaks and other structures that impede downslope movement of sediment. These features are mapped in Figures 36, 37 and 38 for the years under study. Landforms and other features of the landscape are used as reference points or bearings for the purpose of ascertaining the positions of erosion and deposition features on the landscape. Tables 27 and 28 are summaries of information from representative gully profile surveys. As it was not possible to survey all gullies of the catchment, only two representative gullies were surveyed.

A comparison of the 1961, 1979 and 1985 erosion and deposition maps shows that the change in the pattern of deposition seems to follow that of erosion. Deposition features are more pronounced in the 1985 map than the 1979 map and likewise more pronounced on the 1979 map than the 1961 map. Major areas of change are shown in Figures 39 and 40. Which were drawn from separate maps of erosion and deposition for clarity.

SUMMARY OF INFORMATION FROM GULLY PROFILE SURVEYS.

Gully profile surveys were used as a way of groundtruthing aerial photographs, and obtaining information not depicted on photographs. Information from the gully profile surveys is applicable to the 1985 analysis only. Gully profile surveys revealed erosion features such as new incisions on the gully floor, exposure of bedrock, piping and tunnelling on the gully sides, and slumping of the undercut gully walls. Depositional features associated with gullies are gully bottom fills, some of which were measured to obtain depth, and the deposition of blocky material from slumping of the gully walls.

Table 27 GULLY PROFILE SURVEY 1

Distance	Gradient	Gully Floor: Sed Depth	Gully Floor: Bedrock exposed	Gully Floor: Vegetation	Gully Floor: New incision	Gully walls: Slumping	Gully walls: Piping/ Tunnelling	Gully walls: Tributaries	Gully side (Micro) catchment	General Comments
0m	0^o	0		-	-	-	-	-	Sandstone ridges	Recent deposits, gully cuts across residential area.
100m	1^o	15cm	-	Kikuyu grass	-	-	-	-	Sandstone ridges	
100m	3^o	15cm	-	Kikuyu grass	-	-	-	-	Sandstone ridges	Poplar trees lining U-shaped gully. Footpaths along and across gully, leading to extensive sheet and rill erosion.
50m	7^o	0	-	-	-	-	-			Network of footpaths along and across gully. Intersection of five roads. Severe sheet and rill erosion. No culvert across road.
50m	7^o	Slight	-	Kikuyu grass	-	-	-	-	Sandstone ridge	Change of direction of flow due to sandstone obstruction. Sideways expansion checked by sandstone ridge.
100m	2^o	15-20cm	-	Kikuyu grass	-	-	-	-	Housing very close to gully	Gully runs across slope. Cultivated field upslope being developed for housing. Marshy conditions.
100m	$2{,}5^o$		-	Kikuyu grass	-	-	-	-	Housing	Small ponds form in this part of gully.
50m	2^o	-	-	-	-		-	-	Housing	Road running downslope into gully. No culvert.
50m	7^o		-	Kikuyu grass	-		-	-	Grazing land. Fallow fields.	Poplar tree lining gully side. Deposition of blocky material.

Distance	Gradient	Gully Floor				Gully walls			Gully side	
		Sed Depth	Bedrock exposed	Vegetation	New incision	Slumping	Piping/ Tunnelling	Tributaries	(Micro) catchment	General Comments
50m	9°	not measured	-	Kikuyu	-		-		Tarred road	A number of parallel gullies coalesce to form one wide U-shaped gully. Poplar trees dominant. Dumping site. Footpaths growing into deep rills.
50m	13°	10cm	-	-	-				Sandstone ridges	Gully changes direction on sandstone ridge. Footpaths leading to extensive rill and sheet erosion.
50m	$16,5^{\circ}$	-	-	Aloes Poplars		-	-		Old road eroded, no longer in use.	Parallel gullies probably developed from rills. During low flow each gully conducts individual flow. During heavy flow water runs across and above intergully ridges exhibiting single gully characteristics. Extensive footpath network.
50m	$8,5^{\circ}$	not measured	-	Kikuyu grass		-	-			Signs of former parallel gullies forming present U-shaped gully. Car bodies dumped in gullies. Marshy conditions.
*150m	Measured outside gully due to obstructions by car bodies dumped in gully.									
33m	7°		-	-	-	-	-	-	Roads/ housing	Road runs across gully with culvert. Deposition occurs upslope of culvert.
50m	9°	30cm	-	-		-	-	-	Grazing land	Rills developing into small gullies forming tributaries.
100m	9°	30cm	-	-		-	-	-	Grazing land	Rills developing into small gullies, forming tributaries.

Distance	Gradient	Gully Floor				Gully walls			Gully side	
		Sed Depth	Bedrock exposed	Vegetation	New incision	Slumping	Piping/ Tunnelling	Tributaries	(Micro) catchment	General Comments
100m	$10,5^{\circ}$	-	-	*Hormenia palida*, *Datura* spp.	-		-	-	Grazing land	Bank cutting leading to collapse. Deposition of blocky material, edges of blocks being rounded due to flow. Footpaths across gully.
100m	8°	-	-	-		-			Grazing land	Smaller changes on gully floor.
30m	4°	20cm	-	-	-	-	-	-	Grazing land	Slighly marshy conditions. Sandstone ridge on west bank. Dumping of trash into gully.
50m	$9,5^{\circ}$		-	Khaki bush	-	-	-	-	Housing	Gully curves, deposition on curve.
50m	16°	-	-	-	-	-	-	-	Housing	Bed erosion of V-shaped gully. Buildings and land development seem to have stabilized gully. No sideways expansion.
30m	$9,5^{\circ}$	-		-	-	-	-	-	Grazing land.	Gully becomes shallow as one proceeds upslope. Network of steep footpaths across gully.
50m	11°	-		-	-	-	-	-	Grazing land. Rockland	Gully very shallow, < 1m deep. Sandstone ridges exposed.
100m	13°	-		-	-	-	-	-	Grazing land. Rockland	Gully depth about 0,8m rock outcrops.
88m	16°	-		-	-	-	-	-	Rock outcrops	Gully head on sandstone ridge, extensive rilling and rock stripping.

Table 28

GULLY PROFILE SURVEY 2

DISTANCE	GRADIENT	GULLY FLOOR				GULLY WALLS			GULLY SIDE	
		Sed Depth	Bedrock exposed	Vegetation	New incision	Slumping	Piping/ Tunnelling	Tributaries	(Micro) catchment	General Comments
0m	0°	>1m	-	-	-	-	-	-	Brick works	Gully reservoir confluence. Digging on gully side and walls for brickmaking material.
50m	1°	not measured	-	Eragrostis spp. Common weeds	-			-	Brickworks Sandstone ridge on one side.	Gully very deep (about 3m). Wide U-shaped with near vertical walls. Dumping in gully.
50m	3°	0,3m to bedrock	-	Eragrostis spp. Common weeds	-	-	-	-	Sandstone ridge. Severe sheet and rill erosion.	Gully gets shallower up-slope. Extensive network of footpaths along and across gully.
50m	5°	-		-	-	-	-	-	Severe sheet erosion	Gully less than 1m deep. Intersection of 3 roads, one runs along gully. Excessive concentration of water.
100m	7°	-		-	-	-	-	-	Pine trees along gully. Rocky surface.	Gully very wide and shallow, less than 1m in depth.
100m	10°	-		-	-	-	-		LDH	Gully cuts into rocky surface with stony soils, shrubs and some weeds.
100m	13°	-		-	-	-	-		Severe sheet and rill erosion.	A number of converging rills have dev-loped into tributaries. Shallow stony soils. Large boulders and shrubs. Foot of debris slope. Extensive footpath network.
100m	17°	-	-	-	-	-	-		Severe sheet and rill erosion.	Gully more narrow and changing into V-shape.
138m	29°	-	-	-	-	-	-	-	Boulders	Rock outcrop. Gully very narrow and shallow.

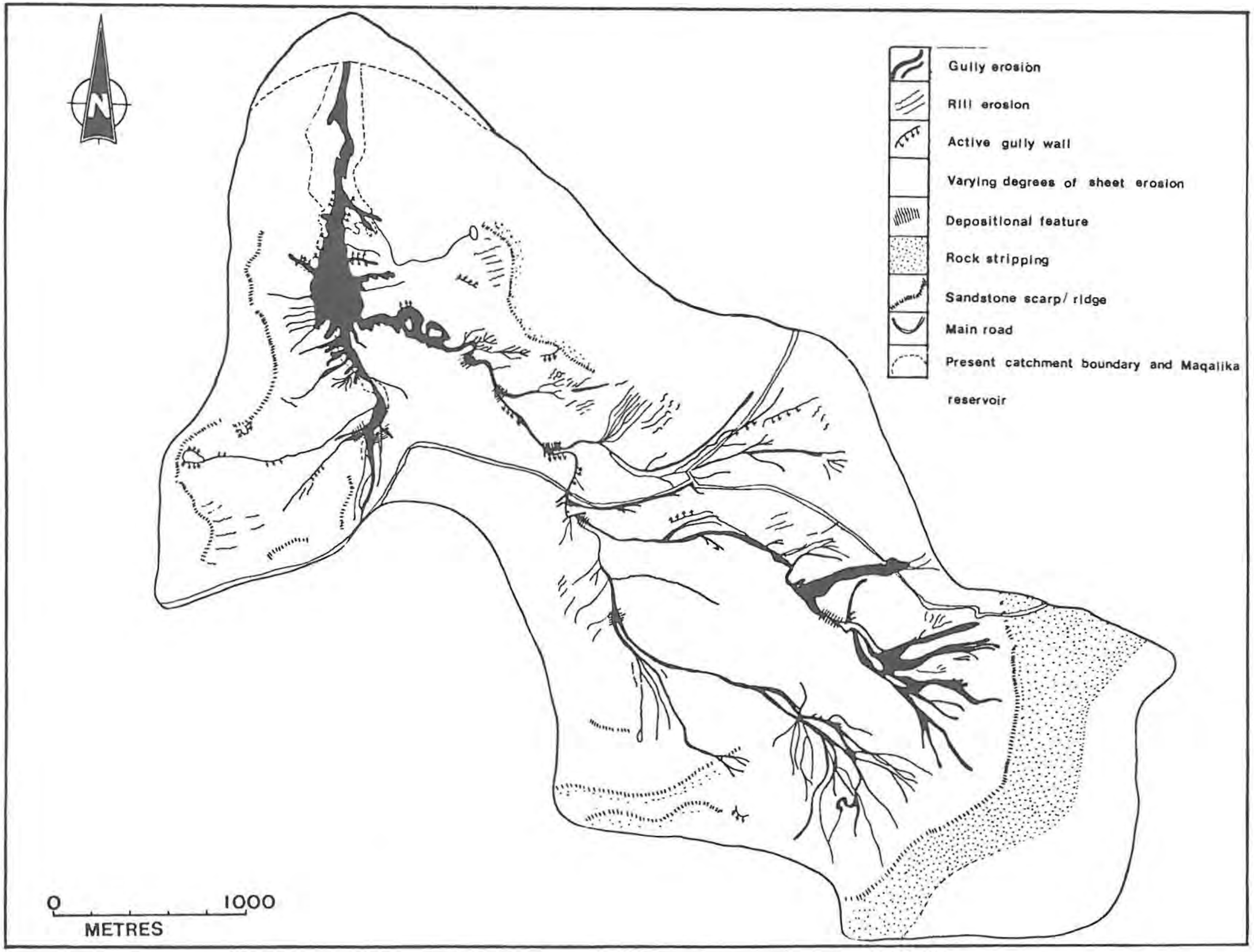

Figure 36 Maqalika catchment: Map of erosion and deposition - 1961.

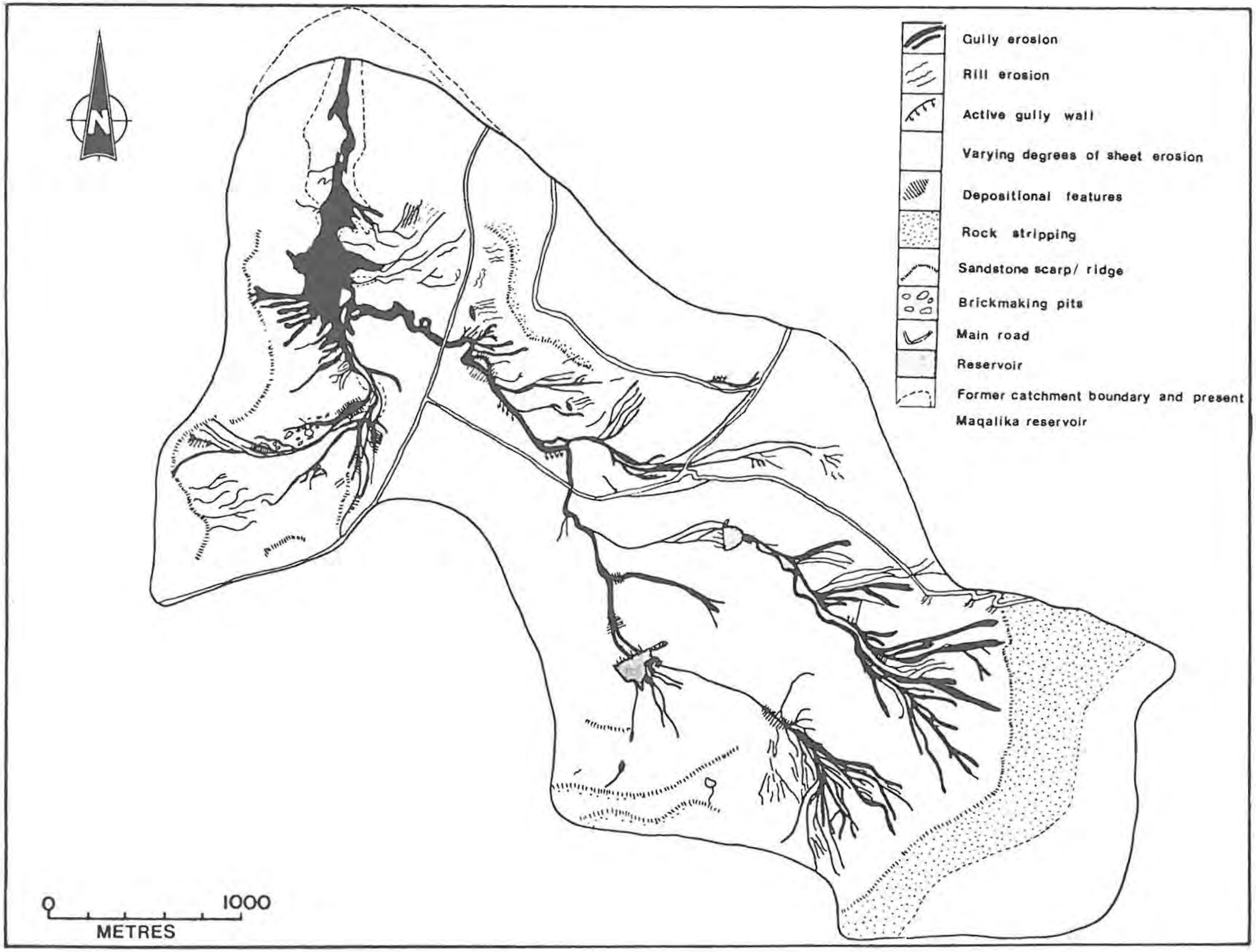

Figure 37 Maqalika catchment: Map of erosion and deposition - 1979.

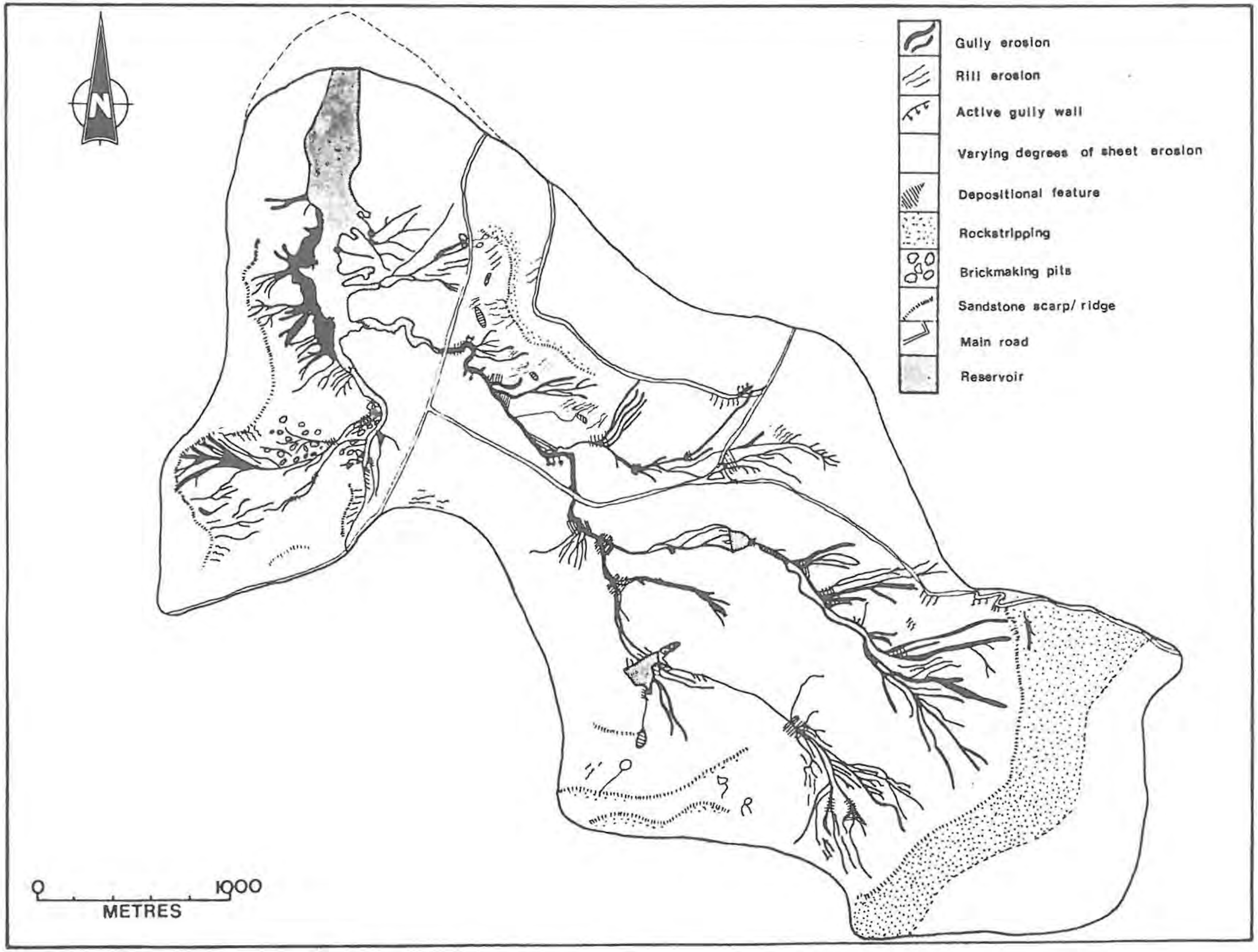

Figure 38 Maqalika catchment: Map of erosion and deposition - 1985.

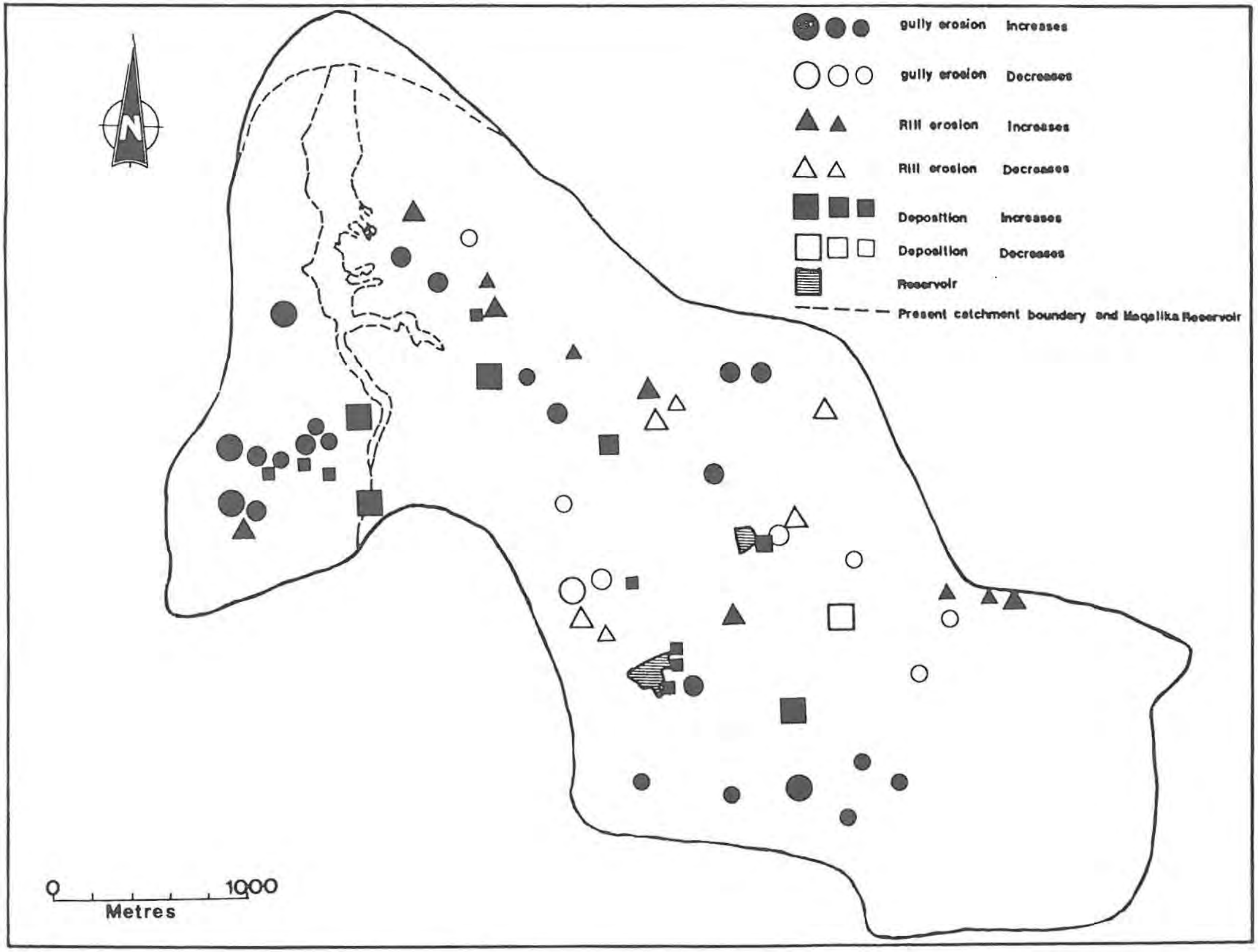

Figure 39 Changes in erosion and deposition 1961-1979.

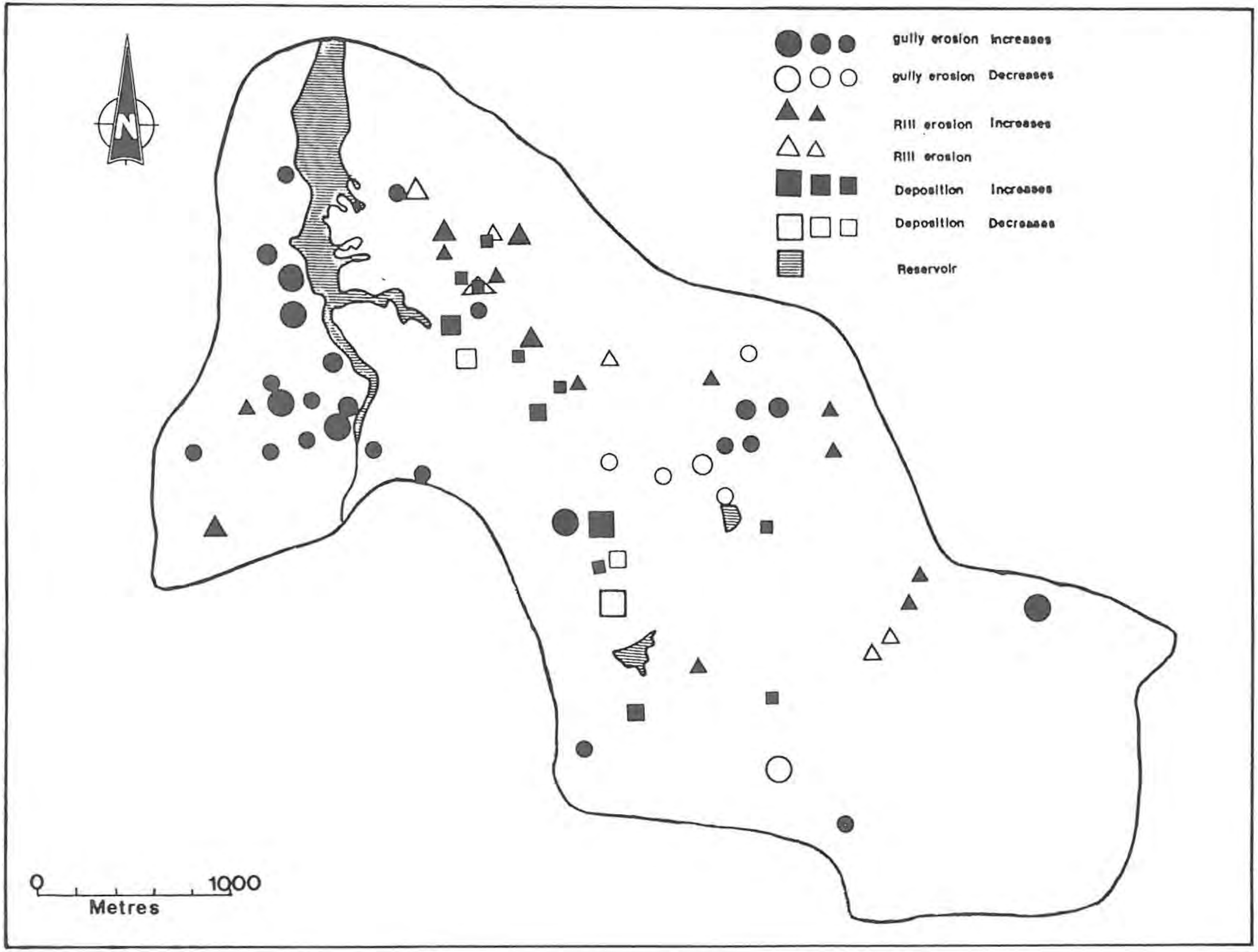

Figure 40 Changes in erosion and deposition 1979-1985.

SEDIMENT ROUTING THROUGH LANDFORMS

Tables 27 and 28 show that the surveyed gullies cut across a number of land use categories, soils, landforms and slopes. These catchment characteristics affect gully initiation and growth. The gully changes in shape and depth throughout the profile. The wide U-shape seems to persist on gentle to flat slopes while the narrow V shape persists on steeper slopes. Sediment depth in gully bottom fills ranges from 10cm to 1m, the greater deposition being associated with gullies delivering direct into the reservoir. Sediment of 1m depth was measured at the gully reservoir confluence of gully 2. Information from erosion and deposition maps, and from gully profile surveys was used to derive a qualitative sediment routing procedure shown in Figure 41.

SEDIMENT SOURCE CAPABILITY RATING.

When investigating sediment source problems it is expedient to include an analysis of transport and delivery mechanisms, since some areas might exhibit erosion problems yet they do not present any sediment problems. Tables 29 and 30 and Figure 42 show the erosion status, and sediment yield capability rating of each erosion unit. For a comparison of erosion status and sediment source rating the following observations were made:

(i) There are some severely eroded areas which have a high sediment yield capability rating,

(ii) there are some severely eroded areas which have low sediment yield ratings. There are slightly eroded areas with a high sediment yield capability, and

(iii) there are slightly eroded areas with low or no sediment yield capability. Probable reasons for these variations are discussed in Chapter 6.

SEDIMENT YIELD AND EROSION RATES.

Results obtained from the reservoir survey and related computations are presented in Table 31. A sediment yield value of $18{,}1 t.h^{-1}.y^{-1}$ was obtained. This value may be considered as a conservative or minimum erosion rate of the catchment. The value is considered minimum because there is some evidence of large quantities of sediment stored within the catchment, indicating that the true rate of erosion is much higher than the estimated rate.

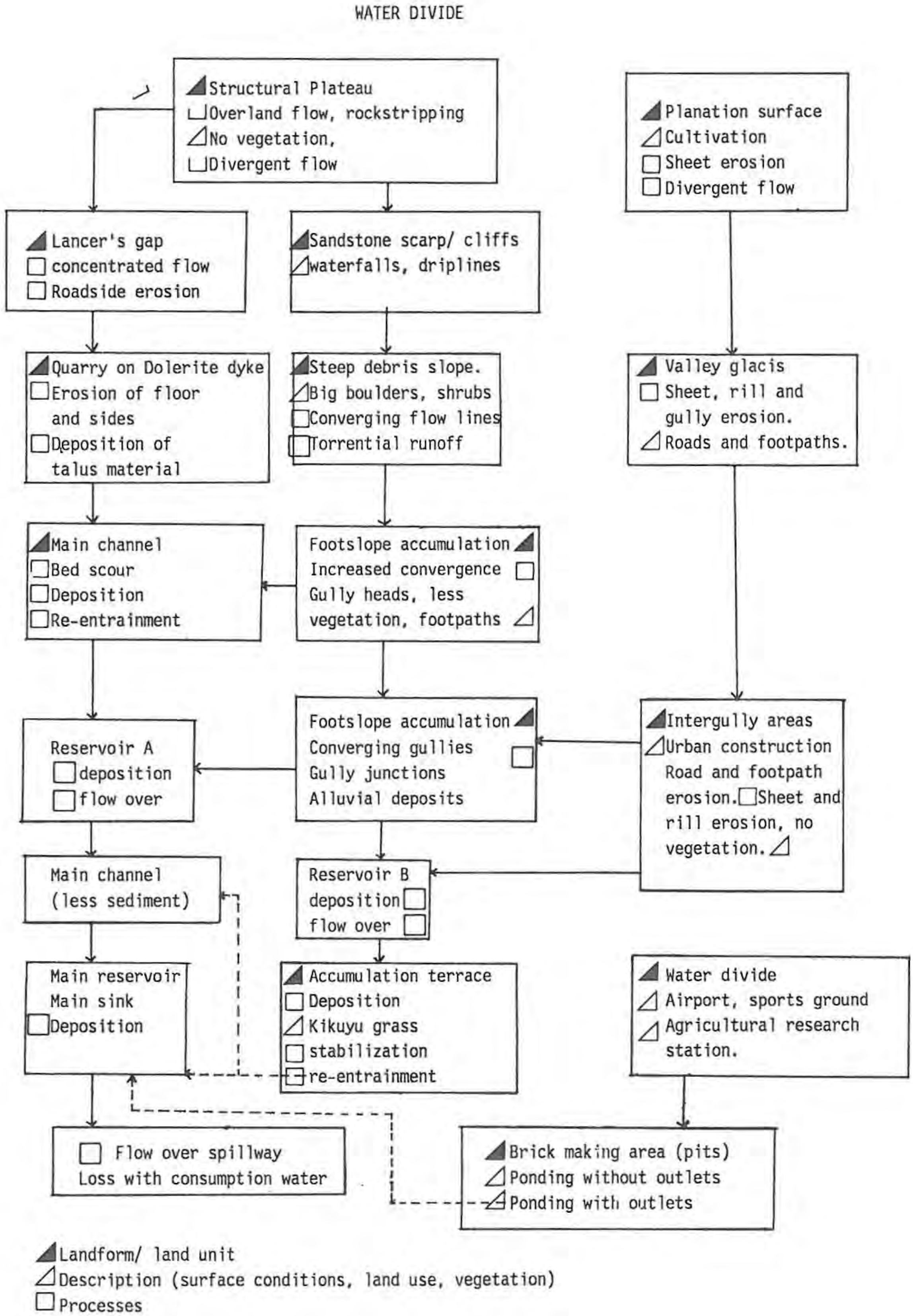

Figure 41 Sediment routing through landforms.

Table 29 Sediment source capability rating.

Erosion unit No.	PRODUCTION FACTORS (P) 1	2	3	SUM	TRANSPORT FACTORS (T) 1	2	3	4	SUM	SUM (P) SUM (T)	RATING
30	1	2	0	3	0	2	2	2	6	18	M
4	2	2	1	5	0	1	2	2	5	25	H
23	1	1	2	4	1	2	2	2	7	28	H
44	2	2	0	4	1	2	2	2	7	28	H
3	2	2	2	6	2	2	2	1	7	42	VH
13	2	2	1	5	0	2	2	2	6	30	VH
10a	2	2	1	5	0	2	1	1	4	20	H
11	2	2	1	5	0	2	2	1	5	25	H
33	2	0	1	3	0	2	2	2	6	18	M
40	2	2	0	4	0	2	1	2	5	20	H
13a	2	2	2	6	0	2	2	2	6	36	VH
28	1	2	1	4	0	2	2	2	6	24	H
9	1	1	2	4	2	2	1	1	6	24	H
26	0	1	2	3	0	2	2	2	6	18	M
1a	0	0	0	0	0	2	2	1	5	0	L
39	2	1	1	4	1	1	2	2	6	24	H
31	1	1	1	3	0	2	2	2	6	18	M
18	2	0	2	4	0	2	1	2	5	20	H
5	2	1	2	5	1	2	2	1	6	30	VH
16	1	0	1	2	0	2	2	2	6	12	M
2	1	1	1	3	0	2	1	1	4	12	M
22	1	1	0	2	2	2	2	2	8	16	M
10	2	0	1	3	0	2	1	1	4	12	M
17	1	2	1	4	0	1	2	2	5	20	H
34	2	1	0	3	0	1	1	2	4	12	M
26a	0	1	1	2	1	1	2	2	6	12	M
42	2	2	2	6	0	2	2	2	6	36	VH
41	2	2	2	6	0	2	2	2	6	36	VH
6	2	2	2	6	0	2	2	1	5	30	VH
1b	0	1	0	1	2	2	2	1	7	7	L
7	2	2	2	6	0	1	2	1	4	24	H
8	1	1	1	3	1	1	2	1	5	15	M
14	2	2	2	6	1	1	2	1	5	30	VH
24	1	1	0	2	2	2	2	2	8	16	M
46	2	2	1	5	0	1	2	2	5	25	H
37	0	1	2	3	0	1	2	2	5	15	M
5a	2	2	2	6	0	1	2	1	4	24	H
43	1	2	1	4	0	1	1	2	4	16	M
38	2	1	1	4	1	1	1	2	5	20	H
12	2	2	0	4	0	1	1	1	3	12	M
15	1	0	1	2	0	1	1	2	4	8	L
19	1	0	1	2	0	1	2	2	5	10	L
21	1	1	1	3	1	1	2	2	6	18	M
32	1	0	0	1	0	1	2	2	5	5	L
35	2	1	0	3	0	1	2	2	5	15	M
27	0	0	1	1	0	1	2	2	5	5	L
36	1	2	1	4	0	1	2	2	5	20	H
29	1	2	2	5	0	1	1	2	4	20	H
1	0	1	2	3	0	1	2	1	4	12	M
20a	0	2	0	2	0	0	1	2	3	6	L
20	1	0	0	1	0	1	2	2	5	5	L

Key

Production factors	Transport factors	Rating
1 - Erodibility	1 - Topography	L - Low
2 - Vegetation	2 - Transport capability	M - Moderate
3 - Construction level	3 - Control measures	H - High
	4 - Distance from reservoir	VH - Very high
		* - C

Table 30 Summary of erosion status and sediment source capability rating of each erosion unit.

Erosion unit No.	SARCCUS (1981) Classification	Erosion class	Sediment cap. rating
30	S4 R3 G4	6	M
4	S4 R3 G3	6	H
23	S4 R3 G3	6	H
44	S4 R3 G3	6	H
3	S3 R2 G3	6	VH
13	S3 R2 G3	6	VH
10a	S3 R2 G3	6	H
11	S3 R2 G3	6	H
33	S3 R2 G3	6	M
40	S3 R2 G3	6	H
13a	S3 R2 G3	6	VH
28	S3 R2 G3	6	H
9	S4 R3 G2	5	H
26	S4 R3 G2	5	M
1a	S3 R2 G2	5	* L
39	S3 R2 G2	5	H
31	S3 R2 G2	5	M
18	S3 R2 G2	5	H
5	S2 R2 G2	5	H
16	S2 R2 G2	5	L
2	S2 R2 G2	5	M
22	S2 R2 G2	5	M
10	S2 R2 G2	5	M
17	S4 R4	4	H
34	S3 R4	4	M
26a	S4 R3	4	M
42	S3 R3	4	VH
41	S3 R3	4	VH
6	S3 R2	3	VH
1b	S3 R2	3	L
7	S3 R2	3	M
8	S3 R2	3	M
14	S3 R2	3	VH
24	S3 R2	3	M
46	S3 R2	3	H
37	S3 R2	3	M
5a	S3 R2	3	H
43	S3 R2	3	M
38	S3 R2	3	H
12	S2 R2	3	M
15	S2 R2	3	L
19	S2 R2	3	L
21	S2 R2	3	M
32	S2 R2	3	L
35	S2 R2	3	M
27	S2	2	L
36	S2	2	H
29	S2	2	H
1	S2	2	M
20a	S2	2	L
20	S1	1	L

* Sediment capability rating = 0.

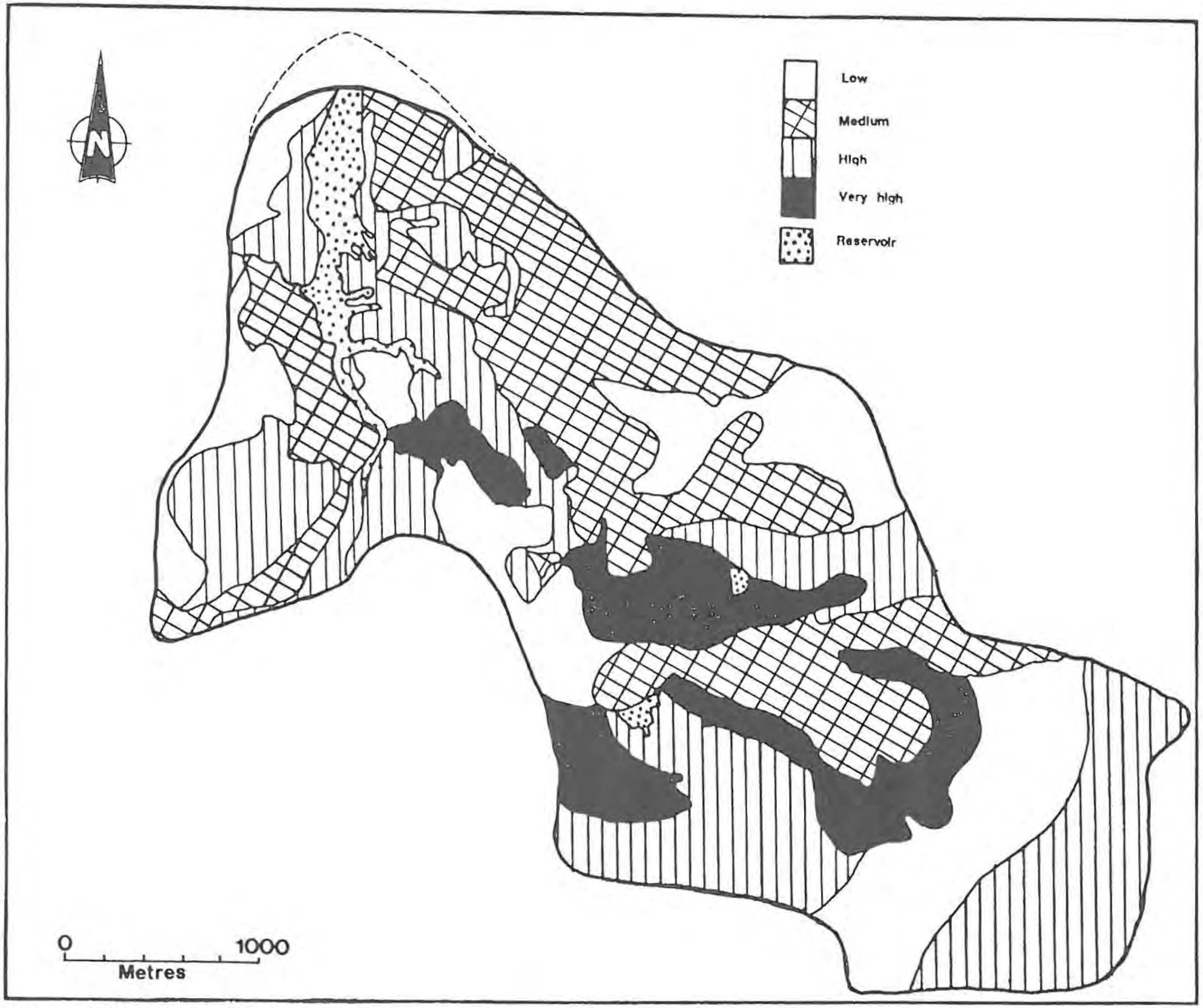

Figure 42 Maqalika catchment : Sediment yield capability rating.

Table 31 Data from reservoir survey and related computations.

Data type	Value	Source
Total catchment area	11.04km^2	computed
Mean annual runoff	600 000m^3.y^{-1}	Binnie and Partners (1979)
Estimated sediment yield	900tkm^2.y^{-1}	Binnie and Partners (1979)
Surface area of reservoir	559 400m^2	computed
Trap efficiency	99,9%	Heinemann (1979)
Original reservoir capacity	4 032 216m^3	computed
Present reservoir capacity	3 932 381m^3	computed
Capacity loss over 5yrs	99 835m^3	computed
Volume of trapped sediment	99 835m^3	computed
Total incoming sediment (Vol)	99 935m^3	computed
Total incoming sediment (mass)	100 934,4t	computed
Mass of sediment from Sebaboleng	1008,4t	computed
Total loss from study catchment (mass)	99 926t	computed
Bulk density of reservoir sediment	1,01g.cm^3	computed
Bulk density of catchment soils	1,7g.cm^3	CDT (1979)
Rate of soil loss (t.km^{2}yr^{-1})	1810,3t.km^2·y^{-1}	computed
Rate of soil loss (t.h^{-1}yr^{-1})	18,1t.ha^{-1}·y^{-1}	computed
Depth of soil loss	1,1mm.yr^{-1}	computed
Lifespan of reservoir	201,8yrs	computed

SOCIO-ECONOMIC CONSEQUENCES OF EROSION AND DEPOSITION

A reservoir lifespan of 201,8yrs has been computed, yielding a useful life of about 101yrs. The original pre-construction reservoir floor topography (Figure 43) has changed, and the 1988 topography is shown in Figure 44, while areas of change are shown in Figure 45. (Figures 43, 44, and 45 are found in map sleeve inside the back cover.) The reservoir capacity curves for 1983 and 1988 are shown in Figure 46. Most of the sediment has been deposited in thalweg areas resulting in an apparent flattening and smoothing of the reservoir floor.

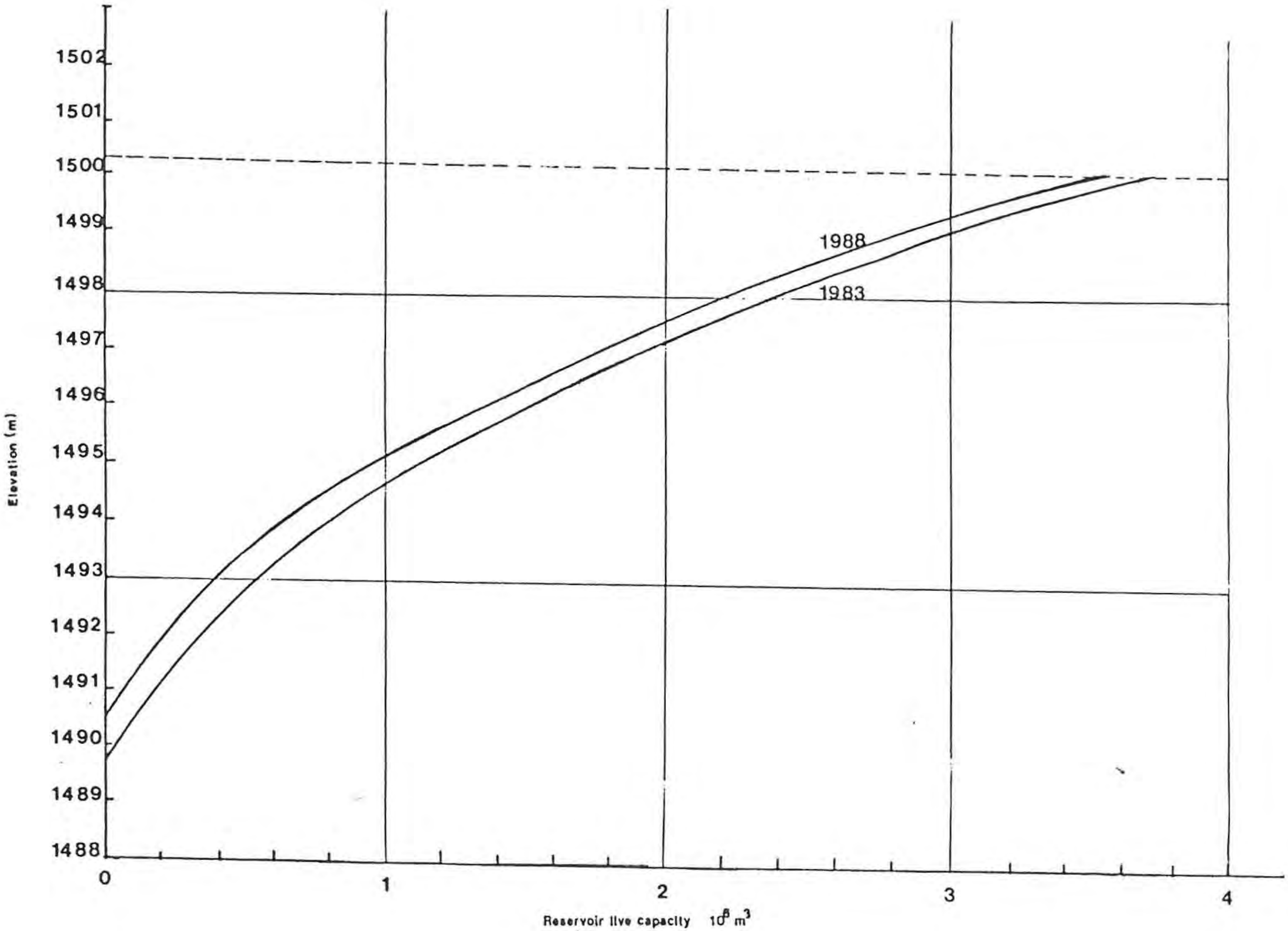

Figure 46 Reservoir capacity for 1983 and 1988.

A catchment soil loss value of 18,1t.ha^{-1}.y^{-1} gives an average ground lowering rate of 1,1mm.y^{-1}. It should be noted that the value is an average taken over the whole catchment area. Some areas could be experiencing a much higher rate of soil loss, while some, like exposed sandstone ridges are not loosing any soil.

There has been a progressive increase in the areal extent and degree of erosion. Large areas of the study area are truncated by dense gully systems, and the intergully areas are experiencing severe sheet and rill erosion. There is no evidence of an attempt to prevent erosion. Most conservation measures in the catchment are sediment traps within the gullies.

CHAPTER SIX

INTERPRETATION AND DISCUSSION

Results of the study were described in Chapter 5. In the current chapter results will be interpreted and discussed in relation to each of the stated study aims. A summary of relevance and limitations of methods was presented in Chapter 4. Some of these limitations become apparent when results are examined with reference to reviewed literature, these limitations are identified as they arise throughout the discussion.

THE HISTORY OF EROSION AND LAND USE.

EROSION HISTORY

Erosion mapping of the catchment (Figure 19) shows that all parts of the catchment except the airport and sports ground were eroded to varying degrees in 1961. The airport and sports grounds have not shown any signs of erosion throughout the period of study and are therefore classified as class 1 erosion. By 1979 class 1 erosion (no erosion) had increased slightly, to 6,0%. These changes occurred on cultivated land probably due to the ability of ploughing to conceal erosion. In 1961 the most extensive form of erosion was sheet erosion without rilling (class 2), which was observed on 32% of the total catchment area. By 1979 class 2 erosion had decreased by half to 16,1%. This was the greatest change observed during period A (Figure 27). During the same period class 3 erosion (severe sheet and slight rill erosion) changed little when compared to other changes recorded. A considerable change was observed on class 4 erosion (severe sheet and rill erosion) which increased from 6,3% in 1961 to 15,8% in 1979 (Table 15). In terms of areal extent, class 4 erosion was observed on a relatively small area of the catchment in both 1961 and 1979. Two forms of gully erosion were identified. (i) Firstly gully network extension (class 5) which comprises the formation of new gullies, which are formed as tributaries of the old gullies. There was very limited expansion of the old gullies. (ii) Secondly gully network incision (class 6) which comprises progressive denudation of the existing gully network. During Period A none of the original gullies extended headward. The total area occupied by gully extensions and their micro-catchments decreased while gully incision increased. This is in keeping with a number of studies in the lowlands of Lesotho, which reveal that "..the main phase of expansion seems to be over" (Schmitz, 1980, p360).

During Period B, 1979 to 1985 there was an apparent decrease in the areal extent of class 1 erosion. A figure of 32% which was recorded in 1961 was recorded again in 1985. This figure supports the contention that the recorded changes to class 1 erosion were either due to the ability of ploughing to conceal erosion or were due to measurement error. Class 1 erosion changes will therefore not be discussed any further. During period B class 2 and class 3 erosion remained unchanged while class 4 was reduced by half. During the same period gully network incision increased notably while changes to gully network extension were minimal (Figure 27).

LAND USE

During 1961 the whole Maqalika catchment could be considered as rural, comprising cropland, grazing land and low density settlements (Figure 22). A small percentage (3%) of the catchment area was occupied by the airport and sports ground. Settlements comprised a combination of traditional open clusters with kraals and a few more modern bungalows with streets and fenced gardens. The settlements were placed on interfluves forming the watershed, while cultivation was limited to the valley bottom and some planation surfaces at the top of the escarpment. The most extensive form of land use was cropland which was observed on 45,7% of the catchment, followed by grazing land which was observed on 30,5% of the catchment (Table 17).

The period 1961 to 1979 was marked by a general change from rural to a predominantly urban status. The roads from the town centre to Teya-teyaneng and to the top of the escarpment (Figure 14) became paved and shifted in position. A number of clustered settlements developed along the roads. Two reservoirs acting as sediment traps were constructed on the two main channels draining the catchment. Settlements developed rapidly around the reservoirs, probably because of proximity to water sources. As reported by Mateka (1987) the period 1966 to 1976 was marked by population increases, uncontrolled construction activity and the conversion of agricultural land to urban development. During the same period the population of Maseru doubled (Bureau of Statistics, 1982), and a large percentage of the population settled in the sub-urban areas of Motimposo, Tsiu, Sebaboleng and Mabote (Figure 14). It should be noted that prior to the enactment of the 1979 Land Act, expansion of the urban area and the allocation of residential sites was not controlled by the Land Surveys and Physical Planning Department, and hence the unplanned residential settlements resulted.

Notable land use changes during period A (1961 to 1979) were decreases in the areal extent of grazing and low density housing, with a subsequent development of medium and high density housing (Figure 29). The conversion of agricultural land to urban development should be expected to be followed by major decreases in the areal extent of cropland. However this was not the case as shown by an almost constant figure of 45,7% in 1961 and 42,6% in 1979 (Table 17). The 1961 and 1979 land use maps (Figures 22 and 23) show that cropland changed location from the valley bottom to the steeper slopes towards the escarpment. The relocation of cropland on steeper slopes amounts to a bad agricultural practice which provides a potential for increased erosion.

The period 1979 to 1985 was marked by a drastic decrease in cropland from 42,6% to 16,3% (Table 17). This was due to two factors. Firstly, cropland was converted to housing development, and, secondly, eroded cropland was abandoned and therefore classified as grazing land. No new cropland was established since some of the available land was already eroded while some was being prepared for more housing development. It should be noted that in a rapidly urbanizing area croplands are abandoned for a variety of reasons including severe erosion and vandalism (LSPP, no date, a). Low density settlements developing on former cropland was characterised by an unplanned road network which is shown in Figure 14. Abandoned cropland resulted in an increase in grazing land (Figure 31). A notable characteristic of land use changes during the period 1979 and 1985 is that there were increases in all other forms of land use, while there was a decrease in cropland. From this observation one may infer that the present residential areas developed at the expense of agricultural land.

THE RELATIONSHIP BETWEEN EROSION AND LANDUSE

As mentioned before class 1 erosion was observed on the airport and sports ground from 1961 through to 1981 (Figure 35). No changes were observed in both study periods 1961 to 1979 and, 1979 to 1985. It should be expected that the airport and sports ground should have no erosion since this area shows a very high level of management. The area is either grassed or paved. The absence of any form of erosion on the airport and sports ground further supports suggestions in the literature that a high level of management prevents erosion.

In both period A and period B, class 2 erosion was persistent on cropland, decreasing gradually with time (Figure 30). The observed decreases in class 2 erosion on cropland were greater in period A than in period B, and were followed by subsequent increases in class 4 erosion. The greatest damage on cropland occurred between 1961 and 1979. Most of the observed changes in erosion status occurred on cropland which had been transposed from the flatter valley bottom to the steeper areas just below the escarpment. The observed changes from class 2 erosion to class 3 and class 4 were also noted on grazing land and low density housing. Class 2 erosion is also associated with a relatively high level of management. Class 2 erosion is common on cultivated land where proper methods of cultivation are followed. The Agricultural Research Station on the north west of the Maqalika catchment (Figure 14) has been cultivated for a long time, however the methods of cultivation employed conform to soil conservation principles. The Agricultural Research Station is fenced and therefore not exposed to population problems such as footpaths, overgrazing and construction activity. Maintenance of the research station at a relatively low erosion status gives further support to the use of proper management as a strategy for erosion control. In period A and period B on medium and high density housing were characterised by erosion classes more severe than class 2 (Figures 33 and 34). On the one hand the housing areas were developed on already eroded land which exhibited severe sheet erosion, and on the the other hand the development of housing accompanied by construction activity created an opportunity for more advanced sheet and rill erosion.

In both 1961 and 1979 class 3 erosion was notable on cropland situated in the valley bottom as opposed to that situated along the watershed. By 1985 cropland that was situated along the watershed remained as class 2 erosion while class 3 erosion was almost absent on cropland. This may be explained by an earlier observation that eroded cropland was abandoned, moreover there is no evidence of any attempt to restore eroded cropland. Class 3 erosion remained unchanged on grazing land in both period A and period B (Figure 31). It has been noted that some grazing land which was classified as class 3 erosion was lost to housing development while some class 3 erosion cropland was lost to grazing land, giving an impression that class 3 erosion persists on grazing land. A comparison of the distribution of class 3 erosion on the three housing densities low, medium and high (Figures 33, 34 and 35) shows that high density housing has relatively less class 3 erosion than the other housing areas.

Class 4 erosion was limited on cropland in 1961, increased in 1979, and was absent in 1985 (Figure 30). An explanation given earlier for the distribution of class 3 erosion on cropland is applicable to class 4 erosion. As mentioned before, the 1961 to 1979 period was marked by the development of medium and high density settlements accompanied by construction activity and severe sheet and rill erosion. Construction activity has been described as a high intensity short duration activity (Walling and Gregory, 1970). It should be expected that by 1985 most construction on medium and high density settlements had stabilized, and was followed by the re-establishment of vegetation and the maintenance of gardens especially on older settlements. Hence there was very limited class 4 erosion on high density housing (Figure 34).

The areal extent of gully network extension (class 5) has been stable through time. In 1961 and 1985 class 5 erosion was more extensive on low density housing and grazing land, while in 1979 it was more extensive on grazing land and cropland. Main gullies observed in the catchment may have developed as early as the 1930's as suggested by Pim (1935). Intermittent gullies occurred throughout the catchment, especially in the valley bottom. Traditional settlements on interfluves were not exposed to much gully erosion which seems to be limited to colluvial material on the valley bottom. Since it is evident that the observed gullies neither changed location nor increased in length, the explanation is that cropland which had very limited gully erosion in 1961 was transferred to severely eroded intergully areas due to urban encroachment. The former intergully grazing land was converted to cropland and hence the observed class 5 erosion on cropland in 1979. In 1985 there was a notable increase in class 5 erosion on grazing land (Figure 31). This was a result of abandoned cropland. There is no evidence of any attempt to restore eroded cropland and hence an increase in grazing land in 1985 (Figure 25) and a decrease in class 5 erosion on cropland (Figure 30). Class 5 erosion was extensive on low density housing in 1961, it decreased appreciably in 1979 and increased again in 1985 (Figure 32). In 1979 former low density housing was converted to medium density housing, while new low density housing was encroaching on cropland and hence there was a low degree of channelized erosion on low density housing in 1979. These observations are an indication that the changing association between erosion and land use is due to a shift in location of land use as a response to urbanization and to erosion itself.

There has been a progressive change in gully network incision (class 6) from 1961 to 1985 (Figure 26). Gully network incision is found mainly in the valley bottom and around Maqalika reservoir (Figure 21). Class 6 erosion has been persistent on grazing land throughout the period of study (Figure 31). The area classified as class 6 erosion is so severely eroded and incised that it is not suitable for either cropland or housing. However due to land pressure experienced from 1976 (Mateka, 1987) low and medium density settlements were developed around the gullies. The development of settlements around the gullies probably resulted in increased incision due to runoff concentration from roads, road drains and other impervious surfaces. By 1985 some of the small gullies in the medium density settlements were stabilized by urban development and disappeared (Figure 33). Some of the gullied medium density housing was converted to high density housing by 1985, and hence the increase in gullied (class 6) high density housing (Figure 34). The housing areas are expected to have more roads, road drains and other urban structures which are associated with channelized erosion. It should therefore be expected that housing development will be followed by extensive incision of the drainage network.

Grazing land is generally dominated by gully erosion in the form of gully heads. This may be explained through the observation that the relatively steep debris slopes are neither settled nor cultivated and are classified as grazing land. Gully heads are persistent at the foot of debris slopes, where they cut into bedrock or very shallow soils. Most land upslope of the foot of debris slopes does not exhibit gully erosion.

Land use changes throughout the period of study do not provide any accurate or reliable information to explain observed changes in erosion status and distribution. Workers on erosion promoting factors such as Morgan (1986) and Stocking (1987) emphasize the fact that erosion is affected by numerous inter-dependent factors. Weaver (1988c) suggests that in order to make valid conclusions about causes of erosion, the spatial variability of factors affecting erosion must be analysed. Hand factor analysis described in Chapter 4 aids in indicating factors which are important to erosion. It has been noted that the distribution of some erosion causing factors changes with time hence the hand factor analysis was applied to the three study periods, 1961, 1979 and 1985.

FACTORS AFFECTING EROSION

Results from the factor analyses of all three time periods are summarized in Table 22, 23 and 24. Factors which appear to be prevalent throughout the study period are erodibility, road density and housing density. To keep this section succinct and within the framework of the outlined purpose of factor analysis the ensueing discussion will focus only on those catchment characteristics which seem to load highly on derived erosion factors, and come out clearly throughout the period of study.

An examination of the 1961 hand factor analysis results, (Table 22) shows that the derived 1st factor responsible for the observed erosion distribution was highly associated with components of the physical environment such as erodibility, slopes and geology. These characteristics acted together with cultivation and low road density to give an erosion pattern dominated by erosion classes 2, 3 and 6 which are sheet erosion without rilling, sheet and rill erosion, and gully network incision. This distribution may be considered as typical for the catchment in its rural state.

A second factor derived from the 1961 analysis is closely associated with steep slopes, low density housing and moderate and high road density. This factor is responsible for the dominance of erosion classes 3 and 4, a shift to higher sheet erosion status but no gullying. Steep slopes in the study area are found mainly on the escarpment bordering the Berea Plateau. The escarpment has been stripped of soil and consists of bedrock and patches of shallow soils where present. Here low density housing and moderate road density probably act together, while steep slopes and high road density probably act independently but give a similar erosion distribution.

In 1979 the observed erosion distribution was dominated by classes 3, 5 and 6, showing an elevated erosion status. The dominance of gullying over sheet and rill erosion was apparent. Results from the factor analysis show that the observed distribution was highly associated with medium and high density housing, grazing land, high road density, high erodibility, and the Molteno and Elliot rock types. With an increase in the number of land uses, slopes no longer show an effect as a controlling factor. From this result one can infer that changes from a low to a relatively higher erosion status were determined by the association of natural catchment characteristics with urban land use.

The second trial factor for 1979 is closely associated with cropland, and low and moderate erodibility. The resultant erosion distribution is dominated by erosion classes 2, 3 and 4, which can be considered less severe than classes 5 and 6. In both 1961 and 1979 cropland was associated with less severe erosion.

In 1985 the observed erosion distribution was dominated by erosion classes 2, 3, 5 and 6. The derived factor responsible for the observed distribution was highly positively associated with high road density, and negatively associated with low road density and low erodibility. The second factor for 1985 is associated with low density housing, medium density housing, high erodibility and Molteno rocks. Erosion distribution is still dominated by gully erosion.

An examination of Table 25 shows that there are a number of catchment characteristics which are components of the major controlling factor combinations at each date. Some of these factors such as erodibility, road density, and to a lesser extent housing density are significant in all three time periods. For purposes of brevity, only those factors which load significantly on the observed erosion distribution are discussed in detail.

SOIL ERODIBILITY

The prevalence of erodibility as an erosion promoting factor is in keeping with Rooyani (1982) who noted that the duplex soils of the Lesotho lowlands have high erodibilities and are heavily eroded. The present study assumes constant erodibilities throughout the study period, since there is no evidence of any changes to the erodibilities of the catchment soils through time. While working in the Ciskei, Weaver (1988c) reported significant relationships between soil erosion and soil type. An examination of soils in the Maqalika catchment reveals a close relationship between soil types and their respective erodibility values. Duplex soils have the highest erodibilities, followed by semi-duplex soils, and other soils with "normal" profile formation (CDT, 1979).

ROAD DENSITY

Results from the hand factor analysis, Table 25 show that road density loads high as a factor associated with erosion. Where present, high road density is positively associated with high erosion status, and negatively associated with low erosion status, while low road density is negatively associated with high erosion status and vice versa. The effect of roads on erosion in Lesotho were recognized by Sheddick (1954) who reported that:-

> "...over-riding regional considerations there exists a virulent form of erosion which occurs all over the country. It may generally be ascribed to "public convenience". Under this head, by far the most destructive item is roads..... In time these earth roads and paths become too deep for comfortable use and the traffic moves further over on to the grassland. It is a common site to see metalled roads parallaled by a dozen or more of such tracks, the oldest of which may already be erosion gullies" Sheddick (1954), pp49-50.

Road erosion manifests itself in a number of ways determined by road construction and management. Erosion of the road surface resulting in deep rills as shown in Plate 5 occurs where road drainage is poor or absent (Nir, 1983), especially when the road runs downslope providing an opportunity for collection and concentration of water. The sequence of events leading to road erosion in the Maqalika catchment is similar to that described by Garland (1983) who ascribed road surface erosion to friction between the surface and wheels of vehicles.

Increases in the density of poorly constructed roads imply that there will be increases in the areal extent and intensity of road erosion. An intricate network of rills develop where the road runs across the slope. Water collecting on the road surface or in an inefficient road drain flows over the side of the road forming rills that run downslope, Plate 6.

Large parts of the Maqalika catchment consists of duplex soils whose eroding characteristics were described earlier. Subsoil erosion resulting from road cuttings has been observed in the catchment. Road cuttings consist of steep unprotected banks, which create an opportunity for undercutting of the less resistant sub-soil.

Plate 5 Extensive rilling on road surface.

Another form of erosion associated with roads is from unpaved road drains. The drains always cut into sub-soils which erode much faster than the road surface. The drains may sometimes reach gully dimensions as shown in Plate 7. Progressive growth of the gully displaces the road from its original course. Omuta (1986) suggests that areas with open surface drains tend to have wider and more numerous gullies than areas without any stormwater control devices, or where devices are covered. Omuta's study concluded that in the absence of covered pipeline stormwater devices, no road drains should be constructed because they promote more erosion than where there is complete absence of drains. Inspection of erosion units in the catchment for the presence or absence of roads drains reveals that there are only two paved drains, and one is covered. The rest of the stormwater devices are unpaved and uncovered resulting in severe rilling which sometimes develops into gullies.

Plate 6 Parallel rills developing on a road side.

Footpaths are present in large parts of the settled area, in between settlements, along and between long winding roads. Footpaths have been observed to develop into rills which displace the original footpath a few metres from its original course. This displacement of footpaths like that of roads (Sheddick, 1954), results in the formation of parallel footpaths. Consequently a large number of footpaths develop into deep rills or even gullies creating a badland, Plate 8. It should be noted that roads and footpaths are conducive to high runoff generation, hence the association with gullying rather than sheetwash. Roads therefore enhance transport due to increased drainage capacity.

Plate 7 Road drain developing into a gully.

Plate 8 Parallel footpaths and rills developing into gullies.

HOUSING DENSITY

Housing patterns and housing densities in the lowlands of Lesotho, especially in the peri-urban areas are a direct manifestation of rapid growth in population and the increasing rural-urban migration (Mateka, 1987; Makatjane and Lesaoana, 1988; Peko, 1988). It has been mentioned earlier that some of the sub-urban areas of the Maqalika catchment are among the most densely populated areas in Lesotho. Peko (1988) mentions shelter as one of the basic needs required by this population, and Mateka (1987) reports that in a bid to obtain shelter in the form of housing, large parts of the cultivated land were transformed into residential sites. In the Maqalika catchment decreases in the areal extent of cropland and subsequent increases in housing land are further confirmation that urban residential development is encroaching on agricultural land. Problems associated with the transformation of agricultural land to urban residential land in Lesotho are well documented by workers such as Mosaase (1988), Nkhahle (1988) and Peko (1988).

Results of the factor analysis do not show very clearly which class of housing density is associated with high or low erosion classes. In 1961 the only form of housing was low density housing (LDH) which was associated with low classes of erosion such as 2 and 3. In 1979 both medium and high density housing, acting together with some characteristics of the natural physical environment were associated with severe erosion. In 1985 none of the housing components were associated with the major trial factor. An interesting point about 1985 is that both low and medium density housing were closely associated with the second trial factor resulting in classes 3, 5 and 6. High density housing was not associated with any of the trial factors.

The observed variable effect of housing density on erosion may be explained in terms of construction activity in the housing area. Construction activity is a short term high intensity phenomenon that changes location (Walling and Gregory, 1970). Taking high and medium density housing as examples, results of the factor analysis show that positive associations with erosion were much higher in 1979 and lower in 1985. It is possible that the present high density settlements were in the process of construction in 1979, and are now stabilized. Construction activity seems to have been transferred to lower density settlements, hence one would expect increased erosion on lower density housing.

Changes in the location of construction activity and its associated erosion problems are important to the application of erosion control measures. Daliaire (1976) draws attention to the importance of erosion and sediment control measures at construction sites and concludes that such measures should be applied to the site where they are needed and at the correct time which is in phase with construction activity.

SEDIMENT SOURCES, SINKS AND TRANSPORT MECHANISMS.

All erosion, deposition and transport features mapped in Figure 38 are sub-components of the geomorphological model described in Chapter 2. These features occur in conjunction with human land use practices which have been identified as factors affecting geomorphological processes. The purpose of this discussion is to determine whether the described geomorphological model applies to the present study area, and to note which components of the model have been modified by catchment characteristics, both natural and human, as recorded in Maqalika catchment.

SEDIMENT SOURCES

Sediment sources have been identified and mapped in Figures 36, 37 and 38. Sediment sources include all forms of surface disturbance and detachment of soil particles. Such disturbances include all forms of erosion, extraction of raw materials and excavations for construction activity. Erosion features identified in the Maqalika area are sheetwash, rills, gullies and pipes.

Erosion features

Sheetwash

Sheetwash has been identified as a sediment source and was observed throughout the catchment save for the airport and sports grounds (Figures 19, 20 and 21). All classes of sheet erosion, ranging from none apparent (class 1) to severe (class 4) were recorded. The 1961 and 1979 photography indicate that severe sheet erosion was typical of footslope pediments bordering the escarpment and on top of the escarpment where rockstripping is extensive. A similar form of sheet erosion distribution was reported by Lunden *et al.* (1986) in a number of catchments in the Lesotho lowlands. Lunden *et al.* (1986) suggest that the steep escarpment slopes and the concentration of surface and subsurface drainage are probably responsible for severe sheet erosion on the footslope pediments. Severe sheet and rill erosion were also observed around homesteads and communal taps. Severe sheet erosion progressed and expanded onto the formerly cultivated valley bottom. This has occurred mainly on duplex soils which have been exposed to housing development.

Rill erosion

Rills are always associated with severe sheet erosion, to the extent that rills are sometimes interpreted as an advanced stage of sheet erosion, and hence rills and sheetwash are usually described together. Rill erosion is more pronounced than sheet erosion, and it is concentrated in certain parts of the catchment, mainly along footpaths, downslope of roads and around homesteads. Like sheet erosion, severe rilling was initially concentrated on the foot of pediment slopes, but with the establishment of settlements, rills have become widespread throughout the catchment. Rills act as sources of sediment in two ways. Firstly the initiation of new rills provides sediment, and secondly, the expansion of existing rills whether in depth or width provides sediment ready for entrainment. Rills also act as a transport system for sediment eroded by sheetwash from interill areas.

Gully erosion

"Gullies are the most spectacular features of the landscape in lowland Lesotho..." (Rooyani, 1982a, p1). This is so for the Maqalika catchment which is truncated by a number of gullies extending from the reservoir or main channel through colluvial material in the valley bottom, to steep debris slopes with shallow rocky soils (Figure 6). These gullies were already present in 1961 (Figure 36) and have not been extended headward. Extension of the gully system is prevented by the presence of bedrock very close to the surface. This pattern of gully development was reported by Strömquist *et al.*(1985) and Lunden *et al.* (1986), in the lowlands of Lesotho, and seems to be common in other parts of the world. Higginson (1973) working in the Hunter valley in Australia notes that most gullies were formed and expanded upslope following drainage lines. These gullies were prevented from expanding by the presence of bedrock in the drainage line. Gullies have been identified as sources of sediment since the floor and walls are constantly eroding. Moreover it has been stated earlier that the expansion of the gully network has not been through headward extension of original gullies, but through the initiation of new gullies acting as tributaries. The formation of new gullies was through the transformation of rills into gullies. This is in keeping with Selby (1982) and Morgan (1986), who suggest that one way of gully formation is through the deepening and expansion of rills.

Sediment from gullies also comes from gully walls which are constantly eroding due to undercutting. Wide U-shaped gullies are a common feature of duplex soils in Lesotho (Rooyani, 1982a). These gullies result from undercutting of the compact and less resistant substratum, and the subsequent slumping of the resistant capping. Stages in the undercutting process leading to the formation of U-shaped gullies are shown in Plates 9 and 10.

Plate 9 Gully wall showing undercutting of the subsoil.

Plate 10 Gully wall showing the resistant top soil capping.

In Plate 9 a gully wall is shown with its distinctive strata. The erodible subsoil is exposed to running water, and gets eroded, leaving the relatively resistant topsoil capping at some height above the gully floor (Plate 10). A height of about 2,3 metres was measured from the gully floor to the bottom of the resistant capping in one of the catchment gullies. Due to further undercutting and wetting of the gully wall, and the pressure caused by the weight of the capping, slumping of the capping is inevitable. Varying sizes of slump blocks are deposited on the gully floor. Some blocks become disaggregated due to impact, and provide loose material ready for entrainment. Some blocks are deposited on the gully floor as big chunks which may not be easily entrained. With time these blocks become rounded due to runoff slowly removing some particles from the blocks. Some of the blocky material is quickly colonized by vegetation, contributing to the stabilization of the gully floor. Chakela (1981) notes that this aggradation of the gully floor may result in reduced slope gradient and more deposition.

Gully expansion through undercutting of the gully was not observed in some gullies. Some of the gullies on duplex soils seemed to have stabilized both headward and sideways. Sideways erosion is impeded by buildings, gardens and tree plantations which have been developed in the intergully areas (Table 27). Chakela (1981) notes that in some cases undercutting is limited by the fact that the gully may have become so wide that concentrated flow was not possible. This is true for the main channel draining Maqalika catchment. In some parts this channel is very wide, and has scoured to bedrock. New incisions on the gully floors are uncommon in the catchment. Only one gully was observed to have been incised after stabilization by gully bottom fills.

Piping

The erodibility of duplex soils of Lesotho has been described by Schmitz (1980), Rooyani (1981) and Faber and Imeson (1982) who suggested that the physical properties of the soil create an opportunity for pipe formation. Pipes were observed on some of the gully walls in the valley bottom, as shown in Plates 11 and 12. Pipe roof collapse was observed in gully No. 2, (Table 28). This gully has two branches, both of which seem to have developed through pipe roof collapse. The inter-branch area remains intact while the branches are connected by several tunnels about 30 to 40cm in height. Piping has been reported in other areas of Lesotho in studies such as those by Schmitz (1980) amd Chakela (1981), who noted that pipe roof collapse was responsible for the initiation of new gullies.

Plate 11 A pipe outlet on gully wall.

Plate 12 A pipe outlet; loose sediment is being removed from the pipe for purposes of building.

Extraction of raw materials

As suggested by Douglas (1983) and Nir (1983), the extraction of raw materials is an integral part of most cities, especially the housing components, or residential areas. This is also the case in the Maqalika catchment. A number of raw materials used in the construction of buildings and roads were discussed in Chapter 3. Brickmaking pits and the sandstone quarry were easily identified on aerial photographs. Areas of sandstone crushing scattered through the foot of the debris slope and at the top of the escarpment were not identifiable on aerial photographs. Some of these areas were recognized during field inspection.

Brickmaking

Brickmaking has been identified as an important sediment source through the excavation of soil from burrow pits, and the disposal of unwanted bricks, and brick pebbles into the reservoir. This activity is common along the western shore of Maqalika reservoir where there are deep clayey soils, and an abundance of water. Brickmaking land covers approximately 0,1km^2. This is not a major land use in terms of areal extent, but as a sediment source this activity and its associated structures contribute appreciable amounts of sediment. The importance of brickmaking in the Maqalika catchment is highlighted by the fact that some of the brick making pits are dug less than a metre away from the reservoir bank. In one instance the reservoir bank receded by about 1,5m due to pit digging. The "man made" tree pedestal shown in Plate 13 gives an idea of the amount of digging that has taken place around the "pedestal'.

In other areas burrow pits are neither protected nor restored during and after extraction. These pits are situated on relatively flat land downslope of a steep debris slope and act as traps for runoff coming from upslope. The walls of the pit become saturated with water while the surface around the pit is covered with vegetation as shown in Plate 14. Undermining of the walls occurs, followed by slumping of the vegetated and relatively resistant capping. The pit increases in surface area resulting in a shallow pond with deposition of sediment at the bottom. A typical pit measured in the field was about 1,8m deep, and about 2 to 3m^2 in surface area (Plate 14). At this depth soils are more compact than at the top, and digging becomes difficult. The pit is then abandoned for a new one a few metres away from the old one. The process continues until part of the slope is covered with numerous pits collecting water from upslope. In some instances the narrow strip of land between two adjacent pits collapses due to the pressure of water in the upslope pit. The two or more pits coalesce to form a long pond that progressively grows into a channel leading to the reservoir (Plate 15).

Plate 13 "Tree pedestal" on reservoir bank.

Plate 14 Brickmaking pit.

Plate 15 Two pits coalesce to form a long pond.

During pit digging, soil from the pits is not used immediately, but is left unprotected next to the pit for long periods of time. Subsequent rainfall events sweep the soil off and transport it downslope into the reservoir. The quantity of soil removed from the burrow pits may be computed from pit dimensions, but the quantity which is not used in brickmaking is not known. The unknown quantity always finds its way into the reservoir. Burrow pits are concentrated around gullies with extensive piping. This is probably because pipes provide loose material which is easier to dig. This is another way by which pipe erosion has been aggravated on some gullies draining into the reservoir. In a densely populated area pits filled with water are not just undesirable as sediment sources but are also environmental hazards in terms of safety. Legislation pertaining to land use in the whole country does not include any clauses on the restoration or protection of such burrow pits.

Quarrying

Quarrying is another land use activity which acts as a sediment source. The Lancer's gap quarry which has been described earlier is the only quarry identified in the study area. Though the total surface area of the quarry is small the degree of land disturbance is considerable because the quarry is a result of mechanised earth movement. The quarry has been abandoned and is no longer in use for the extraction of aggregates (LSPP, no date,a). However the near vertical walls are eroding and depositing coarse talus material at the bottom of the quarry, Plate 16. The quarry drains directly into one of the main gullies draining the catchment. Deposits from the quarry are mainly cobbles and gravels which are expected to be deposited near their source.

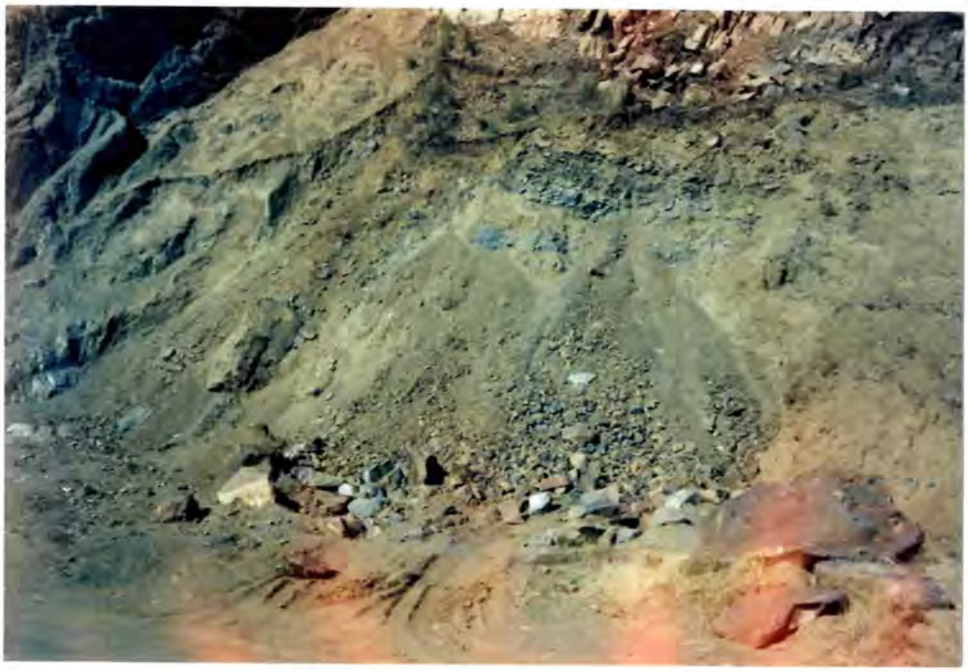

Plate 16 Deposition at quarry bottom.

Sandstone crushing

Sandstone crushing is another important activity which amounts to land disturbance in the Maqalika catchment. Headward gully retreat occurred as a result of the removal of sandstone boulders at the gully head, Plate 17. Some of these boulders, embedded in a matrix of sand and silt play a role in checking headward extension of gullies. Some of the sandstone is removed from gully floors where they had been acting as an armour protecting the gully floor.

Plate 17 Sandstone boulders protecting gully head.

Construction activity

Maqalika catchment is mainly a residential area, hence most construction activity is related to housing development. There is no planned land development (Shaw, 1986), and this results in small scale development of residential sites by individual owners. Sediment production from individual sites is relatively less since there is usually no large scale mechanization. In the present study area the sequence of events starting from the time the piece of land is acquired, to the time the site has been developed is important in determining erosion and sediment production.

In the first instance, the typical newly acquired site is on former agricultural land which has been cultivated for a long time, and probably eroded to a certain degree. On conversion to residential development, the land in question may be left fallow for years before any form of development takes place. Although the Land Act of 1979 states that newly acquired land should be developed within 18 months from the date the title deeds were received, the aforementioned transformation of agricultural land to residential land is usually illegal, and escapes the attention of the authorities responsible for land use planning. It is therefore difficult for land planners to monitor construction activity or any form of development on such land. The end result is usually fallow cropland which gets eroded very easily due to lack of vegetation cover.

Coleman and Scatena (1986) note that the period of surface disturbance is important to construction activity. The longer the period of disturbance the higher the potential of sediment production and transport. Due to lack of prior planning and shortages of financial resources, site owners may take a number of years before completing site development. There is presently a large number of sites where construction activity was abandoned just after excavations for foundations.

An important component of housing development in the Maqalika catchment and other peri-urban areas of Maseru where there are no services, is the construction of pit latrines. Pit latrines are important to sediment production since earth material removed from the pits is piled next to the pit and may become swept away by runoff. This material finds its way into stormwater drains and gullies which transport sediment downstream towards the reservoir. It is also common practice to construct a pit latrine on a gully side. This tendency is not only undesirable as a health hazard but also disturbs the already unstable gully sides.

SEDIMENT SINKS

Sediment sinks include all forms of depositional areas such as ponds, gullies, reservoirs, stormwater drains and relatively flat parts of the valley. It has been noted that channel deposition is more pronounced than off channel deposition.

Valley deposition

Off-channel deposition was observed at relatively few portions of the Maqalika catchment. As shown in Figures 33, 34 and 35 deposition was observed in flat areas downslope of former field boundaries and terraces which constitute sharp slope breaks. The deposited sediment comes from construction sites which are situated on former cropland. Other notable areas of off-channel deposition are behind hedges, fences and buildings which act as sediment traps. Vegetation colonies such as those developing where there is an abundance of water also act as sediment traps. Most of the sediment however becomes re-entrained very easily since deposition is not confined within boundaries. From this observation one may infer that off-channel deposition has a short residence time, hence it appears to be limited in distribution.

Channel deposition

Channel deposition in the Maqalika catchment occurs in the form of gully bottom fills and in artificial channels such as stormwater drains. Information obtained from gully profile surveys (Tables 27 and 28) and aerial photo interpretation (Figure 38) reveals that most deposition occurs in the lower reaches of the gully system as opposed to the upper reaches. This observation should be expected as it has been mentioned that most gullies are no longer cutting headward since they have cut into bedrock. The absence of deposited sediment in the upper gully reaches is due to two factors. Firstly deposition is limited by supply as shown in the sediment routing diagram (Figure 41). There is very limited sediment supply upslope of the gully heads and debris slopes. Secondly the gully heads are situated mainly on the lower parts of the debris slopes which constitute the steepest parts of the catchment. Debris slopes are exposed to torrential runoff which does not allow any form of deposition. Gully bottom fills increase in depth downslope towards the reservoir gully confluences and gully junctions where they reach maximum depths. On gully 2 (Figure 6) gully bottom fills merge on to a delta formed on a small pond. A depth of 0,9m was measured (Table 28).

A closer examination of gully bottom fills shows that some are stabilized with vegetation, mainly Kikuyu grass, while some are covered with old car bodies which are used as conservation measures. Stabilized gully fills act as traps for more sediment. New incisions quickly develop where gully fills have not stabilized or where there is torrential runoff. One such gully was observed in the Maqalika area downslope of a culvert (Table 28). The reactivated gully floor is situated about 30m from Maqalika reservoir.

Gully deposition also occurs upstream of check dams which are used as conservation measures (Plate 18). In some cases vegetation quickly colonizes the trapped sediment and forms a more efficient sediment trap. In some cases however check dams are poorly constructed and not maintained hence they become destroyed and allow sediment to pass through. Conservation measures such as sediment traps modify the geomorphological model described in Chapter 2. Conservation measures tend to increase the sediment residence time in temporary storages, so that sediment transfer from one sink to another takes a longer time.

Plate 18 Check dam within gully.

Deposition has been observed in gullies and drains upstream of and within culverts. Culverts restrict water and sediment movement resulting in deposition upstream of the culvert. Stormwater drains also get choked with sediment. This is especially so in drains which run across the slope and trap sediment from road surfaces and construction sites.

An accumulation terrace was observed immediately downstream of reservoir 2 (Figure 41) which is almost filled with sediment. The reservoir is presently trapping very little sediment and allowing large quantities of sediment to pass through. Due to the height of the dam wall which is causing a waterfall effect, large quantities of sediment are deposited immediately downslope of the reservoir, and form an accumulation terrace. The observed accumulation terrace shows a typical cut and fill mechanism (Schumm and Harvey, 1974; Gryta, 1986) whereby the deposited sediment becomes stabilized with vegetation, but becomes reactivated when there has been flooding.

The sandstone quarry at Lancer's gap (Figure 41, Plate 3) acts as a supply and store of sediment. Large quantities of coarse sediment are stored on the bottom of the quarry, which has formed a pond. Although some parts of the quarry are steep enough to enhance particle entrainment, most of the particles are coarse gravels which do not become entrained very easily. The quarry provides an example of local sedimentation described by Chakela (1981) in which sediment is deposited relatively close to its source.

Reservoir/ pond deposition

There are a number of small garden and stock watering reservoirs and ponds which act as sediment traps. Some of these reservoirs are very small and fill up with sediment very quickly. With time these reservoirs may no longer be regarded as sediment traps but conduits. There are two reservoirs constructed on two main gullies draining Maqalika catchment (Figure 6). Both these reservoirs are reported to be almost filled with sediment (Ntsiki and Mokone, 1986), and hence their trap efficiencies have decreased. Maqalika reservoir acts as the main sediment sink of the catchment.

Changes in erosion and deposition through time

Some sediment sources and sinks have been observed to change both in magnitude and position on the landscape. Both positive (increases) and negative (decreases) changes were recorded in the two periods 1961 to 1979 (Figure 39), and 1979 to 1985 (Figure 40). Some rills and tributary gullies which were present in 1961 (Figure 36) disappeared in 1979 (Figure 37). The apparent disappearance of rills and tributary gullies is due to the ability of urban development to mask certain erosion features. Rill obliteration on one part of the landscape was followed by the initiation of new rills elsewhere, most probably where construction activity was initiated. There have been notable increases in rill and gully erosion along the Main North Highway and the main road leading to the top of the escarpment. There has been a progressive increase in rill and gully erosion throughout the period of study on the western part of the catchment, near Maqalika reservoir. The south western part of the catchment comprises the brickmaking area whose erosion problems have been described earlier.

A comparison of the 1961 to 1979 map (Figure 39) to the 1979 to 1985 map (Figure 40) indicates that initially depositional features were spread in varying degrees through the lengths of gullies. With time these depositional features have been migrating slowly downstream, hence the apparent disappearance of deposition features in the upper reaches of the gully system.

TRANSPORT MECHANISMS

Sediment movement from sources to sinks takes place from the watershed to Maqalika reservoir. Three forms of transport have been observed. Firstly there is off-channel movement which takes place as divergent overland flow outside channels. Secondly there is concentrated flow within defined channels such as rills, gullies and stormwater drains which are directly connected to the drainage network. Thirdly there are transport features which are not connected to the drainage network, but sometimes connect catchment sinks. An examination of the sediment routing diagram (Figure 41) and the drainage and topography map (Figure 6) show that major channelization of the catchment occurs downslope of the debris slopes and the 1600m contour. Transportation from the watershed to the edge of sandstone scarps is by way of divergent flow which is not expected to carry large quantities of sediment. The area between the watershed and the debris slopes has limited sediment supply due to rock stripping on the eastern watershed and the uneroded airport and sports ground on the west.

Debris slopes are the steepest parts of the catchment (Figure 10) experiencing torrential runoff from the sandstone scarps above. This is where flow lines converge downslope, especially in concave depressions. Debris slopes as described earlier are covered with boulders, shrubs and shallow soils which do not encourage local erosion. However the torrential runoff from these slopes does cause erosion problems downslope. Flow lines converge downslope to form gully heads which enhance transport capacity (Figure 41).

Gullies in conjunction with gully pipes constitute channels with the most well defined boundaries. Morgan (1986) contends that because of their size and depth gullies are efficient sediment transporters. In the study area the gully network extends from the lower parts of the debris slopes to the Maqalika reservoir. Gully depth ranges from 50cm to about 3m. The efficiency of the gully system is limited by the flat to gentle slopes which account for 80% of the catchment (Figures 7 and 15). These slopes favour sediment deposition as opposed to transport.

Rills constitute a form of channelization which enhances transport of sediment downslope. The deposition of sediment immediately downslope of extensively rilled slopes (Figure 38) is an indication that the sediment was either transported from upslope through rills, or comes from the initiation and growth of rills. Rills occur in areas of severe sheet erosion and hence the rills act as conduits for sediment coming from sheet erosion. The gully profile surveys (Tables 27 and 28) show that rills also occur in conjunction with gullies, providing transport through the gully micro-catchments, and the intergully areas.

Roads and road drains constitute a form of efficient channelization similar to that of gullies. These "man-made" channels enhance the sediment delivery capability of the catchment. Roads and stormwater drains whether paved or unpaved comprise hard impervious surfaces which do not permit vegetation growth but encourage concentrated runoff. The road running from the Main North Highway from Maseru to the top of the Berea Plateau, through Lancer's gap (Figure 14) acts as a conduit for runoff and sediment coming from the top of the escarpment. Footpaths and stock tracks between homesteads and reservoirs and boreholes, also act as conduits for water and sediment.

SEDIMENT SOURCE CAPABILITY RATING: AN ASSESSMENT OF PRODUCTION AND DELIVERY.

When examining sediment source problems it is expedient to include an analysis of transport mechanisms in order to determine whether the produced sediment poses any threat to downstream structures or activities. A study by Dickinson *et al*, (1984) indicates that some areas might exhibit erosion problems yet they do not present sediment problems when delivery is poor. Results of the sediment source capability assessment used in this study are in agreement with Dickinson *et al.* (1984). Results from the assessment are presented in Tables 29 and 30 and Figure 42. These results further support Coleman and Scatena's (1986) suggestion that areas with the greatest erosion severity are not necessarily areas with the greatest sediment problem. A comparison of column 2 and column 4 of Table 30 reveals that an erosion unit with the highest SARCCUS classification such as No. 30 does not necessarily have the greatest sediment yield capability.

For the purposes of brevity and clarity the discussion on sediment source areas will focus on 4 groups of areas as described by Dickinson *et al.* (1984). (i) Erosion units that exhibit severe sheet erosion and have a high sediment yield capability rating, (ii) units with severe erosion but a low sediment yield capability, (iii) units with limited erosion and limited sediment capability, and (iv) units with limited erosion but showing a high potential for sediment yield.

Group I: units with severe erosion problems and a high sediment yield capability.

Erosion units 3, 13 and 13a on Figure 18 are the most severely eroded land units in the whole catchment, and their sediment yield capability is also very high (Table 29). All three units are within the residential area which was formerly agricultural land, and comprises duplex soils. Road density is high, and the observed erosional forms are severe sheet, rill and gully erosion. The highly erodible duplex soils coupled with construction activity give these units a high sediment production potential, while the channels in the form of roads and gullies, and the absence of control measures give these units a high potential for transport. The afore mentioned land units require control measures to abate both on-site erosion damages and downstream sediment problems. As shown by Meade(1982) the application of erosion control measures on a hillslope that has been eroding for a long time may reduce the progress of erosion. However large quantities of sediment stored on the hillside downslope of the eroded area will continue to augment sediment to the stream and reservoir.

Group II: Units with severe erosion problems and low sediment yield capacity.

Erosion units 30, 33, 1a and 16 (Figure 18) are severely eroded, showing signs of extensive loss of top soil, extensive rilling and gullying. Erosion unit 1a is a typical example of an area where sediment yield is limited by supply. The sum of production factors is 0 (Table 29), and hence the sediment yield capability rating of unit 1a is 0. This unit should not be classified as a sediment source even though it is heavily eroded. The unit occurs on top of the escarpment where there has been extensive rockstripping and very limited shallow soils. The area does not produce any sediment presently. The erosion unit however has no control measures, and efficient transport features which give it a high potential for transport. Units 30, 33 and 16 also have erosion features and general characteristics that enhance transport while production is limited by resistant soils and the establishment of vegetation. Erosion within these units seems to have been active sometime back and has since stabilized, however the scars of past activity are still visible.

Group III: Limited erosion and limited sediment yield capability.

Erosion units 20, 20a, 27, 32, 19 and 15 (Figure 18) show a high level of land management. Surface conditions of the airport and sports grounds, unit 20, and the agricultural research station, unit 20a, have been described earlier. Both are situated on relatively erosion resistant soils, on almost flat planation surfaces on the watershed. Both areas are fenced and may be regarded as government reserves, and hence they are not exposed to population problems such as footpath erosion, construction activity or overgrazing. Erosion units 32 and 15 are almost flat and situated on the watershed in an area with resistant soils. Land use comprises high density settlement which is relatively older and stabilized with well established gardens. Roads show a relatively higher level of maintenance than in other parts of the catchment. Unit 19 is also situated on the watershed which is almost flat. Parts of this unit are still cultivated while some parts are being converted into residential sites. This unit has soils of medium erodibility, vegetation in the form of crops, and the land is contoured. These factors give the area a low sediment production potential (Table 29). Unit 27 is a wooded plantation on a debris slope downslope of the airport. This unit has resistant soils protected by a woodlot. Moreover the debris slopes have shallow stony soils which are protected by boulders and shrubs. The unit has a low sediment production potential.

The afore mentioned land units provide examples of different forms of land management that may promote erosion and sediment control. Amimoto (1981) provides a comprehensive methodology for erosion and sediment control. Among all methods mentioned, the establishment of protective vegetation appears to be the easiest to implement and maintain.

Group IV: Limited erosion but high potential for sediment yield.

Erosion units 1, 14, 5a, 29, 36, 38, 46 (Figure 18) are slightly eroded under the present land use. With changing land use, these units might present erosion and subsequent sediment problems. These units are situated in intergully areas and are being transformed from cropland to settlements. Some of these units are on highly erodible duplex soils but their erosion status is low because of the maintenance of croplands, limited or no construction activity, and flat to gentle slopes (Table 29). The afore mentioned units should be managed with utmost care because they have a potential problem which may be triggered by minor changes in land management. The observed changes from cropland to housing could provide a trigger mechanism that would depict the units as sediment source problems.

CATCHMENT SEDIMENT YIELD AND EROSION RATES.

The average rate of soil erosion in the catchment of Maqalika dam between 1983 and 1988 has been estimated at $18{,}1t.ha^{-1}.yr^{-1}$ (Table 31). This value corresponds to a ground lowering rate of $1{,}1mm.yr^{-1}$, assuming even distribution of erosion throughout the catchment and a bulk density value of $1{,}7g.cm^{3}$. In the ensueing discussion the relevance of the estimated erosion rate is discussed in comparison with "acceptable" rates of erosion, geological rates and rates obtained elsewhere.

An acceptable rate of erosion, or soil loss tolerance is defined as the greatest amount of erosion that can take place without a decline in productivity (Morgan, 1980). Soil loss tolerance values or T-factors of soils in the Maqalika catchment range between 2 and $9t.h^{-1}.yr^{-1}$, as shown in Table 7. This range falls within that of 2 to $11t.h^{-1}.yr^{-1}$ suggested by Hudson (1971). The estimated erosion rate of $18{,}1t.h^{-1}.yr^{-1}$ is in excess of the highest T-factor of catchment soils. The concept of soil loss tolerance is based on or derived from estimations of agricultural productivity. As mentioned earlier the Maqalika dam catchment is undergoing rapid urbanization, and agricultural land is being lost to urban land use. If this trend continues at the present or faster rate the catchment will ultimately be completely built up or used for urban related purposes only. If this be the case, the discussion based on soil loss tolerance related to agricultural productivity will be irrelevant. Blaikie and Brookfield (1987) suggest that a geomorphological process like erosion is termed degradation only if it disturbs one or more functions of the land in question. The main function of Maqalika catchment presently is urban residential development, therefore discussions on degradation in the catchment should focus on the major function which is being disturbed. Kirkby (1980a) recommends a maximum permissible soil loss value of $25t.ha^{-1}.yr^{-1}$ for construction sites which is slightly greater than the estimated value of $18{,}1t.ha^{-1}.yr^{-1}$. However it should be mentioned that the estimated soil loss value is only a minimum value which does not take into consideration large quantities of soil stored in hillside depressions and gully bottoms. Due to observed sediment storage within the catchment, the estimated soil loss value could be much higher in the event of an abnormal flushing event.

Since most catchments have multiple functions, discussion on degradation in such catchments should not focus on any one land use but on some common factor which is pertinent to all functions of the catchment. To achieve this, "..some workers have used geological rates of erosion as benchmark figures against which contemporary erosion rates can be compared" (Weaver, 1988b, in press). Dunne (1979) notes that due to the present intensive human occupation of the land, it is difficult to find areas in which geologic rates of erosion can be evaluated. However Douglas cited in Dunne (1979) reported sediment yield values of $1{,}15t.ha^{-1}.yr^{-1}$ in Australia in catchments that were selected to avoid as much human disturbance as possible. Dunne (1979) reported geologic rates of 0,2 to $3{,}0t.ha^{-1}.yr^{-1}$ in undisturbed Kenyan catchments, Murgatryod (1979) estimated the geologic rate of erosion in the Tugela Basin, Natal at $0{,}16t.ha^{-1}.yr^{-1}$. The estimated erosion rate in the Maqalika catchment is higher than geologic rates obtained elsewhere.

Soil erosion rates which combine both geologic and accelerated erosion have been measured in other Lesotho catchments, and world wide. Examples of these rates are presented in Table 32. Comparisons of the Maqalika catchment erosion rate to rates obtained elsewhere must consider the fact that different methods of measurement yield slightly different results. Another point worth considering is that rates in small catchments can be higher than in large catchments. Le Roux and Roos (1979) note that small catchments have a high possibility of being covered by a single storm, and being exposed to concentrated human activity.

Table 32 Soil erosion rates in Lesotho and elsewhere.

Catchment	Region	Area km^2	Rate t.h^{-1}.yr^{-1}	Source	Type of measure-ment
Little Caledon Basin	Lesotho Lowlands	945,0	19,8	Jacobi (1977)	B
Roma Valley (upper reaches)	Lesotho Lowlands	26,0	3,4	Chakela (1981)	A
Roma Valley (lower reaches)	Lesotho Lowlands	0,5	17,0	Chakela (1981)	A
Maliele catchment	Lesotho Lowlands	6,3	3,5	Chakela (1981)	A
Ha Khitsane Catchment	Lesotho Lowlands	6,2	61,0	Lunden *et al.*, (1986)	C
Mathokoane Catchment	Lesotho Lowlands	10,2	22,0	Lunden *et al.*, (1986)	C
Orange River Basin	Lesotho Highlands	varies	0,09-2,1	Makhoalibe (1984)	B
Orange River Basin	South Africa	666,0	8,9	Rooseboom (1982)	B
Bulbergfontein dam catchment	Southern O.F.S.	4,77	0,46	Le Roux and Roos (1982)	A
Roxeni Basin	Ciskei	11,4	113,0	Weaver (1988b)	A
Ikowa Catchment	Tanzania	6,2	16,0-57,0	Christianson (1981)	A
Various Kenyan Catchments	Kenya	8,51	20,0-200,0	Dunne (1979)	B

Key: A - reservoir survey
B - suspended sediment measurement
C - photographic measurement.

The estimated erosion rate in the Maqalika catchment is within the range of 3,4 to 61,0t.h^{-1}.yr^{-1} reported in a number of studies in the Lesotho lowlands (Table 32). Makhoalibe (1984) notes that the lowland catchments of Lesotho yield more sediment than the highlands because of differences in erodibilities of the underlying soils, geologic material and population pressure. Makhoalibe's study goes on to indicate that within the highland catchments differences in sediment yield do occur due to changes in land use. However the popularly held belief that the lowland areas of Lesotho are more prone to erosion than the highlands has been questioned in a study by Chakela and Stocking (1988) who showed that the mountain areas of Lesotho have a higher erosion hazard despite the lower aggressivity of rainfall. The study further draws attention to the fact that "the lowlands have suffered years of mismanagement which accounts for the past history of severe soil erosion....If similar mismanagement had been effected in the mountains, our erosion hazard analysis indicates that the result would have been catastrophic" (Chakela and Stocking, 1988, pp187).

The problem of land management or mismanagement is further accentuated by a comparison of the estimated value of $18,1t.h^{-1}.yr^{-1}$ for the Maqalika catchment, and other values for the Lesotho lowlands to the value of $0,46t.h^{-1}.yr^{-1}$ reported by Le Roux and Roos (1982) for the Southern Orange Free State. The Western lowlands of Lesotho are continuous with lands in the Southern Orange Free State (Figure 5), and have nearly similar soil groups; however sediment yield values in the Lesotho catchments are in some cases about fifty times higher than those of the O.F.S. The differences may not be explained by pure physical factors alone. The Lesotho lowlands and the O.F.S. are divided by a political border only. It should therefore be expected that the differences in erosion and sediment yield are due to differences in land management practices which are determined by social, political and economic problems experienced in the Lesotho lowlands. Problems of overpopulation which result in overgrazing (Mokhothu, 1988) and uncontrolled human settlements (Peko, 1988) are a common feature of the Lesotho lowlands. The conversion of agricultural lands into uncontrolled and unserviced sites stems from the lack of planning on the part of the government machinery and lack of cooperation on the part of local inhabitants who do not have an alternative means of survival. Migrant labour is one aspect of the socio-economic structure in large parts of Lesotho which has been widely researched (Crush and Namasasu, 1982), and found to be a major contributing factor to the present shift from agricultural land use to settlements.

Le Roux and Roos (1982) note that the reliability of erosion rate arrived at using the present and similar studies may be questioned due to the rather short life of the sediment trap. The representativeness of the sediment trap depends on the type and frequency of events that are responsible for geomorphic processes in the area under study. Le Roux and Roos (1982) argue that if processes are a result of extreme events which are probably infrequent then data from short term sediment measurement become irrelevant. However if processes are a result of frequent flows of moderate magnitude then the data from short term measurements can be relied on. This implies that reliability of the data is also dependent on the representativeness of the time period of study.

Sediment delivery ratio

No attempt was made to quantify the sediment delivery ratio (SDR) of Maqalika catchment. However a qualitative description may be presented, based on the evaluation of sources, sinks and transport mechanisms. Although there is severe erosion in large parts of the catchment (Figure 21), this does not imply that all the eroded spots are active sediment sources. The sediment rating capability procedure (Tables 13 and 29) shows that in those parts of the catchment with steep slopes favouring runoff, sediment yield is limited by supply, while some parts which have a high supply of sediment, movement is limited by low transport efficiency. Sediment storage within the catchment was not quantified, however an examination of deposition mapping (Figure 38) shows that large quantities of sediment are stored within the catchment, especially as gully bottom fills in the lower reaches of the gully system (Table 27 and 28). From these observations one may infer that at present the sediment delivery ratio of the catchment is low.

The sediment delivery ratio of a catchment varies both spatially and temporally (Walling, 1983). In the Maqalika catchment spatial variability seems to be controlled by slopes. SDR is higher in the upper reaches of the gully system which are much steeper than the lower reaches. On the question of temporal variation, rainfall is one of the major controlling factors. An examination of the annual rainfall data (Figure 12) shows that there is a recurring pattern of dry periods followed by wet periods. The present study was undertaken towards the end of relatively dry period. If the dry period is followed by a relatively wet period sediment stored in the catchment would be readily swept downslope towards the catchment outlet.

Urban land use with all its associated structures influences both the spatial and temporal controls of SDR. Urban land use increases the efficiency of catchment drainage so that any sinks could be converted into sources of supply leading to increased sedimentation of reservoirs downstream. The reactivation of gully bottom fills downstream of a defective culvert is further confirmation that certain urban structures aggravate erosion and sediment movement. It may therefore be expected that with more urban expansion (spatial), and urban concentration (temporal) the sediment delivery ratio of the catchment will increase, with a subsequent increased sedimentation of Maqalika reservoir.

SOCIO-ECONOMIC CONSEQUENCES OF EROSION AND SEDIMENTATION.

The total lifespan of Maqalika reservoir has been estimated at 201,8 years, while the useful life is 100,9 years. These values assume a constant rate of sediment yield throughout the reservoir's lifespan. "Determination of the useful life of a reservoir is an important design parameter which may crucially affect the economic feasibility of a water resources project..."(Gill, 1979, p1). It should be noted that the useful life value was estimated from five years' data and the analysis of rainfall (Figure 12) shows that since dam construction in 1983 annual rainfall figures have always been below average. The rate of sediment yield and the concentration of sediment in runoff may increase with increasing rainfall amounts. In terms of downstream effects (off-site costs), the present estimated erosion rates do not pose any threat to the useful life of the reservoir.

The estimated catchment erosion rate has been shown to be way above the soil loss tolerance for agricultural productivity, and approaching the maximum allowable soil loss value for construction sites. Land use changes from 1961 to 1985 indicate a reduction in cropland and an increase in grazing land. Some cropland has been lost to urban development, while some was lost to grazing land by way of abandoned fields. Most of these lands are void of grasses which would make them productive grazing lands, or give them some aesthetic value.

Erosion undermines the aesthetic value of land (Nir, 1983). The present study did not attempt to measure the aesthetic or economic value of land in the catchment. The large gully systems and absence of vegetation tend to deprive the land of its value and thereby disturbing the land market where present. Severely eroded land requires methods of reclamation in the form of land levelling and revegetation. These methods become a burden to the developer who more often than not will employ the easiest and cheapest methods of reclamation. Plate 19 shows a gully that has been filled with loose sediment from construction upslope. This form of gully filling is common in the residential area of Maqalika catchment where there is a shortage of residential sites. The mass of sediment shown in Plate 19 may take time before it becomes colonized by vegetation, and thus provides loose material which is ready for entrainment downslope.

Plate 19 Gully filled with loose sediment from a construction site.

Gullying does not only undermine productivity and aesthetic value, but also has a bearing on the cost of road maintenance. Gullies that cut across roads or vice versa require culverts to maintain road continuity. These culverts add to the overall expense of the road construction. Road drains which become gullies sometimes migrate in the direction of the road, undermining the paved road surface and result in road collapse. Re-surfacing of the road is inevitable, as was the case with the Main North Highway which was re-surfaced in 1985. Thus gullying has had a direct effect on the cost of maintenance of the highway.

CHAPTER SEVEN

CONCLUSIONS AND RECOMMENDATIONS

Sequential surveys of Maqalika catchment have provided a re-construction of the history of erosion and land use in the catchment, and thus the first aim of the study has been achieved. In terms of this aim it can be concluded that there have been increases in both the areal extent and severity of erosion throughout the study period 1961 to 1985. During the same period Maqalika catchment changed from rural to a predominantly urban status. Most of the land use change occurred during the period 1979 to 1985 which was also marked by increased population and uncontrolled growth in the general peri-urban areas of Maseru. Presently the most extensive form of land use is residential urban development which occupies former cropland on the valley bottom. There has been a notable shift from low to relatively high erosion status in areas experiencing land use changes. Slight sheet erosion persists on cropland, while severe sheet and rill erosion persist on construction sites associated with urban development.

It was not possible to derive any meaningful relationships between erosion and land use because of the multiplicity of factors affecting erosion, as well as the various combinations of factors. The hand factor analysis shows that the distribution and severity of erosion are controlled by different combinations of factors from time to time. Throughout the three study dates soil erodibility was found to be a component of all major combinations. The highly erodible duplex soils of the Lesotho lowlands, Sephula and Maseru Series are widespread in the Maqalika catchment, and wherever they occur these soils are characterized by dense systems of gullies.

The study further shows that whereas the highly erodible duplex soils are an important contributor to erosion, their use or misuse aggravates the problem. A change from natural grassland or scrub to cropland and haphazard construction activity results in a higher incidence of erosion. Road density seems to be the most important land use component determining erosion in the Maqalika catchment. There has been a notable incidence of rill and gully erosion across and along roads. The greater the road density the higher the incidence of rill and gully erosion. This should be expected as most of the roads are poorly constructed and the road cuttings are not protected. Road erosion becomes more pronounced on duplex soils whose sub-strata are vulnerable to undercutting. A combination of poorly constructed roads and duplex soils provides conditions which are conducive to severe erosion.

Housing densities also play a role in explaining the observed erosion distribution. Medium and high density housing which were absent in 1961, were components of the major controlling combination in 1979. This should be expected as this was the beginning of intense construction activity. Construction activity changes location and is more pronounced in the early stages of the development of a settlement. Construction activity which was going on in the medium and high density settlements in 1979 was probably stabilized by 1985 and transferred to low density housing. It can therefore be concluded that the level and extent of construction activity are important factors of erosion in the urban *enviroment. Other components of the physical *enviroment such as slopes and geology were important during 1961 when the catchment had a relatively low erosion status and limited urban land use. On the one hand urban land use in the form of construction sites is associated with sheet and rill erosion, which constitute sediment sources. On the other hand urban structures such as roads and road drains are associated with gullying and severe rilling which provide a more efficient transport mechanism.

Major areas of sediment production (sources) have been identified as construction sites, road sides and surfaces, gully walls and sites for the extraction of raw materials. The absence or removal of vegetation from these sites further elevates their potential as sediment sources. Major sediment sinks are gully bottom fills in the lower reaches of the gully system, reservoirs constructed along certain channels, stockwatering ponds and depositional areas at slope breaks. Off-channel sinks are not as extensive as sinks that occur within channels and reservoirs. Presently the two reservoirs constructed as sediment traps on the two main channels are not acting as sinks but as conduits for sediment. These reservoirs are almost filled with sediment and their trap efficiencies are reduced. Transportation of sediment from sources to sinks follows three routes. Firstly there is off channel transportation whereby sediment is entrained by overland flow. Secondly there is channelized transportation which takes place within gullies and road drains which are directly connected to the drainage network delivering into Maqalika reservoir. Thirdly there is transportation within channels that do not have any link with the drainage network, but link sources to certain catchment sinks. The upper reaches of the gully system have been found to be the most efficient form of transport, while the lower reaches are poor transporters. The road network which is more dense in the valley bottom enhances the efficiency of the lower gully reaches. It has been observed that although at present most of the eroded sediment does not reach the catchment outlet, but becomes deposited as gully bottom fills, urban development and its associated structures may reactivate the sediment and enhance transportation in the near future.

The sediment yield capability assessment indicates that areas which have a very high sediment yield capability comprise a small percentage of the total catchment area. Suggestions by Mosley (1980) and Coleman and Scatena (1986) that only a few areas contribute the bulk of sediment holds true for Maqalika catchment. Sediment yield from the catchment is limited by availability or transport. The most severely eroded areas are not necessarily the most important sediment sources at the present day. This observation has a bearing on the choice and application of control measures. For purposes of erosion and sediment control in the Maqalika catchment, areas identified as having the greatest erosion and sediment yield problems should be given the highest priority when implementing control measures.

There is a rapid rate of soil loss from the catchment as shown by an estimated sediment yield figure of $18,1t.ha^{-1}.yr^{-1}$. This rate of erosion is more important to on-site than off-site damage. Off-site damage in the form of sedimentation of Maqalika reservoir has been found to be minimal at present, as signified by the estimated reservoir useful life of 100,9yrs. On-site erosion damage is determined in terms of "acceptable" erosion rates and in comparison to erosion rates obtained elsewhere. The rate obtained in the Maqalika area is much higher than the "acceptable rates", but falls within the range of other areas in the lowlands of Lesotho. The high rates of erosion in the Maqalika catchment and other areas of lowland Lesotho may be attributed to poor land management in the form of the conversion of agricultural land to urban land use without prior planning.

The study has managed to identify problem areas and quantify sediment yield and erosion rates. At this point one may be able to suggest appropriate control measures from a wide documentation of control measures such as those by Hudson (1971), Amimoto (1981) and Rooyani (1982a). If attempted, the application of control measures on individual sites would be complicated by the fact that development of the sites is illegal and unrecorded in land planning projects. As shown by Mateka (1987) and Mosaase (1988) the implementation of legislation to control land development has failed in many parts of peri-urban Maseru, this also applies to Maqalika catchment. Uncontrolled site development is always followed by unplanned road development comprising poorly constructed roads and stormwater drains which lead to erosion. It is beyond the scope of this study to decide on legislation pertaining to land use in the catchment, but it can be concluded that the present legislative structure has failed to curb uncontrolled residential urban development. The failure manifests itself in unrecorded and unmonitored site and road developments which have been shown to promote erosion. Although brickmaking pits cover a small area of the catchment their impact as sediment sources is substantial. There does not seem to be any record and control of the brick making area which is expanding very rapidly. In its present state the area requires methods of protection and restoration. Legislation similar to that applied to mining (The mining rights Act of 1968) which among other things requires that on cessation of mining at any site, the land be substantially restored to its prior condition by the holder of the mining lease, should also apply to brickmaking, quarrying and other forms of land disturbance that would render the land unsuitable for any other use. The brickmaking area is severely eroded and has turned into a badland.

Apart from the identification and assessment of geomorphological processes and forms, this study has helped, indirectly, to assess certain methods of research and analysis for their relevance to erosion study. For instance the conventional use of aerial photographs was aided by an extensive use of oblique photographs which helped to show certain erosion and deposition forms at close range. Sequential oblique photography should be used more extensively in soil erosion research to monitor those processes and forms that are not depicted on aerial photographs. It has been possible to analyse erosion factors using a non-parametric and non-computer dependent method of hand factor analysis whose advantages were outlined in Chapter 4. This method is scarcely used in geography as it was developed for the analysis of repertory grids in Psychology (Potter and Coshall, 1986). Having analysed erosion factors in the same area at three different periods, it has been possible to show that erosion problems and their causative factors change from time to time. This also has a bearing on control measures which may differ from one period to another.

The study has also supported earlier suggestions by workers such as Cambell (1986) that sediment yield at the catchment outlet does not always give a true rate of catchment erosion. Furthermore sediment yield does not show areas of major sediment production. While well aware of the inherent problems of the sediment delivery ratio concept, the use of such an index would give a more reliable estimate of erosion rate. This concept should be included perhaps as an exploratory method in erosion rate measurements using sediment yield. Reservoir trap efficiency is used extensively to determine the quantity of sediment trapped in or passing through the reservoir. Catchment trap efficiency should be given an equal or similar priority in determining sediment trapped in and sediment passing through the catchment.

The study has provided an analysis of sources in terms of their past, present and probable future activity. The sources have also been evaluated in terms of their capability to supply sediment. This analysis coupled with the identification of factors or combinations of factors affecting erosion is important to the choice, timing and application of control measures and to land use planning which is important in preventing erosion.

While the measurement of sediment yield at the catchment outlet or any other control point is a well explored method of research, quantification of source areas and temporary storages remains a relatively neglected area of research. Quantification of sediment supply, movement and storage within the catchment should be included in sediment yield measurements. This would require knowledge of interacting processes and forms such as the various components of the geomorphological model. Results from the hand factor analysis may be used as field based methods of deciding which factors are important in a particular area. It remains a difficult task to study the various components of the geomorphological model in detail within the framework of the present research. Quantification of processes is difficult, moreover processes are slow and variable over space and time. Detailed small scale studies of each component of the erosion and deposition problem would be ideal, but would have to be parts of a larger research project.

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APPENDIX 1

A LIST OF SOIL SERIES ACCORDING TO CDT (1979), CARROLL AND BASCOMBE (1967), BINNIE AND PARTNERS (1972), U.S.D.A. TAXONOMY AND THE S.A. BINOMIAL SYSTEM.

CDT (1979)	Carroll and Bascombe (1967)	Binnie and Partners (1972)	U.S.D.A. Taxonomy	South African Binomial System
Maseru Series	Claypan soils of Maseru set	Duplex soils	Typic Albaqualfs	Rosemead series of the Escourt form.
Sephula Series	Claypan soils of Sephula set	Duplex soils	Aeric Albaqualfs	Estcourt series of the Estcourt form.
Berea Series	Fersiallitic soils of the Berea set	Berea Series A	Aquic Dystrochrepts	Oatsdale series of the Clovelly form.
Maseru dark variant	Intergrade between vertisols of topographic depressions and claypan soils	Phechela or Maseru Series	Cumulic Haplaquolls	Emfuleni series of the Willowbrook form.
Ntsi series	Lithosols on sedimentary rocks	Lithosols	Lithic Udothents	Mispah series of the Mispah form.
Rama Series	-	-	Aquic argiudolls	Intergrade between Estcourt series of Estcourt form and the Oatsdale Series of Clovelly form.
Thoteng Series	-	Berea Series A	Typic Udipsamments	Maputa series of Fernwood form.
Matela Series	-	-	Typic Hapludolls	Mayo series of the Mayo form.

APPENDIX 2

A LIST OF SCIENTIFIC PLANT NAMES WITH CORRESPONDING SESOTHO AND ENGLISH NAMES.

Scientific	Sesotho	English
Aloe polyphylla	Lekhala-la-thaba	Aloe
Aristida congesta	Lefielo/ Lemanamana	Poverty grass/ Stick grass
Aster fillifolius	Leholo/ Sehalahala	Karro bush
Chenopodium album	Serue	White goose foot
Chrysocoma tenuifolia	Sehalahala	Bitter Karro bush
Datura stramonium	Letjoi	Stinkweed
Eragrostis capensis	Seriana/ Senana	Blue grass
Eragrostis chloromelas	Seritsoane/ Moseeka	Love grass
Eragrostis curvula	Seritsoana/ Motola	Weeping love grass
Eragrostis plana	Selile/ Molula	Drop seed grass
Festuca caprina	Boleane/ Letsiri	Sour grass
Homernia pallida	Teele	Bulbous plant
Hyparrhenia hirta	Mohlomo	Thatching grass
Koeleria cristata	Boshoane	Mountain June grass
Leucosidea sericea	Cheche	Oudebos (A
Pennisetum clandestinum	-	Kikuyu grass
Populus alba	-	Poplar
Rosa rubiginosa	Khunoane	Rose hip
Salix capensis	Moluoane	Willow
Tagentes minuta	Lechuchutha	Blackjack
Themeda trianda	Seboku	Red oat grass
Xanthium spinosum	Hlaba-hlabane	Spiny clot-bur
Jacot-Guillarmod (no date)	Jacot-Guillarmod (no date)	
Staples and Hudson (1938)	Staples and Hudson (1938)	
Schmitz-Ruch (1984).	Schmitz-Ruch (1984).	

APPENDIX 3

DATA ON EROSION PROMOTING FACTORS IN EACH EROSION UNIT.

1961

EROSION UNIT	EROSION CLASS	AREA	FREQ	LAND USE	SOIL SERIES	K-FACTOR	SLOPE CLASS	ROAD DENSITY	GEOLOGY
1	1	0,28	14	C	Md	0,33	1	0,0	3
2	2	0,59	30	C	Th	0,24	1	0,0	3
3	3	0,26	13	C	Rs	-	2	0,0	3
4	5	0,28	14	G	Sc	0,76	3	0,0	2
5	3	0,28	14	G	Rs	-	1	0,0	2
6	5	0,14	7	G	Rs	-	1	0,0	2
7	6	0,28	14	G	Sc	0,76	1	0,0	2
8	6	0,24	12	G	Md	0,33	1	0,0	2
9	2	0,55	27	C	Sc	0,76	1	0,1	2
10	2	0,58	29	G	Rs	-	2	0,2	2
11	5	0,22	11	G	Sc	0,76	2	0,1	2
12	6	0,10	5	C	Sc	0,76	1	0,0	2
13	5	0,09	5	G	Sc	0,76	1	0,3	2
14	6	0,26	13	C	Sc	0,76	2	0,4	2
15	6	0,12	6	C	Md	0,33	1	0,6	2
16	2	0,28	14	C	Md	0,33	2	0,3	2
17	3	0,31	15	C	Ba	0,40	1	0,0	2
18	5	0,26	13	C	Me	0,79	1	0,0	2
19	5	0,06	3	G	Me	0,79	1	0,1	2
20	4	0,06	3	SL	Me	0,79	1	0,8	2
21	6	0,24	12	G	Me	0,79	1	0,1	2
22	5	0,04	2	C	Rm	0,24	2	0,1	2
23	4	0,11	6	SL	Rm	0,24	1	0,6	2
24	5	0,05	3	C	Me	0,79	2	0,6	2
25	3	0,14	7	C	Me	0,79	2	0,3	2
26	2	1,25	62	C	Ba	0,40	1	0,0	2
27	3	0,75	38	C	Me	0,79	1	0,1	2
28	4	0,12	6	C	Rm	0,24	1	0,1	2
29	6	0,24	12	C	Rm	0,24	1	0,0	2
30	3	0,68	34	C	Rm	0,24	2	0,1	2
31	6	0,10	5	C	Rm	0,24	2	0,3	1
32	4	0,08	4	C	Rs	-	1	0,6	3
33	4	0,10	5	C	Me	0,79	1	0,0	2
34	5	0,10	5	C	Ba	0,40	1	0,3	2
35	6	0,06	3	C	Ba	0,40	1	0,0	1
36	2	0,30	15	C	Rm	0,24	1	0,0	2
37	3	0,08	4	G	Rm	0,24	1	0,0	2
38	1	0,32	16	A/s	Ba	0,40	2	0,0	2
39	6	0,10	5	G	Ba	0,40	1	0,0	2

1961

EROSION UNIT	EROSION CLASS	AREA	FREQ	LAND USE	SOIL SERIES	K-FACTOR	SLOPE CLASS	ROAD DENSITY	GEOLOGY
40	3	0,12	6	G	Ba	0,40	1	0,0	2
41	3	0,20	10	G	Ba	0,40	1	0,0	2
42	3	0,12	6	G	Rm	0,24	2	0,0	2
43	4	0,09	5	G	Rm	0,24	2	0,0	1
44	4	0,08	4	SL	Rm	0,24	2	0,6	1
45	6	0,10	5	G	Ba	0,40	2	0,0	1
46	5	0,04	2	G	Ba	0,40	2	0,0	2
47	4	0,06	3	G	Rm	0,24	2	0,0	1
48	3	0,06	3	SL	Sc	0,76	1	0,6	3
49	5	0,03	1	C	Md	0,33	1	0,0	2
50	5	0,04	2	G	Rm	0,24	1	0,0	1
51	6	0,04	2	G	Rm	0,24	1	0,0	1

Geology class: 1 - Molteno Beds
2 - Red Beds
3 - Clarens Formation.

Soil Series: Me - Maseru
Se - Sephula
Mk - Maseru (dark variant)
Rm - Rama
Md - Matela
Nt - Ntsi
Th - Thoteng
Rs - Escarpment/ Rockland

Slope class: 1 - 0^o-5^o
2 - 5^o-15^o
3 - >15^o

Road Density: Low - 0,0 - 0,1 $km.km^2$
Medium - 0,1 - 1,4 $km.km^2$
High - 1,5 - 3,25 $km.km^2$

1979

EROSION UNIT	EROSION CLASS	AREA	FREQ	LAND USE	SOIL SERIES	K-FACTOR	SLOPE CLASS	ROAD DENSITY	GEOLOGY
1	1	0,24	12	C	Md	0,33	1	0,0	3
2	2	0,44	22	C	Th	0,24	1	0,0	3
3	4	0,52	26	C	Rs	-	2	0,0	3
4	5	0,52	26	G	Rs	-	3	0,1	3
5	6	0,20	10	G	Se	0,76	1	0,1	2
6	6	0,28	14	C	Se	0,76	1	0,1	2
7	3	0,38	19	C	Se	0,76	1	1,5	2
8	2	0,16	8	C	Se	0,76	1	0,3	2
9	4	0,12	6	C	Se	0,76	1	0,1	2
10	3	0,32	16	SL	Rs	-	2	1,1	2
11	3	0,16	8	SL	Se	0,76	2	1,1	2
12	5	0,18	9	C	Se	0,76	1	0,6	2
13	5	0,03	2	SL	Se	0,76	1	0,5	2
14	6	0,50	3	SM	Se	0,76	1	1,8	2
15	3	0,62	31	SH	Rm	0,24	1	1,0	2
16	5	0,06	3	SM	Rm	0,24	2	1,0	2
17	4	0,20	1	SM	Me	0,79	1	1,7	2
18	2	0,16	8	C	Se	0,76	1	0,2	2
19	3	0,58	29	G	Ba	0,40	1	1,5	2
20	5	0,04	2	G	Md	0,33	1	0,6	2
21	5	0,26	13	SL	Me	0,79	1	1,6	2
22	4	0,18	9	SM	Me	0,79	2	0,7	2
23	2	0,84	42	C	Ba	0,40	1	0,1	2
24	3	0,34	17	SM	Me	0,79	2	0,6	2
25	4	0,12	6	SM	Mk	0,60	2	0,3	2
26	5	0,06	3	C	Ba	0,40	1	0,2	2
27	3	0,18	9	SL	Ba	0,40	1	0,1	2
28	2	0,18	9	C	Rm	0,24	1	0,1	2
29	1	0,32	16	A/s	Rm	0,24	1	0,0	2
30	5	0,04	2	G	Ba	0,40	2	0,0	2
31	3	0,22	11	SL	Rm	0,24	2	0,5	2
32	4	0,14	7	SL	Ba	0,40	1	0,8	2
33	4	0,08	4	SL	Rm	0,24	1	1,3	2
34	6	0,20	10	SL	Ba	0,40	1	0,9	2
35	3	0,16	8	G	Ba	0,40	1	0,2	2
36	3	0,04	2	G	Rm	0,24	1	0,0	2
37	4	0,26	13	SM	Rm	0,24	2	0,6	2
38	5	0,07	3	SM	Me	0,79	2	0,9	2
39	6	0,18	9	C	Ba	0,40	1	0,2	2
40	6	0,32	16	G	Ba	0,40	1	0,1	1
41	6	0,06	3	C	Rm	0,24	1	0,0	1
42	4	0,12	6	SL	Rm	0,24	2	0,1	1
43	6	0,08	4	G	Ba	0,40	2	0,1	1
44	3	0,02	1	C	Md	0,33	2	1,1	2
45	6	0,10	5	G	Rm	0,24	1	0,1	2
46	3	0,18	9	G	Me	0,79	2	0,2	2
47	6	0,30	15	SM	Rm	0,24	2	1,2	2
48	6	0,18	9	C	Rm	0,24	1	0,0	2

1985

EROSION UNIT	EROSION CLASS	AREA	FREQ	LAND USE	SOIL SERIES	K-FACTOR	SLOPE CLASS	ROAD DENSITY	GEOLOGY
1	2	0,68	34	C	Th	0,24	1	0,0	3
1a	4	0,56	28	G	Rs	-	2	0,1	3
1b	5	0,44	22	G	Rs	-	3	0,3	3
2	5	0,14	7	SL	Rs	-	1	0,7	2
3	6	0,14	7	SL	Se	0,76	1	1,1	2
4	6	0,18	9	SL	Se	0,76	1	1,2	2
5	5	0,24	12	SL	Md	0,33	2	1,2	2
5a	3	0,38	19	SM	Se	0,76	1	1,6	2
6	6	0,12	6	SM	Se	0,76	1	1,4	2
7	3	0,24	12	SL	Se	0,76	1	1,9	2
8	3	0,28	14	SL	Rs	-	2	0,4	2
9	5	0,14	7	G	Se	0,76	3	1,4	2
10	5	0,14	7	SM	Se	0,76	1	1,7	2
10a	6	0,14	7	SM	Se	0,76	1	2,3	2
11	6	0,16	8	SL	Md	0,33	2	2,0	2
12	3	0,26	13	SL	Me	0,79	1	1,6	2
13	5	0,12	6	SL	Me	0,79	2	2,2	2
13a	6	0,38	19	SM	Se	0,76	1	3,0	2
14	3	0,20	10	SM	Se	0,76	1	1,6	2
15	3	0,40	20	SH	Rm	0,24	1	1,9	2
16	6	0,06	3	SM	Me	0,79	2	1,1	2
17	4	0,02	1	SM	Rm	0,24	1	1,5	2
18	5	0,20	10	SM	Me	0,79	1	2,0	2
19	3	0,48	24	SM	Ba	0,40	1	1,7	2
20	1	0,32	16	A/s	Rm	0,24	1	0,0	2
20a	2	0,16	8	C	Rm	0,24	1	0,1	2
21	3	0,06	3	G	Rm	0,24	1	0,1	2
22	6	0,03	2	G	Rm	0,24	2	0,0	2
23	6	0,34	17	G	Ba	0,40	2	0,3	1
24	3	0,08	4	G	Rm	0,24	1	0,5	2
26	6	0,30	15	SH	Ba	0,40	2	1,8	2
26a	3	0,12	6	SH	Ba	0,40	1	1,3	2
27	2	0,06	3	G	Ba	0,40	3	0,0	2
28	6	0,18	9	G	Rm	0,24	1	1,0	1
29	2	0,26	13	SH	Rm	0,24	1	1,5	2
30	6	0,24	12	SH	Rm	0,24	1	0,9	1
31	6	0,02	1	G	Rm	0,24	1	0,0	1
32	3	0,08	4	G	Rm	0,24	1	0,1	1
33	6	0,44	22	G	Rm	0,24	1	0,7	1
34	4	0,12	6	G	Mk	0,60	2	0,1	1
35	3	0,10	5	G	Ba	0,40	1	0,0	1
36	2	0,76	38	C	Ba	0,40	1	0,4	2
37	3	0,06	3	SL	Ba	0,40	1	0,1	2
38	3	0,16	8	G	Me	0,79	2	0,5	1
39	5	0,08	4	G	Me	0,79	1	0,1	1
40	5	0,10	5	SM	Me	0,79	2	1,4	2
41	4	0,04	2	SH	Me	0,76	2	0,8	1
42	4	0,20	10	SH	Rm	0,24	1	0,4	1
43	3	0,12	6	SH	Rm	0,24	1	3,25	2
44	6	0,44	22	SL	Me	0,79	2	1,9	2
46	3	0,06	3	G	Me	0,79	2	1,2	2

APPENDIX 4

AN EXPLANATION OF THE NON PARAMETRIC HAND FACTOR ANALYSIS (Potter and Coshall, 1986).

To prepare a data matrix, the areal extent of each erosion class was measured and recorded on land units exhibiting catchment characteristics listed in Table 11. The resultant data matrices are presented in Appendix 5.

To start the analysis the data are first dichotomized using the mean or median as a threshold value. In the present analysis the median was used because of the highly skewed nature of the data. Erosion classes which have a frequency above the median are marked with a stroke (/) and those below are marked with a dash (-), as shown in Tables 22, 23 and 24. The strokes in each column (erosion class) are summed and presented in row 1To of the data matrix.

To determine which erosion classes are well represented in the catchment at each date, about half of the column totals with the largest number of strokes in row 1To are circled. The circled totals represent erosion classes which are dominant. The dominant erosion distribution is determined by inter-correlations existing between erosion factors listed in the data matrix. To determine the dominant inter-correlations or the dominant single factor responsible for the observed erosion distribution the pattern of circled and uncircled totals in row 1To are compared to the strokes and dashes in each of the rows 1 to 18. To make the matching easier, the circled totals are considered as strokes while the uncircled totals are considered as dashes. The number of times the strokes and dashes of the summary row (1To) match those of the original row is recorded in column 1To which may be positive or negative. The number and sign of matchings indicate the strength and direction of associations between the unknown factor (inter-correlation) and the listed catchment characteristics.

Example (i) Using the 1985 analysis (Table 24).

	Erosion class 1	2	3	4	5	6
Total number of strokes (1To)	5 -	9 /	9 /	7 -	10 /	10 /
Comparison to cropland (row 1)	-	/	/	-	-	-
Matching	+ve	+ve	-ve	+ve	-ve	-ve

Total matching = 3 which is recorded in column 1To.
Therefore cropland does not form part of the major controlling factor combination.

Example (ii)

	Erosion class 1	2	3	4	5	6
Total number of strokes	5 -	9 /	9 /	7 -	1C /	10 /
Comparison to high road density (row 9)	-	/	/	-	/	/
Matching	+ve	+ve	+ve	+ve	+ve	+ve

Total matching = +6 recorded in column 1To.
Therefore high road density forms part of the major controlling factor combination.

The next stage is to determine whether the observed matchings load significantly on the major controlling factor combination (the derived new factor), using the Binomial distribution table adapted from Kelly (1955) (Table A4). Erosion factors which load significantly on the derived factors are marked F in column 1F. In the present analysis high road density (+6) has a high positive association with the derived factor, and also loads significantiy (Table A4). A case where a strong negative association such as -5 which does not load significartly, this row is "reflected", that is treated as if the strokes were dashes and the dashes were strokes. The total number of strokes and dashes in the summary row will change accordingly as shown in row 1T1. This new summary row is then compared to row 1 to 18 to see if a slightly better matching exists. The matchings are presented in column 1T1. There may or may not be any improvement to the matching.

Example (iii) Using the 1985 analysis.

	Erosion class					
	1	2	3	4	5	6
Summary row 1To	5	9	9	7	10	10
	-	/	/	-	/	/
Comparison to low erodibility (row 1o)	/	/	-	/	-	-
Matching	-	+	-	-	-	-

Total matching = -5 (strong negative association).
(column 1To)
Check significance from Table A4:- does not load significantly.

Similar results are obtained for Airport and Sports grounds (row 6), low road density (row 7).

"Reflection"

A/s	-	/	/	/	/	/
low road density	-	-	/	-	/	/
low erodibility	-	-	/	-	/	/
New Summary (1T1)	3	9	12	5	12	12
	-	-	/	-	/	/

Matching with A/s = -4
Matching with low road density = -6
Matching with low erodibility = -6

The same procedure is carried out again with the exclusion of rows which have been labled 1F, meaning that they load significantly on the first unfnown factor, or first major intercorrelation. The second unknown factor is derived in the same manner as the first, showing its dominant erosion distribution in row 2To. The procedure is repeated until no associations are apparent from the data matrix.

Table A4 P-values for the number of cell matches (Kelley, 1955).

No. of Cells in Row	Number of Matches (Arithmetic)																				
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
1	1,00																				
2	1,00	,50																			
3		1,00	,25	*																	
4		1,00	,62	,12																	
5			1,00	,37	,06																
6			1,00	,69	,22	,03															
7				1,00	,45	,12	,02														
8				1,00	,73	,29	,07	,01													
9					1,00	,51	,18	,04	,00												
10					1,00	,75	,34	,11	,02	,00											
11						1,00	,55	,23	,07	,01	,00										
12						1,00	,77	,38	,15	,04	,00	,00									
13							1,00	,58	,27	,09	,02	,00	,00								
14							1,00	,79	,42	,18	,06	,01	,00	,00							
15								1,00	,61	,30	,12	,04	,01	,00	,00						
16								1,00	,80	,45	,21	,08	,02	,00	,00	,00					
17									1,00	,63	,33	,14	,05	,01	,00	,00	,00				
18									1,00	,81	,48	,24	,10	,03	,01	,00	,00	,00			
19										1,00	,65	,36	,17	,06	,02	,00	,00	,00	,00		
20										1,00	,82	,50	,26	,12	,04	,01	,00	,00	,00	,00	
21											1,00	,66	,38	,19	,08	,03	,01	,00	,00	,00	,00
22											1,00	,83	,52	,29	,13	,05	,02	,00	,00	,00	,00

APPENDIX 5

DATA ON THE SPATIAL DISTRIBUTION OF FACTORS AFFECTING EROSION FOR 1961.

	EROSION FACTOR	EROSION CLASS FREQUENCY % 1	2	3	4	5	6	0
	C	4,1	43,0	31,4	3,2	7,0	11,3	9,2
LAND USE	G	0,0	25,2	22,6	9,6	38,3	4,3	16,1
	LDH	0,0	0,0	20,0	80,0	0,0	0,0	0,0
	MDH	NOT	APPLICABLE					
	HDH	NOT	APPLICABLE					
	A/s	100,0	0,0	0,0	0,0	0,0	0,0	0,0
	LOW	6,4	20,8	23,4	6,2	13,1	30,1	16,9
ROAD	MED	0,0	0,0	88,3	11,7	0,0	0,0	0,0
DENSITY	HIGH	0,0	0,0	8,2	91,8	0,0	0,0	0,0
	LOW	17,9	33,1	24,7	10,7	2,8	10,8	14,4
ERODIBILITY	MOD	26,0	42,5	21,2	0,0	4,8	5,5	13,3
	HIGH	0,0	25,7	28,1	4,7	15,7	25,7	20,7
	LOW	10,3	40,9	18,9	7,6	7,9	14,4	12,4
SLOPE	MOD	0,0	26,1	28,8	6,3	9,9	28,8	18,0
CLASS	HIGH	0,0	0,0	96,0	4,0	0,0	0,0	0,0
	MOLTENO	0,0	0,0	6,8	40,0	6,5	46,7	6,7
GEOLOGY	RED BEDS	3,5	31,6	21,6	11,7	14,5	17,1	15,8
	CLARENS	21,9	46,8	25,0	6,3	0,0	0,0	14,1

DATA ON THE SPATIAL DISTRIBUTION OF FACTORS AFFECTING EROSION FOR 1979.

	EROSION FACTOR	1	2	3	4	5	6	Ū
				EROSION CLASS FREQUENCY %				
	C	7,2	33,8	27,9	18,7	9,4	3,0	14,1
LAND USE	G	0,0	1,9	27,1	12,9	19,5	38,6	16,2
	LDH	0,0	7,8	31,7	25,6	5,6	29,4	16,7
	MDH	0,0	0,7	9,0	7,2	21,8	61,3	8,1
	HDH	0,0	0,0	90,0	0,0	2,0	7,1	1,0
	A/s	100,0	0,0	0,0	0,0	0,0	0,0	0,0
	LOW	8,9	25,6	21,5	12,0	9,8	22,2	16,8
ROAD	MED	0,0	4,4	45,9	21,3	11,5	16,9	16,4
DENSITY	HIGH	0,0	0,0	73,8	1,5	2,0	4,7	3,1
	LOW	0,0	18,0	36,6	15,2	11,6	18,6	16,6
ERODIBILITY	MOD	7,8	27,3	30,5	15,6	4,4	14,4	15,0
	HIGH	10,7	10,8	29,5	11,5	4,1	23,4	12,8
	LOW	9,5	27,5	23,3	10,5	8,5	20,7	15,6
SLOPE	MOD	0,0	0,0	44,1	33,3	3,5	19,1	11,3
CLASS	HIGH	0,0	0,0	0,0	16,1	83,9	0,0	0,0
	MOLTENO	0,0	0,0	17,1	6,0	16,0	61,0	3,0
GEOLOGY	RED BEDS	3,5	13,2	25,8	0,2	20,2	20,3	16,7
	CLARENS	6,3	40,4	0,0	27,0	26,3	0,0	13,1

DATA ON THE SPATIAL DISTRIBUTION OF FACTORS AFFECTING EROSION FOR 1985.

	EROSION FACTOR	EROSION CLASS FREQUENCY % 1	2	3	4	5	6	Ū
	C	0,0	100,0	0,0	0,0	0,0	0,0	0,0
LAND USE	G	0,0	7,1	12,4	24,9	30,0	25,6	18,7
	LDH	0,0	0,0	29,6	15,5	26,7	25,2	21,1
	MDH	0,0	0,0	26,5	7,2	31,8	34,5	16,9
	HDH	0,0	5,7	39,9	24,5	8,8	21,1	15,0
	A/s	100,0	0,0	0,0	0,0	0,0	0,0	0,0
	LOW	19,8	24,3	9,5	20,7	9,0	16,7	18,25
ROAD	MED	0,0	17,5	13,9	8,8	23,8	36,0	15,7
DENSITY	HIGH	0,0	18,7	21,4	7,9	18,7	33,3	18,7
	LOW	18,9	26,1	13,8	21,1	12,6	7,5	16,4
ERODIBILITY	MOD	0,0	13,9	49,9	0,0	0,0	36,2	7,0
	HIGH	0,0	0,0	28,4	7,2	35,8	28,6	17,8
	LOW	18,4	19,9	26,6	7,4	9,6	18,1	18,3
SLOPE	MOD	0,0	12,5	16,7	20,5	25,0	26,2	18,6
CLASS	HIGH	0,0	6,9	0,0	0,0	93,1	0,0	0,0
	MOLTENO	0,0	0,0	14,8	5,5	14,2	65,5	9,9
GEOLOGY	RED BEDS	17,5	20,3	25,4	10,1	10,9	15,8	16,7
	CLARENS	0,0	31,1	7,9	30,1	18,7	12,2	15,5

APPENDIX 6

SAMPLE CATCHMENT DATA FORM

Erosion unit No. ....

Lithology ....

Geomorphological unit ....

Soils ....

Slope ....

Erosion unit boundary .... changed .... unchanged ....

SARCCUS erosion class .... Pre-field................ post field ....

Erosion description ....

....

....

Deposition from API ....

Deposition Post field ....

General land use ....

Notes/ comments ....

....

EROSION FEATURES	DEPOSITION FEATURES	TRANSPORT FEATURES
1. Sheet erosion	1. Alluvial terrace	1. Permanent stream
2. Rill erosion	2. Point bars	2. Ephemeral stream
3. Gully erosion	3. Bed deposition	3. Continuous gully
4. Headward erosion	4. Cut off channel	4. Discontinuous gully
5. Streambank erosion	5. Delta	5. Rills
6. Reservoir bank erosion	6. Alluvial fan	6. Storm water drain
7. Downward bed cutting	7. Gully bottom fills	7. Divergent flow lines
8. Diffuse runoff	8. Accumulation terrace	8. Convergent flow lines
9. Concentrated flow	9. Undefined deposition (at slope breaks and vegetation colonies)	9. Pond
10. Slumping		10. Dam wall
11. Rockslide		
12. Rockstripping		
13. Rockland		

LANDUSE	VEGETATION	SOIL SERIES
1. High density housing	1. Forest/ Woodlot	1. Maseru
2. Medium density housing	2. Scrub	2. Sephula
3. Low density housing	3. Grassland	3. Rama
4. Gardens	4. Cropland	4. Maseru (dark)
5. On going construction	5. Weeds/ non-vegetated	5. Matela
6. Cultivation	6. Rocky outcrop	6. Thoteng
7. Grazing		7. Ntsi
8. Dumping site		8. Berea
9. Conservation structures		9. Gullied land
10. Pit latrine		10. Escarpment
11. Quarry		
12. Sandstone crushing		
13. Brickmaking		

LANDFORM UNIT	SLOPE CLASS
1. Plateau	1. $0 - 5^{o}$
2. Debris slope	2. $5 - 15^{o}$
3. Footslope glacis	3. 15^{o} and above
4. Valley glacis	
5. Planation surface	

APPENDIX 7

Particle size analysis using the pipette method (method based on the British Standards Institution, 1975).

Required apparatus

Sampling pipette described by the BSI (1975).
Sedimentation tube
Constant temperature bath (fixed) maintained at 25°C
Mechanical shaker
Standard sieves as follows; 2mm, 600mm, 212mm, 63mm
Thermostatically controlled oven capable of maintaining a temperature of 105°C to 110°C
Balance readable and accurate to 0,01g
Sample divider
Stop clock
Dessicator containing anhydrous silica pellets
1 litre conical beaker with cover glass and small beaker
Centrifuge and centrifuge bottles
100ml measuring cylinder
10ml pipette
Filter funnel about 100mm in diameter
Plastic wash bottle containing distilled water
Glass rod about 150mm to 200mm long
Rubber bung.

Required reagents

Hydrogen peroxide solution
Sodium hexametaphosphate 20 volume solution freshly prepared from 33g of sodium hexametaphosphate and 7g of sodium carbonate and distilled water to make 1 litre of solution.

Pretreatment of soil

A sub-sample of sediment 20g, is obtained by riffling. The sample is placed in a conical beaker, 50ml of distilled water is added and the suspension boiled until the volume is reduced to about 40ml. After cooling, 75ml of hydrogen peroxide is added and the mixture allowed to stand overnight covered with a cover glass. The mixture is then heated gently. When vigourous frothing has subsided, the suspension is boiled until the volume is reduced to about 50ml. The contents of the beaker are transfered to a centrifuge bottle of known weight. The volume of water in the bottle is adjusted to about 200ml and the bottle stoppered and centrifuged for 15 mins at about 2000 rev/min. The clear supernatant liquid is decanted and the bottle and its remaining contents placed in an oven and allowed to dry overnight. The bottle is then restoppered and allowed to cool in a dessicator containing silica anhydrous pellets. When cool the bottle is reweighed and the mass of oven dry pretreated soil (-m) calculated.

Dispersion of soil

100ml of water is added to the centrifuge bottle and the bottle is shaken vigorously until all the sediment is brought to suspension. 25ml of sodium hexametaphosphate is added using a pipette. The suspension is shaken on the mechanical shaker for at least 4 hours. The suspension is then transfered to a 63mm sieve placed on a receiver. The sediment is then washed from the sieve with a jet of distilled water which does not exceed 150ml. The suspension that has passed through the sieve is then transfered to a graduated sedimentation tube using the glass funnel. The volume of liquid is then made up to 500ml with distilled water.

The material retained on the 63mm sieve is transferred to an evaporating dish and oven dried at 110^{o}C. After drying the material is sieved through the 2mm, 600mm, 212mm and 63mm sieves. The retained material in each sieve is transferred to pre-weighed glass bottles and weighed. The mass of dry material retained on these sieves is recorded as the mass of gravel, coarse, medium and fine sand in the sample (Mg, Mcs, Mms, Mfs respectively). The material passing the 63mm sieve shall be added to the original suspension.

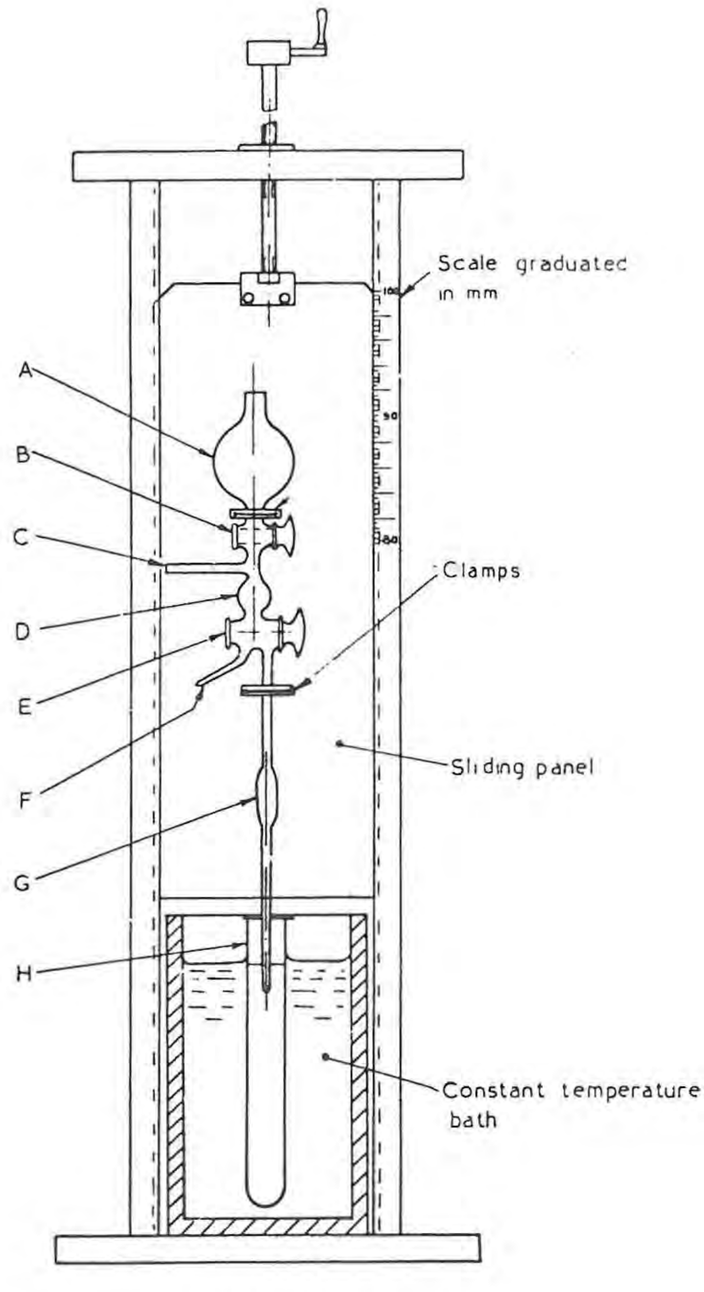
<u>Sedimentation</u> (as shown in Figure A7).

25ml of sodium hexametphosphate solution is added to a graduated 500ml sedimentation tube and diluted with distilled water to exactly 500ml. This sedimentation tube and that containing the sedimentation suspension are transfered to a water bath and stoppered with rubber bungs. The tubes are left immersed in water up to the 500ml graduation mark until they reach the temperature of the bath. The tubes are then taken and shaken by inverting several times and then replaced in the bath.

At the same instant as the tube containing the soil suspension is replaced in the bath the stop watch or clock shall be started. The rubber bungs shall then be removed carefully and laid lightly on the top of each tube.

The pipette with the tap E closed shall be lowered vertically into the soil suspension until the end is 100 ± 1 mm below the surface of the solution. It shall be lowered some 15s before the sample is due to be taken. Great care should be taken to avoid causing any turbulence in the suspension. Approximately 10s shall be taken to complete this operation.

The tap E shall be opened and a sample ($V_p$ml) drawn up into the pipette. The pipette and bore in the tap E shall be filled with the solution and tap E closed. This sampling operation shall take 10s to complete. This procedure shall be carried out at the three sampling times shown in Table A7 below corresponding to the appropriate relative density of the silt and clay particles. The sampling operation shall begin at the times shown from the time the suspension was shaken up.



A and B. 125 ml bulb funnel with stopcock.
C. Safety bulb suction inlet tube.
D. Safety bulb.
F. Outlet tube.
G. Sampling pipette.
H. Sedimentation tube.
D, F and G are joined to three-way stopcock E.

This design has been found satisfactory, but alternative designs may be employed provided the essential requirements are fulfilled.

Figure A-7 Diagram of pipette used for particle size analysis (BSI, 1975).

Table A7 Sampling times for the sedimentation procedure.

Relative density of silt and clay fraction	1st sample		2nd sample		3rd sample	
	min	s	min	s	h	min
2,50	4	30	50	30	7	35
2,55	4	20	49	0	7	21
2,60	4	10	47	30	7	7
2,65	4	5	46	0	6	54
2,70	4	0	44	30	6	42
2,75	3	50	43	30	6	30
2,80	3	40	42	0	6	20
2,85	3	35	41	0	6	10
2,90	3	30	40	0	6	0
2,95	3	25	39	0	5	50
3,00	3	20	38	0	5	41
3,05	3	15	37	0	5	33
3,10	3	10	36	0	5	25
3,15	3	5	35	0	5	18
3,20	3	0	34	30	5	10

The pipette shall then be withdrawn from the suspension (taking approximately 10s to complete the operation).

During the sampling a small amount of the suspension may have been drawn up into the bulb D above the bore of tap E. This surplus shall be washed away into the beaker down the outlet tube F by opening the tap E in such a way as to connect D and F. Distilled water shall then be allowed from the bulb funnel A into D and out through F until no solution remains in the system.

A weighing bottle of known mass shall be placed under the end of the pipette and the tap E opened so that the contents of the pipette are delivered into the weighing bottle by allowing distilled water from the bulb A to run through B, D and E into the pipette. The weighing bottle and contents shall be placed in the oven and maintained at a temperature of 105°C to 110°C and the sample evaporated to dryness. After cooling in a desiccator the weighing bottle and contents shall be weighed to the nearest 0,001g and the mass of solid material in the sample determined (m_1, m_2 and m_3, for each respective sampling time).

Between any of the times in which the above sampling is taking place ($V_p$ml) shall be taken from the sedimentation tube containing the sodium hexametaphosphate solution. This sample of the solution shall be taken as described before except that there is no need to time the operation of taking the solution. The depth of sampling is also unimportant.

The mass of solid material in the sample shall be determined (m4).

Calculations The mass of pretreated soil (m) shall be used to calculate the percentages below.

Fine sieving The calculations are as follows.
The percentage of gravel in the original sample shall be calculated from the following equation:

$$\text{Percentage gravel (over 2.0mm)} = \frac{100m_g}{m}$$

The percentage of coarse sand in the original sample shall be calculated from the following equation:

$$\text{Percentage coarse sand (2.0mm to 0.6mm)} = \frac{100m_{cs}}{m}$$

The percentage of medium sand in the original sample shall be calculated from the following equation:

$$\text{Percentage medium sand (0.6mm to 0.2mm)} = \frac{100m_{ms}}{m}$$

The percentage of fine sand in the original sample shall be calculated from the following equation:

$$\text{Percentage fine sand (o.2mm to 0.06mm)} = \frac{100m_{fs}}{m}$$

Sedimentation The calculations are as follows.

The mass of solid material in 500ml of suspension for each respective sampling time shall be calculated from the equation:

$$W_1 \text{ or } W_2 \text{ or } W_3 \text{ or } W_4 = \frac{m_1 \text{ or } m_2 \text{ or } m_3 \text{ or } m_4}{V_p} * 500\text{g}$$

where

W_1 is the mass of material in 500ml from the first sampling (g);

W_2 is the mass of material in 500ml from the second sampling (g);

W_3 is the mass of material in 500ml from the third sampling (g);

W_4 is the mass of sodium hexametaphosphate in 500ml (g);

V_p is the calibrated volume of the pipette (ml).

The percentage of medium silt in the original sample shall be calculated from the following equation:

$$\text{Percentage medium silt (0.02mm to 0.006mm)} = \frac{W_1 - W_2}{m} * 100$$

The percentage of fine silt in the original sample shall be calculated from the following equation:

$$\text{Percentage fine silt (0.006mm to 0.002mm)} = \frac{W_2 - W_3}{m} * 100$$

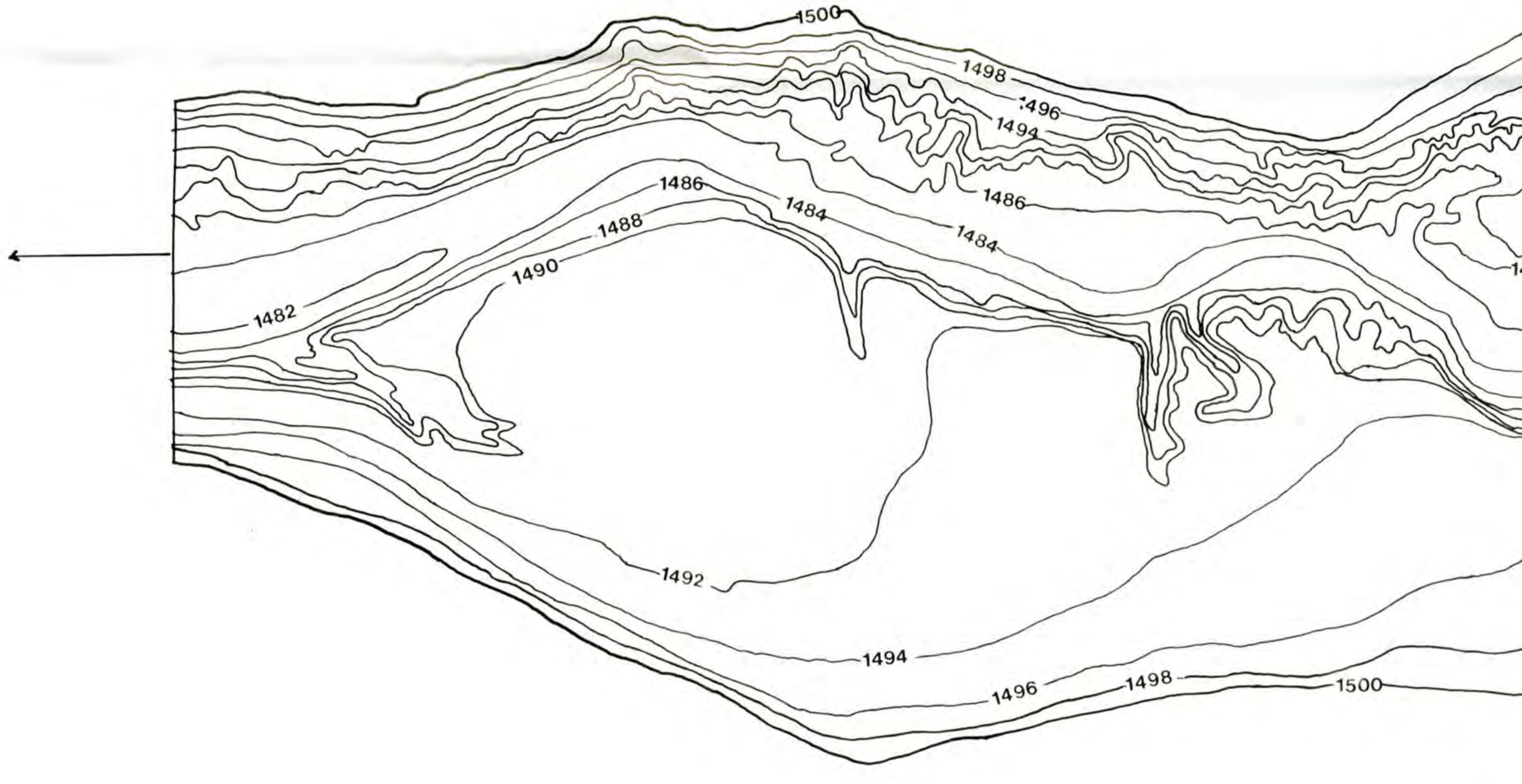
The percentage clay in the original sample shall be calculated from the following equation:

$$\text{Percentage clay (less than 0.002mm)} = \frac{W_3 - W_4}{m} * 100$$

The percentage coarse silt in the original sample shall be calculated from the following equation:

$$\text{Percentage coarse silt (0.06mm to 0.02mm)} = \frac{m - (m_g + m_{cs} + m_{ms} + m_{fs} + W_1 - W_4)}{m} * 100$$

MAQALIKA RESERVOIR PRE-CONSTRUCTION FI



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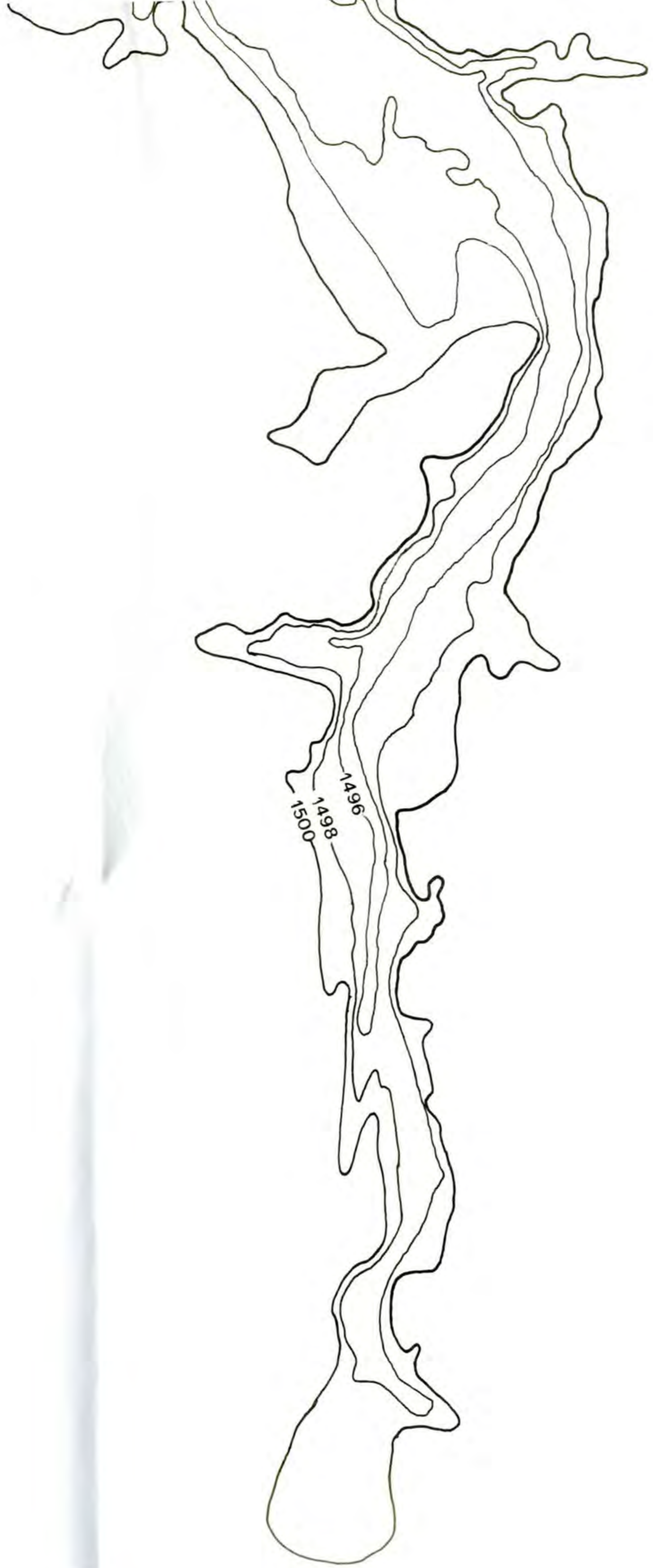
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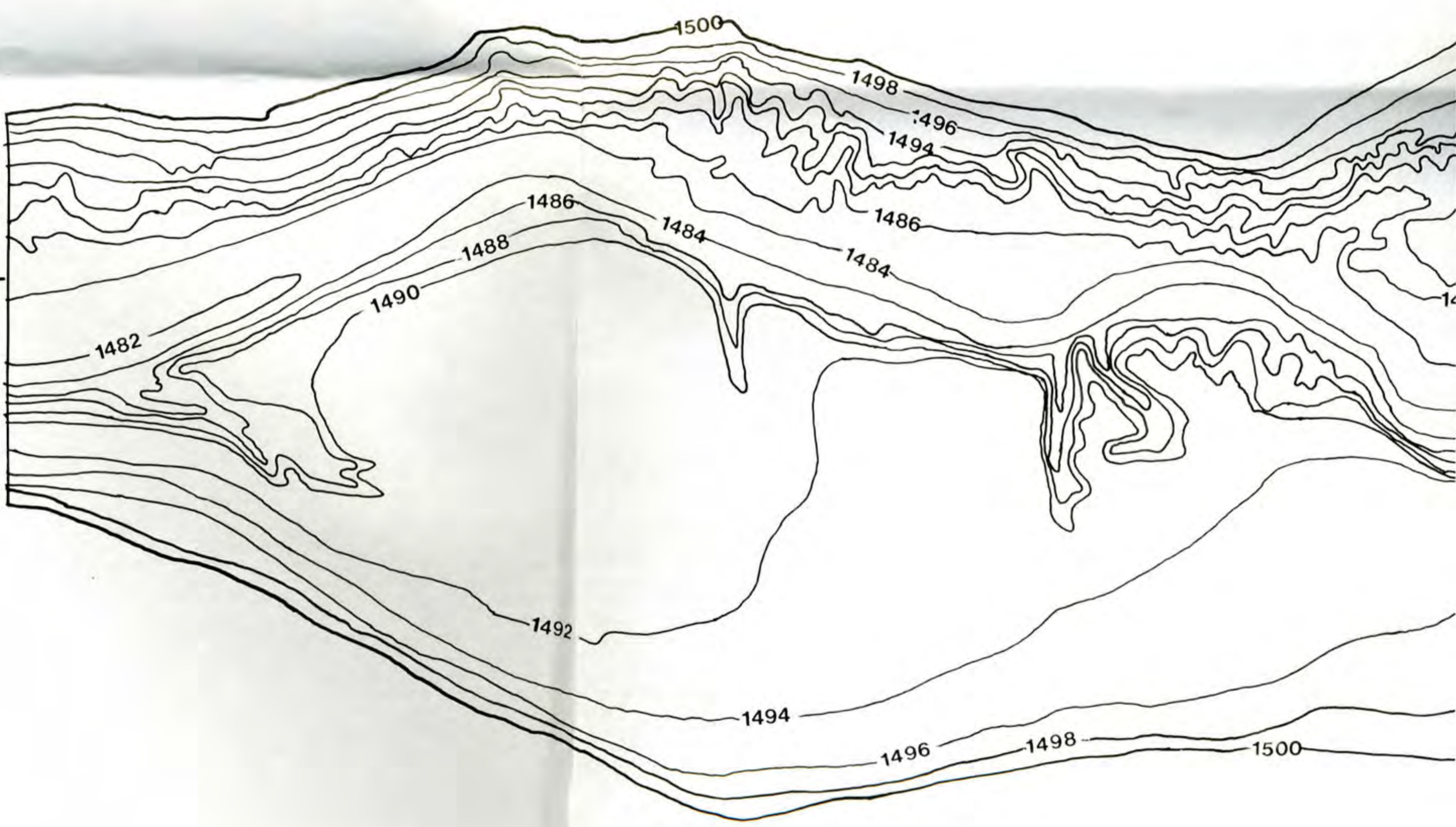
MAQALIKA RESERVOIR PRE-CONSTRUCTION FL



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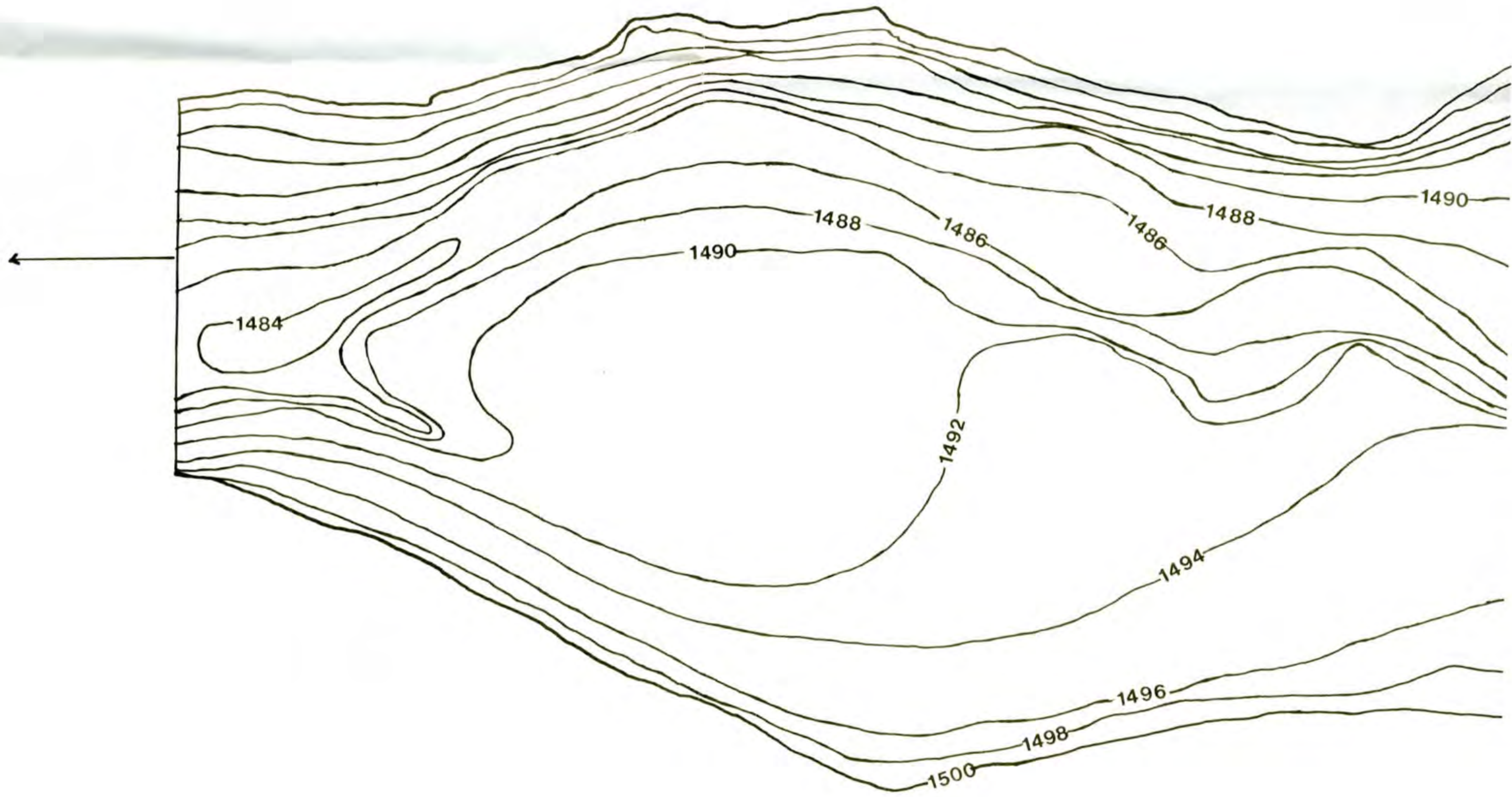
MAQALIKA RESERVOIR FLOOR TOPOGRAPHY FIV



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VERTICAL CONTOUR INTERVAL 2

VE YEARS AFTER CONSTRUCTION.

2 METRES