Land Use Change as a Contributing Factor to Sedimentation Rates in the Hazelmere Catchment, KwaZulu-Natal, South Africa

By

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DECLARATION

The work described in this dissertation was carried out in the Discipline of Geography, School of Applied Environmental Sciences, at University of Natal, Pietermaritzburg, from April 2000 to August 2001, under the supervision of Dr. T. Hill and Prof. H.R. Beckedahl. These studies represent original work by the author and have not otherwise been submitted in any form, for any degree or diploma, to any other University. Where use has been made of the work of others, it is duly acknowledged in the text.

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ABSTRACT

Hazelmere Dam situated on the Mdloti River in KwaZulu-Natal has, since its completion in 1977, lost 25 % of its original design capacity through sedimentation. This storage loss has brought about an environmental concern as well as a socio-economic threat to the region. The aim of this research was to investigate the effect of land use change on the sedimentation rate in the catchment. This was undertaken to obtain a better understanding of the processes and leads towards an integrated catchment management strategy. Geographical information systems afforded the opportunity to determine land use change from a number of sequential land use maps and to run statistical analyses and overlays. It was determined that a large change in land use had taken place between subsistence cultivation/small-scale agriculture and subsistence grazing. The rainfall, soil and slope conditions cause the catchment to have a naturally high erosion potential. As a result of the interrelated nature of all these factors in the catchment the most effective manner in which to deal with the sedimentation problem is through a multidisciplinary approach such as is afforded by integrated catchment management strategies. In terms of controlling the sedimentation problem in the Hazelmere Dam recommendations concerning conservation practices necessary in minimising the impact of the land use practices and changes are made for inclusion in such a management approach.

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CHAPTER 1

INTRODUCTION

1.1. INTRODUCTION TO ENVIRONMENTAL DEGRADATION & MANAGEMENT

All species modify the natural environment to some extent. Humans, however, have had a significant and intense effect (Dollar & Goudie, 2000). Modifications to the natural environment, by human activity, often results in a reduction in plant and animal diversity as well as an increase in the rate of erosion creating a new set of environmental impacts (Mather, 1986). Consequently, human-induced environmental change and the ability to manage the future are now at the centre of modern environmental research (Dollar & Goudie, 2000). Human-induced change, however, has not always been the focus of environmental research despite the realisation of the consequences of degradation to the environment as early as the ninth century BC (Homer, undated). 'Western intellectualism' influenced research up to the 1960s. Society was viewed independent of the environment and human activities were deemed to be beneficial to the environment (Mannion, 1992). Since the 1960s there has been a growing awareness that human activity does affect the physical environment and this in turn impacts on society. This shift in approach was branded a move from 'environmental determinism' to 'human possibilism' (Mannion, 1992). The 'human possibilism' approach examined the manner in which social, political, economic and environmental interrelationships differ by locality. In geography, this approach has had a noteworthy effect on the manner in which research is conducted, with particular regard for the individuality of each location. It is, therefore, imperative that in order to fully understand environmental degradation, one must first acknowledge the relationship between the location properties (terrain, climate, soil properties) and the local society (land use, economics, politics and other social behaviours).

To date, Integrated Catchment Management (ICM) has arguably been the most successful management system, both locally and globally, in the protection of water and land resources while sustaining the needs of the people at the catchment level (Department of Water Affairs and Forestry (DWAF), 1996; Görgens *et al.*, 1998). ICM is the term given to the systems approach to management of natural resources within the confines of a catchment area of a single river system (DWAF, 1996). The advantage of such a management approach is its ability to divide the river system into logical management units at the catchment scale (i.e. the catchment of each tributary or a sub-catchment separated by a dam) which, when sectioned together, create one comprehensive management plan. In order for an ICM strategy to be successful, all aspects of the environment, including economic and social issues, need to be incorporated into the overall management philosophy, process and plan to ensure an optimum combination of sustainable benefits for future generations and communities in the area. At the same time the ICM strategy must protect the natural resources used by these communities and minimise adverse social, economic and environmental consequences (DWAF, 1996).

Management of water is a complex task due to the interactions between land and water, yet it is critical for sustaining life and expanding development (Stoffberg *et al.*, 1992). The specifics of the catchment highlight how particular interactions between the hydrological processes shape the landscape and the way the geomorphological and geological structure of the catchment determines the streamflow response (Rowntree, 2000). For example, the volume of water flowing into the river channel is dependent on the rate and quantity of runoff as well as the water storage capabilities of the land as determined by the climatological, topographical and geological nature of the area (Viessman *et al.*, 1989; Rowntree, 2000). The velocity of runoff determines the size and amount of sediment particles (and related pollutants adhering to these sediment particles) that can be transported by overland flow as well as the suspended or bedload material of rivers, all contributing to the water quality. The sediment trapped within an impoundment is determined by catchment factors that control rates of hillslope erosion and storage at different points in the system, implying therefore, impacts by land management practices, particularly vegetation cover and soil structure (Rowntree, 2000). Thus, the most detrimental impacts on rivers are often a consequence of land management practices.

The water quality reaching the river is important when taking into account the treatment cost necessary to provide a safe resource to the people. One of the key-controlling variables to water quality is sediment. Sediment in itself, although harmless in terms of water quality, creates a negative aesthetic appeal to the water user and therefore requires that it be removed in the treatment of the water for consumption. Sediment also provides a transport medium for disease and these potentially harmful particles need to be removed in the treatment process before safe water consumption can take place (Holmes, 1996).

Land use change exacerbates the detachment of soil particles from their aggregated state making particles available for removal. This loss of these particles from the land not only impacts on the water quality in the river but also on the land use productivity. Through the correct holistic management of the catchment, future long-term water and land demands can be controlled (Jordaan *et al.*, 1993).

A river's condition is a reflection of all activities, both past and present, within the river and its catchment (Barmuta *et al.*, 1992). It is therefore increasingly necessary to study physical processes in the light of human impact on the landscape. As it is often not possible to separate human activity from geomorphological processes, geographers need to transcend the barrier of physical studies of soil erosion phenomena to include ideological examinations as to whether to determine if these issues are of concern if so, how and to whom (Stocking, 1995). The development of hydrological and geomorphological research must provide a trade-off between the conflicting priorities of long-term scientific enquiry and that of the immediate application to social, economic and other national and local level problems (Kundzewicz *et al.*, 1987). This is an important consideration in land use planning and soil conservation initiatives.

The nature of the effects of land use and management on surface water supplies has long been acknowledged (Thomas, 1995). The magnitude of these effects on water resources remains a somewhat unknown quantity, hindered by a lack of input parameter data. Now, with the increasing demand for land and water resources focusing the attention of all stakeholders, it is becoming necessary to be able to predict the influence of changes in land use and conservation practices. There is, therefore, a need for greater insight into the mechanisms and consequences of land degradation within the catchment, in terms of the inter-relationships between the socio-economic issues governing the use of the land and the environment factors, in order to bring about better catchment management.

1.2. AIMS AND OBJECTIVES

The aim of this study is to investigate the extent to which sedimentation within an impoundment can be attributed to land use change. This will be achieved by considering the case study of the Hazelmere Dam within the Mdloti River Catchment. It is hoped that the knowledge of sediment sources and their potential causes will assist in the integrated management of the catchment in such a way as to reduce the costs incurred by water treatment and to prolong the life expectancy of the dam. The consequential loss of such a valuable water storage system, in the context of the substantial increase in the demand for water in South Africa, equates to far more than economic losses and should be avoided. In order to achieve the stated aim the following specific objectives have been considered:

1. to identify the processes involved in the removal, transport and deposition of sediment by means of a literature review. As well as to review the capabilities of geographical information systems (GIS) as a tool for modelling these processes and integrated catchment management (ICM) for monitoring and maintaining process thresholds,

2. to understand the catchment characteristics of the study catchment within its environmental and social contexts in order to determine the physical factors and the socio-economic influences important in providing a holistic view of the catchment,

3. to deriving a classification system for categorising land uses,

4. to identify land uses in the catchment and categorize them according to the classification system derived in objective 3,

5. to develop a series of land use maps utilising a GIS and to undertaking time-series analyses to determine changes in land use through time,

6. to identify the influences governing land use and the consequences of land use change on the catchment characteristics by employing overlays of interrelated factors aiding visualisation of the landscape.

7. to review existing studies on the Hazelmere Catchment that highlight other factors contributing to the cause of sedimentation in the dam,

8. to put forward management recommendations, based on the findings of this study, to be used towards setting up the ICM strategy for the catchment aimed, in particular, at sustaining water and land resources while meeting the demands of the users. In so doing, to identify scope for further research.

Prior to investigating changes in land use in the Hazelmere Catchment it is necessary to become familiar with the literature related to land use change and catchment processes, which result in the delivery of sediment to an impoundment. This is undertaken in Chapter two, the literature review chapter. Chapter two also provides background information on ICM and the use of GIS in the ICM process. In Chapter three the environmental setting of the study area is described and provides background information on various aspects of the environment. A description of the methods employed to gain the requisite data follows in Chapter four. The results gained through these methods are presented in Chapter five. Chapter six discusses the relevant findings within the context of the research followed in Chapter seven by a discussion of other factors influencing the sedimentation. Recommendations are also included throughout, and are brought together in the conclusion to address possible approaches to an ICM strategy for the catchment. The conclusion also provides suggestions for future research with a view towards a better understanding of the catchment and subsequent improvements to ICM strategies.

CHAPTER 2

LITERATURE REVIEW

2.1. LAND USE CHANGE & MANAGEMENT

Land use is the way in which, and the purpose for which, human beings employ the land and its resources, with emphasis on the functional role of land in economic activities although physical, social, legal and political factors also play a role (Campbell, 1983; Meyer, 1995). Land use is not to be confused with land cover, which is the physical cover of the earth's surface. The vast array of physical characteristics - climate, physiography, soil, biota and the varieties of past and present human utilisation, combine to make each parcel of land on the surface of the earth unique in the cover it possesses and the opportunities for use that it offers (Meyer, 1995).

In South Africa the competition for land between agriculture, housing, recreation and conservation has resulted, for example, in parcels of land with a high agricultural potential coming under threat from non-agricultural land uses, further restricting the area for productive agriculture (Marcus *et al.*, 1996). According to Laker (1993), only 13.5% of the country is suitable for agriculture, creating a concern for sustainability should this land be used for any other purpose. The lack of suitable agricultural land forces agriculturalists to seek land with lower potential to sustain the country's population, leading to the abuse of soil resources and resulting in the acceleration of soil erosion (Marcus *et al.*, 1996). Accelerated erosion occurs as a result of human modifications to the natural state of the land through the removal of the natural vegetation and the employment of incorrect land use practices (Zachar, 1982). Accelerated erosion is particularly problematic in developing countries where access to resources, finances, information and technology is insufficient to implement correct land use practices. Such activities which bring about accelerated erosion in developing countries are: overgrazing, cultivation on steep slopes, improper conservation structures, stripping of trees and shrubs for fuel and the creation of footpaths in order to access resources (Laker, 1993).

Socio-economic and political factors are often at the root of accelerated soil erosion, a cause for concern in terms of agricultural productivity (Dollar & Goudie, 2000). In South Africa, apartheid policies (especially the 'betterment' schemes and the creation of 'homelands') aggravated environmental degradation by exerting pressure on the carrying capacity of selected pieces of land. This was achieved by means of forced removals: the crowding of people onto small isolated parcels of land unable to sustain these populations and away from employment opportunities. The socio-economic situation that developed within these isolated 'homeland' areas dictated the type of land use and practices utilised, namely, subsistence agriculture. The intensity and misuse of the land, brought about as a result of both the political situation and the socio-economic position of the people, has resulted in irreversible environmental degradation (Dollar & Goudie, 2000). Dollar and Goudie (2000) state that as long as there are vast inequalities in wealth, standards of living, quality of life and access to resources in southern Africa, little can be done about environmental degradation, since these issues are closely interlinked.

The close association between environmental degradation and the socio-economic status of the people is due to the fact that people's needs and their immediate interests govern the way in which they assess deterioration of their environment. Despite the recognition by the scientific community of South Africa, that soil erosion is a serious and rapidly increasing threat to land productivity and environmental sustainability, the community regard soil erosion as a problem only when it creates a significant and noticeable practical problem, which consequently affects their daily routine (Brinkcate & Hanvey, 1996). With South Africa in a transition phase of the country's political policies, careful planning can ensure that further loss of good agricultural land to unregulated urban settlement is not incurred and that the inequalities of the past are settled. Furthermore, cost effective use of resources by the country's current rural population, must be sustained through conservation of resources to ensure food security (Marcus *et al.*, 1996). Such policies, set down by politicians, influence the lives of all the people of the country directly or indirectly and translating these policies into action requires the co-operation of the public. Policies relating to soil conservation and the use of optimum farming practices, for example, requires educating the land users of the importance of soil conservation and the benefits of optimum farming practices as well as providing incentives, such as discounts on products, tools and labour necessary to ensure soil conservation and change existing farming practices to those recommended by the policies (Brinkcate & Hanvey, 1996).

The growing awareness of processes caused by human intervention and their resultant influence on the environment, has created considerable interest in experimental studies that attempt to evaluate the effects of land use change on the complex interrelationships between fluvial geomorphology and the erosion–sedimentation regimes of a catchment. Although relatively complex deterministic models representing these interrelationships exist, such models remain of limited practical value owing to the requirements of input parameters, which are usually unobtainable due to a lack of accessibility, manpower, finances and technology, particularly in developing countries (Lorentz & Schulze, 1995). Simple empirical methods do, however, meet the requirements for initial planning and design and, in the absence of gauged data, are the bases for most water resource decisions. The Universal Soil Loss Equation (USLE) (Wischmeier *et al.,* 1971) is an empirical method developed from a large database of the component factors of the equation in the United States of America (USA), and is the foundation for many other empirical equations. The USLE is valid for establishing long-term average annual soil loss in the USA. Although cautioned against its use in calculating soil loss outside of the USA without suitable validation (Bergsma & Valenzuela, 1981), it has received large recognition worldwide. Notwithstanding that it has largely been superseded by the Revised Soil Loss Equation (RUSLE) (Renard *et al*, 1991) in the developed world, its relative simplicity and ease of use has resulted in its continued popularity in the developing countries.

There are many studies worldwide using the USLE or derivatives thereof to estimate sediment yields for fields and catchments. Each one agrees that land use is an important contributor to sediment yield (Troch *et al.*, 1980; Krishna *et al.,* 1988). No agreement, however, has been reached as to what the key concern with land use is that makes it such an important contributor. Suggestions, including the ability of vegetation cover to resist erosive action, land use change, soil properties and socio-economic factors, have periodically been identified as the appropriate key concerns in sediment yield (Daniel, 1983; Schulze, 1987; Brinkcate & Hanvey, 1996).

Schulze (1987) argues that the ability of the vegetation cover to intercept rainfall, reduce raindrop erosion and encourage infiltration and evaporation is the critical aspect of land use in reducing sediment yield. This view ignores the control exerted by the soil mass and the consequences of tillage in relation to the sediment-land use debate. Water flow is the means by which sediment is transported over the surface of the land. Vegetation cover will slow this flow allowing time for infiltration into the soil profile thus preventing the sediment being transported over the surface.

Krishna *et al.* (1988) agree that vegetation cover is crucial in minimising erosion from the surface. In studies undertaken by Krishna *et al.* (1988), precipitation events have been identified as particularly erosive in row cropped areas where canopy cover and ground cover are inadequate. The canopy intercepts raindrops, breaking the fall, and thereby reducing raindrop erosion. Inadequate ground cover reduces the surface roughness and infiltration, therefore increasing overland flow and erosion. The studies showed changes in sediment yield as a result of differences in canopy density and ground cover from row crop fields and grassland pastures in areas of high erosivity. Row crops yielded a monthly mean of 0.54 to 0.63 tons/hectare (t/ha) of sediment while mean monthly sediment yield under pasture was between 0.05 and 0.06 t/ha (Krishna *et al.*, 1988).

Crops vary significantly in their effect on water erosion due to the variations in canopy cover and land use practices. For example, fallow land has the highest erosion potential as there is no vegetation to prevent rainsplash or overland flow, while rotation crops have a considerably lower erosion potential (Troch *et al.*, 1980). A natural, fully stocked forest and undisturbed area of natural vegetation have maximum protection due to a number of different species ranging in canopy heights, creating a layered effect to intercept raindrops and minimise rainsplash (Troch *et al.*, 1980). Adequate ground cover, such as leaf litter, mulch, or grass increases surface roughness, allowing maximum time for infiltration and evaporation. Thick grass covered pastures also provide good protection because of the thick, low canopy cover exposing minimal soil, and therefore, if managed correctly, grazing land should contribute little sediment (Highfill & Kimberlin, 1977).

Troch *et al.* (1980) agree that the amount and type of vegetation cover needed to protect the soil structure is dependent on the intensity of the erosive force as well as the nature of the soil particles. Loose soils on steep slopes, for example, should be kept under permanent cover to limit rainsplash erosion, as well as the amount and velocity of runoff erosion. Vegetation cover also increases soil fertility and stability aiding in the prevention of erosion and increasing the overall land productivity. Root support and organic matter content provide a base to which soil particles bind, encouraging aggregation and soil structure stability. A stable aggregate structure is important in supporting the plants and preventing soil particles becoming detached, and thereby available for transport. Vegetation also increases the porosity of the soil through root action, encouraging aggregation by increasing surface roughness, slowing runoff and encouraging infiltration.

Troch *et al.* (1980) have also identified that change in vegetation cover contributes significantly to sediment yields, particularly the influence of past land cover on present land cover and sediment yields. Forestry converted to row crop, for example, displays an increase in sediment yield by 100 to 1000 times while pastoral land converted to row crops shows an increase of between 10 and 90 times (Troch *et al.,* 1980). The type of crops and the methods used in their cultivation are crucial in affecting the extent of erosion. Vegetation cover can be altered dramatically within a short time period, but biophysical changes within the soil, which also affect erosion rates, take longer to readjust (Tiffen *et al.*, 1994).

Wolman (1967) represented the sequential developments in land use change and their corresponding sediment yield contributions that have taken place in the developed world over the last two centuries (Figure 2.1). Most notable from the figure is the distinctively sharp peak in the sediment yield associated with construction, showing that the initial disturbance is severe, yet short lived. Once the landscape has adjusted to the new set of circumstances and the area re-vegetated, soil loss decreases sharply. Other changes in land use showed a slow, continuous increase in sediment yield due to the continued disturbance of converting more land and intensifying its use. This model is typical of the progressions noticed in the developed countries, particularly evident by the construction peak. Rehabilitation of the area after construction is often not carried out in the rural areas of developing countries, as it is traditional to keep the immediate surroundings of dwellings clear of vegetation. This transpires into an escalation in sediment yield at the on-set of construction and continuing to remain high after construction (Beckedahl, 2001). Although Figure 2.1 is typical of land use change and sediment yield of developed countries it has been included in this research to demonstrate possible sediment yields from comparable land uses in the study area, the Hazelmere Catchment.

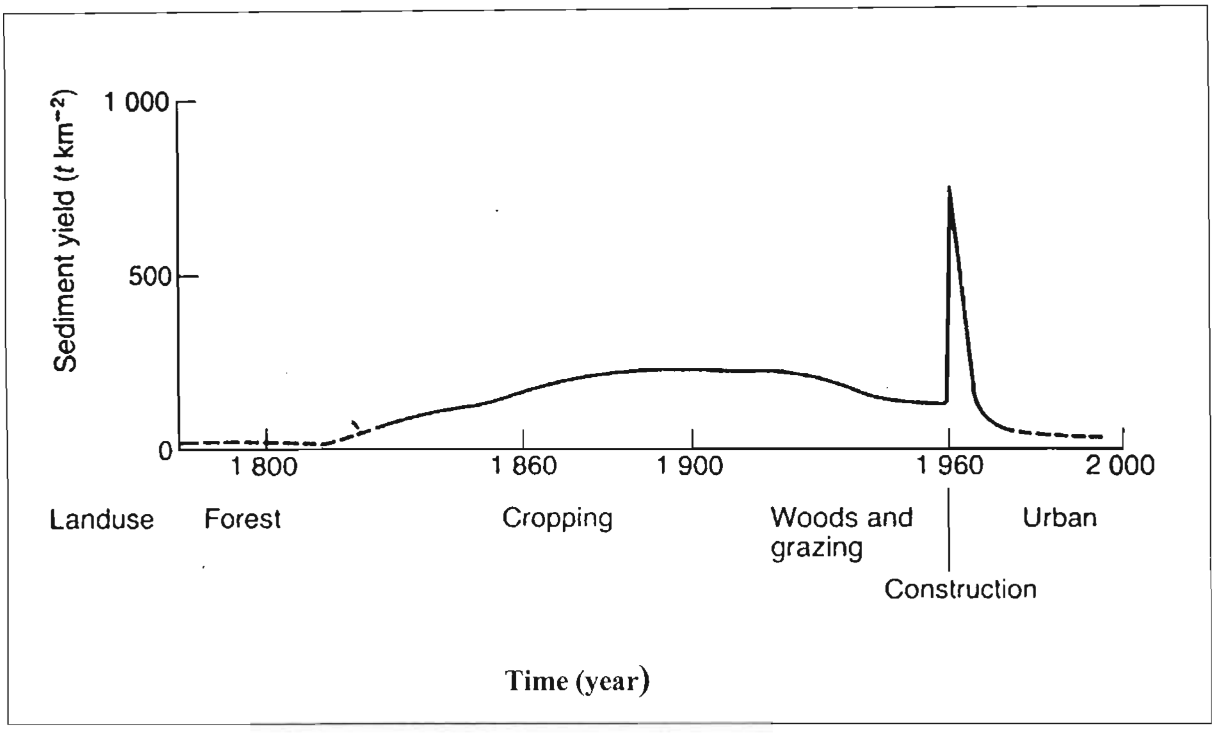

Figure 2.1: The theoretical relationship between land use change and sediment yield (Wolman, 1967)

Parameters for deterministic models, such as runoff and water quality, can be measured while land use patterns and change can be mapped, yet land management relies on human beings and human decisions, which are not always objective or rational (Daniel, 1983). Influence on land management decisions rests largely with political, social and economic factors as these govern the levels of technology and education available to particular socio-economic groups and the availability of capital to sustain their interests (Daniel, 1983). Poverty and high population densities culminate in overstocking and misuse of the land. A vast quantity of literature exists attempting to pinpoint how socio-economic and political factors govern the type of land use and management thereof (eg: Hefts, 1977; Daniel, 1983; Stocking, 1988; Brinkcate & Hanvey, 1996). It is therefore felt, by Stocking (1988) and Brinkcate and Hanvey (1996), that the status of the land users and the policies of the country are critical aspects governing erosion and sediment yields.

It is clear from the literature above that, although vegetation and land use control sediment yield, soil loss is also related to the amount and intensity of precipitation, soil erodibility, and slope length and steepness (Rooseboom *et al.*, 1992). It is, therefore, appropriate to discuss the role of these other factors in the erosion and sediment delivery processes as identified by empirical models.

2.2. EROSIVITY OF PRECIPITATION

Erosivity is the term given to the potential ability of rain to cause erosion, measured by the kinetic energy and the maximum 30-minute intensity of a rainfall event (EI_{30}) (Hudson, 1981). Raindrops are a source of energy which, when released on impact with the surface, detaches soil particles from their aggregated structure and are, therefore, an important contributor to erosion (Hudson, 1981; Morgan, 1986). The amount of energy delivered by raindrops is dependent on the height of the fall and the size of the raindrop (Epema & Riezebos, 1983). A maximum energy level is reached at maximum velocity, approximately two metres above the ground (Epema & Riezebos, 1983). The height and density of the vegetation's canopy cover can, thus, be important in reducing the amount of energy and water delivered to the surface and consequently the amount of sediment detached by raindrop impact.

By contrast, in some areas, soil particles dislodged through rainsplash can initiate surface sealing, whereby suspended soil particles fill the pores in between soil aggregates. Sealing reduces infiltration, encouraging runoff and, although fewer loose particles are eroded, runoff velocity and volume increases, accumulating energy used to remove particles downslope of these sealed sections (Russell, 1998a). Prolonged surface sealing in turn leads to crusting which further reduces the amount of infiltration, impacting on the vegetation cover (Russell, 1998a).

Rainwater not only acts as a source of energy in the detachment of soil particles from aggregates, but also provides the energy to transport these disaggregated particles downslope with the flow of water. Rainwater either infiltrates into the soil or begins flowing downslope depending on the landscape characteristics at that point and the intensity of the rainfall event. Landscape characteristics, such as a steep slope gradient, and an intense rainfall event decrease the time available for water to infiltrate causing water to move over the surface more readily. Infiltration also depends on soil properties including: porosity, texture and antecedent moisture conditions of the soil (Morgan, 1986). Once the soil is saturated, the remaining water will stagnate in pools on the surface or flow downslope over the surface. The ground cover and leaf litter content affects the time for infiltration, as surface roughness is increased and runoff is slowed. As the velocity of moving water increases so the potential for that water to gather loose particles and transport them downslope increases. The velocity of the flowing water also determines the size of the particles that can be transported. The stronger and faster the flow the more energy it has to pick-up and carry sediment and the larger the particles that can be transported (Hudson, 1981). Water infiltration can also cause erosion by removing particles through the soil profile.

The mode of rainwater flow results in two forms of erosion: surface and subsurface erosion (Cooke & Doornkamp, 1990). Surface erosion results in three erosional features namely, rills, gullies and sheet wash. Rills form when runoff flow is concentrated into rivulets. As rills become exaggerated to greater than one metre in depth they develop into gullies, though there are other mechanisms for gully initiation. Sheet wash is the removal of soil uniformly from the soil surface (Cooke & Doornkamp, 1990). Sub-surface erosion occurs below the surface where sediment is removed physically in suspension by throughflow or by chemical removal in solution and dispersion resulting in sub-surface piping (Beckedahl, 1998). When the roof of a subsurface pipe becomes too thin it collapses exposing large amounts of loose soil to erosion. This collapsed pipe is then referred to as a gully system. Other resultant features of water infiltration and runoff are those of mass movement, for example rockfalls and landslides. Although mass movement is only indirectly related to water, the failure related to an unstable slope is often triggered by rainfall. Such features include: terracettes and slip scars, which form as a result of soil creep, landslides and rockfalls (Cooke & Doornkamp, 1990). Instability can also be brought about by slope steepening in construction of infrastructure and by land use changes (Cooke & Doornkamp, 1990).

Precipitation is the provider of energy to remove particles from the surface, however, the properties of the soil, its structure, texture and permeability contribute largely to the number of particles available for removal and this is described in the following section.

2.3. SOIL ERODIBILITY

Soil erodibility is the term given to the ability of soil to withstand detachment and transport by rainsplash and surface flow whilst allowing water to infiltrate into the soil profile. Soil erodibility may be determined according to the soil nomograph of the USLE, which uses soil texture, structure, organic matter and permeability (Wischmeier *et al.,* 1971) or it can be determined empirically in the field from standardised runoff plots.

Soil texture is dependent on the size of soil particles and is important in determining pore space and consequently the aeration and drainage of the soil. Pore spacing is also dependent on the structure of the soil aggregates. Clay soils have small pores and good cohesive properties meaning their water draining ability is poor. Clay soils are, therefore, usually saturated which prevents further infiltration into the soil. Conversely, coarse sandy soils have good drainage but tend not to hold water for long and therefore dry up quickly. The texture of the soil is, therefore, important in choosing crops as those grown in sandy soils would need additional water and nutrients, while crops on clay soils suffer a lack of oxygen to the roots. As far as erodibility is concerned the more silt and fine sand percentage texture content, the higher the erodibility (Wischmeier *et al.,* 1971). Increases in clay and organic matter content decreases the susceptibility of soil to erosion (Russell, 1998a). Although clay particles are smaller than silt and are easily moved in suspension, they have a strong coherent nature and in order to remove them they need to be broken up into single units. Some clay particles are, however, also hydrophilic and absorb water causing the aggregates to swell impacting on aggregate stability (Schulze *et al.*, 1995). Associated with high sodium absorption, clay aggregates held together by hydrogen bonds are broken down and are considered highly dispersive and easily removed (Schulze et al., 1995; Beckedahl, 1998). Therefore, aggregate stability has a greater influence than individual mineral particles on the prevention of erosion.

In addition to replacing minerals important to fertility, organic matter provides a foundation on to which soil can bind (Russell, 1998a). The extent to which soil erodibility decreases as organic matter increases, is dependent on the texture of the soil (Wischmeier *et al.*, 1971).

Structural type and size has an appreciable influence on the erodibility of the soil although the strength does not significantly affect erodibility (Wischmeier *et al.*, 1971). Structural classes range from very fine granular to blocky, or platy structures (Wischmeier *et al.*, 1971). The structural type and size determines pores size and porosity (the space available for water and gas in the soil. The particle size (soil texture) and structure also plays an important role in permeability. Permeability is the ability of the soil to allow water to infiltrate. Permeability changes with varying intensities of precipitation events: during an intense storm the permeability of the soil will be less than during a light rainfall event. Rainfall intensity is determined by the infiltration rate. Likewise, the degree of permeability will be dependent on the existing antecedent moisture conditions as this restricts the amount of storage space available for water to infiltrate. The lack of vegetation cover and the pounding of raindrops cause surface crusting and sealing, contributing further to the reduction in permeability (Schulze *et al.*, 1995).

2.4. SLOPE LENGTH AND SLOPE ANGLE

Two factors concerning erosion with regard to relief are slope length and slope angle. Both these factors influence the velocity of the water moving over the surface and the accumulation of energy that will be exerted downslope on collecting and transporting of materials (Thornes, 1980). Slope length determines the distance particles in suspension can be carried before being deposited as well as the amount of energy that can accumulate with distance downslope. The angle of the slope influences the time water takes to infiltrate, as the steeper the slope the stronger the gravitational pull to move water downslope. The steepness of the slope plays a crucial role in slope stability in relation to mass movement. Soils are usually shallow on steep slopes reaching saturation quicker, becoming waterlogged and causing increased runoff, thereby restricting the vegetation on these slopes to plants with shallow root systems (Russell, 1998b). The increase in volume of runoff gains velocity with distance down slope resulting in large losses of soil. Ideally, steep slopes should remain under permanent grass (Russell, 1998b). Slope gradient also impacts on rainsplash by increasing the number of soil particles displaced downslope, having a similar effect to soil creep (Thornes, 1980).

Slope length and slope angle aid in the transportation of water and detached soil particles to the river channel. Once in the river channel, however, different forces are involved in transporting sediment along the channel to reservoirs or into the ocean. A detailed account of these forces goes beyond the scope of the study however general mention is made in the section on fluvial transport and deposition to illustrate the holistic nature of land and water processes.

2.5. FLUVIAL TRANSPORT AND DEPOSITION

Once a soil particle has been eroded a number of possibilities exist as to where it may be deposited. Deposition, for example, could occur at any distance downslope due to a decrease in flow velocity or an increase in surface roughness. If the soil particles are transported off the land and into the river, numerous processes take place depending on the forces available. Sediment is either deposited immediately on entering the river where it becomes a part of the channel bottom or it is kept in suspension depending on particle size and flow velocity. Should the sediment be deposited on the riverbed it can be eroded again and transported further with a change in velocity either as a result of added volume, increased gradient or reduced friction. Such movement of larger bottom sediment is generally by rolling or bouncing downslope. Particles that are kept in suspension are transported in the flow of water. Decreases in channel gradient, channel roughness, velocity and volume cause particles to be deposited. Studies of fluvial discharge show that the grain size most easily eroded is the fine silt soils, while the grain size of clay soils is smaller, it tends to adhere together making erosion more difficult (Morisawa, 1968). Once eroded, however, clay particles remain in suspension despite reductions in flow velocity. It is these suspended particles that cause the discolouration of water that heightens the cost of water treatment. Heavier particles are often deposited not far from where they are eroded as a high flow velocity is needed to erode and transport them. It is these larger and heavier particles that cause sedimentation of the river channels and reservoirs, necessitating the dam wall to be raised or the bottom dredged in order to maintain or prolong the designated life of the reservoir. Figure 2.2 displays the relationship between particle size and velocity in terms of erosion, transport, entrainment and deposition.

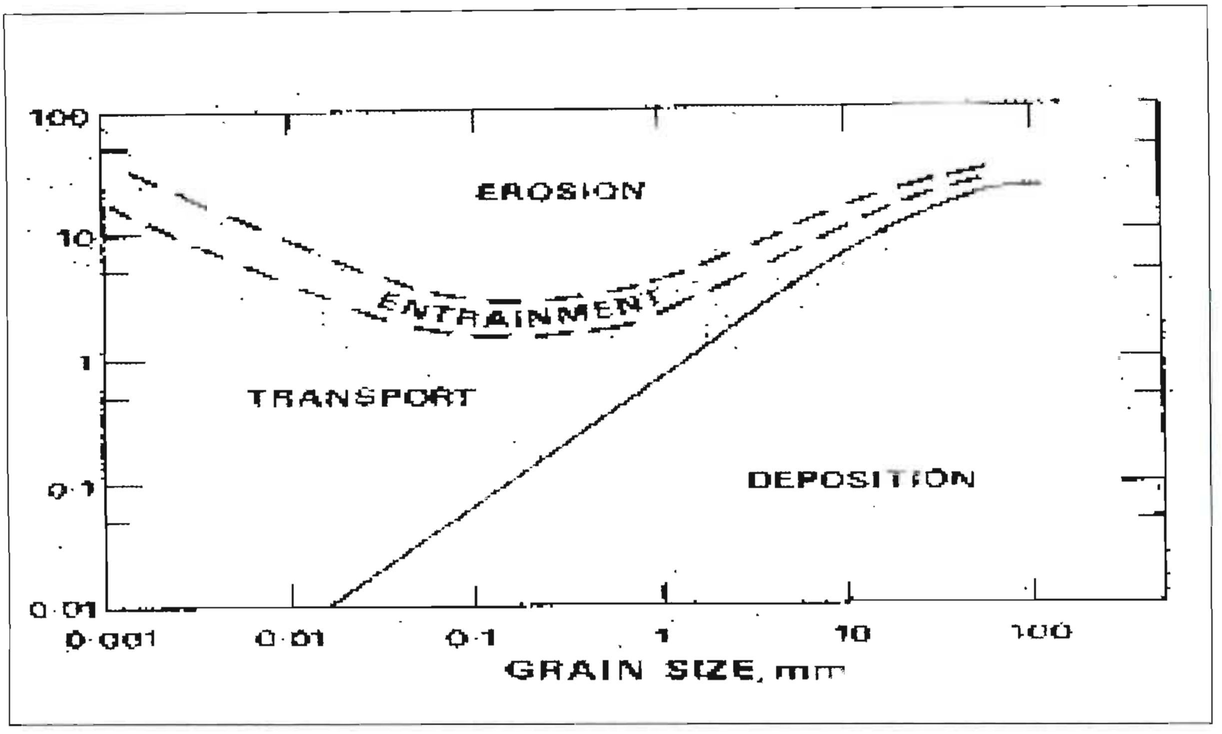

Figure 2.2: The relationship between particle size and velocity (Knighton, 1984)

Turbulence, volume of water and volume of sediment in the channel also influence the suspended load. Turbulence is greatest at the sides and bottom of the channel due to the friction from the rough channel profile, while volume changes with channel width, tributary inlets or blockages in the channel and discharge (Knighton, 1984). Increased turbulence disturbs settling particles and scours the channel causing particles to become suspended while an increase in volume allows for more particles to be held in suspension and transported downstream with the flow of water (Knighton, 1984).

Having described above the factors involved in erosion and the processes used in the delivery of the eroded material to the river and consequently the transport of the material in the river channel, it is evident that it is a complex interrelated process concerning a number of factors simultaneously. The management of such a system, therefore, needs a similarly complex yet holistic approach, such as the Integrated Catchment Management (ICM) strategy, detailed below.

2.6. INTEGRATED CATCHMENT MANAGEMENT

In conjunction with the current trend towards a holistic approach to management of the environment, DWAF recognises that water can only be effectively and efficiently managed within a river catchment area by enhancing the interdependent roles in resource protection and utilisation (DWAF, 1996). Having recognised the relationship between land and water resources and that its sustainability is dependent on the socio-economic, physical, chemical and biotic attributes, it is not possible to successfully manage these independently (DWAF, 1996 & Görgens *et al.*, 1998). Co-ordination, planning and action are required at all levels, from national government to the individual landowners (DWAF, 1996).

The relevant stages of the process for an ICM strategy are similar to those of an integrated environmental management (IEM) procedure and include initiation, assessment, planning, implementation, monitoring and audit stages (Department of Environmental Affairs and Tourism (DEAT), 1997). The catchment management strategy has a specific role within the ICM process. The strategy represents a single, though crucial, step of the wider process and records a vision for the catchment, formalising the understanding of the water, land, social and aquatic ecology issues in terms of that vision. The concept of an interest-focussed approach will ultimately define how issues are addressed through agreed management strategies. In addition, legislative, procedural and technical frameworks for implementation are reflected and as such, legal status is required (DEAT, 1997).

The ICM approach was first adopted by DWAF in South Africa in the 1980s as a means of managing catchments in the former Eastern and Northern Transvaal provinces. The ICM approach was to assess the quantity and quality of available water resources, to identify the needs of different water use sectors, to predict likely future developments and to develop holistic approaches to water resource management for the catchments, such as the Sabie River Basin (Hollingworth & Mullins, 1995). The approaches had varying degrees of success and each study revealed further issues of concern. Such issues included the need to improve the process of public participation; to develop appropriate institutional structures which could facilitate communication, promote information sharing at all levels, assist in the decision making process and define the role and responsibility of participants; to involve all water users in the planning and implementation phases of water resource management; and for DWAF to take responsibility for leadership and the provision of technical guidance in a management framework for water resource management (DWAF, 1996). The improvement of collaboration and liaison between different government departments at a local and national level, and the implementation of complementary legislation pertaining to resource management by the various government departments need to be addressed and included in the ICM process for South Africa (Görgens *et al.*, 1998).

The management of water resources in South Africa, through the implementation of an ICM strategy, is challenging as management needs to be manifested at, and integrated across, many different scales ranging from local tributary sub-catchment through to catchment, regional, provincial and national scales up to an international level. The new National Water Act (36 of 1998) for South Africa arose as a result of the government's acceptance of these administrative and other complexities. Twenty-eight principles guide the processes of integrated water resource management and the following principles are of particular relevance (Görgens *et al.*, 1998):

1. water quality and water quantity are inter-dependent and shall be managed in an integrated manner consistent with broader environmental approaches (Principle 15),

2. water resource development and supply activities shall be managed in a manner consistent with broader national approaches to environmental management (Principle 17),

3. since many land uses have significant impacts on the hydrological cycle, the regulation of land use shall, where appropriate be used as a tool to manage water resources within the broader integrated framework of land use management (Principle 18),

4. the institutional framework of water management shall, as far as possible, be simple, practical and understandable. It shall be self-driven and must minimise the

necessity of state intervention (Principle 22),

5. responsibility of the development, distribution and the management of the available water resources shall, where possible and appropriate, be delegated to the catchment or regional level to enable interested parties to participate (Principle 23).

The practicality of these principles is limited as the ICM approach is currently confined to water resource management whereas, in theory, ICM is founded on the notion that the different components of the hydrological cycle are intrinsically linked together (DWAF, 1996). The fragmentation, feasibility and institutional uncertainty with the legislative state in South Africa limits the integration of water with land and environmental management. This is due, in part, to the fact that environmental, water and land use legislation has, in the past, been severely disjointed (Rabie & Fuggle, 1992). Despite current reforms within Government, fragmentation is likely to persist as the South African Constitution recognises water management and certain land use related subjects, such as mining, energy and land affairs, as central government competencies. Other land use related subjects such as agriculture, conservation, roads, urban and rural development, tourism and soil conservation, are rendered provincial competencies (Görgens *et al.*, 1998).

All aspects of the environment, including economic and social issues, need to be incorporated into the overall management philosophy, process and plan of an ICM (DWAF, 1996). These should ensure the optimum combination of sustainable benefits, for future generations and affected communities, whilst protecting the natural resources used by these communities minimising possible adverse social, economic and environmental consequences (Görgens *et al.*, 1998). If the notion of a catchment as an integrated system is to be successfully adopted and implemented, then management of the catchment requires careful planning and enforcement of actions designed to maintain the system at a status agreed upon by stakeholders. Management actions need to focus on the land and the activities that impact on water resources ensuring adequate storage, distribution and rehabilitation is implemented. The selected series of management actions, debated by the stakeholders and communities, to determine a preferred sequence of action and associated consequences, would be chartered as a catchment management plan, which requires the formal approval of the Minister of Water Affairs (Görgens *et al.*, 1998).

ICM, therefore, provides a philosophy which underlies rigorous natural resource management, on which a consideration for the whole natural system is based, as well as a recognition that systems respond to disturbance or utilisation as systems, not as individual components in isolation from each other (DWAF, 1996). The ICM provides a process in which both the community and government are involved in a partnership, designed to achieve better natural resource management at the local catchment level, taking into account the needs and ideas of the whole community (DWAF, 1996). The product the ICM provides incorporates environmental, social and economic considerations based on a set of development objectives that are identified jointly by the community and government (DWAF, 1996).

To ensure effective ICM, five principles have been outlined by DWAF (1996):

1. a systems approach which identifies individual components and the linkages between them, as well as addressing the needs of both the human and natural systems,

2. an integrated approach in which attention is directed towards principal issues of concern identified by all stakeholders in the process,

3. a stakeholders approach which recognises the importance of public participation, as well as that of government agencies, in an attempt to define all decisions around the conservation and use of natural resources which affect their lives,

4. a partnership approach which promotes the search for common objectives, and defines the roles, responsibilities and accountabilities of each agency and individual/s who participates in the process of decision making,

5. a balanced approach where decisions are designed to achieve a sustainable blend of economic development, protection of resource integrity, whilst meeting social

norms and expectations.

The limitation of arable land and water resources, the inequitable access to potable water supplies, and the state of environmental degradation and pollution in South Africa has brought about awareness for ICM strategies to be implemented on a catchment scale, nationwide. This overdue initiation of ICM in South Africa has benefited from international experiences; the knowledge gained preventing shortfalls and failures. It is important to note, however, that ICM procedures in South Africa need to be tailor-made for what is best for the country.

The implementation of ICM in South Africa, although a relatively new concept, is conceivable as it takes into consideration and meets the demands of people empowerment, cooperation, participation, partnership, accountability, responsibility and transparency being initiated at present (DWAF, 1996; Görgens *et al.*, 1998). ICM is an on-going management plan that needs continuous monitoring and updating, thus it should become a way of life. Public participation and involvement through public workshops and, improved education of the population are important considerations for the effective management of natural resources (DWAF, 1996).

2.7. GEOGRAPHICAL INFORMATION SYSTEMS IN LAND USE MANAGEMENT & ICM

Geography and many other disciplines (hydrology and geology) are concerned with spatial patterns and processes on the surface of the earth and areas immediately adjacent (atmosphere, oceans and subsurface) The data required, therefore, are of a multidimensional nature tied to a specific set of locations (Longley *et al.*, 1999). Data from several sources need to be integrated into a consistent form in order to simulate the relationships, connectivity and accessibility with nearby features of interest.

A Geographical Information System (GIS) is the use of computer software to create and digitally depict space and time. A typical GIS consists of: a data input system which collects and processes spatial data, a data storage and retrieval system, a data manipulation and analysis system which transforms the data into a common form allowing for spatial analysis, and a data reporting system which displays the data as graphs or maps

(Environmental Systems Research Institute (ESRI), 2001). Applying the principles of GIS provides a spatially referenced medium for examining one or more fundamental issue/s pertaining to the surface of the earth (Longley *et al.*, 1999).

The use of a GIS application could facilitate the monitoring of the spatial and temporal relationship among geographical entities (mountains, rivers) and phenomena (weather, erosion) through which entities evolve (Longley *et al.*, 1999). GIS in South Africa currently plays a very important role in determining and facilitating decisions on planning (Hill & McConnachie, 2001). Issues of development can have adverse effects on the natural environment as well as on human activities and it is the obligation of planners to ensure sustainability. Planners have a number of objectives, most prominent of which are transparency, accountability, flexibility and participation to best serve the needs of the people, in particular, previously disadvantages rural communities (Hill & McConnachie, 2001). The ability to understand and predict the effect changes will have to the stability of an environment leads to an improvement of development techniques and the prediction of future effects. It is important, particularly with frequently occurring planning functions, such as land use, site selection and zoning that suitability of the land is understood. Misuse of land is costly to productivity levels as well as to the environment in terms of losses of habitat and diversity. GIS in land use planning is seen as a tool to bring together disparate data and information about characteristics and activities by identifying areas of compatibility and conflict (Longley *et al.*, 1999). GIS has the potential to assist managerial tasks, policy design, decision-making and communication (Hill & McConnachie, 2001). The high quality graphical capability of GIS enables one, in this manner, to display changes occurring in the landscape over a period of time. By identifying the limitations of the land, management and development planning are made easier. The graphical capability enhances the ability to communicate complex spatial problems and concepts to less knowledgeable stakeholders, critical in the success of management strategies. This ensures that the public are able to voice appropriate concerns, expectations and make more knowledgeable decisions on managing resources. GIS also facilitates trans-disciplinary co-ordination, seen to be lacking in the South African government structure mentioned in Section 2.6 on ICM.

Environmental decisions are complex and require analysis via a number of options involving risk and uncertainty. GIS has predictive capabilities to avoid irreparable damage to the environment. Models are used to simulate possible implications of changes in one or more variables to the rest of the equation and therefore measure the extent of destruction or conservation that can be achieved by that particular change.

As a large quantity of data are required for spatial analysis, initial studies are time consuming and costly. The storage facility of GIS, however, reduces the time factor in further studies, which in turn is cost effective (Hill & McConnachie, 2001). The analytical capabilities of GIS allow one to identify patterns between sets of data thereby aiding management decisions and saving time. ICM, for example, requires on-going studies of changes and developments, effects and consequences of action. GIS saves time by storing previous data, hence further developments simply need to be added. Patterns between catchments can be easily identified and successful management quickly implemented.

Despite the vision of the GIS having shifted significantly over the years it has always included the notion of processing geographical information within an integrated environment (Longley *et al.*, 1999). One of the most important aspects of GIS is in its use in spatial decision support systems however, its full capabilities are yet to be fully understood, which can lead to misuse and misinterpretation.

2.8. SUMMARY

A number of models, using the capabilities of GIS, have attempted to assimilate the interdependent relationship between land characteristics and water quality, such as USLE and derivatives thereof. However, the complexity of the environment is such that the relationship is difficult to comprehensively replicate in a model. Thus the factors and processes, established by these various models, have been discussed in sections 2.1 to 2.5 in relation to their ability to bring about change in the relationship. This background literature provides the foundation for a more specific investigation of the relationships between land use change and the other forces acting on sedimentation rates in the study catchment. Such information can then be included as part of an ICM strategy for management of this catchment. In order to undertake such research, a description of the factors in the catchment is first necessary and provided by the environmental settings in Chapter three.

CHAPTER 3

ENVIRONMENTAL SETTING

3.1. INTRODUCTION

The Mdloti River Catchment is situated on South Africa's eastern seaboard, within the province of KwaZulu-Natal (Figure 3.1). The Noodsberg area, in the midlands of the province (New Hanover District), is the source of the Mdloti River, which flows in a southeasterly direction to drain into the Indian Ocean some 30 km north of Durban (extending from 29°15'02"S, 30°47'29"E to 29°45'53"S, 31°07'10"E). The river is dammed five kilometres north of the town of Verulam, approximately 12 km short of the mouth. This dam, known as the Hazelmere Dam, divides the Mdloti River Catchment into two sub-catchments. The main sub-catchment, upstream of the dam, is referred to as the Hazelmere Sub-catchment [I-3 (U3R001)][1] and drains an area of approximately 376 km^2, representing 80 % of the Mdloti River Catchment (Walmsley & Butty, 1980). The Hazelmere Sub-catchment drains into the Hazelmere Dam. As the aim of this research is to investigate the extent to which sedimentation within an impoundment can be attributed to land use change, the Hazelmere Sub-catchment has been selected as the appropriate area of study.

[1] I-3 (U3R001) is the reference number given by the Department of Water Affairs and Forestry (DWAF) for the sub-catchment upstream of the Hazelmere Dam.

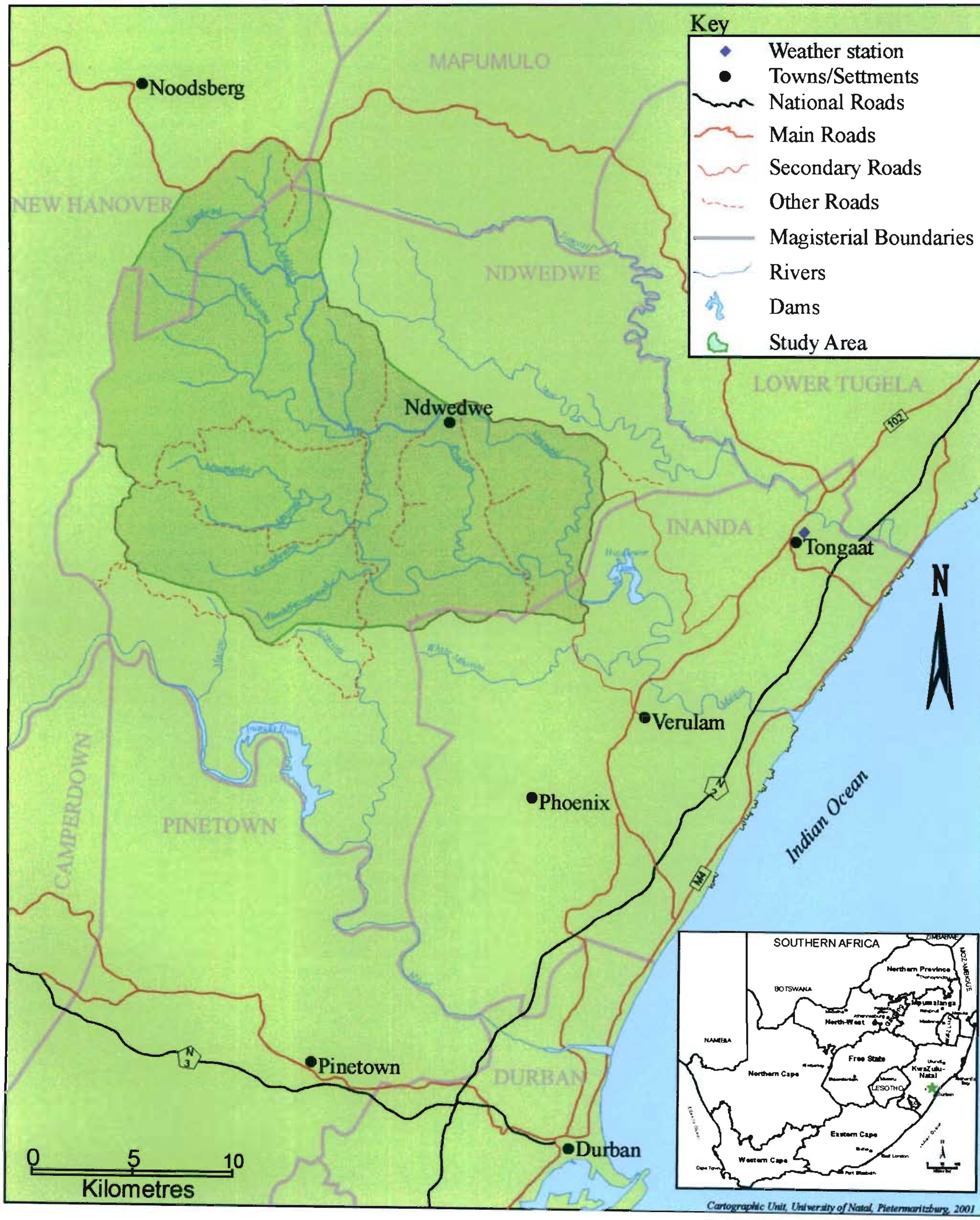

Figure3.1:The locale of the Hazelmere Catchment, KwaZulu-Natal North Coast

3.2. DRAINAGE

The drainage pattern of the Hazelmere Catchment is dendritic with a drainage density of 0.343 m/km^2 (Currie, 1997). The Mdloti River Catchment is bordered by the Tongati River Catchment to the north and by the Mgeni River Catchment to the south. Major tributaries of the upper Mdloti River include: Mdlotshana, Mapofu, Gudwini, KwaMwema, Mwangala, KwaZini, Msumduzi and KwaMfazozopayo rivers (Figure 3.1).

The Hazelmere Dam covers an area of 2.18 km^2 (Walmsley & Butty, 1980) and has been regarded as one of the most turbid systems in KwaZulu-Natal since its establishment in 1977. The dam was constructed to cater for the anticipated development of the Verulam area as a result of the proposed La Mercy airport development nearby. The airport was to service the North Coast of KwaZulu-Natal as well as to eventually supersede the original Durban Airport, to the South of Durban. Adverse economic factors have stopped the progress of the airport and thereby slowed the development of the Verulam area (Walmsley & Butty, 1980). At present, however, the North Coast is experiencing an economic expansion as businesses are moving out of the Durban city centre to the Umhlanga Ridge area, and as a result water supply demands are increasing. The dam has lost more than 25% of its original design capacity since its completion (DWAF, 1993). This loss equates to a reduction from the original design capacity of 6 million m^3 at an average sediment accumulation rate of 0.3358 million m^3/annum (DWAF, 1993). The largest loss in design capacity occurred during the 1980s when two large flood events affected KwaZulu-Natal: the flood of 1987 and the Demoina flood of 1984 (DWAF, 1993). Following these two flood events a comparison of siltation levels was made by DWAF (1993). The comparison showed that Hazelmere Dam had a 25 times greater level of siltation than those of the Ntshongweni Dam on the Mlazi River and the Henley Dam on the Msunduze River. As both these dams are in close proximity to the Hazelmere Dam this comparison would indicate that influences other than flood events are impacting on the Hazelmere Dam's siltation rate.

Rooseboom *et al.* (1992) study on the sediment yield from river networks throughout South Africa estimated the Hazelmere Dam's annual sediment yield to be approximately 723 metric tonnes per square kilometre, with only 33% of the mean annual runoff reaching the dam. Previous reports have also voiced concerns for the extensive erosion features visible throughout the area (Currie, 1997; Russow & Garland, 2000). The sheer aesthetic effect of the turbid water is sufficient evidence of the extent to which sediment is washing off the land and affecting the water quality.

3.3. GEOLOGY

KwaZulu-Natal (Figure 3.2) consists of lithologies belonging predominately to the Karoo Sequence, with exposure of Natal Group sandstones and basement granite and gneiss of the Namaqua Natal Mobile Belt (Table 3.1). Subsequent erosion and incision by rivers of these lithologies resulted in the rugged terrain of KwaZulu-Natal (King 1982).

Table 3.1: Generalised stratigraphy of the Hazelmere Catchment (modified after South African Committee of Stratigraphy (SACS), 1980; Tankard *et al.*, 1982)

Classification			**Lithology**
Karoo Sequence	Ecca Group	Dwyka Formation	Diamictite, subordinate varved shale and boulder shale
Cape Supergroup	Natal Group	Inanda Formation	Red-brown coarse-grained arkosic to subarkosic sandstone, quartz arenite, micaceous sandstone, small pebble conglomerate, subordinate siltstone and mudstone
Namaqua Natal Mobile Belt			Biotite gneiss, biotite-hornbelde subordinate gneiss, pelitic schist and gneiss, micaceous gneiss and schist, biotite-feldspar gneiss

The Karoo Sequence covers a large portion of southern Africa and is characterised by a changing tectonic framework, recording the crustal break-up and migration of Gondwanaland from polar to tropical latitudes (Tankard *et al.*, 1982). In KwaZulu-Natal, the Ecca Group of the Karoo Sequence is divided into various formations. The Dwyka Formation is found in the Hazelmere Catchment lying unconformably above rocks of the Natal Group. This formation is characterised by the presence of clastic rock containing rudaceous material of diamictite, varved shale and mudstone with dispersed stones and conglomerates, which weather to fine clays and sand (SACS, 1980). In the Hazelmere Catchment area, outcrops of the Dwyka Formation are restricted to a narrow band that extends from the northeast to the southwest in the vicinity of the dam (Figure 3.2). These outcrops are controlled by numerous faults in the area.

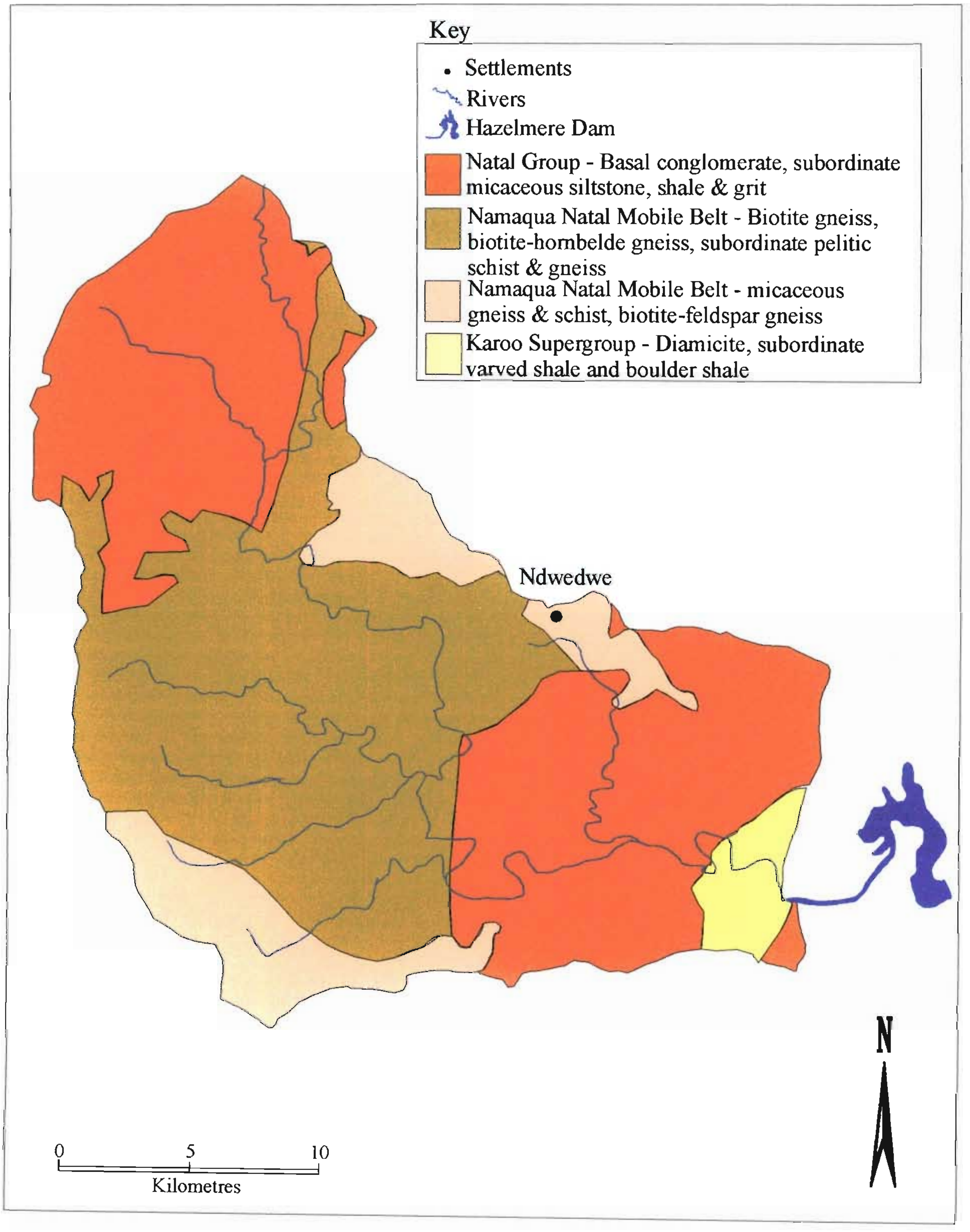

Figure 3.2: Geology of the Hazelmere Catchment (modified after the KwaZulu-Natal Hydrogeological Map, 1999)

The Natal Group sandstones cover the granite-gneiss basement rocks of the Namaqua Natal Mobile Belt. The sandstones of the Durban-Verulam area correlate with the Table Mountain Series of the Cape Supergroup (SACS, 1980). Composed almost entirely of feldspathic sandstone with quartzite, shale and mudstone distributed irregularly within the sequence, these weather to highly erodible sandy clays (King & Maud 1964). Natal Group Sandstones constitute a large portion of the geology in the Hazelmere Catchment. This Natal Group sandstone outcrop was split by the extensive northeast-southwest faults and can found at the headwaters of the Mdloti River and in the lower central region of the catchment (Figure 3.2).

The basement rocks of the Mdloti River Catchment, belonging to the Namaqua Natal Mobile Belt, are characterised by crystalline granite, gneiss and schists exposed by crustal uplift and erosion of the overlying rock series (King, 1982). At the surface, component minerals are unstable and inclined to weather rapidly. The feldspar crystals weather to clay and the quartz crystals to sand (King, 1982). Outcrops extend westward from the town of Ndwedwe (Figure 3.2).

3.4. SOILS

The soils of the Hazelmere Catchment, like most in South Africa, conform closely to the underlying geology. According to de Villiers (1962), the Hazelmere Catchment is comprised of soils of the Cartref Series (from the Natal Group Sandstones), Glenrosa Series (from the Basement Complex), and leached soils of the Inhoek Series derived from the basement complex (Figure 3.3).

Soils, derived from the Natal Group sandstones, are typically those of the Cartref Series and are characterised by an orthic A-horizon overlying an E-horizon that in turn overlies a lithocutanic B-horizon (Soil Classification Working Group (SCWG), 1991). They are generally shallow and characteristically young (newly generated soils weathered from the parent rock) due to the highly undulating nature of the topography in the catchment. They also tend towards silty sands due to the textural composition of the parent material and as a result are susceptible to erosion. The Cartref Series is found closest to the Hazelmere Dam and extends the width of the catchment to the settlement of Ndwedwe.

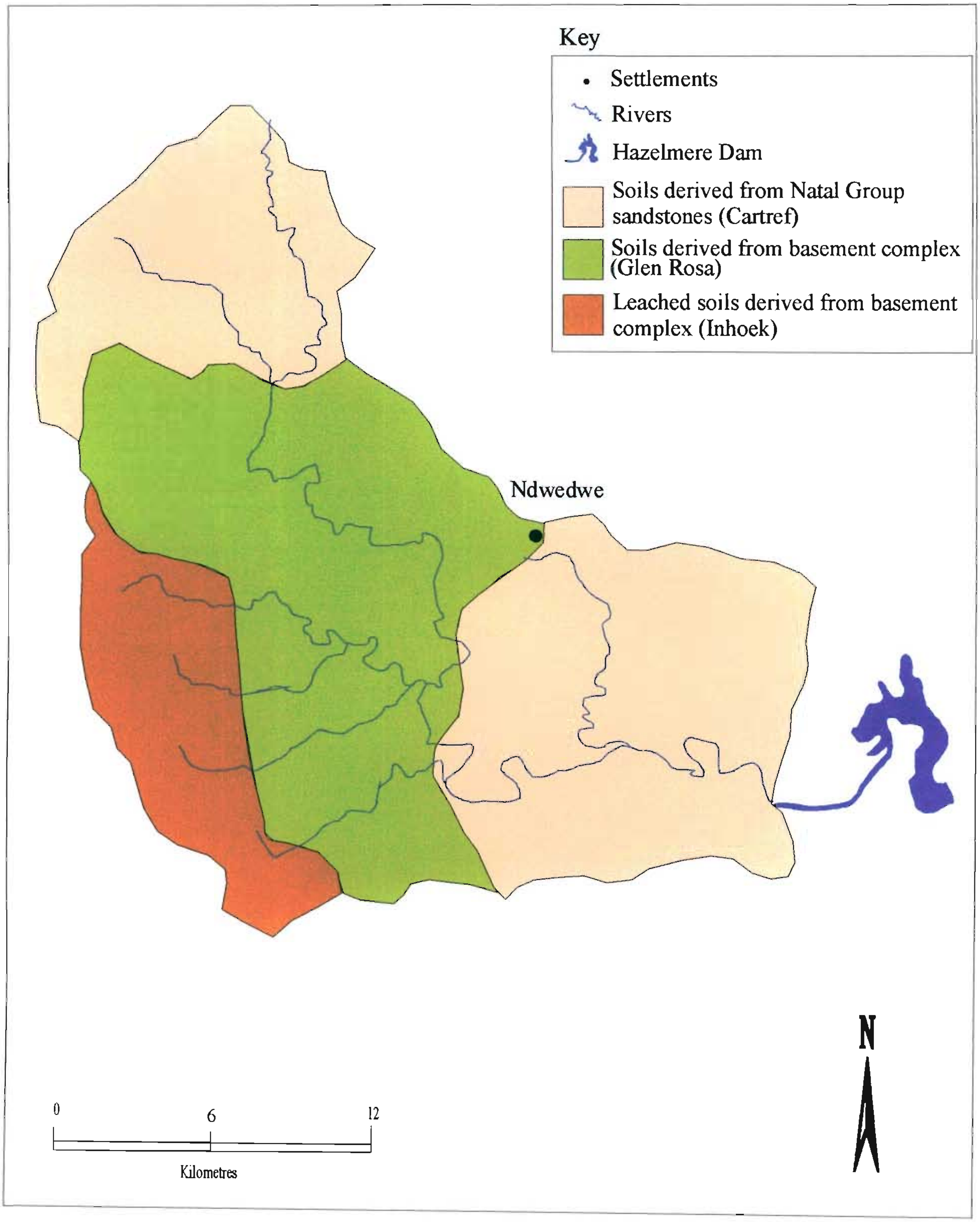

Figure 3.3: Soils of the Hazelmere Catchment (de Villiers, 1962)

The Glenrosa Series is derived from the granite gneiss basement complex of the Namaqua Natal Mobile Belt (basement complex) in the Mdloti River Catchment. The Glenrosa Series constitutes an orthic A-horizon overlying a lithocutanic B-horizon. In humid regions granite decomposes into residual soils of great depth. Mica particles (particularly muscovite) remain unaltered except in the upper zones of the soil profile where they decompose, while quartz grains remain unchanged. Feldspars are, however, kaolinised by a chemical reaction with water charged with carbon dioxide. Particles of colloidal kaolinite are fine-grained and conducive to leaching. These particles are, therefore, removed in suspension leaving behind a residuum of micaceous silty sand that collapses easily (Brink, 1979). Such mass wasting features are common on the steep slopes in the central area of the Hazelmere Catchment (Figure 3.3). The sand fraction is also easily mobilised by surface runoff.

The Inhoek Series is derived from the rocks of the Namaqua Natal Mobile Belt (basement complex) and is characterised as a melanic A-horizon overlying an unspecified horizon. The unspecified horizon material either depicts alluvial stratification or unconsolidated sediments in which soil formation has not yet progressed sufficiently to produce a G-horizon, pedocutanic B-horizon or a soft or hardpan carbonate horizon. The melanic A-horizon exhibits a wide range of dark, usually well-structured topsoils, developed under sub-humid and humid climates such as that in the Hazelmere Catchment during summer months (SCWG, 1991). These sandy clay soils of the Inhoek Series are found in the south west of the catchment.

3.5. RELIEF

The Mdloti River Catchment is characterised by gently undulating hills in the lower reaches (0 - 450 m above mean sea level (amsl)), becoming steeper and more rugged (450 - 1068 m amsl) with distance inland (Figure 3.4). The gradient of the river responds to the changes between lithologies by decreasing significantly downstream and incising through the Natal Group sandstones to form gorges. A percentage slope map (Figure 3.5) displays that one fifth of the catchment has slopes greater than 20 %. This is particularly problematic for cultivation and housing development (Russow & Garland, 2000).

An aspect map of the catchment (Figure 3.6) shows predominately northwest and southeast slopes. Northwest slopes receive sun most of the day, particularly in the mornings, due to the catchment's latitudinal location. These slopes are therefore drier than the southeast slopes and are prone to desiccation.

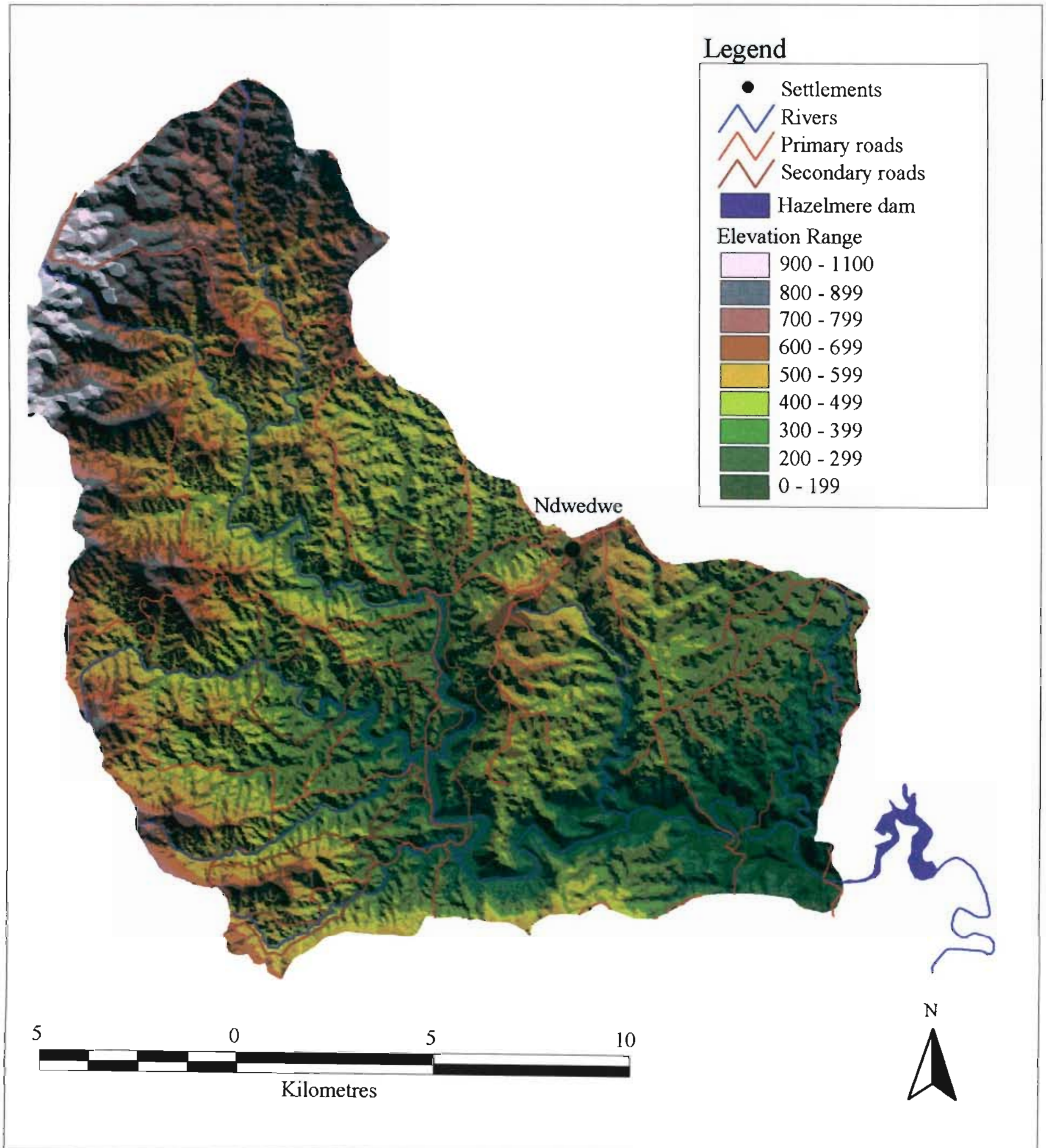

Figure 3.4: The relief in the Hazelmere Catchment

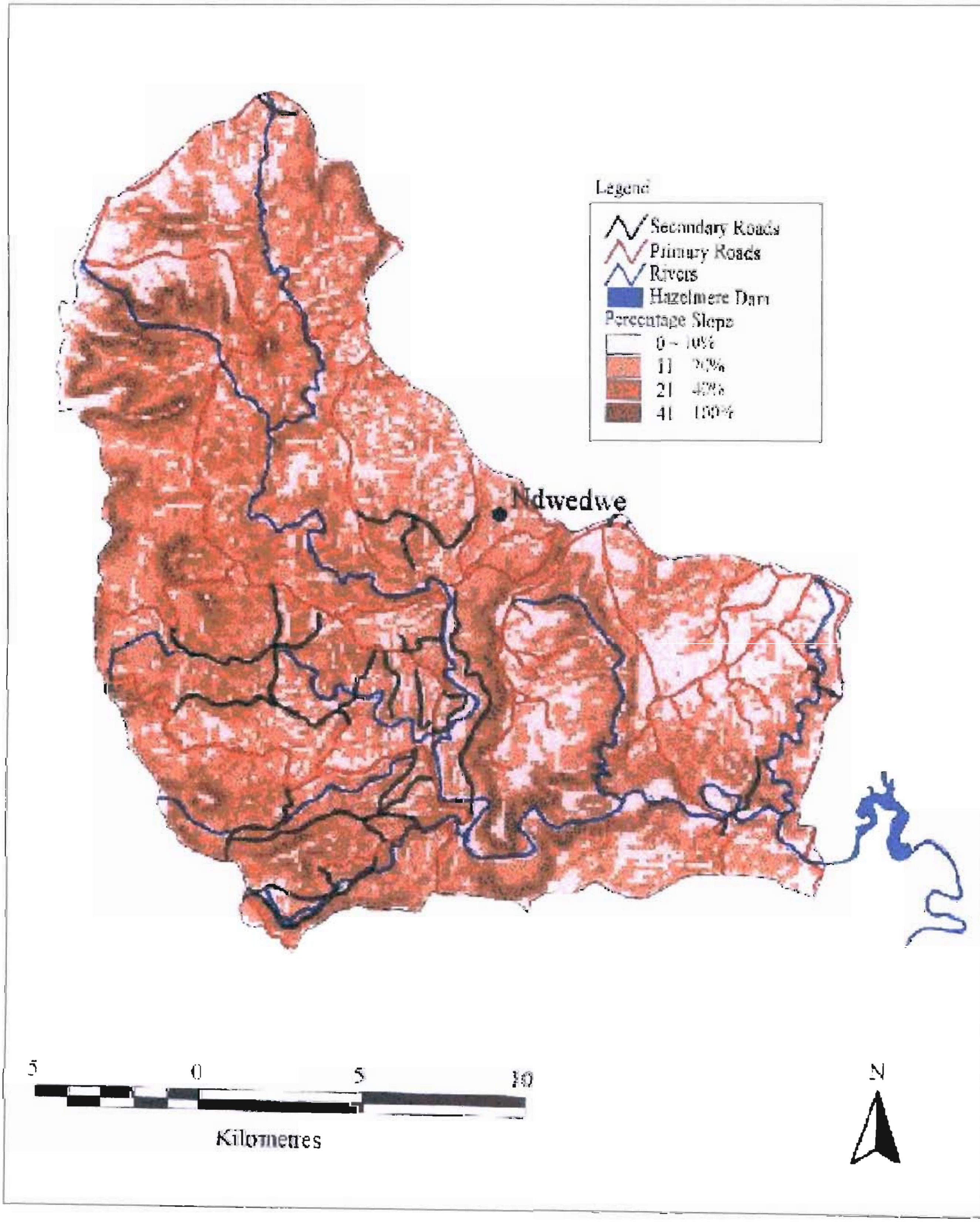

Figure 3.5: Percentage slope within the Hazelmere Catchment

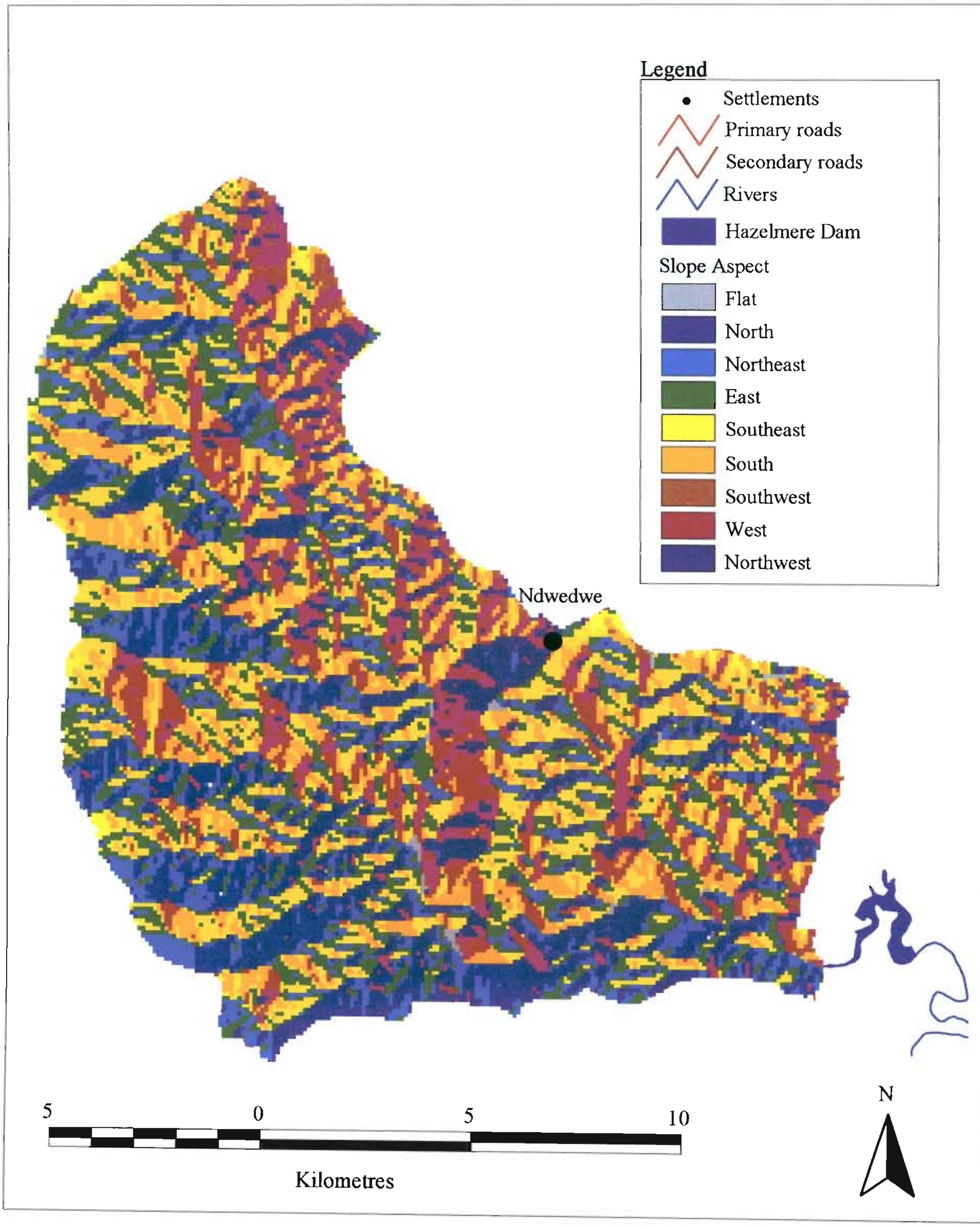

Figure 3.6: The aspect of slopes in the Hazelmere Catchment

3.6. CLIMATE

The Hazelmere Catchment is situated within the Subtropical Climatic Zone of southern Africa (Schulze, 1965). Characteristics of this zone include: warm to hot temperatures with high humidity levels. Mean daily maximum temperatures range from 11.0°C in winter to 27.2°C in summer (Table 3.2). Daily temperatures fluctuate depending on proximity to the coast. In general, coastal temperatures are warmer than those inland because of the warm maritime air. Although the mean daily temperature is 20.3°C, the highest and lowest recorded temperatures are 40.2°C and 0.0°C respectively (Table 3.2).

Annual precipitation ranges from 760 mm in the interior to 1250 mm along the coast and against the interior mountain ranges (Beater, 1970). Most of the precipitation occurs during the summer months (September to March) and is experienced for 120 to 140 days per year in the form of thunderstorms that periodically cause flash flooding. The short duration, high intensity nature of such rainfall events favours surface runoff (Beater, 1970). The nature of precipitation events in the catchment brings about high erosivity (EI30) values for the area. Rooseboom *et al.* (1992) reported erosivity for the catchment to range between 300 and 500 $MJ.mm.ha^{-1}.h^{-1}.annum^{-1}$. According to Smithen and Schulze (1982), erosion values for South Africa range between 50 and 500 $MJ.mm.ha^{-1}.h^{-1}.annum^{-1}$, generally increasing from west to east.

The actual evaporation values from the land are relatively low, approximately equivalent to one winter month's precipitation. Low evaporation from the catchment is caused by the consistently high humidity levels as a result of evaporation off the Indian Ocean and advection into the interior. Mean annual runoff has been estimated at 70.54 million m^3 (Maré & Mallory, 1994). In comparison to annual inflows into the Hazelmere Dam, however, only 17-35 % of the precipitation over the Hazelmere Catchment reaches the dam (Umgeni Water, 1993).

Table 3.2: Climatic statistics from the Tongaat weather station (South African Sugar Association, 2001)

	Rainfall (mm)		Temperature (°C)				Evaporation (mm)
			Mean daily		Extremes		
Month	Mean Monthly Total	Maximum 24 hr	Max	Min	Highest	Lowest	Class A Pan
January	127.0	98.0	27.2	20.1	38.3	0.0	6.0
February	127.9	97.5	27.2	20.2	40.0	0.0	6.0
March	112.0	93.0	26.9	19.3	34.4	12.8	5.2
April	60.7	72.0	25.3	16.7	35.8	0.0	4.2
May	41.3	216.0	23.9	13.8	38.6	0.0	3.2
June	22.6	95.5	22.4	11.3	35.0	5.0	2.6
July	40.7	60.0	22.2	11.0	3.2	4.4	2.7
August	44.3	96.0	22.5	12.3	36.4	4.9	3.4
September	85.3	72.0	23.0	14.6	38.1	5.4	4.0
October	125.1	71.5	23.7	16.0	40.2	8.1	4.6
November	120.7	80.2	24.8	17.6	37.6	10.1	5.3
December	104.0	99.9	26.4	19.2	37.5	10.8	6.1

At present there are no weather stations in operation within the Mdloti River Catchment. The five stations previously in operation have, since 1992, been systematically closed due to reasons of economic feasibility and the theft of equipment. The nearest weather station for current daily climatic statistics is located at Tongaat (Figure 3.1 p. 27), approximately 6 kilometres south east of Hazelmere Dam. This is problematic in that the real time relationship between precipitation and discharge can only be inferred. Actual rainfall distribution, therefore, cannot be mapped for the catchment. Recurrence intervals of extreme events and actual rainfall erosivity can only be obtained through inference from past events or by mathematical modelling. However, mean annual precipitation (MAP) values from the weather stations in the Mdloti Catchment (prior to their closure in 1992) showed a comparison with corresponding values from the Tongaat Weather Station. Due to the comparability of the MAP values, up-to-date climatic statistics from the Tongaat Weather Station were used in this research (Appendix 2).

3.7. NATURAL VEGETATION

Natural vegetation suggests the condition and vegetation characteristics best suited to the catchment. The Mdloti Catchment has a high biodiversity with respect to the natural vegetation (Low & Rebelo, 1996). Such areas remain isolated and the conservation status of the catchment is low as a consequence of modifications in land use and presence of invasive alien species. Low and Rebelo's (1996) classification, based on agricultural potential with the focus for planning, development and conservation, classifies the Hazelmere Catchment into Afromontane Forest, Valley Thicket, Coastal Bushveld-Grassland, Coast-Hinterland Bushveld and Short Mistbelt Grassland (Figure 3.7). These divisions equate to Acocks' (1988) Moist Coast-Hinterland Ngongoni Veld and the Thorn and Palm Veld vegetation types, which are based exclusively on grazing potential.

Afromontane Forest vegetation is found in patches along south facing ridges in the catchment (Lubke & McKenzie, 1996). As water is the key limiting factor for this vegetation group the south facing slopes in the catchment are preferred. These slopes maximise the southwesterly and southeasterly driven rainfall. They also experience less sunlight exposure than north-facing slopes thereby retaining a high moisture content in the soil. Encroaching alien vegetation reduces the availability of water and sunlight restricting the areas suitable for habitation of Afromontane Forest vegetation in the catchment. Soils are shallow on these steep slopes and are often leached due to the high rainfall. Exploitation of the forests for firewood by the local inhabitants of the catchment impacts on the preservation of this natural vegetation type.

Valley Thicket vegetation is comprised of very dense thicket of woody shrubs and trees occurring in the river valleys (Figure 3.7) (Lubke, 1996). Such riparian vegetation facilitates bank and channel stability, but with increasing demands on food productivity and human population pressures, farmers are removing this natural riparian vegetation to use the land for crop cultivation in the Hazelmere Catchment.

Coastal Bushveld-Grassland occurs on flat to gently undulating slopes (up to 300 m amsl) (Figure 3.7). The vegetation is restricted to sandy soils and influenced by fire and grazing of cattle (Granger *et al.*, 1996). As the slopes are gentle in this part of the catchment it is also cleared for cultivation and little of the natural vegetation remains.

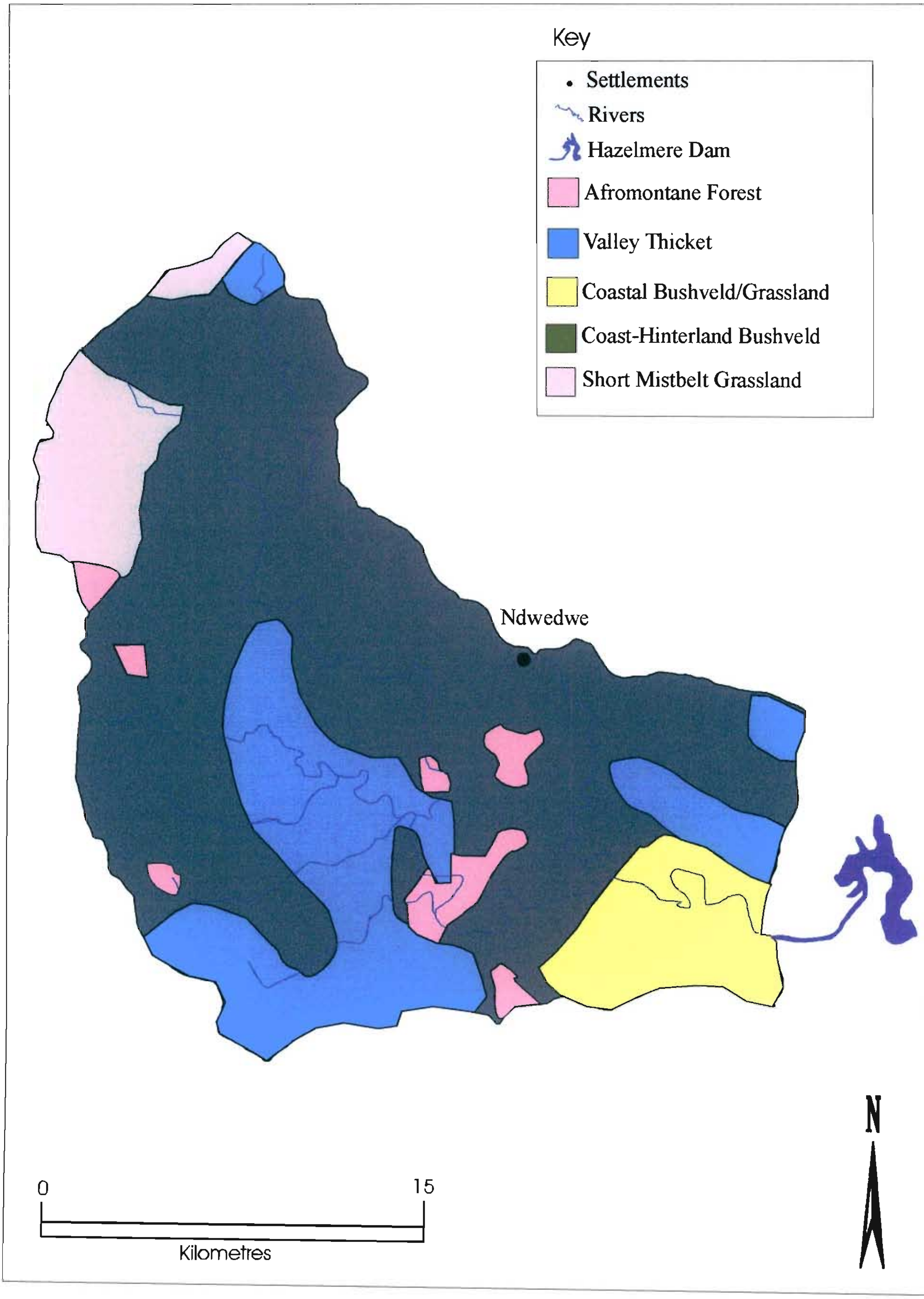

Figure 3.7: Natural Vegetation of the Hazelmere Catchment (Low & Rebelo, 1996)

Coast-Hinterland Bushveld occupies exposed upland hilltops and ridges of the lower escarpment slopes from 450-900 m amsl (Figure 3.7). Poor conservation of the natural vegetation in this area of the catchment has been attributed to grazing by cattle due to the socio-economic and socio-political pressures outlined in section 2.1 (Granger, 1996).

Short Mistbelt Grassland vegetation is found at the headwaters of the catchment (Granger & Bredenkamp, 1996). Large areas have been afforested or poorly conserved by invading vegetation, in particular Wattle species.

3.8. ECOTOPES AND LAND UNIT CLASSIFICATION

Ecotopes are the smallest divisible unit within the Bioresource Group (BRG) classification system developed by the KwaZulu-Natal Department of Agriculture (Camp, 1999a). This land unit classification system was established based on the geomorphological-land-systems-type-mapping concepts described in Cooke and Doornkamp (1990). The ecotope system classifies land according to the types of plant species present and their preferences in terms of relief, water and nutrient needs in order to determine the narrow range of farming activities each land unit can support, potential yield, as well as production techniques necessary for each activity (Camp, 1999b). This system is, therefore, used to define land use capabilities for particular sites, according to the nature of its attributes, when farm planning (Camp, 1999b). The Hazelmere Catchment has been divided into seven ecotope groupings (Figure 3.8), described in Table 3.3 below (Liam, 2001).

From Table 3.3 and the other information provided in the above chapter it is evident that the high precipitation, moderately steep rolling hills and the former grassland/bushveld or forest vegetation areas provide the optimum conditions for perennial crops such as sugarcane and timber plantations. The steeper reaches of the catchment are ideal as pastoral or grazing land, while the gentler slopes are more suited to the cultivation of seasonal crops.

Table 3.3: A Summary of ecotope groupings found in the Hazelmere Catchment (Liam, 2001)

Ecotope	PPT	Elev	Slope angle	Natural vegetation	BRG	Land use dominance
eMakuluzeni - Wa6	800 – 850 mm/a	126 – 548m amsl	Steep >12%	Valley Thicket; Coastal Hinterland Bushveld	1.3	48 % perennial pastures, sugarcane & timber. Gentle slopes for cropping
Kwanyuswa – Xb10	850 – 900 mm/a	346 – 850m amsl	Steep	Coastal Hinterland Bushveld	3.5a	61 % perennial pastures, sugarcane & timber
North Coast – Ya14	900 - 1100 mm/a	3 – 661m amsl	Steep to moderate > 5%	Valley Thicket; Coastal Bushveld-Grassland	1.3	54 % crop farming & steeper slopes for sugarcane and timber
Ozwatini – Yb13	900 – 1100 mm/a	283 – 1042m amsl	Steep	Coastal Hinterland Bushveld	3.5a	70 % sugarcane and timber use.
Inanda – Yb14	900 - 1100 mm/a	466 – 586m amsl	Moderate to steep	Coastal Bushveld/Grassland; Afromontane Forest	3.5c	53 % sugarcane and timber cultivation. Gentler slopes for cultivation
Bruyn's Hill – Yc21	900 - 1100 mm/a	748 – 1071m amsl	Gentle to moderate	Short Mistbelt Grassland	5.2	74 % of the area suitable for growing crops
Ndwedwe – Zb3	>1100 mm/a	409 – 661m amsl	Steep	Coastal Hinterland Bushveld; Afromontane Forest	3.5a	63 % sugarcane and timber crops

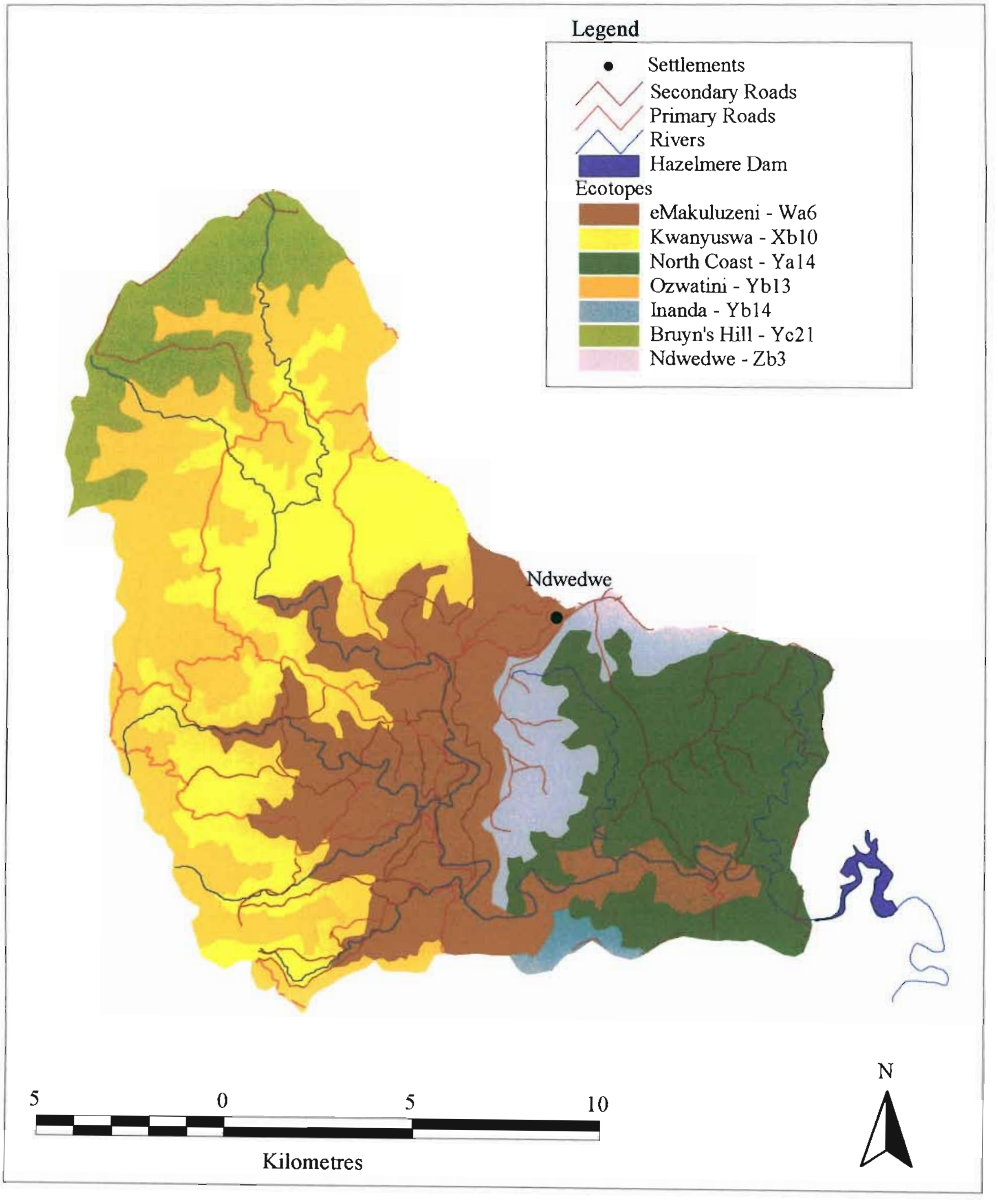

Figure 3.8: The ecotope areas for the Hazelmere Catchment (modified after Camp, 1999b)

3.9. LAND COVER

According to the National Land Cover Database for South Africa (Thompson, 1999), the Hazelmere Catchment consists of ten land cover classes (Figure 3.9). The most dominant classes are those of the thicket and bushveld or degraded thicket and bushveld extending across the northwest, west and central regions of the catchment used by grazing animals. The northeastern region of the catchment is dominated by cultivated, temporary, semi-commercial/subsistence dryland while the extreme north of the catchment is classified as cultivated, permanent, commercial sugarcane or forest plantations. Little natural forest and grassland areas remain and are found scattered across the catchment. Two small areas of urban/built-up land, used as residential areas, are found in the vicinity of the Ndwedwe settlement (marked on the figure).

This database is useful for consideration in conjunction with the natural vegetation of the catchment and ecotope areas described above. The natural vegetation and the ecotopes describe the vegetation naturally occurring in the catchment or the types of vegetation that are likely to establish given the soils, climate and topography of the area. Land cover describes the actual vegetation types and, to some extent, the land uses existing in the catchment. The natural vegetation suggests the possible composition of the catchment prior to human occupation aiding in understanding the natural erodibility of the catchment. Conversely, land cover describes the vegetation at present identifying the changes that have been brought about with the occupation of humankind and therefore their contribution to the erodibility of the catchment.

3.10. ANTHROPOGENIC FACTORS

The Hazelmere Catchment, as of the 1996 census, lay within four magisterial districts (Figure 3.1 p. 27). The Ndwedwe district comprises 90 % of the catchment area, while the Mapumulo district 2 %, the New Hanover district 5 %, and the Inanda district 3 %. The total population of the catchment is difficult to measure, to any degree of confidence, as these magisterial districts do not coincide with the boundary of the catchment (Currie, 1997; Russow & Garland, 2000).

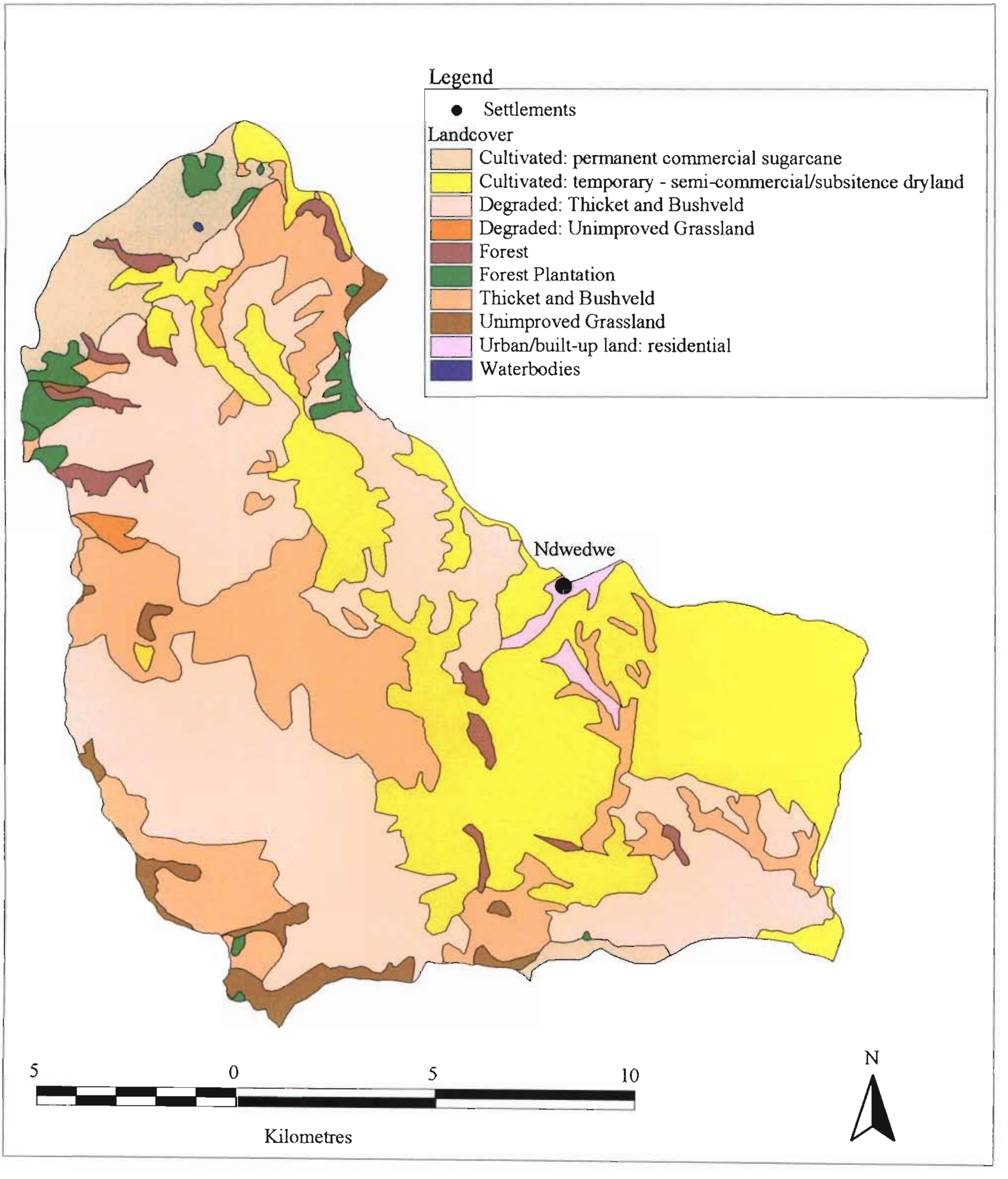

Figure 3.9: Land cover of the Hazelmere Catchment (modified after Thompson, 1999)

The population for the Ndwedwe district was approximately 318 093 people in 1991 which was an increase from the 1985 census where it estimated 138 588 people inhabited the same district (Currie, 1997; Russow & Garland, 2000). The 1996 census showed that the population then declined to 144 172 people which equates to 163 people per square kilometre (Mommen, 2001).

The people inhabiting the catchment are primarily from the Zulu tribal group, as the majority of this area was part of the former KwaZulu 'homeland' area. The land owned by the tribal council has been divided into small parcels and distributed to the tribal community. It was observed, by the author, that the homes have been built using traditional methods of mud walls supported by branches of wattle trees with thatched roofs, although the 'western' galvanised iron roofing is being increasingly adopted by the inhabitants. These dwellings are found in clusters, generally surrounded by cultivated fields from which extends a communal grazing area.

Infrastructure decreases with distance from the road networks and urban centres, yet schools, religious centres, police stations, shops and clinics are numerous throughout the catchment, although poorly equipped. A large hospital servicing the area is situated near Verulam. Although basic services are increasing steadily, electricity, water and telephones have not yet reached all dwellings. Public telephones, water pumps and postal access are scattered through the catchment and streetlights line the main access routes to the towns of Verulam and Ndwedwe, only. The people live off the land by cultivating staple foods, such as mealies, potatoes, cabbages, and beans. Cattle are kept as a symbol of wealth and also as a livelihood strategy, often causing serious overgrazing problems in these areas.

The population statistics on education from the 1996 census shows that 24 % of the people inhabiting the catchment area have no education while only 15 % have grade 12 or higher (Statistics South Africa (StatsSA), 2001). Virtually half of the population is unemployed and of those that do have employment 56 % earn less than R 1000 per month (StatsSA, 2001). The majority of the men have become migrant workers since the lifting of influx control laws, leaving women, children and the elderly to tend the households and farms. This accounts for the slightly larger female to male ratio (1.2:1) in the catchment area (StatsSA, 2001).

The small section in the north of the catchment that falls within part of the New Hanover magisterial district (approximately 5%), and outside the former 'homeland', has well-established commercial sugarcane and timber farms.

3.11. SUMMARY

The Hazelmere Dam drains an area that has high rainfall, a rugged terrain, steep slopes, erosive sandy clay soils as well as poorly conserved natural vegetation that for a significant period of time, has been under rural and tribal land use, but has also included some commercial land use areas. The increasing demands being placed on the land to sustain the growing populations and the diverse socio-economic status of the people affords the opportunity to investigate the extent to which sedimentation in the Hazelmere Dam can be attributed to land use change in the light of the natural environment.

CHAPTER 4

METHODS OF DATA ACQUISTION

Various methods have been employed to derive data pertinent to determining the extent to which the sedimentation in the Hazelmere Dam can be attributed to land use change and to improving understanding of the catchment's composition. The methods, which include appropriate mapping procedures, population counts, field surveys and slope and aspect consideration of the terrain, were carried out by the author. Soil surveys and sediment sampling methods used by other researchers were included to confirm and/or substantiate data analysis.

4.1. SEDIMENT SAMPLING

In order to identify the extent to which sedimentation within an impoundment can be attributed to land use change, as is the aim stated in Chapter one, it is imperative that an analysis of sediment data be completed to identify spatial and temporal changes in sediment supply. Sediment traps, used for the purpose of recording sediment yields from plots of land, disturb the vegetation and soil on application and need to remain undisturbed for a period of time to re-establish conditions before accurate measurements can be taken (Auerbach, 1992). Direct measurement and analysis of sediment produced from each land use, using sediment traps, was not possible in this research due to the restricted time-scale over which the research was conducted, quite apart from the difficulties of scaling from runoff plots to the landscape (Auerbach, 1992). Although it is not possible to estimate sediment yield directly, change in the quantity of sediment in the river through the use of existing suspended solids, turbidity and inflow volume data, can assist in a time-series comparison with land use change (Hadly & Mizuyama, 1993).

No standard method for sampling sediment in rivers exists due to the widely variable composition of water bodies. The sampling method adopted must, however, ensure true representation of the water. Umgeni Water used the 'grab' sampling technique in collecting weekly samples from the Mdloti River at the inlet of the dam (Karar, 2001). Sediment values vary with depth, velocity of flow and distance from the riverbank. The samples should, therefore, be taken mid-depth and midstream, without disturbing the settled particles. The sample bottle was suspended from an overhead bridge and submerged, into the Mdloti River below, approximately midstream and mid-depth. Five samples were taken from the river at each sampling site to ensure that the present conditions were well represented (Karar, 2001). Care was taken to ensure that no contamination of the samples occurred after collection. This was achieved by sterilizing the containers before testing, to extract any contaminants from a previous use. The containers were also rinsed twice through the river water at the sampling site before the samples were taken. Glass containers were used to prevent any sediment from sticking to the sides and to resist corrosion from cleansing products, which could contaminate the sample (Karar, 2001). Handling the sample prior to it reaching the laboratory should be minimal and the sample should be stored at a low temperature to avoid the growth of bacteria before analysis can be undertaken. Temperature control is difficult when the sample sites and the laboratory are of significant distance from each other, such as in the case of the Mdloti River and the Umgeni Water laboratory in Pietermaritzburg (Karar, 2001). Clear labelling of each sample must be carried out at the time of sampling to prevent confusing samples with others taken from other sites and catchments. Once the samples reach the laboratory, analysis of the samples can begin. In analysing the samples for suspended solids, the sample is centrifuged to separate the sediment from the water. The sediment is dried to ensure all the water is removed and then weighed to calculate sediment per volume of water (Karar, 2001). Particles contributing to the suspended solids measurement include: clay and silt, fine organic and inorganic matter, plankton and micro-organisms, which are kept in suspension by turbulence (World Health Organisation (WHO), 1984).

The turbidity and inflow volume measures are taken on-site and do not require lengthy laboratory analysis. A nephelometric turbidity recorder was used to measure turbidity at the inlet to the dam (Karar, 2001). The recorder was placed in the water column at the same point as that for sediment sampling and for the same reasons given above. A value in nephelometric turbidity units (NTUs) was then recorded. Turbidity is an expression of the light scattering ability of water indicative of the concentration of suspended and colloidal matter (10 μm– 0.1mm) in water (Holmes, 1996). Contributing particles include clays, organic particles from decomposing plant tissue and fibrous particles (WHO, 1984).

Turbidity directly affects the amount of chlorine that is needed to disinfect the water. The inflow volume for the Hazelmere Dam was measured by placing a gauge plate in the water at the inlet to the dam (Karar, 2001). Inflow volume is an indication of the amount of water that flows into the Hazelmere Dam daily and is important in determining the maximum potential sediment load at that point.

Inconsistencies exist in the sampling data made available by Umgeni Water. Inconsistencies vary both within a set and between sets of data, making scientific interpretation of the data difficult (Appendix 1). Turbidity readings, for example, started in 1989 with samples being taken irregularly either once or twice a month yet by 1991 readings had increased to four or five samples per month. Due to this inconsistency in the sampling, monthly averages had to be calculated for analysis of the entire time period. This monthly average was then seen to represent the conditions of the river for the entire month rather than for that of a single event making identifying and analysing factors that act on turbidity difficult and, thus, the management of turbidity. The same inconsistencies exist in the suspended solids data. No indication of the weather conditions prior to or at the time of sampling accompanied the data. Weather conditions significantly alter the streamflow rate and volume affecting the turbulence and therefore the suspended solids and turbidity values. Information on the weather conditions in the catchment would provide a clearer understanding of conditions in the river and provide possible reasoning for changes in turbidity and suspended solids values. Another problem with the sampling is the incomplete datasets. Values of inflow volume started in 1980 but stopped temporarily for 1986 and during 1994, the latter of which was due to political unrest. These inconsistencies imply that conclusive studies of inflow volume cannot be determined until after this period. Only an eight-year period of overlapping data for turbidity, suspended solids and inflow volumes was available for analysing the sediment-flow relationship. Although this data provides no indication of the sediment source or its time of removal, analysis of change over time is possible and necessary in terms of objective five.

4.2. THE MAPPING PROCEDURE

Documenting spatial and temporal variations in land use components aids the understanding of the processes that have shaped the landscape, essential when formulating land management strategies for the area in question (objective 8, p. 5) (Mather, 1986). The thematic ability of GIS, reviewed in Chapter two as per objective one p. 4, facilitates both land use mapping and the analysis of change through time. This ability is important in enabling many different role-players to visualise the problem of changes in land use and, therefore, to model management options to determine the consequential effects before implementation. This ability is significant in allowing more informed decision-making on the utilisation and sustainability of natural resources (Tomlin & Johnston, 1990). The mapping process, summarised in Figure 4.1, is dictated by the aims and objectives of the study (Chapter one p. 4), which requires the mapping of land use in the catchment through the use of a classification system to analyse changes in land use through time.

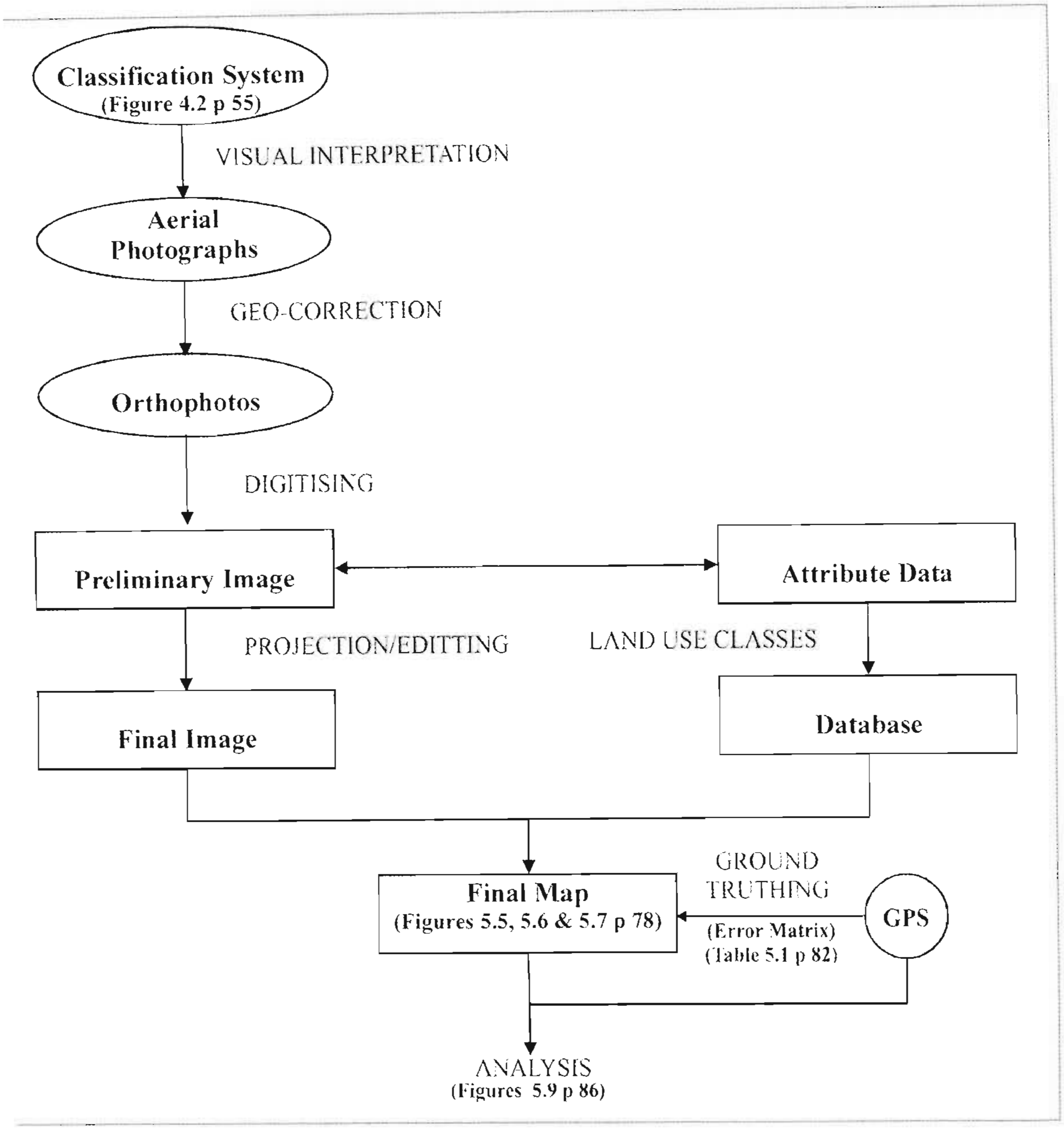

Figure 4.1: Flowchart of procedures used in mapping land use in the Hazelmere Catchment

4.2.1. The Classification System

A classification system is required for the purposes of land use mapping in order to ensure consistency in the degree of generalisation used across the catchment (objective 5, p. 4). Classification is the process of arranging objects into groups, based on their relationship with each other (Sokal, 1974). The purpose of classifying is to group objects of a similar nature together, in order to simplify all environments (social, political, ecological) into sections that require almost identical management efforts. Classifiers, the criteria used to group objects in terms of land use, are based on the function of the land to produce goods or services (Campbell, 1983; Di Gregorio, 1996). The classifiers will change as land uses change, and in so doing modify the classification system (Moore *et al.*, 1994). It is for this reason that no uniform land use classification system exists, only criteria to aid the structuring of a classification system (Di Gregorio, 1996). The criteria were established to provide comparable land cover or land use data globally without limiting research by stipulating the degree of detail that could be classified (Di Gregorio, 1996). The criteria arose from a joint effort between the AFRICOVER working group, the Food and Agriculture Organisation (FAO) and the United Nations Environmental Programme (UNEP) in 1996 to standardise land classification. The structural criteria for an acceptable classification system include:

1. a hierarchical classification structure whereby classes originate broadly to allow for the flexibility of subdivision into more detailed sub-classes, if so required, so as to meet the needs of a variety of study objectives. This allows for use of the system at different scales and for cross-referencing between continental or global maps with local or regional ones (Di Gregorio, 1996),

2. *a priori* system requires that the classes be defined prior to data collection. This method standardises classes independent of the area under consideration and creates a comprehensive system (Di Gregorio, 1996),

3. classes must be mutually exclusive and unambiguous; be defined by specific diagnostic criteria which are easily measured and which do not vary with season (Di Gregorio, 1996).

These aids were also used in the development of the National Land Cover Database for South Africa (Thompson, 1999). Figure 3.9 p. 45) shows the land cover of the Hazelmere Catchment from the National Land Cover Database of South Africa to illustrate the general land cover classes that can currently be found in the catchment. The scale (1:250 000) at which land cover was mapped for the database restricted its use in this research in developing land use maps for comparison through time. The general structure of this land cover classification system was, however, adapted to classify land use in the catchment in keeping with national and global standards. All the possible land use classes were narrowed down to the specific scale of interest required by this research. Once the system had been implemented, in the manner discussed below, and the catchment classified, those classes not found in the catchment were eliminated from Figure 4.2. Figure 4.2, therefore, illustrates the classification system for the Hazelmere Catchment only.

As the catchment is situated in a rural area of South Africa the first step in classifying the catchment was to distinguish between settlement areas and agricultural areas. There were no formal settlement areas within the catchment that could be distinguished from the dense, communal farming populations. The next division within agricultural areas was the clear distinction between cultivated land and non-cultivated land. In the cultivated division commercial cultivation could also be adequately differentiated from small-scale agriculture and subsistence cultivation. The two commercially cultivated crops in the catchment are timber and sugarcane, each clearly distinguishable from each other, and therefore classed in separate units. The subsistence agriculture was, however, more difficult to classify as cultivated patches included a mosaic of various fruits (bananas) and vegetables (mealies, potatoes, legumes, pumpkin). A disadvantage of the classification system in this class is that it includes many crop types, ranging in canopy height, ground cover and root depth, as well as nutrient and water needs. Changes in any of these factors can significantly alter erosion potential, as was highlighted in Chapter two. Furthermore, the classification system does not take cognisance of any conservation practices as these practices change from field to field depending on the farmer's preference and many could not be identified from aerial photography. The mapping of crop type and conservation practices for the entire catchment at the farm scale, had it been possible, would have contributed considerably to estimates of erosion (i.e. sediment source areas). Non-cultivated land could be divided into two sub-divisions: subsistence grazing land and woodlots. As described in the environmental settings, little natural vegetation remains in the catchment and was indistinguishable on aerial photographs from the woodlot vegetation or subsistence grazing land. The woodlot areas in the catchment are, therefore, areas that have been left to grow uncontrolled, consisting of a mixture of indigenous and alien vegetation, harvested for use as building materials, fuel and firewood. To overcome the difficulty of differentiating between the land uses in the non-cultivated areas land cover was used to identify the land use practiced. Grassland vegetation was used to identify subsistence grazing land while bushveld vegetation or wooded areas were classified as woodlots. The inclusion of primary (district) roads and secondary (other roads and tracks) roads, as well as the river system (main stream, tributaries and the dam), was determined in order to explain the mode of land use according to proximity to water supply and accessibility to transport.

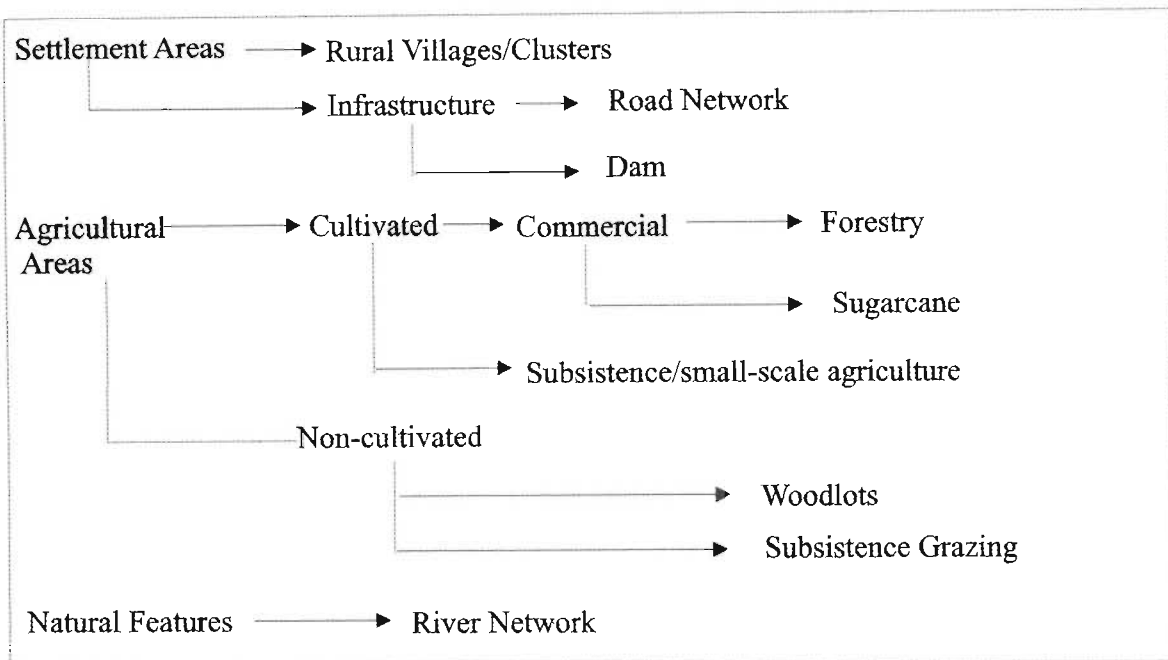

Figure 4.2: The classification system of land use utilized in the present research

4.2.2. Data Types and Sources

Remote sensing provides the opportunity to develop inventories of surface resources in a systematic way (Stabins, 1978). Aerial photography is the original form of remote sensing and is still widely used in topographic mapping and environmental studies. The format of aerial photographs lends itself to the compilation of maps since they are concise representations of the patterns on the ground. Vertical photographs are easier to use when locating objects and measuring the distance between them, than oblique photographs and can also be compared to older photographs, to depict changes through time (Eastman, 1995). Since changes in time-series analysis are required and the relative aerial photograph series covering the catchment are available it is more accurate, cost-effective and quicker to use aerial photographs than field surveys. Although ground truthing of maps created from aerial photographs is essential, aerial photographs allow access to otherwise inaccessible areas (Stabins, 1978; Campbell, 1983). A bird's eye view of an area, as opposed to a surface view, is also more useful in terms of identifying patterns of land use.

In this research the advantage of aerial photography over other remote sensing images, for example: radar and satellite images, is the cost-effectiveness. Remotely sensed images are more expensive than a series of aerial photographs. The software and experience required to process the remotely sensed images into meaningful information adds to the expense. Despite the speed and accuracy of remote sensing processes, the scale of aerial photographs is greater thereby showing more detail. Conversely, the quality of the image plays a major limiting role in the amount of information that can be acquired. Resolution, the accuracy at which a given map scale can depict the location and shape of geographic features, is impacted on by contrast, colour and tone of the photographs (Arnold, 1996). This can lead to changes in interpretation of the land use patterns. The photographs are subject to distortion from the variations in ground relief, curvature of the camera lens and the tilt of the aircraft (Barnes, 1982), leading to inaccurate representations of the earth's surface. This is most evident by the stretching of objects at the edges of the photographs where the greatest curvature of the camera lens is experienced. In hilly terrain, where the higher ground is closer to the camera lens than the valley areas, the objects on the hill will appear to have a greater area than those in the valley, creating a distorted image. Although aerial photographs make the task of land use surveys quicker and easier than the labour intensive, costly field surveys, the distortions can make the image somewhat inaccurate.

Two methods exist to reduce the degree of distortion on aerial photographs. The first method is known as the warping process. This process records reference points of dominant stationary landmarks on the photographs and the corresponding points on the ground. The process then fits the points on the photograph to align with the reference points from the ground, stretching and pulling the photographs to the new co-ordinates. This process has been shown, by past research, to be a labour-intensive and extremely inaccurate technique in remote areas as, approximately, 16 reference points per aerial photograph are needed (Rivers-Moore, 1997). The area of the Hazelmere Catchment (the study area) is a very remote area with undulating topography, which meant that the aerial photographs were especially distorted. Using a Global Positioning System (GPS), to determine the reference points on the ground proved equally problematical due to the limited accessibility of the areas as well as an inadequate number of stationary landmarks.

Due to the limitations with the warping process and the high possibility of error (noted in past research) it was befitting to employ the second method known as the tracing process. This process is a simpler method for reducing distortion of photographs and is less user-subjective (Hill, 2000). Areas of interest derived by the classification process are identified on the aerial photograph and transcribed to the same location on the orthophoto by association with dominant features. Orthophotos are aerial photographs that have been geo-corrected to eliminate the complications of distortion. Unfortunately their availability is insufficient for time-series analysis due to the high costs of productivity. User-subjectivity in the tracing process is kept to a minimum as only one person worked on the mapping process. The reference points were taken to be the tic points[1] on the orthophotos and therefore the map did not need geo-correcting, thus reducing the processing time considerably.

In order to carry out the mapping process the following source data was purchased. Aerial photographs covering the Hazelmere Catchment for three epochs were purchased for the use of mapping land use over time. The 1978 aerial photograph series was chosen to depict land use at the time of the dam's construction while the 1996 aerial photograph series was the latest available series. The 1989 series was selected at a roughly equal time interval between the 1978 and 1996 photograph series based on the availability of the aerial photographs. Table 4.1 summarises the metadata of the source data used in this research. In order to have a reasonably consistent scale for classifying land, photographs were bought at contact scale (1:30 000) except the 1989 series, which was bought at double contact scale (1:25 000). The orthophotos covering the catchment could not be purchased for one year or from one centre due to the former division of the catchment into the

[1]Tic point – geographic control points used in order to register a digitised image to a known location on the earth surface (ESRI, 2001)

KwaZulu 'homeland' area and into the Natal area and no complete series for the entire catchment was available for the same year. These discrepancies between datasets were, however, resolved in the tracing process. The discrepancy in scale of the aerial photographs was resolved by tracing onto the orthophotos that have fixed scale (1:10 000) while the inconsistency in years between orthophotos is eliminated by identifying and classifying areas on the aerial photographs. Once the tracing of the land use patterns onto the orthophotos was complete, the traced sheets could then be digitised (see Section 4.2.3).

4.2.3. Digitising

Digitising is the process of converting the features traced on the orthophotos into digital format through the use of a digitising tablet (ESRI, 1996a). The digitising tablet is an electromagnetic device that is able to detect and transmit the position of the puck (mouse) with a very high degree of precision (Martin, 1991). Once the document is positioned on the surface of the tablet, a number of tic points (a minimum of four points per map sheet is required to register the map sheet with ArcView 3.2) are recorded, to which known real world co-ordinates are given (Martin, 1991). A Root Mean Square Error (RMSE) is calculated indicating the difference between each measurement and its true value. The RMSE remained at less than 0.01 inches, which at the orthophoto scale of 1:10 000 converts to an error of no more than 2.5 m on the ground. These tic points are then used to geographically position the features digitised according to the distance from these known positions. The digitiser works by tracing the boundaries of features by drawing a series of straight lines to represent the true curved line.

Digitising is one of the major restrictions in the creation of digital map databases due to the many errors created whilst capturing data, often as a direct result of its tedious nature. The quality of the source document is another major constraint. Improper handling of paper maps, such as the orthophotos used in this study, causes folds and creases to distort the map. Inadequate storage conditions cause the maps to stretch and shrink as a result of exposure to humidity and changes in temperature. These errors become most evident when a number of neighbouring map sheets are matched together, as was required to cover the catchment in the study area (Martin, 1991; Mackenzie *et al.*, 1999).

Table 4.1: Metadata of the data sources used in the study

Series / Data Source	1978	1989	1996
Aerial Photos	Black & white Job = 807 Contact scale = 1:30 000 Month = unknown Obtained from = Surveys & Mapping, Mobray, Cape Town	Black & white Job = 933 Contact scale = 1:50 000 Month = July Obtained from = Surveys & Mapping, Mobray, Cape Town	Black & white Job = 985 Contact scale = 1:30 000 Month = February Obtained from = Surveyor General, Pietermaritzburg
Orthophotos	2830BD 12, 16, 17, 21; 2830DB 6, 9, 14, 15; 2831CA 1, 6, 11. Obtained from Surveyor General, Pietermaritzburg. 2830BD 18, 22, 23; 2830DB 1, 2, 3, 4, 5, 7, 8, 10, 12, 13 Obtained from Survey & Mapping, Mayville Durban. Years varied from 1981 to 1994.		
Digital Maps	Shapefiles* of contours, rivers, roads, district boundaries, land type Received from Umgeni Water		

*A Shapefile is a specific name for a vector file type in ESRI's ArcView GIS software (ESRI, 2001)

Digitising is essentially scale-dependent, meaning the digital representation can never contain greater detail or achieve higher locational accuracy than the original document. The degree of line generalisation that takes place during input is under the subjective control of the operator. In this study generalisation was also dependent on the degree of detail set by the classification system. Poor linework and labelling leads to increased operational error in, what is already, a time consuming, tedious and error prone process (Martin, 1991; Mackenzie *et al.,* 1999). Considerable care is required to avoid errors such as mislabelling, digitising features twice and missing features altogether (Martin, 1991).

Editing out errors occurring during digitising, including overshoots and undershoots is necessary to close the arcs[2] to create polygons[3] of related land use. This process introduces positional error as the exact position of where a line should have ended is difficult to determine. The digitised shapefiles are converted on PC ARCInfo 3.5.1 to a coverage file[4]. Each orthophoto sheet is appended to the adjacent sheets to make one complete coverage of

[2] Arcs - an ordered string of vertices that begin at one location and end at another (ESRI, 2001)

[3] Polygons - a feature class used to represent area of a geographic feature (an arc that starts and ends at the same point) (ESRI, 2001)

[4] Coverage file - is a specific name for a file type in ESRI's PC ARCInfo 3.5.1 GIS software (ESRI, 2001)

the entire catchment (ESRI, 1996b). Each arc's start and end points, as well as the intersections between polygons, is identified and manually joined. A snap tolerance[5] was not used to automatically snap arcs together as some of these arcs were closely set and would have been joined incorrectly to arcs representing different features (ESRI, 1996b). The clean operation in PC ARCInfo 3.5.1 was used to build topology (ESRI, 1996b). At this point the polygons are meaningless until a relevant database is created to assign a land use type to each polygon. The coverage is then converted back to a shapefile, where editing of the corresponding table to include the land use type for each polygon, in each image, is undertaken and further analysis on the datasets can begin. Further discussion of errors in mapping is provided in 4.2.5 titled Error Management. The next step in the mapping process is to project the digitised image to match the source data projection.

4.2.4. Map Projection

Map projections refer to the representation of a spherical earth onto a flat medium (paper or computer screen) (Dana, 1997). Since it is physically impossible to flatten the globe without distortion in scale, area, distance, direction and conformity, various projections have been designed to limit the effect of one or more distortions at the expense of others (ESRI, 1996a). The projection that is used will, therefore, depend on the scale and the purpose of the map (ESRI, 1996a).

South Africa's standard projection has recently been changed to incorporate the World Geodetic System, 1984 (WGS84). This change in projection was necessary with the advancements in modern positioning technologies and the globalisation of techniques and data (Wonnacott, 1997). The datum is referred to as the Hartebeeshoek 94 datum because of the location of its reference points (Wonnacott, 1997). The projection used in this study, however, varies from the standard system, as the base maps originated prior to the change in systems and, therefore, uses the former standard projection. This projection had reference co-ordinates at Buffelsfontein based on the modified Clarke 1880 spheroid, comprising the Cape datum. The projection is the Gauss (conform) projection, more commonly referred to as the Transverse Mercator (TM) projection. The TM projection

[5] Snap Tolerance - automatically joins the ends of arcs together within a given distance to produce complete polygons (ESRI, 2001)

projects a sphere onto the inside of a cylinder, tangent to the central meridian (ESRI, 1996a). The TM is conformal meaning that the meridians (longitude) and parallels (latitude) intersect at right angles preserving the shape in any direction at a regional scale. Distortion of area, scale, distance and direction, however, increases with distance from the central meridians (Dana, 1997). South Africa uses a number of TM projections, adjacent to each other, to cover the large east-west extent of the country. The projections are centred on every odd meridian with two-degree zone widths (one degree on either side of the central meridian). LO31 is the projection used for the Hazelmere Catchment as the meridian is centred on 31°, which runs through the catchment (Wonnacott, 1997). As the catchment is situated in such close proximity to the meridian distortion is minimal, and therefore, this projection can be used to adequately calculate distances and area.

4.2.5. Error Management

GIS is a powerful spatial tool for enabling analyses of a range of spatial interaction, however, GIS products may possess significant amounts of error. By ensuring that high standards are applied to the preparation and editing of the maps some errors can be avoided, minimised, or corrected. Other errors are inevitable artefacts of the complexity of the landscape and characteristics of the cartographic models used (Campbell, 1983).

The main source of error in using a GIS is inherent error. These errors are those present in the original data sources, or those arising from data capture and representation. Inherent errors include both positional and attribute error (Woods, 1998). From inherent error, operational error occurs through the analysis and manipulation of uncertain data. There are several inherent errors to be aware of and to take into consideration when preparing maps. Firstly, errors occur when interpreting aerial photographs. There are two errors that can occur when interpreting aerial photographs: the error of omission and the error of commission (Woods, 1998). In this study, for example, some types of land use are identified more accurately and reliably than others. This results in areas being omitted or commissioned to the wrong category because of the resolution or degree of generalisation of the classification system used. The second form of inherent error occurs when transcribing polygon boundaries from photographs to a permanent medium, such as the orthophotos (Woods, 1998). The distortion of photographs previously mentioned, and the inconsistency of dates between the photographs and the orthophotos, makes transcribing the boundaries of polygons uncertain. With ground truthing, however, this error is cleared as many of the boundaries are along roads or river courses. The third form of inherent error arises when converting spatial data to digital format (Woods, 1998). In this study the digitising process was used and the errors relating to this process have been discussed in Section 4.2.3. The last form of inherent error occurs when coding attribute data (Woods, 1998). This occurs when labelling polygons with the incorrect land use, not because of incorrect classification but because of input errors (Rivers-Moore, 1997).

Ground truthing is field surveys undertaken to check that the information on the map conforms to that actually on the ground. Ground truthing is made easier by the use of a GPS (the Garmen Explorer III and the Trimble GPSs were used subject to availability) that can pinpoint one's position on the globe through satellites, to an accuracy of within metres. Random points along access routes are taken with a note of the relevant land use at each point. These points are then matched to the same point on the map and the corresponding land use recorded. A comparison of points is easily seen from an error matrix (Table 5.1), a table of *N*-by-*N* arrays of interpreted land use values versus actual land use values, showing omission and commission errors, as described above. Kappa statistics (Appendix 3) were carried out on the error matrix to test the viability of results (results provided in chapter five) (Woods, 1998). It is important to keep in mind while ground truthing that the dominant land use is recorded. At each specific site it is this general pattern of the surroundings that is recorded and not the actual practice at that exact point. This is important as general assumptions identify spatial patterns and trends that make for better decisions in management. This process quantifies the level of error of the maps.

4.2.6. Analysis & Statistical Tests

With the process of mapping complete and the knowledge of errors in the data made evident, manipulation of the data is required to provide meaningful information. From the land use maps the total area of each land class is calculated by running the summary function in ArcView 3.2, specifying total area. The chi-squared test (one-way contingency tables) was used to verify hypotheses concerning the values (Clarke, 1987). The chi-squared test calculates the degree to which the observed frequencies differ from the expected ones (see Appendix 3) showing the significance of change between the three land use maps.

Further analysis has been undertaken on the land use maps in order to produce an image showing all areas that have undergone change between 1989 and 1996. In order to achieve this, each land use map was converted to a grid and, using the map calculator in ArcView 3.2, the 1989 land use grid was subtracted from the 1996 land use grid (ESRI, 1996a). A simple Boolean image showing areas of change against areas of no change is thus produced. The results of the analysis and statistics are discussed in Chapter five.

4.3. SOIL SAMPLING

A Masters program is currently underway to investigate soil properties of the Mdloti Catchment. Fifty random soil samples were collected throughout the catchment ensuring that each ecotope was well represented (Myeza, 2002). Samples were extracted from the surface and the bottom of the soil profile or at a depth of one metre. Land use type was recorded at the sample site in terms of conservation practices, canopy cover and height of vegetation as well as leaf litter and organic matter. The structure of the soil was also recorded. The samples were sent to the soil laboratory at the Cedara Agricultural College where analysis of the physical and chemical properties was undertaken. The analysis of the soil included tests for organic carbon percentage, pH, Electronic Conductivity (EC), Cation Exchange Capacity (CEC), Exchangeable Sodium Potential (ESP) and textural (particle size) analysis. Standard methods of analysis (Baize, 1993) were used to determine these properties and a summary of results, available at the time of submission for this dissertation, is presented in appendix 4. This analysis will aid in determining the degree of aggregation and therefore the stability of the soil resulting in a more comprehensive understanding of the integrated aspects of the catchment for holistic management and to determine cause of the sedimentation rate in the Hazelmere Dam. Coverage of the results is provided in Chapter five and a discussion of the findings in terms of land use and sedimentation is provided in Chapter six.

The aerial photographs used in this study were also used to map erosion features in the masters program investigating soil. A Southern African Regional Commission for the

Conservation and Utilization of Soils (SARCCUS) type map was generated indicating the degree of erosion according to the number and severity of visible erosion forms (SARCCUS, 1989). This map of erosion features can be compared with the map of land use change to aid in visualising the interrelated characteristics of components and processes for holistic management (objective 6, p. 4).

4.4. POPULATION COUNTS

The 25 % error reported for the 1996 census as the lowest of all previous census results, in addition to the inconsistency between district boundaries and the catchment boundary, motivated for a random house count to be carried out by the author on the aerial photographs (Currie, 1997; Russow & Garland, 2000; StatsSA, 2001).

A transparent square, three square-centimetres in size, was placed randomly on the photographs and the number of houses within the square was counted. This process was repeated three times per aerial photograph and the totals averaged providing an average number of houses per square. The actual area of catchment that the square covers can be calculated by using the scale of the photographs (1:30 000 for 1978 and 1996 aerial photographs; 1.25 000 for 1989 aerial photographs) making the actual size of the square 0.9 km^2 (1:30 000) or 0.75km^2 (1:25 000). The actual area of the catchment (376km^2) is then divided by the actual size of the square to determine the number of times the square fits into the catchment (418 and 501 times). Once the average number of houses per square has been determined for the catchment it is then multiplied by the number of squares that fits into the catchment area. The total is an average number of houses for the catchment. An average number of nine people per household was established according to random questioning of the local inhabitants by the author. This random questioning was achieved by stopping frequently to ask inhabitants nearby (either walking along a road or in properties adjacent to the road) and questioning them on the number of people that occupied their household and how that compared with other households around them. The average number of houses was then multiplied by the factor of nine in order to estimate the number of people in the catchment.

Although not an accurate measure of population by any means, it does provide an estimate for the catchment and the results coincide with the photograph years for comparison of change in land use intensity over time (objective 7). A comparison of these population counts with values from the census is given in Chapter five. Tables 5.2 and 5.3 p. 90) reflect the values from each. The concentration of houses is generalised for the entire catchment rather than the scattered pattern in reality. This restricts the comparison between areas in order to establish spatial changes in intensity.

4.5. SLOPE & ASPECT

The figures presented in Chapter three p. 34, 35 and 36) of relief, percentage slope and aspect were developed from ten-metre interval contour data provided by Umgeni Water for the catchment area. The contour ArcView shapefile was converted to a Triangular Irregular Network (TIN)[6] using ArcView 3.2 software extension – 3D-analyst 2.1. This TIN is illustrated in Figure 3.4 p. 34) showing the relief of the catchment. The TIN was then used to calculate percentage slope and aspect using ArcView 3.2 software extension – Model Builder. These images are illustrated in Figure 3.5 and 3.6 p. 35 & 36) respectively. The understanding of the percentage slope and aspect is important when considering management alternatives for the different land uses as well as contributing to the understanding of integrated factors influencing the sedimentation rate of the Hazelmere Dam (objective 7, p. 4).

4.6. FIELD SURVEYS

A number of visits to the catchment area were undertaken to observe land use activities, such as the conservation practices employed by the different land users, and to identify possible causes for the extensive erosion features visible throughout the surroundings, such as roads, footpaths and poor land use practices (objective six and seven, p. 4). Later visits were undertaken to ground truth the land use maps and to monitor sand mining operations, visible in the catchment, for positive and negative environmental impacts and its contributions to the sedimentation rate (objective 7, p. 4). As described above, ground truthing was undertaken with a GPS marking random points and noting the dominant land use type at each point, to crosscheck the land uses on the ground with those on the 1996 map derived from aerial photographs. In association with another Masters program, a number of trips were undertaken together, whereby soil samples were taken (see Section 4.3 above).

4.7. SUMMARY

The stated aim of the research is to investigate the extent to which sedimentation within an impoundment can be attributed to land use change, thus, the key methodology was to accurately represent the land use of the catchment with the use of a GIS and to compare this against the sediment data supplied by Umgeni Water, presented in Chapter five. This process produced a series of maps representing land use, from which analyses of the change in land use over the past two decades could be compared with changes in sediment data. These land use maps and changes over time are presented in Chapter five, with a discussion of the findings. However, land use often changes due to external pressures, some of which were also observed from aerial photographs and/or visits to the field during ground truthing, such as soil characteristics, percentage slope and aspect and land use intensity. These pressures, influencing changes in land use, are also mentioned in the Chapters five and six.

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[6] TIN - method used to create a surface from point data by joining points to form a set of contiguous overlapping triangles. The height between nodes is thereby interpolated (ESRI, 2001).

CHAPTER 5
RESULTS

5.1. SEDIMENT CHANGES

The values of suspended solids, turbidity and inflow volume, measured at the inlet of the dam and made available by Umgeni water for the time period between 1989 and 1999, are reproduced in Appendix 1. It was established, in Section 2.5, that a number of variables, including friction, volume and velocity, affect the amount and size of sediment that can be kept in suspension in the river. However, only values of inflow volume were available for analysing changes in suspended solids. The methods used to obtain the values and the limitations with regards the sampling have been discussed in Section 4.1. These values are included to illustrate the extent of the problem of sedimentation, outlined in Chapter three, and in order to compare changes in sediment with changes in land use.

Figures 5.1 and 5.2 (a) show the monthly changes in turbidity and suspended solids concentrations at the inlet of the dam over an eight-year period, 1989 to 1996. The data from 1996 have not been included on the graphs as land use values for this period are unavailable and therefore cannot be used in a comparison of change. The bar graphs highlight trends in the datasets by clustering common values together. Generally, very high values exist for both turbidity and suspended solids, displaying distinct seasonal trends with summer maximums related to precipitation and discharge. Figure 5.1 depicts the range in turbidity values between 2.7 and 1227.5 NTU. In comparison, the acceptable levels of turbidity for domestic use as stipulated by the Department of Water Affairs and Forestry (DWAF) are between zero and one NTU while ten NTU is considered severe (Holmes, 1996). Suspended solid values depicted in Figure 5.2 (a), range from 7.2 to 628.8 mg/l. Acceptable concentrations of suspended solids are given by DWAF for industrial and agricultural use only. Acceptable levels range from 0-50 mg/l in this category (Holmes, 1996). These high recordings for both turbidity and suspended solid values indicates a concerning health risk for the local people reliant on the river water for consumption as a result of the infectious nature of the micro-organisms (bilharzia, *Escherichia coli* (*E.coli*)) that attach themselves to the soil particles (WHO, 1984). These recordings also demonstrate the quantity of sediment entering the dam and implicating on the storage capacity.

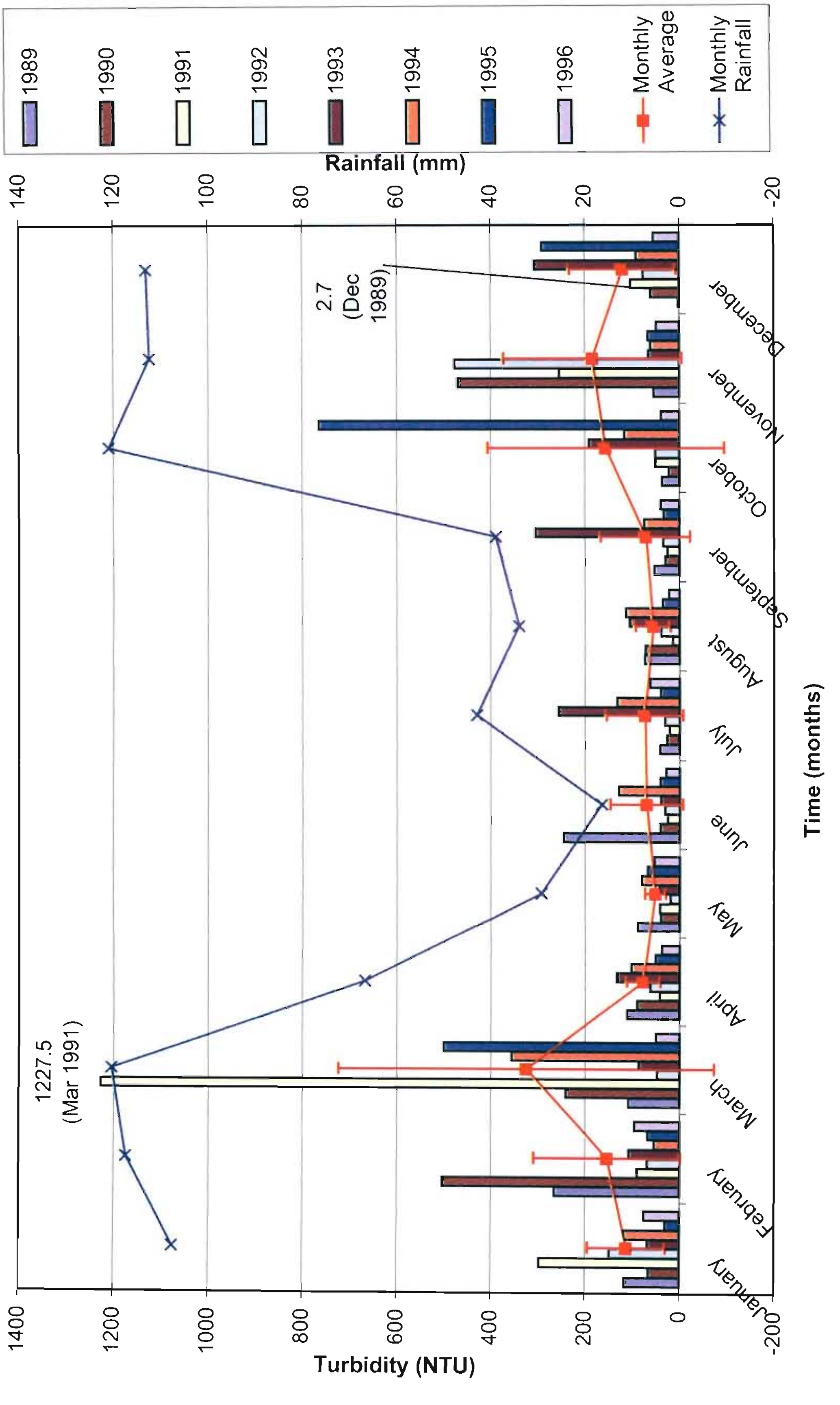


Figure 5.1: Monthly changes in Turbidity concentration

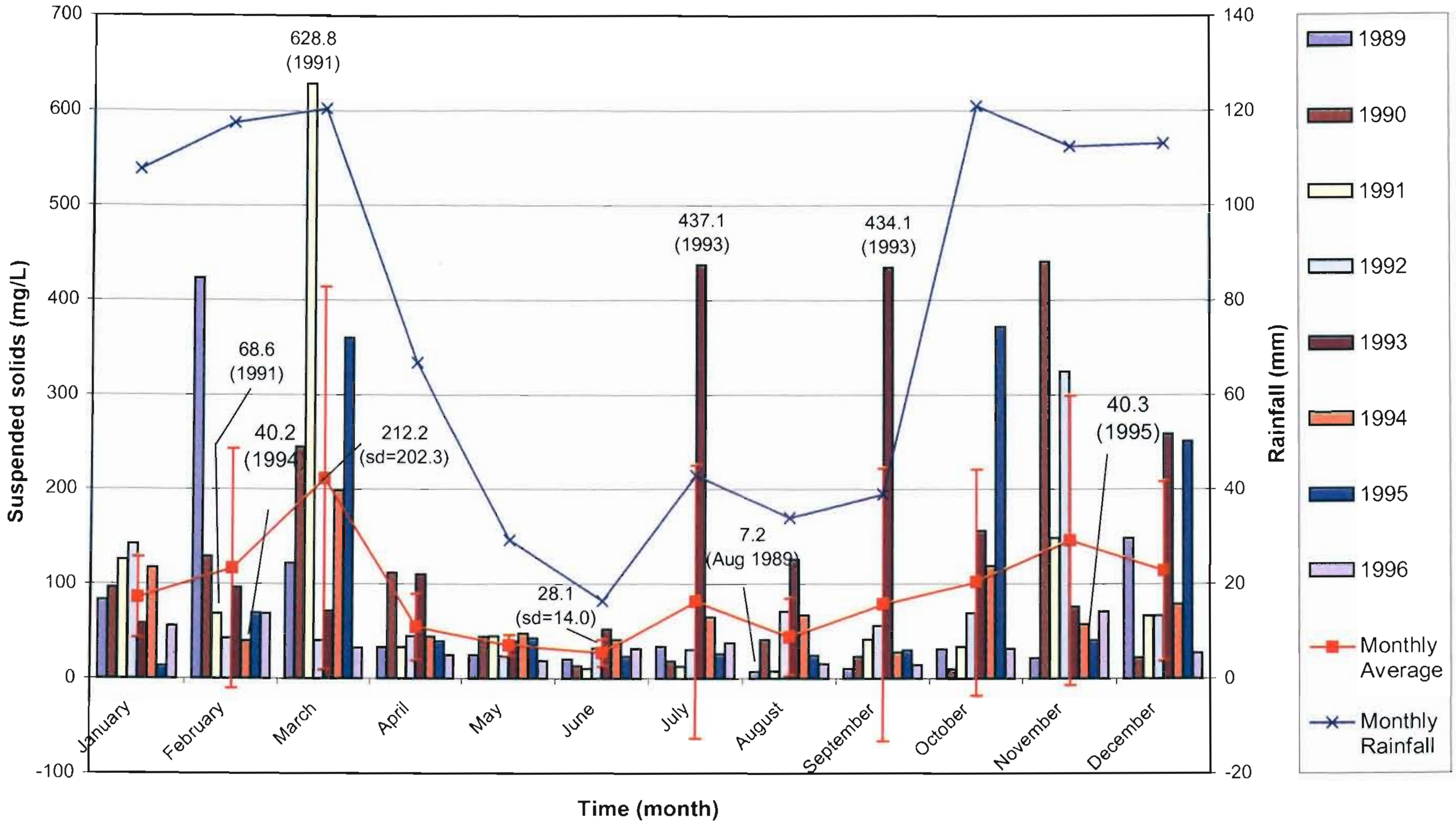


Figure 5.2. (a): Monthly changes in Suspended Solids concentrations, showing mean monthly precipitation, monthly mean suspended solids and standard deviations

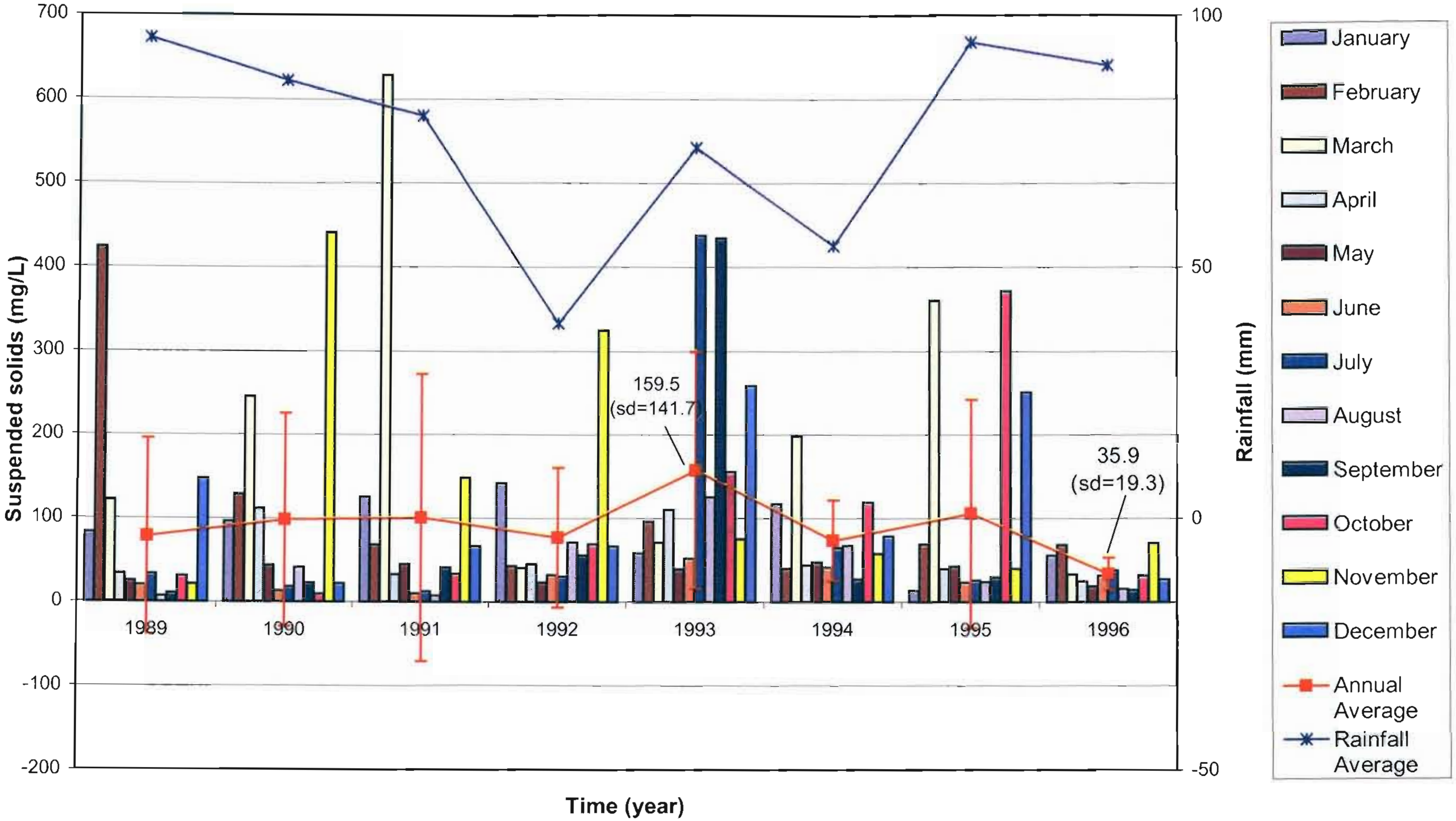


Figure 5.2.(b): Annual changes in Suspended Solids concentrations, showing MAP, annual mean and standard deviation

The suspended solids values shown in Figures 5.2 (a) and (b) display a wide range of values. Mean monthly suspended solids ranged between 28.1 mg/l (std dev = 14.0) in June and 212.4 mg/l (std dev = 202.3) in March, again showing the seasonal variation in values (Figure 5.2 a). Mean annual suspended solids values range between 35.9 mg/l (std dev = 19.3) in 1996 and 159.5 mg/l (std dev = 141.7) in 1993 (Figure 5.2 b). Figures 5.3 (a) and (b) show the changes in monthly and annual inflow volume, respectively. Mean monthly inflow volumes ranged from $2.2x10^6$l/day (std dev = 1.1) in the month of August to $24.3x10^6$l/day (std dev = 30.0) in December, showing a distinct seasonal variation in inflow volume (Figure 5.3 a). The seasonal variations in the suspended solids, however, do not coincide with the inflow volume. Mean annual inflow volume also differed greatly over the sampling period. Values ranged from 1.8 $x10^6$l/day (std dev = 1.2) in 1992, excluding 1994 where the data is incomplete, to 12.2 $x10^6$l/day (std dev = 14.9) in 1989 (Figure 5.3 b). Annual inflow values and annual suspended solids values showed a stronger correlation than the monthly averages. A drier year with low annual inflow volume values generally correlated with a low annual suspended solids value. The lowest inflow volume year does not, however, correspond with the lowest suspended solid year. Monthly values vary more radically as two months may have similar monthly inflows yet one, for example, may have had one intense rainfall event lasting a few days or hours while the other may have had gentler rain over a longer period of time. The difference in inflow is negligible but the difference in suspended solids values could be quite considerable. Suspended solids are, therefore, more dependent on the other variables, as outlined in Chapter two. The high standard deviations indicate that the mean values vary greatly within any given month or year. These standard deviations confirm the concerns raised over the inconsistencies discussed in Section 4.1.

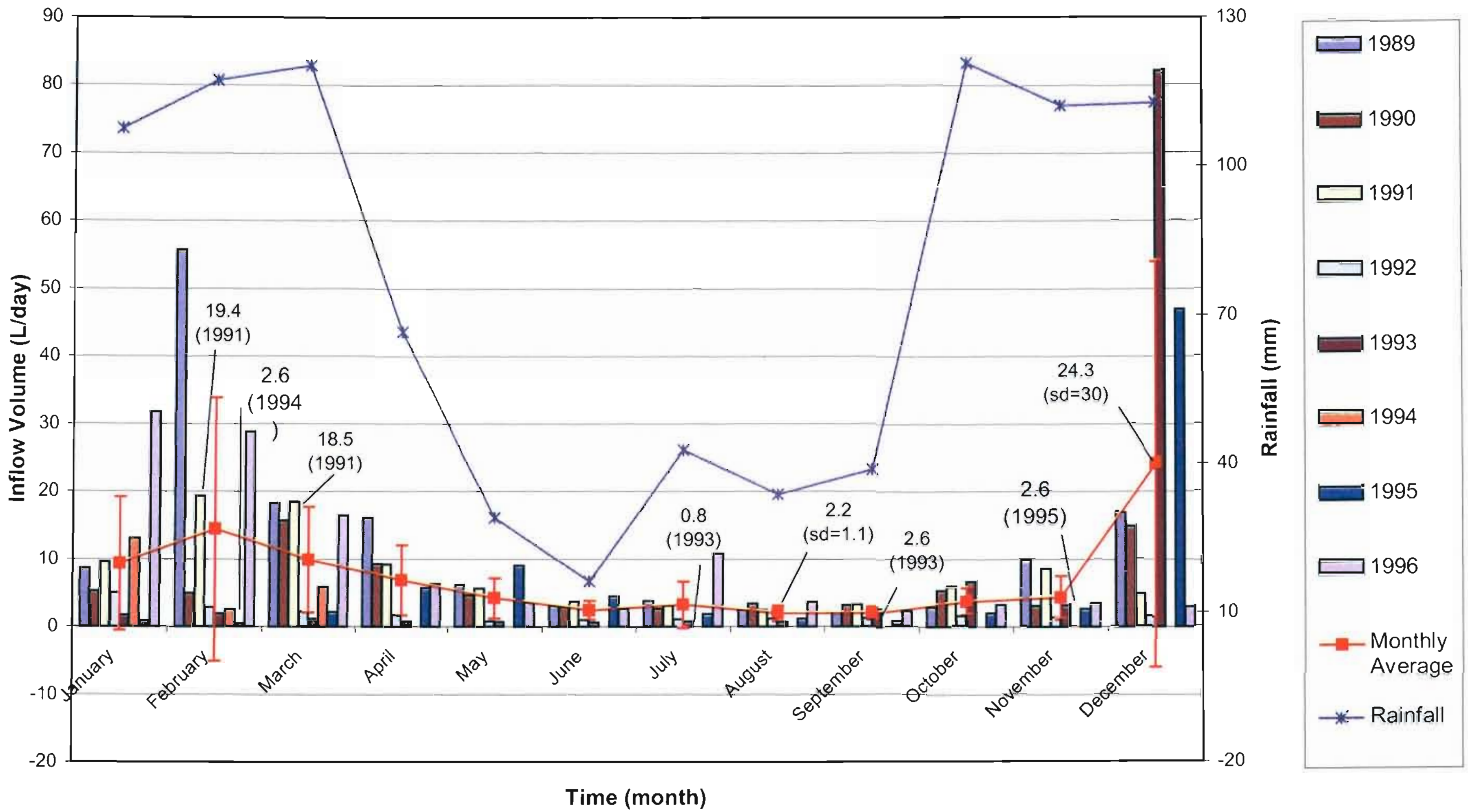


Figure 5.3.(a): Monthly changes in Inflow Volume, showing monthly mean precipiation, monthly mean imflow volumes and standard deviations

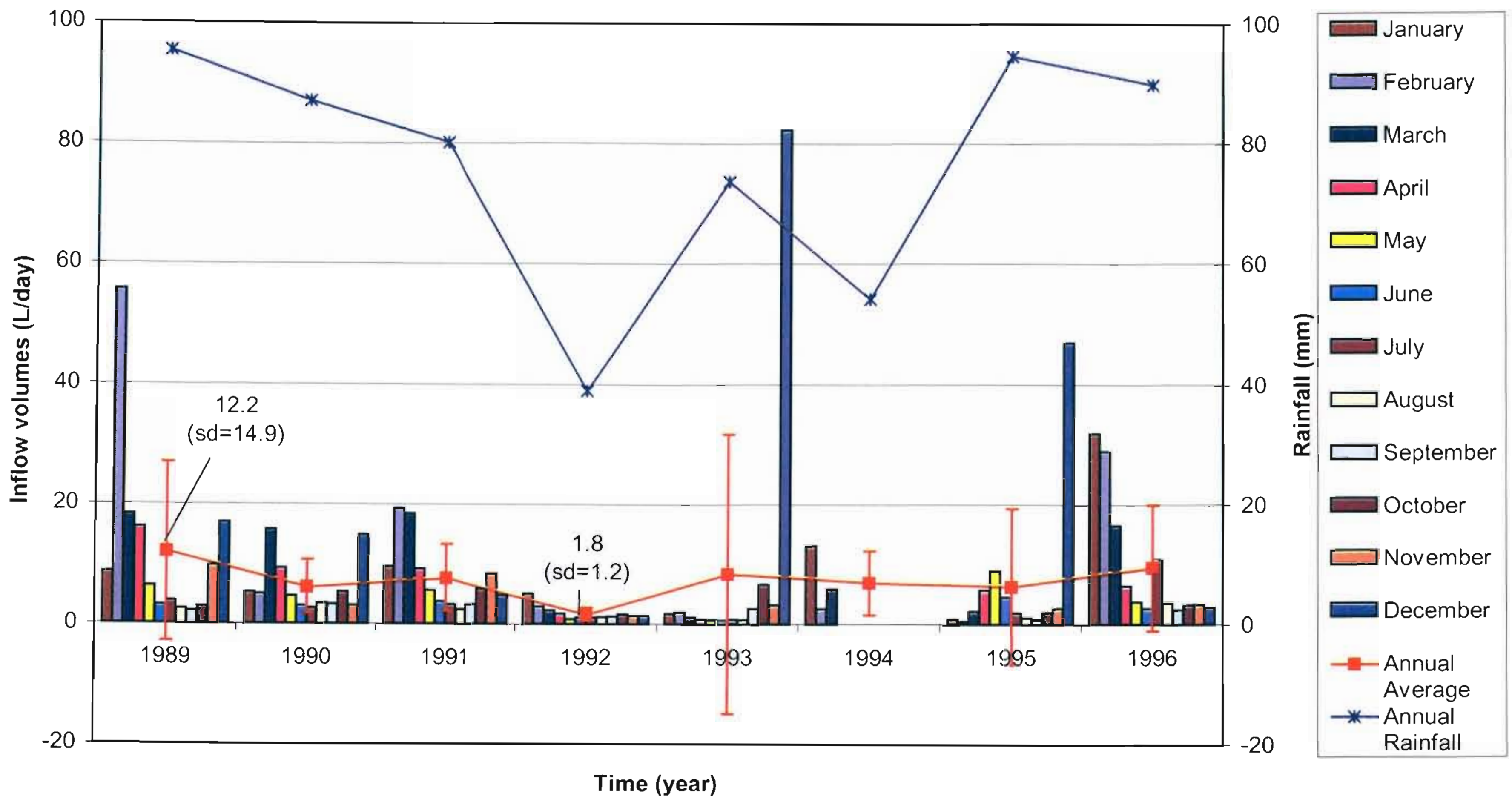


Figure 5.3.(b): Annual changes in Inflow Volume, showing MAP, annual mean inflow volumes and standard deviations

To determine the extent of the relationship between inflow volume and suspended solids, similar values were extracted and compared. For example, mean monthly inflow volumes (Figure 5.3 a) for February 1991 and March 1991 have similar values of 19.4 and 18.5×10^6l/day respectively, yet the suspended solids values for the same period differ substantially. For February 1991, the mean suspended solids value (Figure 5.2 a) was calculated as 68.6 mg/l while March 1991 was 628.8 mg/l. Likewise, similar suspended solid values (Figure 5.2 a) in July 1993 (437.1 mg/l) and September 1993 (434.1 mg/l) do not yield similar inflow volumes. In July 1993, the mean monthly inflow volume (Figure 5.3 a) was 0.8×10^6l/day and in September 1993, the mean inflow volume was 2.6×10^6l/day. It is also evident from these figures that an inflow volume between 0.8 and 19.4×10^6l/day can yield a suspended solid value from 68.6 to 628.8 mg/l. From these examples it can be noted that the highest inflow volumes in fact yielded the lowest suspended solids volume (February, 1991) which appears to contradict the relationship between inflow volume and suspended solids suggested by the literature in Chapter two. In contrast, the similar inflow volumes (Figure 5.3 a) for February 1994 and November 1995 (2.6×10^6l/day), reflected similar suspended solids values (Figure 5.2 a) (40.2 and 40.3 mg/l respectively). The inconsistency in these observations initiated the notion to run a regression analysis to test the relationship of the two datasets.

The regression line illustrated in Figure 5.4 has an equation of $y = 882\ln(x) - 762$; $r^2 = 0.7$. This line summarises the association between the values of inflow and suspended solids. The correlation (r^2) of the inflow volume and suspended sediment values determines the strength of their association. The regression equation illustrates a positive slope suggesting an increase in inflow volume (x) is reflected by an increase in suspended solids (y). The natural log (ln) in the equation denotes that the increase in suspended solids (y) is not consistent with the increase in inflow volume (x). As inflow volume increase, the increase in suspended solids slows. For example, a volume of 5×10^6l can contain approximately 650 kg of suspended solids, depending on availability of sediment. At a volume of 10×10^6l the amount of suspended solids that can be carried has approximately 1270 kg showing a slower increase in sediment between 5×10^6 and 10×10^6l than between 0 and 5×10^6l.

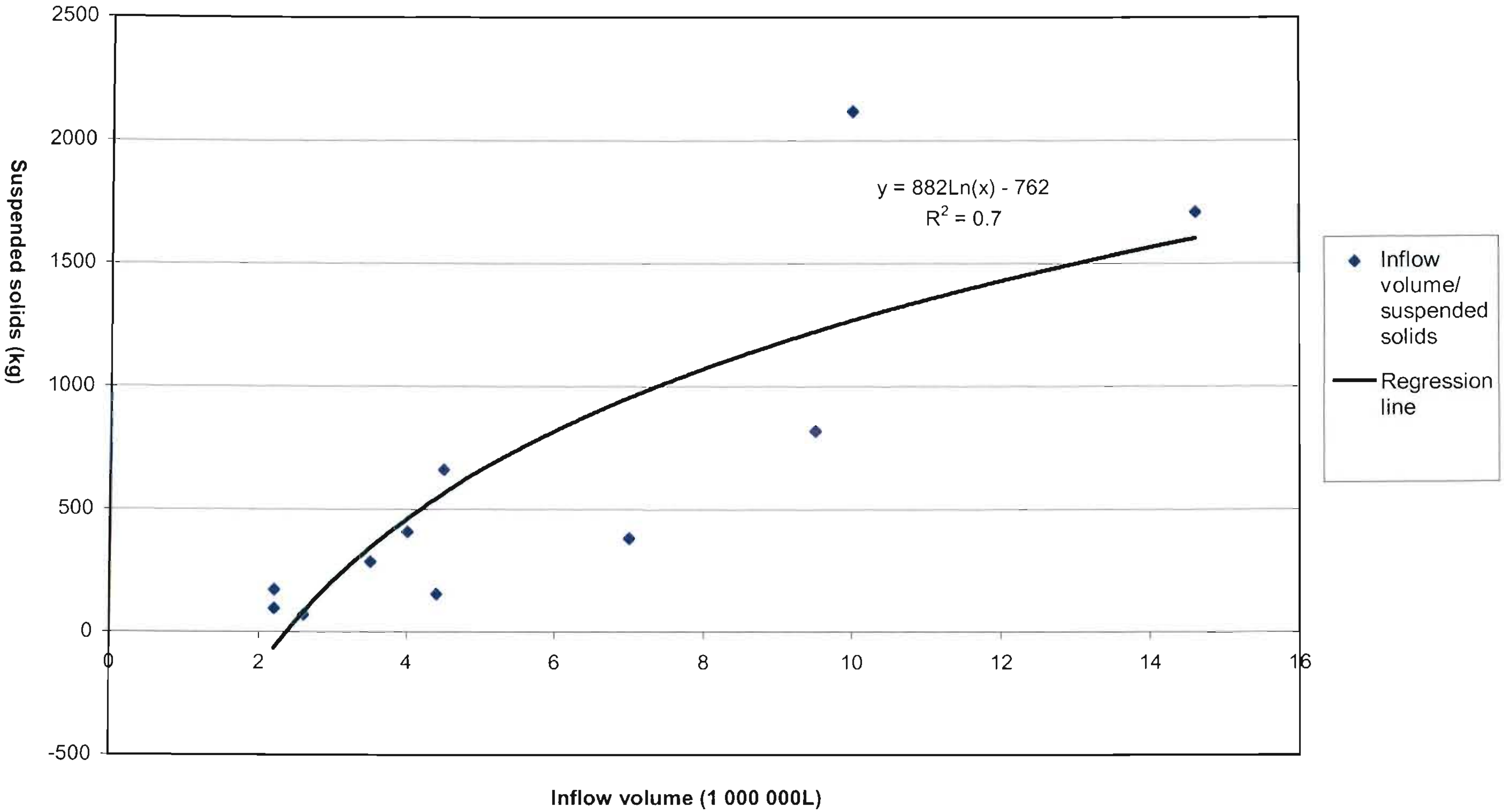


Figure 5.4: Regression analysis of inflow volumes and suspended solids between 1989 and 1996

A greater amount of sediment in suspension as a result of an increase in volume does not necessarily mean more sediment-laden runoff is washing off the land into the river system. It could equally mean that sediment previously deposited in the river channel is now entrained by the flow and transported further in suspension as the discharge volume increases. These particles are larger than those already in suspension resulting in larger particles entering the dam and being deposited where the velocity slows, but where the volume is greatest; evidence that other factors may play a role in keeping particles in suspension. The nature of the sediment is also likely to be a factor in transportation as sandy soils are more difficult to carry in suspension yet easier to deposit than clay soils. Alternatively, clay soils are more difficult to erode but once eroded are easy to transport and to keep in suspension (Figure 2.2 p. 17). The correlation (r^2) of suspended solids and inflow volume of 0.7 is strong enough to suggest that there is a relationship, yet weak enough to suggest that other factors are also influential (Figure 5.4). Due to the lack of available data on water quality monitored over an extended time-period, such relationships and trends could not be established with any degree of confidence.

The seasonal variations depicted in Figure 5.1 and 5.2 (a) display a distinct increase in both turbidity and suspended solids from September through to March. These months correspond with KwaZulu-Natal wet period as illustrated in the figures by the line representing average rainfall and in Table 3.2 p. 38). Particularly high peaks in the values are visible in September/October, coinciding with the first rains after a dry winter. A discussion of the role of temporal and spatial changes in land use on the transport of sediment to the river and dam is discussed in Chapter six. High peaks are also evident for February/March when rainfall and moisture levels are high as well as high antecedent soil moisture conditions from the preceding months' rainfall. This soil moisture reduces the amount of infiltration, as the soil becomes saturated easily. This period also sees the change in seasonal rainfall. Temperatures are still high enough for instability showers to occur, but frontal conditions, common with winter, start to develop in the cooler western region of the country and move over the country bringing frontal rainfall to the catchment. This is also the time for harvesting of the summer crops and planting of new winter crops by subsistence farmers, reducing vegetation cover and exposing soil to raindrop impact and runoff. Evident during winter, are generally much lower turbidity and suspended solid values from the absence of water to transport sediment, however, turbidity values are higher than suspended solid values. These higher turbidity values are attributed to the very fine material remaining in suspension while larger particles are deposited as the flow volume and velocity decrease.

Figures 5.2 (a & b) and 5.3 (a & b) also show the monthly and annual average rainfall (Appendix 2) in comparison to the inflow volume and suspended solids. Rainfall determines the amount of water that is available for transporting sediment to the river. Rainfall intensity determines the amount of sediment that is removed, however, such intensity values were unavailable. A comparison of monthly average rainfall with monthly average suspended solids shows a good relationship. Peaks in rainfall are temporally comparable with peaks in suspended solids. The peaks in suspended solids are less distinct than those in the rainfall figures, which can be directly related to the intensity of the rainfall and the erodibility of the soil. The relationship between monthly and annual rainfall and monthly and annual inflow volumes is less apparent. This could be explained by a change in the velocity of the water flow in the river or by the loss of 67 % of runoff before reaching the dam, as mentioned in Chapter three. The loss in runoff may be due to soil storage, evaporation and/or collection by the local people for consumption and irrigation. The change in the velocity of the water flow in the river is due to the energy supplied by the raindrops and will not necessarily reflect in the volume.

5.2. LAND USE CHANGES

The land use maps for the three years; 1978, 1989 and 1996 were created as described in Chapter four and are represented in Figures 5.5, 5.6 and 5.7 respectively. Pie charts, given in Figure 5.8, graphically display the total area under each land use type based on an analysis of the maps presented in Figures 5.5 to 5.7. The limitations and errors pertaining to the creation and accuracy of these maps have been discussed in Chapter four and the results of statistical tests carried out on the maps are presented below to illustrate the accuracy of the maps to be used for analysis of land use change.

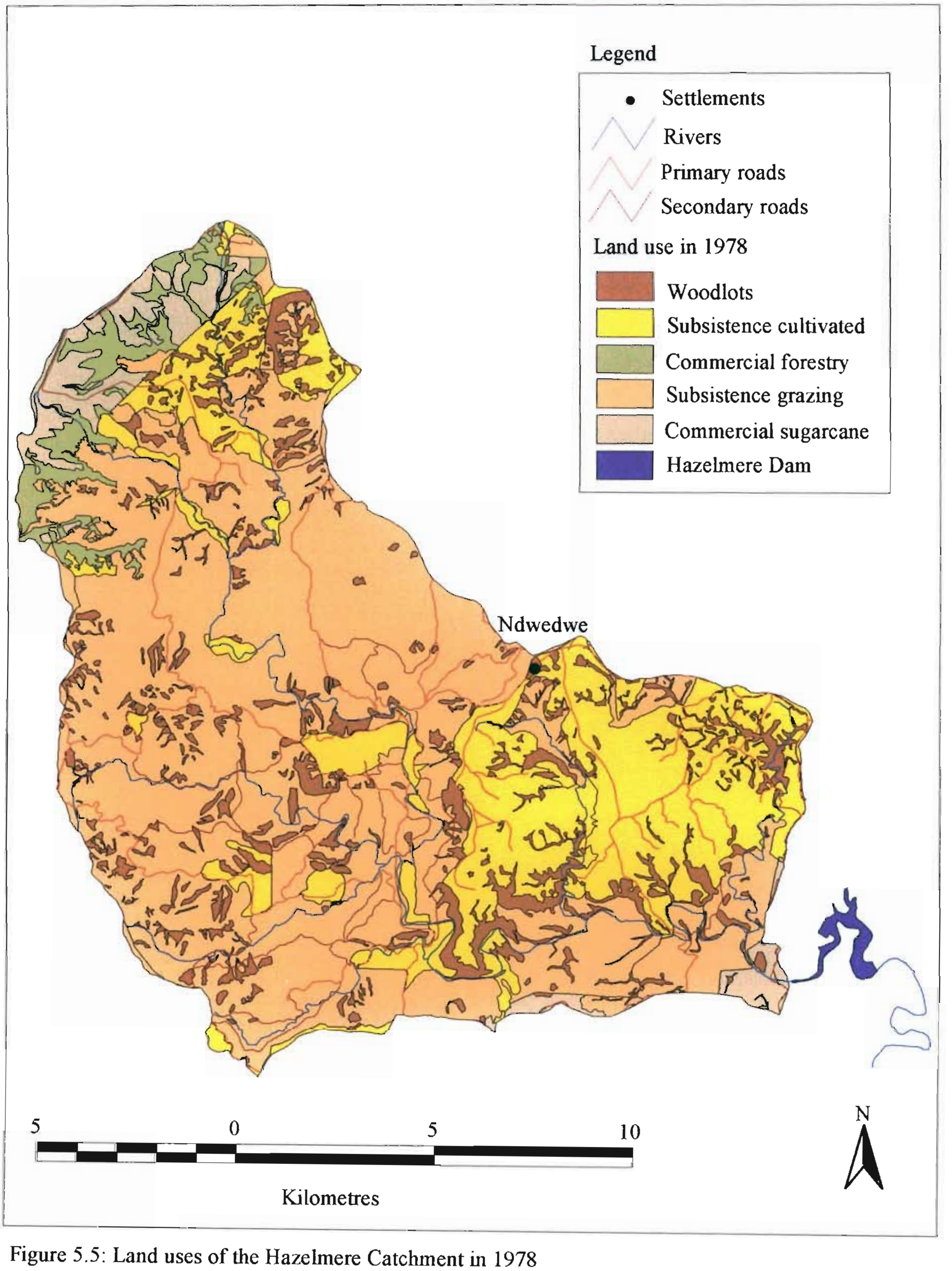


Figure 5.5: Land uses of the Hazelmere Catchment in 1978

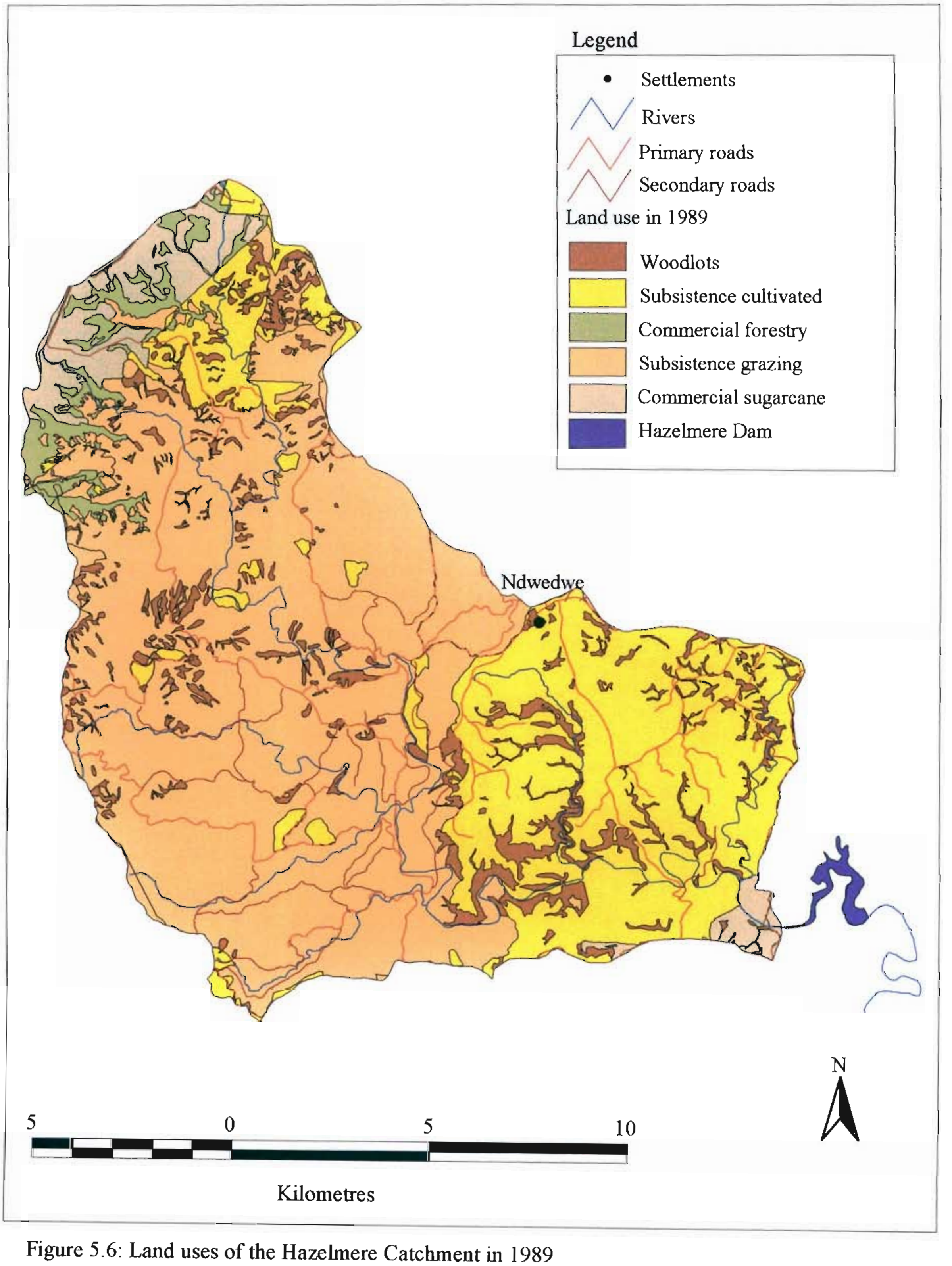


Figure 5.6: Land uses of the Hazelmere Catchment in 1989

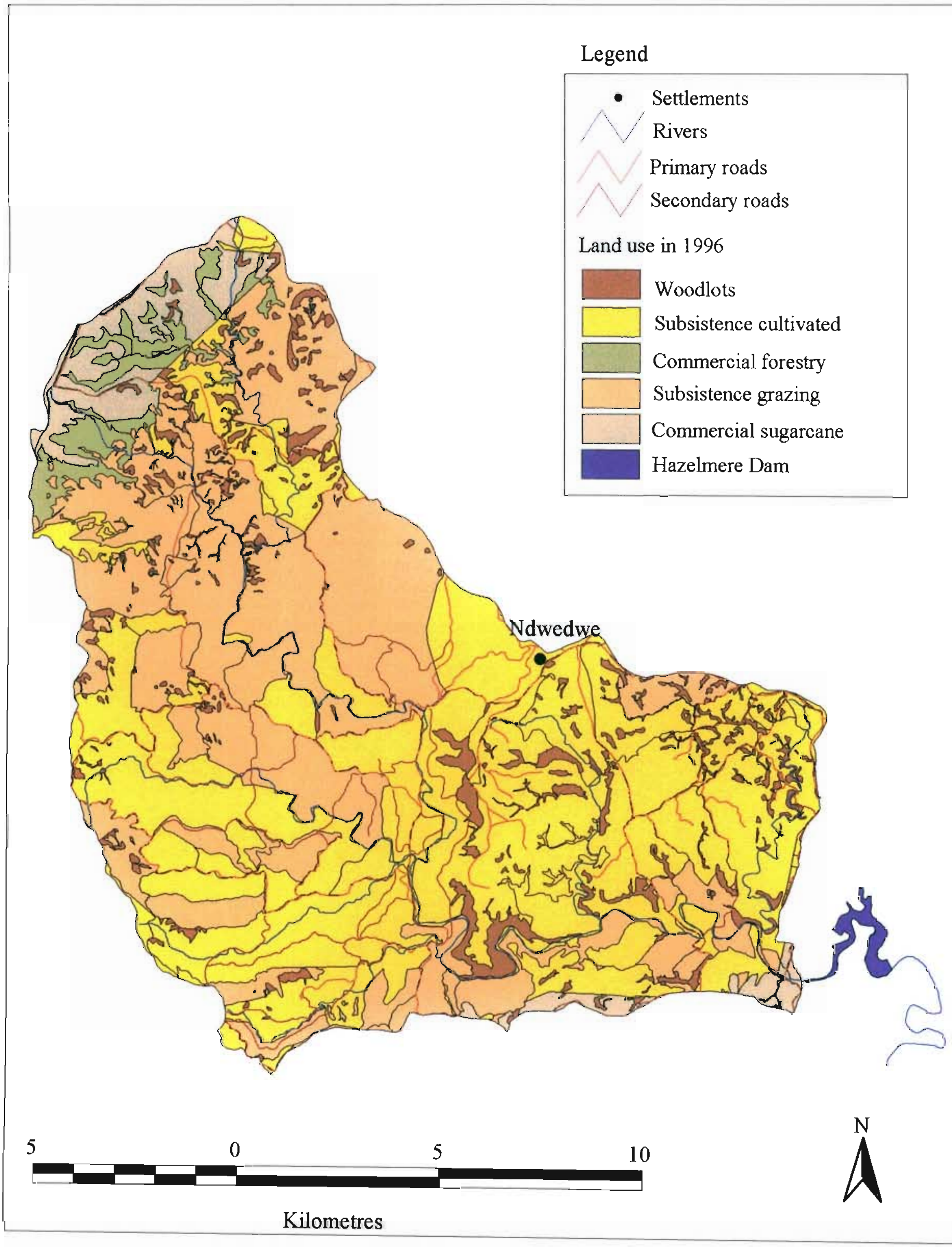
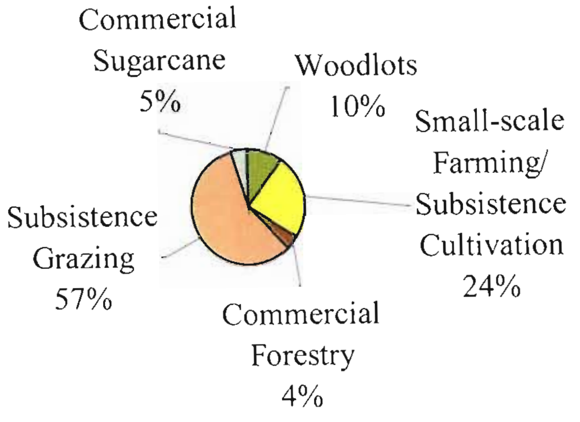
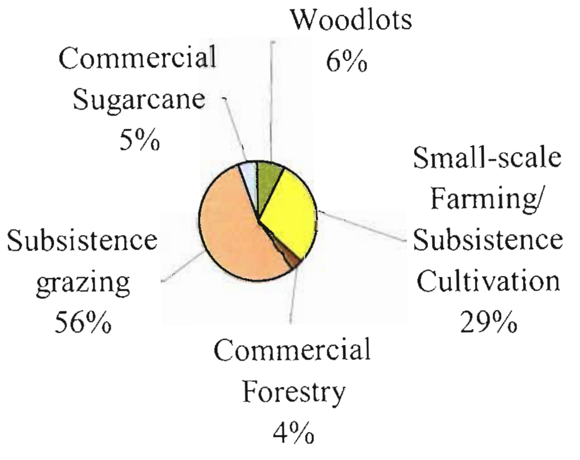


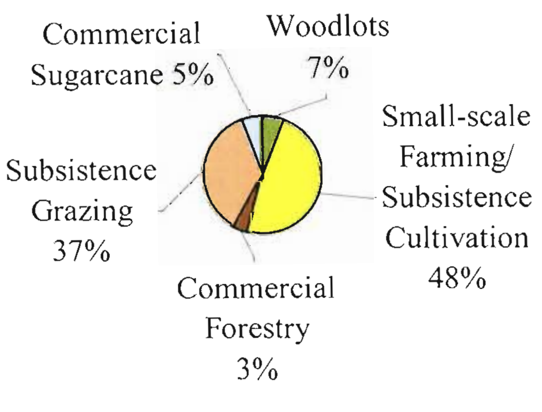
Figure 5.7: Land uses of the Hazelmere Catchment in 1996



a) Percentage area of each land use in 1978



b) Percentage area of each land use in 1989



c) Percentage area of each land use in 1996

Figure 5.8: Percentage area covered by each land use for (a) 1978, (b) 1989 and (c) 1996

Ground truthing checks the information on the map to ensure it conforms to that actually on the ground to a reasonable level of confidence. Ground truthing of the land use maps was severely limited by the impassable roads in the catchment. Forty reference points were, however, taken with a GPS throughout the catchment. According to the error matrix (Table 5.1), for the most recent land use map (1996) versus the ground truthing carried out in 2001, a 20 % error occurred. The difference in scale between the 1996 land use map (1:30 000) and the land cover database (1:250 000), completed in 2001 (Figure 3.9 p. 45) made ground truthing the 1996 land use map by this means also prone to large error. However, in relation to the 40 % change in land use between the 1989 and 1996 maps, some of this 20 % error is more likely to be accredited to changes since 1996 than inaccuracies in classification and mapping. Kappa statistics (Woods, 1998) were calculated on the results of the ground truthing indicates that the observed values exceeded the expected values by chance. A result of 0.7 was calculated which is greater than the 90% confidence value of significance meaning that the values are statistically viable.

Table 5.1: The error matrix of the 1996 land use map versus the 2001 ground truthing

Map / **Ground**	**Sugarcane**	**Cultivated**	**Woodlots**	**Grazing**	**Forestry**	**Total**
Sugarcane	4	0	0	0	0	4
Cultivated	1	16	0	4	0	21
Woodlots	0	0	0	0	0	0
Grazing	0	3	0	12	0	15
Forestry	0	0	0	0	0	0
Total	5	19	0	16	0	40

The percentage land use values were also tested for the significance of change over time by using the chi-squared test (χ^2) (see calculations in Appendix 3). The chi-squared test assesses the degree to which the observed frequencies differ from the expected ones. The null hypothesis was that there was no significant change between each epoch, from 1978 to 1989 and from 1989 to 1996. For this analysis the critical value for four degrees of freedom (n - 1; n = land use classes), at the five percent confidence level was 9.488, while at the one percent confidence level, the value is 13.277 (Clarke, 1987). The value calculated for the 1978 to 1989 epoch was 2.7; well below the acceptable levels. The null hypothesis was accepted and the conclusion drawn that there was no significant change in land use from 1978 to 1989. However, the value calculated for the 1989 to 1996 epoch was 19.2; above the acceptable levels. The null hypothesis was rejected as a result, the conclusion being that significant change in land use had occurred during this epoch. Although a small percentage of change is evident in the 1978 and 1989 pie charts it cannot be ascertained that this is as a result of land use change or other influences such as mapping error. The 1989 to 1996 epoch, however, shows a high percentage of change indicating that despite the possibilities of error, significant change in land use has occurred.

The maps in Figures 5.5 to 5.7 highlight the significant land use changes that have occurred, namely: the change from predominantly subsistence grazing land to small-scale agriculture and subsistence cultivated land. This change from subsistence grazing to small-scale agriculture and subsistence cultivation is seen by the change in percentage area under these two land use types for each epoch (Figure 5.8). The grazing section decreased in area from 57 % in 1978 to 37 % in 1996, whereas cultivation increased in area from 24 % in 1978 to 48 % in 1996. The majority of this change was noticed between 1989 and 1996 when the grazing diminished by 34 % and the cultivated section increased by 66 %. The change to cultivated land was most prominent in the lower reaches of the catchment, closest to the town of Verulam. Verulam provides a market for the produce and where employment can be obtained. The growth of the north coast of KwaZulu-Natal has opened up opportunities for small business development and there is a growing need for labour and the outsourcing of cheap supplies. As a result, the people from this rural region of the catchment, mostly men, were able to seek employment further afield, leaving the women, children and elderly to tend the land. The attraction of earning money through cash cropping has caused the increase in agriculture activity, despite the loss of labour. This change in population is most evident between 1989 and 1996, during which time the 'homeland' system was abolished and local business regulations relaxed. Such changes are borne out by the social survey data presented in Section 5.4. Although grazing land has been converted for cultivation and cash cropping, the number of cattle has not necessarily decreased. Land available for grazing has been restricted to smaller fields to make way for cultivation. The social status associated with the number of cattle affording such a statement is given in Section 3.10.

The woodlot sections have been steadily declining in area from ten percent in 1978 to six percent in 1989. This decline is then followed by an increase between 1989 and 1996 of one percent (Figure 5.8). Determined by the dominant land use in the vicinity, the four percent decrease in the woodlot sections has been replaced by either subsistence grazing or small-scale agriculture and subsistence cultivation. Wood, extracted from these woodlots, was used as fuel to cook and provide heat compensating for the lack of services such as electricity and piped water. Also impacting on the decline of woodlots is the removal of woodlot vegetation from floodplains due to the fertile soils that are ideal for cultivating on. The woodlot vegetation on the floodplains is important for filtering sediment before it reaches the river and for controlling floods by restricting the scour from overtopped streams. There is no evidence in the catchment that trees are grown or harvested for sale.

The region outside the former 'homeland', particularly in the extreme north of the catchment, has remained relatively unchanged. Activities here include cultivating timber and sugarcane for commercial purposes. These are large-scale, privately owned, farms with all the necessary services (electricity, potable water), and sufficient finances to produce profitable crops to afford these services. The total area under commercial sugarcane did not change over the 18-year period covered by the study, while the forestry section that had reduced from four percent to three percent by 1989 regained the one percent by 1996 (Figure 5.8). This change in forestry area may be attributed to an error in classification related to the harvesting of a section of forestry land in 1989, rather than an actual change in land use.

Commercial forestry and sugarcane together comprised ten percent (33 km^2) of the catchment in 1996, while small-scale agriculture and subsistence cultivation comprised 48 % (167 km^2) in the same year. The proportion of the catchment under each respective land use is an important aspect to consider in terms of its contribution to the sedimentation problem. Hypothetically, if commercial sugarcane has the highest sediment yield per unit area it may contribute the least to the sedimentation of the dam as it covers only a small portion of the catchment. It would be important to manage the sediment yield from sugarcane although it becomes less significant than for subsistence cultivation that covers a larger portion of the catchment and therefore contributes greater to the total sediment of the dam.

Figure 5.9 was produced by combining the maps in Figures 5.6 to 5.7 as described in Chapter four to produce an image showing all areas that have undergone change between 1989 and 1996. The change between 1978 and 1989 has already been shown to be insignificant and was, therefore, excluded from this map of land use change. During the same period sediment values fluctuated, neither increasing nor decreasing within this epoch. Unfortunately, sediment values prior to 1989 were not available. Such values could have assisted in determining the extent of the relationship between changes in land use and sedimentation rates. Assuming an assessment of sediment yield occurred as part of a feasibility study for the dam prior to construction it can be inferred that the high sedimentation rate, certainly from 1989, was not apparent at the time of the dam's construction and has, therefore, increased.

Despite the uncertain association with high sediment values extensive changes in land use occurred, particularly around the growing settlement of Ndwedwe where transport and basic services, such as schools, shops and clinics, are available and in the immediate vicinity of the rivers indicative of the lack of potable water. Change is also noticeable along the southern boundary of the catchment, close to the market town of Verulam in the east and to the Mgeni Catchment in the west. This area, adjacent to the Mgeni Catchment and closest to the Inanda Dam, is where people were displaced in order to allow for the construction of the Inanda Dam in 1990. An investigation of the mean number of households present on the aerial photographs in 1978 showed 15 048 housing clusters compared with 22 545 in 1989 confirms that the catchment underwent additional habitation (Table 5.3). It was also observed from the aerial photographs that the concentration of households is greater in the southwestern reaches of the catchment than for other areas of the catchment. These population dynamics are discussed in more detail in Chapter six. Generally, the areas of highest population density are those closest to major centres, water sources and road networks, which can again be attributed to the lack of services as mentioned previously.

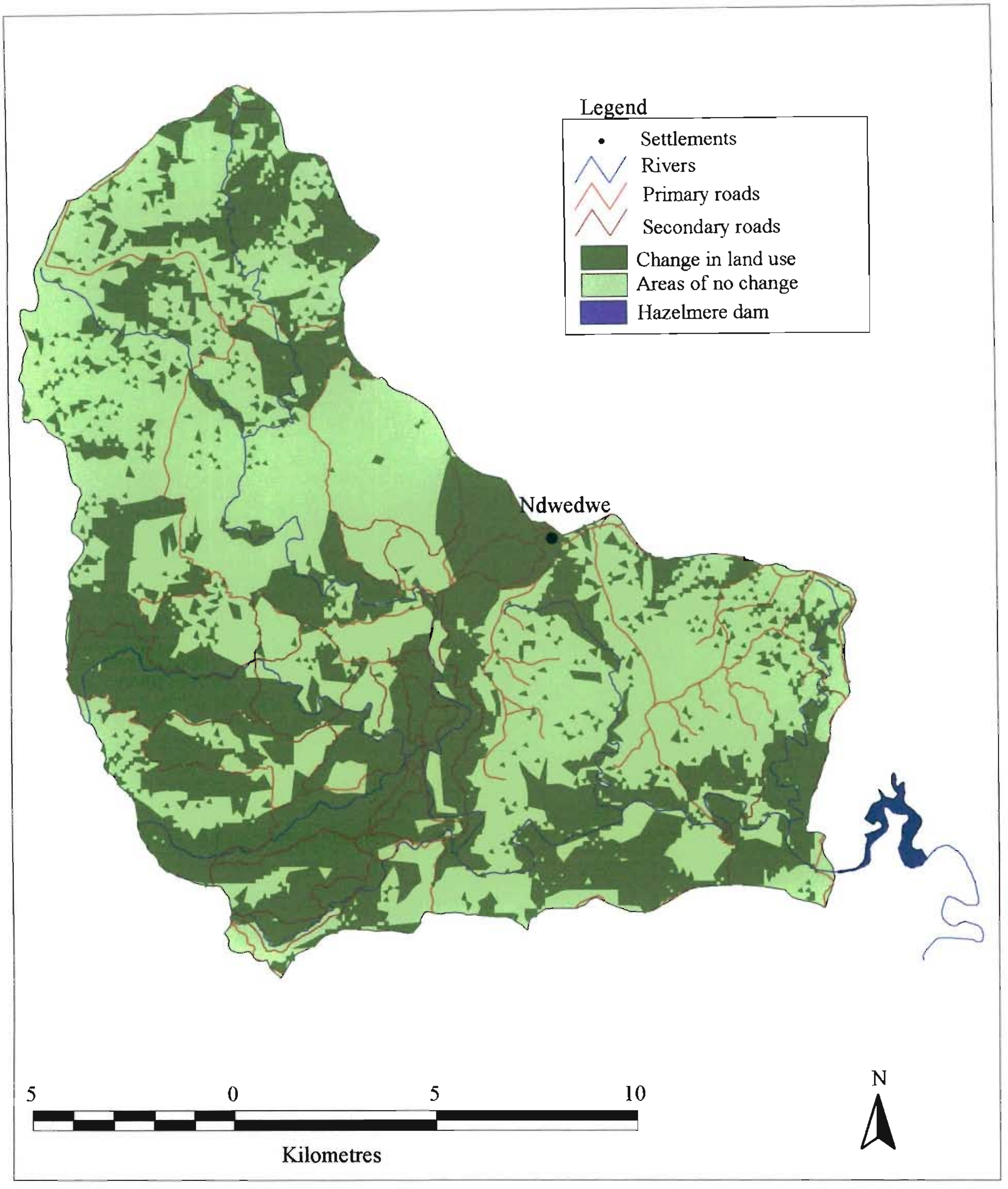


Figure 5.9: Areas of land use having undergone change between 1989 and 1996

5.3. SOIL PROPERTIES

The soil analysis results, available at the time of submission, include aspects of the physical and the chemical properties of the soil (Appendix 4). Physical properties of the soil include the texture of the soil, which is dictated by the parent material and not influenced by human activity. The chemical properties govern, for example, the fertility, salinity and acidity of the soil, in turn determining stability and structure. These chemical properties can be significantly influenced by land use, particularly by the organic matter content, which influences the fertility and stability of the soil.

The textural analysis showed that sand dominated soils are most prominent in the catchment. This fraction of the soils is as a result of weathered sandstone, dominating the geology of the catchment. The topographic condition of the catchment, discussed in Section 3.5, causes the soils to be shallow, young and strongly dominated by the parent material making them conducive to erosion. Soils with greater than a 35 % clay portion, such as those in the Ndwedwe (Zb3) ecotope are generally poorly drained causing the soil to retain water which is conducive to cation exchange bringing about their highly dispersive nature.

The structure of the soil determines the aggregate stability and permeability of the soil. Stable aggregates are more resistant to erosion than loose particles as the chemical bonds binding the particles together have to be broken down before they are transported. The soil structure, observed in the field during the collection of the soil samples, showed that large textured soils, such as sandy soils, tended to have a coarse granular structure, whilst the finer textured soils, namely clays, were moist and held firmly together in a blocky structure. Therefore, the structures observed in the catchment would indicate that the sandy soils, due to their granular structure, are more easily eroded.

Organic matter is important in soil fertility due to its release of nitrogen, phosphorus and sulphur upon oxidation. Organic carbon levels indicate that the soils in the catchment have low organic matter content. Organic matter is higher in clay soils than sandy soils as sandy soils have little cohesion and organic matter is therefore lost to surface erosion.

Cation exchange is the process by which nutrients, absorbed by clay particles become detached to be absorbed by plant roots in exchange for hydrogen cations. This release of hydrogen increases the acidity of the soil accelerating the weathering of parent rock causing the release of mineral to replace those used by the plant. Cation exchange capacity (CEC), the ability to retain cations, is generally lowest in sand. CEC of the catchment soils are particularly low, ranging from 0.4 to 3 meq/100g. Sand values should range between 0 – 5 meq/100g while clay can be as much as 50 meq/100g (Hazelton & Murphy, 1992). The pH of the soils in the catchment, as a result of the low CEC, ranges from 4.1 to 5 indicating acidity. Acidic soils are most apparent where precipitation exceeds evaporation such as in the catchment.

Electrical conductivity (EC) determines the level of salinity, the presence of water soluble salts, which severely affect plant growth, land use and soil stability. An EC greater than 4 mS/m is defined as saline (Hazelton & Murphy, 1992). All of the soil samples from the catchment show values greater than 4 mS/m indicating saline soils throughout the catchment. Exchangeable Sodium Potential (ESP) is the measure of sodicity. The higher the ESP values the more dispersive the soils and hence the greater their susceptibility to erosion. ESP values range between 5.2 and 38.7 meq/100g for the catchment while 6 meq/100g is considered sodic (Hazelton & Murphy, 1992).

SARCCUS-type map is generalised into three levels of severity, low, medium and high (Figure 5.10). Although this level of resolution is insufficient for drawing specific conclusions it does provide a basis for comparison with the generalised land use maps. Comparing the SARCCUS-type map with the map of land use change aids in determining whether land use change is a cause of the erosion features and the resultant sedimentation in the dam. Further discussion of this comparison is provided in Chapter six. The highest concentration of erosion has been found to occur in the centre of the catchment where the most severe forms of erosion transpire. The areas of low and medium levels of severity are those in the north of the catchment and those closest to the town of Verulam in the southeast. The majority of the catchment has been mapped as having a high concentration of erosion features echoed by observations made during field surveys.

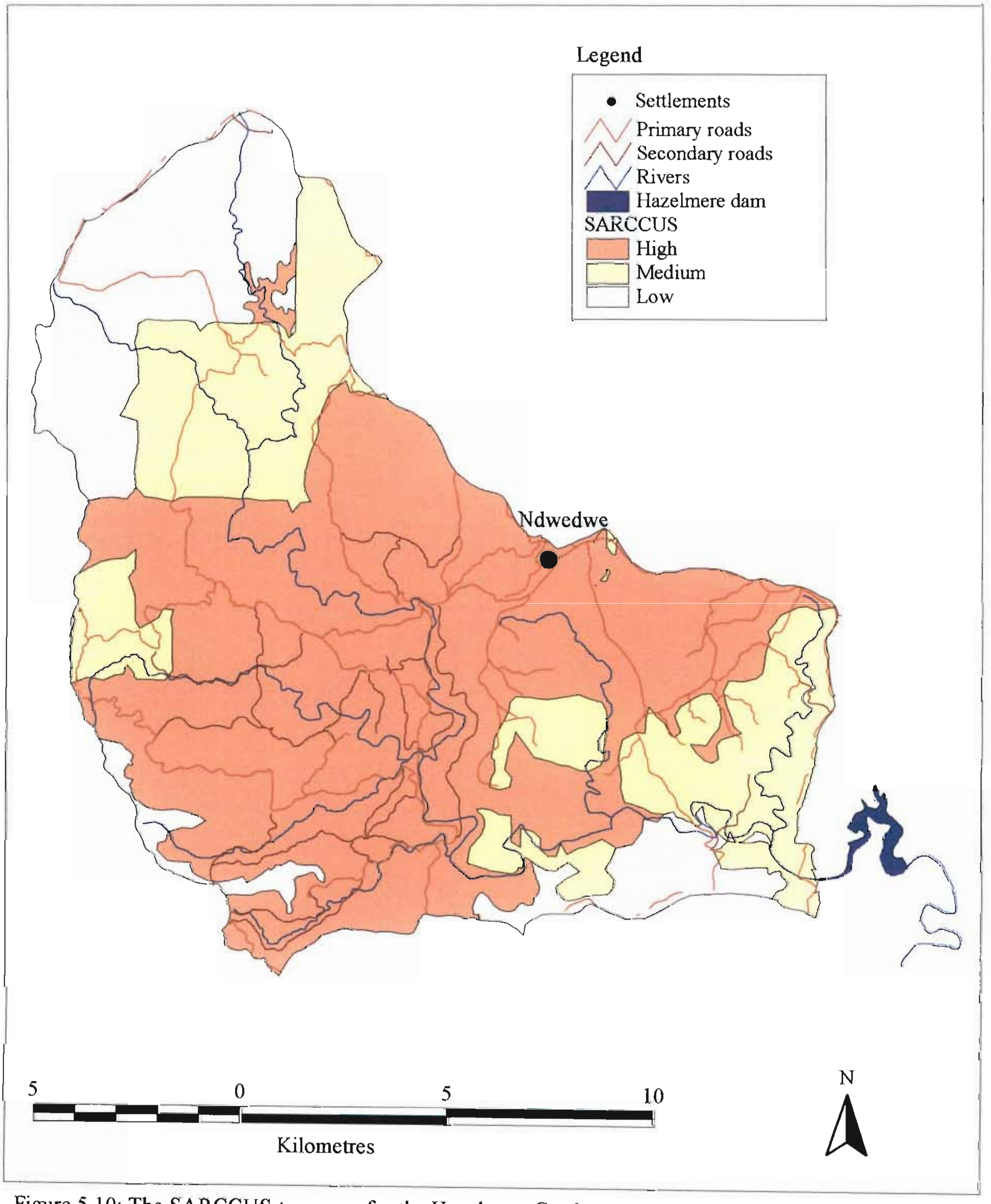


Figure 5.10: The SARCCUS-type map for the Hazelmere Catchment (Myeza, 2002)

The properties of the soil show that the sandy soils in the catchment have poor aggregate stability while the clay soils are highly dispersive, indicating a low resistance to erosion. The map of erosion features also shows that the severity of erosion is high and widespread. The consequence of such highly erodible soils in terms of the influence by, and on, land use is discussed in Chapter six.

5.4. POPULATION CHANGES

The census data for 1985, 1991 and 1996 for the Ndwedwe magisterial districts, which covers 90 % of the catchment area, are shown in Table 5.2. According to the census records a population increase of approximately 130 % was noted between 1985 and 1991, which was then almost completely reversed by 1996. The results from the house counts carried out on the aerial photographs, as described in the Chapter four, are given in Table 5.3. Although there is still a substantial change in population between 1978 and 1989 the house counts suggest that this is not as great as that depicted by the census data. This could be due to the inaccuracy of the census data as reported in Chapter four. The increase in population figures between 1985 and 1991 has, as previously mentioned been attributed to the displacement of people from the adjacent Mgeni Catchment to make way for the development of the Inanda Dam.

Table 5.2 Census results of the Ndwedwe magisterial district for 1985, 1991 and 1996 (modified after Russow & Garland, 2000; StatsSA, 2001)

Years / Magisterial District	1985		1991		1996	
	Total Pop	Density (km^2)	Total Pop	Density (km^2)	Total Pop	Density (km^2)
Ndwedwe (90%)	138 588	156	318 093	358	144 172	163

Table 5.3: Results of the population counts on aerial photographs

Years / Numbers	1978	1989	1996
House counts	15 048	22 545	15 884
Population counts (density km^2)	135 432 (324)	202 905 (405)	142 956 (342)

5.5. SUMMARY

The results illustrated above have shown high sediment and turbidity values fluctuating annually. The sediment values also show a correspondence with rainfall and volume indicating that sediment movement is strongly influenced by availability of water, the transport medium of sediment. Large areas of the catchment have experienced land use change from extensive grazing to intensive cultivation and small-scale agriculture, particularly between 1989 and 1996. Soil analysis showed young, sandy soils with low organic matter content to bind the sand together, conducive to surface erosion or highly dispersive clays. Such soil properties indicate that the catchment is prone to erosion. The changes in population showed an increase until 1991 followed by a decrease thereafter, which influences the land use intensity. A discussion of these results in relation to each other and to other interlinked influences, identified by the literature in Chapter two, follows in Chapter six. Analysing the results to identifying the link to land use will facilitate implementation of better management practices in the catchment.

CHAPTER 6

DISCUSSION

6.1. CHANGES IN LAND USE & IMPLICATIONS FOR SEDIMENTATION RATES

Comparison between the changes in land use and the suspended sediment values, as presented in Chapter five, suggests that a diverse array of changes has occurred in the Hazelmere Catchment. Due to the unavailability of sediment values prior to 1989, comparisons with the 1978 to 1989 epoch of the land use maps could not be made. This series of maps would, however, suggest that only a small percentage of the catchment underwent change during this period. Between 1989 and 1996 a considerable change occurred in the land use. Subsistence grazing land changed mainly to small-scale agriculture and subsistence cultivation. During the same period the suspended solids values were high compared with acceptable levels (0-10 mg/l), referred to in Chapter five. Mean annual suspended solids values ranged between 75.3 to 159.5 mg/l between 1989 and 1996. While a plausible argument can be made that the high suspended sediment between 1989 and 1996 is due to the high rate of land use change (which would also correspond with the theoretical discussion of Wolman (1967) in Chapter two), there is insufficient data available to conclusively relate the two variables. Of the five land use types identified in the catchment and the significant land use changes reported between 1989 and 1996 it is essential to consider their respective roles in facilitating detachment or aggregation of soil particles and their influence on the sediment delivery to the river. Revealed in the literature review in Chapter two is that different types of land use in the catchment impact significantly on the sediment yields. Row crops, for example, produce monthly average sediment yields of 0.6 t/ha in the United States of America while grazing land yields 0.06 t/ha (Krishna *et al.*, 1988). The change in land use is also important when determining sediment yield. The change from grazing land to subsistence agriculture could increase sediment yields by up to 90 times. (Troch *et al,* 1980).

Two dominant commercial land uses were identified in the catchment, namely: sugarcane and timber farming. Although the area covered by these land uses is small in comparison to other land uses their potential contribution to the sediment yield is significant enough for inclusion in the holistic management of the catchment to reduce the sedimentation rate of the dam.

The timber production in the commercial forestry areas of the catchment (shown previously in Figures 5.1 to 5.3) is a quasi-permanent land use, utilised over many years. The near permanent nature of the timber production limits the disturbance of the land compared to land uses relying on annual crops. Long periods of limited disturbance allow the soil to bind with the roots, developing stable structures thereby reducing the risk of erosion. This, however, impacts on the fertility of the soil as trees require large amounts of nutrients and water. A reduction in fertility indicates a decline in organic matter necessary for soil stability and future productivity. Although leaf litter aids in replenishing nutrients to the soil it is often removed to prevent pest infestation. Competitive species (i.e. plant species not used for agricultural productivity) removed to improve soil fertility leave the soil exposed to detachment by rainsplash erosion.

The canopy cover of the mature trees is higher than the critical two metres, at which maximum velocity of raindrops is reached. Despite coming into contact with the canopy rainsplash has a significant effect on exposed soil. Before falling from the canopy the raindrops accumulate on the leaves and branches increasing in size. The larger the raindrops, the larger the indentations in the soil and the more soil that is displaced on impact. Leaf litter, beneficial in replacing nutrients in the soil, also protects the soil from rainsplash and overland flow.

The felling process of the trees is the most erosive period. Large areas of land used for timber production in the catchment are clear-felled, the trash frequently burnt and the soil left bare. Such practices are necessary so as to prevent pests from lying dormant in the residue and subsequently infesting the next planting of trees. This is particularly problematic in this area of the country. Studies to find biological controls and pesticides to eradicate these pests are being carried out at the Institute of Commercial Forestry Research (ICFR) (Samways, 1998). Until success of biological controls can be ascertained the practice of clear-felling and trashing will continue to provide the necessary relief from pests. Trash burning renders the soil hydrophobic preventing the infiltration of water and causing overland flow. The bare soil creates little friction to inhibit overland flow. The disaggregation of particles during the felling process and loss of aggregate stability in the removal of organic material during burning exposes soil particles to be transported by overland flow.

Forestry is often limited to the steep slopes that cannot be used for any other land use and this is no exception in the study catchment. The steep slopes at the headwaters of the catchment are being used for commercial timber production. The change in weight on the slope is important when considering slope stability and mass movement as well as the above mentioned concerns of overland flow (Cooke & Doornkamp, 1990). A sudden change in weight alters the natural balance and causes a shift in the soil's physical properties. The amount of moisture in the soil determines the type of mass movement that occurs, as well as the distance of soil displacement. A large number of landslide, rockfall and mudflow scars are evident on the aerial photographs, particularly on the steep slopes in the north of the catchment, indicating the importance of stabilising the slopes. These scars are indicative of the contribution sediment ultimately has on the river. To reduce mass movement and the resultant sediment loss it is important to implement precautionary measures at felling sites. One of the most effective measures is the retention of residue during felling on the slope. This, however, raises the issue of soil conservation versus pest control to be addressed by those concerned to ensure stability of the slopes as well as successful timber production in the future.

Collection of the felled timber involves the use of large trucks and specially constructed forest roads. The contribution of these heavy vehicles and the roads in the catchment on the sediment problem is considered further in Chapter seven.

Sugarcane is grown on a commercial scale and as a small-scale cash crop within the catchment. The areas indicated as sugarcane fields on the land use maps (Figures 5.5 – 5.7) are, however, only those commercially grown. Small-scale sugarcane fields are incorporated with small-scale agriculture and subsistence cultivation. The small-scale sugarcane is usually grown in conjunction with other crops making it difficult to identify each parcel separately. Discussion of small-scale sugarcane production is given as part of the following discussion on small-scale and subsistence agriculture.

Disturbances of the soil for cultivation of commercial sugarcane occur prior to the initial planting of the crops. Such disturbances include: levelling and contouring of the ground and the implementation of drainage systems (Huletts, 2000). These disturbances result in large quantities of soil loss as a consequence of the removal of vegetation. The removal of vegetation causes disaggregation and exposure of the soil to rainfall. Once the crop has established, clearing of competitive plant species around the cane takes place. This, along with the height of the cane at maturity (greater than the critical two metres for maximum drop velocity), indicates a high potential for rainsplash erosion.

In some areas irrigation is used, however irrigation methods can compound the detachment and transport of soil by simulate rainsplash and overland flow. Sprinkler systems release water at a set time every day by means of a timer system. This method has no regard for prior or forthcoming weather phenomenon and results in either excess water or excess evaporation. Excess water occurs when irrigation continues despite a precipitation event. As a result there is increased runoff from the saturated soils. Excess evaporation results when irrigation takes place during the heat of the day. This, in turn, wastes the water resource and causes saline soils to develop. Fertilizers are used to replace nutrients since the land is not rested between crops resulting in a build-up of excess nutrients not used by the sugarcane and promoting the development of acidic soils (Huletts, 2000). Before harvesting, the sugarcane is burnt and then removed at ground level; no mulch is left in order to prevent pests from lying dormant in the fields until the next crop is planted (Huletts, 2000). (The South African Sugar Association is also researching biological controls for pests associated with sugarcane on the North Coast of KwaZulu-Natal.) The same implications as discussed for forestry in terms of burning and stripping the fields is applicable to sugarcane. The mechanical nature of commercial sugarcane cropping requires that the land be completely fallow before planting and that sufficient space between the rows of cane be left bare for irrigation and harvesting machinery (Huletts, 2000). As a result, fallow times leave the area exposed to rainsplash and overland flow. The rows left bare for machinery provide a clear channel along which the water can run, accumulating velocity and energy to pick up available particles disturbed by the machinery. The exposure of the roots of the sugarcane, as observed in the field, was evidence of the amount of sediment that is removed from mechanically grown sugarcane.

The very nature of sugarcane (eg: its canopy height and lack of foliage) contributes to the sediment yield but the land practices used by these commercial sugarcane farmers also contribute considerably.

Observations made during field surveys showed that the small-scale and subsistence farmers grow a variety of crops, ranging in properties, such as that of canopy height. These properties impact on the sediment contribution each crop is capable of producing. Without a closer inspection of these variations in the crops it is difficult to assess their contribution to the sediment yield. Although the crops were numerous and indistinguishable on the aerial photographs, a number of observations, in terms of the type of practices utilised by these land users, were made in the field and are discussed below.

Crops were not planted close together and the areas between the crops were cleared of non-agricultural species resulting in exposure of large amounts of soil. The implication of such bare ground has been mentioned previously in the commercial cultivation category. Planting on steep slopes owing to population pressures and the undulating landscape and without correct conservation measures is another practice causing concern. Figure 6.1 is a photograph taken, in the catchment, of small-scale agriculture and subsistence cultivation on the slopes. The slope in question is approximately a 30 % slope and the cultivation of annual row crops has taken place on the steepest section that is most vulnerable to slope wash. Depending on the erodibility of the soils, steep slopes should be used for permanent land uses, such as the growing of trees, while high erosion hazard crops should be restricted to the gentler slopes. A slope with moderately erodible soils and cultivated by annual row crops should not exceed slopes of six percent. Those under sugarcane should not exceed 15 % and under timber, 30 % (Russell, 1998a). Maize, for example, the staple food of the local people, erodes at a rate of between three and ten tonnes per hectare when grown on gentle slopes with contour conservation (Russell, 1998a). With two thirds of the catchment having a slope greater than 10 % (Chapter three) these areas should ideally be left for sugarcane and timber production. The socio-economic nature of the catchment makes this an impractical suggestion. Therefore, conservation practices, such as terracing, to lower the slope steepness and slope length, is crucial to the sustainability of land in the catchment. Further discussion of cultivation on steep slopes continues in Section 6.4.

Rotation was one of the indigenous conservation measures observed. Due to increased population densities the availability of land is limited and crop rotation as a result has declined. Also impacting on the traditional method of rotation is the lack of available labour to plough new fields, a consequence of the men leaving the land to become migrant workers. The land now supports a number of crops, which are grown simultaneously in adjacent plots. These are varied seasonally ensuring food all year round to sustain the livelihoods of the family. This is also a traditional conservation practice known as multi-cropping. Rotating crops and multi-cropping changes the nutrients used and replaced increasing fertility and productivity, while decreasing diseases. These practices should be encouraged and improved upon through co-operation with the land users.

Figure 6.1: Cultivation on steep slopes in the Hazelmere Catchment

Land available for grazing in the catchment has been reduced over the time period researched by 20 % from 57 % to 37 %. The status of cattle in the community areas of developing countries is one of well-being (Stocking, 1988), as cattle are seen as an investment that grows through breeding and that can be sold in hard times. It is, therefore, unlikely that the number of cattle has been reduced but rather that more land has been converted to cultivating fields. Animals compact the soil and destroy young vegetation through their trampling. This results in surface sealing and reduced vegetation, which in turn increases runoff. The vegetation is then further reduced due to the reduction in soil-water availability. More runoff means that more sediment and organic matter is removed, reducing the quality of fodder. In a counteractive manner the trampling of the animals affects the quality of their food, which ultimately impacts on the worth of the animal by reducing its total mass (Russell, 1998b). Studies by Camp (1981) in the Weenen region of the Tugela Catchment, north of the Mdloti Catchment in KwaZulu-Natal, have discovered that 27 000 hectares have been completely lost due to overgrazing, and in other areas the grazing capacity has been halved. Rotating grazing land would allow parcels of land to rejuvenate thereby providing better quality fodder and reducing overgrazing effects, such as soil compaction and paths. The impact of paths is discussed further in chapter seven

The woodlot areas in the catchment are areas that have been left to grow uncontrolled, and consist of a mixture of natural vegetation and alien vegetation, harvested for fuel and firewood. Alien vegetation, because of its ease and speed of growth, has infested the naturally vegetated areas. Their light, nutrient and water sapping characteristics are, however, detrimental to indigenous species, soil fertility and overall land productivity. As services, such as electricity, replace the need to harvest wood for fuel, two possibilities arise. The first is that the woodlot areas will be converted into cultivation or grazing land. The second is that there will be an increase in the woodlot areas and the wood harvested for timber sales giving rise to the cultivation of fast growing alien trees as a small-scale crop. Whichever eventuality occurs in the catchment the reduction of riparian vegetation and the removal of natural vegetation from the steep slopes will have concerning consequences, addressed in sections above. The importance of conserving natural vegetation in these areas needs to be understood by the inhabitants to ensure the future productivity in the catchment.

It has been repeatedly emphasised that all the factors involved in sediment availability and removal are interlinked and therefore land use cannot be held solely accountable for the 6 million m^3 of sediment that has settled in the dam since its completion in 1977. During the investigation of land use changes in the catchment and from the field surveys, a number of other factors stand out as possible contributors. These factors have varying implications, some affecting land uses and the extent of vegetation cover while others have a direct contribution on the sediment. A full investigation and quantification of these factors extends beyond the scope of this study. Their inclusion is made in order to provide a holistic picture of the processes in the catchment that impact, to some extent, on the sedimentation problem, and to assist more effective management of the catchment.

6.2. LAND USE CHANGE & INFLUENCES OF SOIL PROPERTIES

A discussion of the results of analysis presented in Chapter five is provided below in order to understand the behaviour of the soil, in particular the availability of particles for transport, the impact of different types of land use and the impact these have on the sedimentation rates in the catchment.

The sandy soils dominating the catchment are well drained and aerated; good for cultivation as they permit crop roots to penetrate. They need fertilizers as they are often leached. The subsistence farmers in the catchment cannot afford artificial fertilizers and, from the results of the organic carbon percentage in the soil, few returns are made to the soil resulting in leached soils and a high erosion rate. Clay soils in the catchment are prone to waterlogging in wet periods and crusting in dry periods making them easily eroded as discussed in Chapter two. Loam soils are the most ideal for agriculture as there is sufficient clay for moisture and nutrients, sufficient sand to prevent waterlogging and allow root penetration, and sufficient silt to act as an adhesive to hold the clay and sand together. In the Bruyn's Hill ecotope (Yc21) in the North of the catchment these loamy soils currently support sugarcane and timber cultivation. The North Coast ecotope (Ya14) falls within a low gradient area in close proximity to the town of Verulam and has been extensively developed into small-scale and subsistence cultivated land according to the land use maps. These areas correspond with areas of low erosion features according to the SARCCUS-type map (Figure 5.10). These variations between soils should be taken into consideration when implementing management practices to ensure these practices complement the soils. Practices, for example, that encourage infiltration in clay soils, need to be monitored closely to ensure that soils do not become saturated and waterlogged as this has adverse effects on the vegetation it supports. Additional organic matter in clay soils will help to improve texture and thereby encourage better drainage. Alternatively, sandy soils allow infiltration more readily but drain very well becoming too dry to support crop growth. The water-holding capacity can be improved by adding organic matter to help prevent leaching.

Although the natural physical and chemical composition of the soils in the catchment are conducive to erosion, the lack of organic matter, as a result of poor land use practices, has exacerbated the susceptibility of these soils to erosion. Organic matter strongly influences structure, stability, fertility and the nutrients necessary for productivity. To improve the condition of the soil, increasing organic matter within the soils is achieved in the same manner as that described for combating rainsplash (residue and mulch practices). These are natural practices which cost little to implement and do not negatively influence the yield capabilities of the land. Encouraging organic matter and increasing permeability through aeration of the soil, aids the structure of the soil and consequently soil stability by making the removal of particles more difficult. Earthworms play an important role in the aeration of soil and can be encouraged by ensuring fertile soil and the presence of organic matter. Some burrowing animals, however, tend to contribute to the detachment of particles and the delivery of loose particles to the surface. Of particular concern in the catchment are termites, which can reduce plant cover, remove organic matter, affect aggregate stability and bring fine material to the surface ready for transportation (Goudie, 1988). Russow & Garland (2000), estimated the number of mounds visible in the catchment to be 1000 to 1500 termitaria/ha (these termitaria could not be identified at the scale of the aerial photographs to determine a more exact figure nor temporal variations). This number equates to an increase in surface area by 550 m^2/ha, and an additional 23 m^3 of available erodible material per hectare. This is an important consideration in accounting for the sedimentation. Measures to reduce the number of termites in the catchment should form part of its management strategy. An entomologist should be consulted in this regard, for affordable and effective management of the termites.

It is interesting to compare the recently generated SARCCUS-type map of the catchment (Myeza, 2002), with the extent of land use change acknowledging the limitation in the level of resolution established in Chapter five. The information in Figure 6.2 represents such a comparison. The highest concentration of erosional features in the centre of the

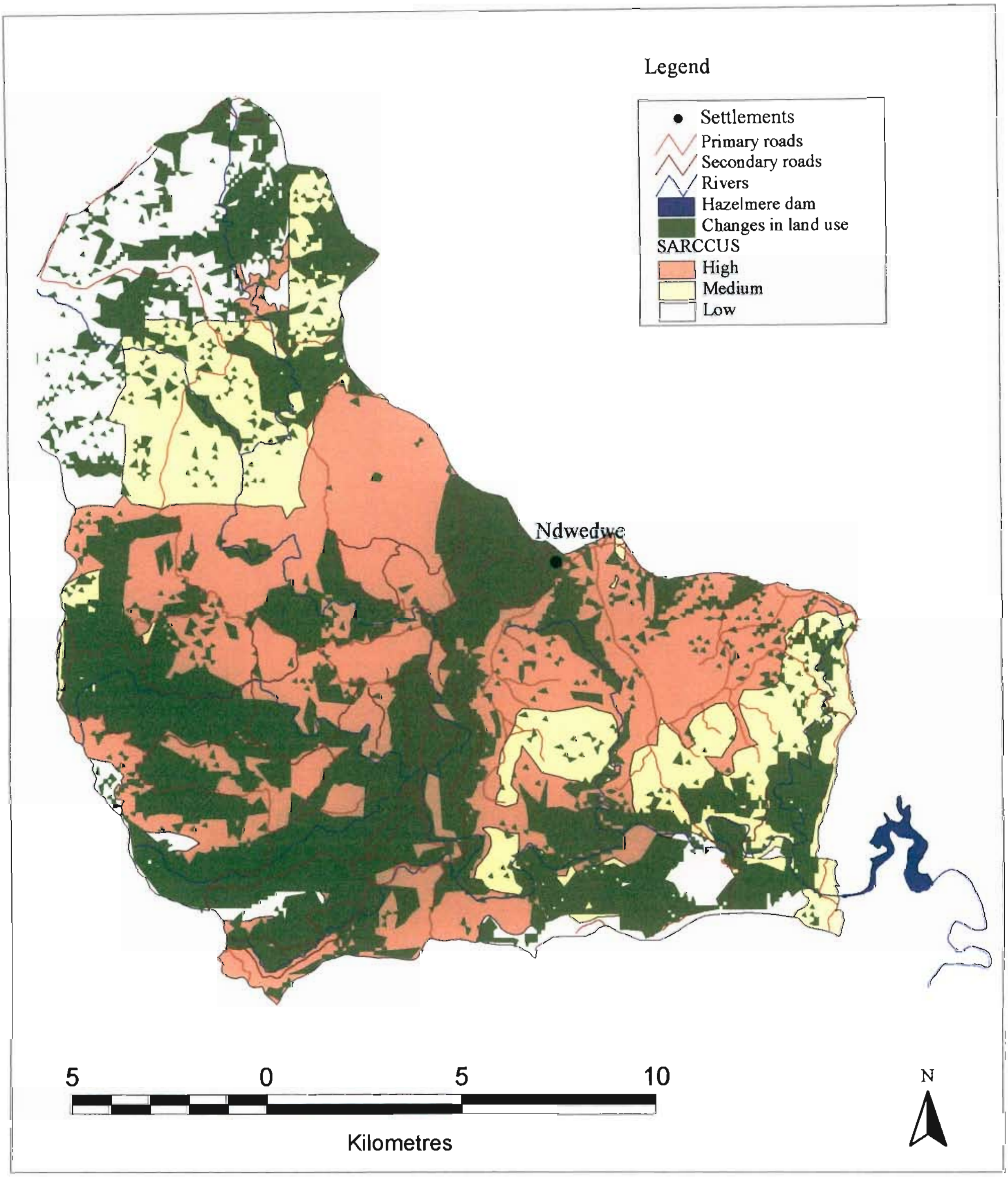


Figure 6.2: Land use change superimposed onto the SARCCUS map of the Hazelmere Catchment

catchment corresponds well, in a spatial sense, with the area of most intense land use change within the catchment. On this basis, it is tempting to infer a causal relationship.

While the literature (reviewed in Chapter 2) would support this, it is important to emphasise that erosion and the associated sediment loss are multivariate processes. Although the area in question has undergone considerable change in land use, mainly from grazing land to small-scale agriculture and subsistence cultivated land, it also matches the occurrence of the argillaceous Natal Group sandstones and basement complex sediments. Such parent material is readily weathered to erodible sandy soils and dispersive clays. Land use and vegetation cover further impacts the soil by affecting the organic content important for the aggregation and stability of soils, as well as influencing the effect of rainsplash and overland flow.

As there are at least two variables playing an interdependent role on the area of high concentration of erosional features, a relationship between land use change and the incidents of erosion features cannot be conclusively established. It is clear, however, that land use changes on susceptible soils will contribute to the severity of the erosion features but the inconclusiveness of the relationship can be further disputed by comparing other areas of the catchment. High concentrations of erosion features exist where no significant land use change has occurred, such as the area northwest of Ndwedwe. Likewise, areas of significant land use change occur where low concentrations of erosion features exist, such as in the extreme north of the catchment (Figure 6.2). Without the knowledge of the sediment yield from this area prior to the land use changes, the two variables cannot be separated and the primary cause for the high concentration of the erosion features in the area remains unfounded.

6.3. CLIMATIC INFLUENCES ON LAND USE & SEDIMENT

Precipitation in the Hazelmere Catchment region is mostly summer convective storms, which are characterised by their short-lived, intense rainfall events as described in Chapter three. These often result in flash floods because of the reduced time over which energy is supplied, detachment and runoff increases and infiltration decreases (Beater, 1970). Intense storms of known frequency require inclusion in management plans to control the energy and water reaching the surface during such storms (Larson *et al.*, 1997). Land management practices to dissipate energy and water on the surface include applying residue or mulch to bare surfaces or leaving ground cover between crops, effectively preventing large amounts of rainsplash and increasing surface roughness to encourage infiltration (Larson *et al.*, 1997). Other management practices, such as terraces, sediment traps, contour strips and buffer strips, can also be used but are more costly and less effective (Larson *et al.*, 1997).

The Hazelmere Catchment is also prone to flooding caused by the perimeter effects of tropical cyclones that lash the coast of Mozambique. Cut-off lows may also bring moist maritime air over the land causing prolonged rainfall and flooding to the catchment region of the North Coast. One such event in 1987 brought some 800-900 mm of rainfall to the catchment over a five-day period, approximately equivalent to the mean annual precipitation for this region (van Bladeren & Burger, 1989). This event followed that of a convective storm, ensuring that antecedent soil moisture levels were high, thereby minimizing infiltration (van Bladeren & Burger, 1989). With high intensity rainfall events, the exchange of energy to the surface results in the removal of large quantities of sediment carried away by the excess water flow.

It has been calculated, from data collected over a 132-year period, that the return period for a serious flood event in this region is every 3.8 years (Triegaardt *et al.*, 1988). These authors, however, have not defined a serious flood event and it is therefore difficult to determine the severity of conditions experienced, as well as to predicting potential erosion values to be expected from such an event. Flood events occurring at this rate of return require consideration in the catchment management plan, but the absence of measurements into the extent of destruction, during and after a flood event, make suggestions for management difficult. One important suggestion would be to keep cultivation and infrastructure off the floodplain areas. The feasibility of this, however, is not realistic as floodplains have very fertile soil conducive to high levels of productivity. The proximity of the floodplain to the river also makes it an ideal location for people relying on the river as their main source of water. Usage of the floodplain, nevertheless, can cause substantial loss of property and lives from a flood event. The floodplains should, therefore be left undisturbed, not only to minimise flood disasters, but to allow the floodplain to act as a sediment trap (de Villiers & Maharaj, 1993). If left undisturbed the riparian vegetation along with the low gradient of the floodplain will slow runoff, allowing time for infiltration and deposition, and limiting the amount of sediment reaching the river. However, in a survey conducted in the Mdloti Catchment after the 1987 flood, 32 % of people living in the flood prone areas indicated they would relocate back to the same area (de Villiers & Maharaj, 1993). Forty-eight percent of the people were completely unaware of the potential hazard of flooding demonstrating the importance of education about flood-dangers and the processes responsible for their occurrence. Legislation preventing development of floodplain areas is vital and needs to be carefully explained to the affected communities. Unfortunately, with the present land crisis, removing people from the floodplains will require substantial compensation and incentives.

The lack of winter precipitation, coupled with relatively high winter temperatures causes vegetation to die-off, exposing the bare soil to the elements and allowing a large quantity of loose material to become available, by the trampling of animals and the expansion/contraction processes. At the start of the rainy season this loose material is readily available for transport. Low vegetation cover allows an increased rainsplash impact on the bare ground, as well as a clear path to accumulated energy and speed, in order to transport loose sediment. Figure 6.3 (a) is a photograph taken in the catchment during summer. Figure 6.3 (b) is a photograph taken in the catchment during winter. Although the areas covered by the photographs are different they were taken in the same direction, to eliminate changes in aspect. The photographs are useful in illustrating the extent of vegetation cover change on a seasonal time-scale. The decrease in vegetation cover and the resulting exposure of soil in the dry winter months allows for intensified sheet and rill erosion at the onset of the summer rainfall.

The low summer evaporation rate and high rainfall, reported in Chapter three, leads to high antecedent moisture conditions in the soil, which adds weight to the slopes, causing added stress that has the potential to cause mass movement. High antecedent moisture conditions decrease the chance of further infiltration as the soil remains close to saturation, consequently increasing runoff rates.

a) Summer months in the Hazelmere Catchment

b) Winter months in the Hazelmere Catchment

Figure 6.3: Seasonal changes in vegetation cover in the Hazelmere Catchment

The temperature changes experienced in the catchment fluctuate from daily minimums of approximately 11°C to daily maximums of 22°C, sufficient to cause expansion and contraction of aggregates and rock fragments on a daily basis (Renard *et al.*, 1991). A similar phenomenon, shrink and swell, occurs in clay soils as a result of absorbing water and drying out (Schulze *et al.*, 1995). This continuous action results in the detachment of soil particles from their aggregate structure. In addition, cracks that occur within exposed parent material as a result of expansion and contraction, allow chemical weathering to take place. Chemical weathering, in turn, is responsible for the formation of soil. Valuable minerals are released with weathering of parent material, increasing the fertility of the soil (Renard *et al.*, 1991). With the extent of soil material removed and the high agricultural demand on the soil in the catchment, this increase in the fertility of the soil is important to sustain the productivity of the land. The effective management of this runoff water and maintenance of adequate vegetation cover can minimise the effect of climate on erosion, by reducing the effect of splash erosion and encouraging infiltration.

The characteristics of climate in the catchment are naturally conducive to high erosion rates. Fluctuations in temperature, seasonal rainfall and high intensity rainfall cause detachment of soil particles through expansion/contraction processes, rainsplash and exposure of the soil as a result of the vegetation loss during the dry winter months. The large amounts of precipitation provide the medium needed to transport the detached particles. The type of land use and changes therein determines the amount and type of vegetation cover that magnifies the effect of climate through the exposure of bare soil to rainsplash and affecting soil stability reducing infiltration.

6.4. SLOPE INFLUENCES ON SEDIMENT & LAND USE

The relief of the catchment was described in Chapter three as rugged, with sheer cliffs in the upper catchment, and rolling hills in the lower catchment. From the percentage slope represented in Figure 3.5 p. 35), it was possible to calculate that two thirds of the catchment has slopes greater than ten percent, and one fifth greater than 20%. Given Russell's (1998a) findings that the steeper and longer the slope, the higher the velocity of runoff water indicating that there is the possibility for substantial losses of soil in the catchment. The extent of erosion features illustrated in Figure 5.10 and the observation in the field of slip scars and gully erosion confirm that the steep slopes in the study area have contributed considerably to the loss of soil. Measurements by Russell (1998a) concluded that the capacity for runoff to transport sediment is five times the velocity, which in turn is the square root of the percentage slope (Russell, 1998a). For example, should the gradient of the slope change such that the velocity of runoff doubles, the transportive power would increase 32 times (Russell, 1998a). The change in slope by cut-fill platforms for dwellings and road construction or the levelling of ground for planting crops, increases the velocity of runoff downslope of the construction and therefore the capacity of the runoff to carry away loose particles. The continuous land use changes occurring on the slopes in the catchment also tend to destabilise the slopes triggering erosion and mass movement processes. Management plans should include practices that divide up the slopes, shorten the length so as to slow runoff flow and encourage infiltration. Terracing or tillage practices are both methods that can be used on slopes to shorten the slope and to level the gradient of the area used for cultivation (Russell, 1998a & b). Such practices are expensive to implement and require a loss of land currently productive. Although the rewards are considerable, convincing the farmers that the loss of land to conservation is necessary to increase productivity is the challenge. Intensive education programs and incentives are needed to ensure co-operation with the implementation of these conservation practices.

Figure 3.6 p. 36) reflects the aspect of the slopes in the Hazelmere Catchment. As the aspect of the slope influences soil moisture conditions, the more direct the sun's rays, the more evaporation that occurs. Increased evaporation reduces the availability of water for plants which, in turn, lowers the vegetation cover and results in reduced time for infiltration and, therefore, more runoff (Tiffen *et al.*, 1994). Aspect should be considered in the management of different slopes and the types of vegetation necessary under the different conditions. For example, housing should be encouraged on the drier north-facing slopes while cultivation is better on the cooler south-facing slopes.

6.5. SOCIO-ECONOMIC INFLUENCES ON LAND USE

The socio-economic status of inhabitants in the catchment influences the way in which the land is used and managed. In the subsistence farming areas, the size of the family determines the intensity at which the land is used to sustain their livelihoods. By contrast, the commercial farming intensity is determined by consumer demand for the produce. Changes in intensity will have cumulative effects on land use and sediment yield. Change in population size in the catchment is an indicator of the intensity of subsistence land use.

The results of the population counts showed a remarkable increase in numbers between 1978 and 1989 (Table 5.3). The significance of such population increases to the impact on sediment yield is due to the removal of vegetation and the disruption of soil in the construction of dwellings and preparation of fields. The intensity at which the natural resources, such as wood used for their dwellings and as fuel for cooking and warmth, are used also increases as demographic pressures accelerate, translating into degradation from overuse and mismanagement (Clay *et al.*, 1994). A study of a similar sudden increase in population in the Mfolozi Catchment, north of the Mdloti Catchment showed that modifications in land use exacerbated soil loss greater than variations in intensity (Watson, 1993). This observation was shown by Wolman's (1967) theoretical diagram illustrating the relationship between land use developments and sediment yield (Figure 2.1, p. 11).

Such an increase in population size within a confined area, as seen by the population figures for 1985 and 1991 (Table 5.2), implies that land subdivision is required, thereby decreasing farm sizes and increasing intensity of use. Dividing of farmland causes fragmentation of the landscape and forces the use of unsuitable areas such as steep slopes and marginal land for cultivation (Clay *et al.*, 1994). As farm size decreases greater care is needed to sustain long-term productivity through the use of conservation practices.

The changes in political policies in South Africa, particularly those that have allowed free movement of people, have resulted in expanding urbanisation. Since 1990, 2.8 million people have moved from rural to urban areas countrywide, increasing runoff, pollution, and construction disturbances (Gardiner & Archibald, 1992; Coleman & Simpson, 1996). Although the population within the Hazelmere Catchment has decreased by approximately

173 921 people from 1991 to 1996 (Table 5.2), the area nearest to the dam and which is in close proximity to Verulam is increasing. This evidence of expanding urbanisation leads to a serious concern for future management of the resources in the area. Although the trend of rapid urbanisation may appear to mean more concrete and less bare soil, results from urbanisation show sediment yields increase in the order of 100 - 250 times that of rural areas. This increase in sediment yield in urban areas is as a consequence of the denudation of sites and the upsetting of natural drainage networks during and after periods of development (Viessman *et al.*, 1989). Thus, the growth of Verulam and Ndwedwe in the Hazelmere Catchment is of concern to the siltation issue. The peak illustrating sediment yield from construction in Figure 2.1 p. 11) will continue to peak as construction frequency increases so much so that the landscape does not have time to adjust before the next construction site commences. Management of future major centre locations and their layout needs to be undertaken in order to avoid future erosional problems.

Human kind consists of many cultures and traditions that influence land use decisions and practices. The local people of the Hazelmere Catchment have some impacting social behaviours including the clearing of vegetation on a cut and fill platform for building their dwellings. The area immediately around the dwelling remains clear of vegetation leaving the compacted bare soil exposed. Previously, their dwellings had thatch roofing. This is now being replaced by corrugated iron without gutters. Whereas the thatch roof absorbed the rain the change to corrugated iron without gutters increases rainsplash erosion on the bare soil surrounding the dwelling. By attaching gutters to catch the water running off the roof it would be possible to prevent this erosion of the soil thereby eliminating possible instability of the slope and the potential danger of the dwelling collapsing. Storing the water caught by the gutter could be used to supply water for the family, which would otherwise require fetching from the river channel. Figure 6.4 shows a typical hillside in the catchment with dwellings set on bare cut and fill platforms without any stabilising structures. Another traditional practice is the burning of vegetation in the winter to encourage new growth. In a study by Watson (1984) it was observed that burning had no substantial effect on storm water runoff or sediment supply to the stream, however the continued use of these burnt fields for grazing prevents the re-establishment of vegetation resulting in impacts of overgrazing. The time of burning also plays a significant role in its effect on the sediment supply. Provided vegetation has established itself before the first rains of the wet season there is little concern of increased sediment supply. However, should the ground remain exposed at the start of the rainy season rainsplash will detach a large number of particles as there is little to bind to and expansion/contraction processes during winter have left particles detached, ready for removal by flowing water.

Figure 6.4: A typical hillside in the catchment showing the distribution of dwellings.

6.6. SUMMARY

The natural characteristics of the catchment presented above predispose to this area being susceptible to high erosion rates. Steep slopes, intense rainfall as well as the sandy and dispersive clay textured soils are all conducive to sediment removal. The interdependency of these natural characteristics and land use, however, have a combined effect directly and indirectly on the sediment accumulation in the dam. The reduction in ground cover, organic matter and nutrients in the soil as well as the steepening of slopes during construction all exacerbate the removal of sediment. Although land use cannot be held solely responsible for high rate of the sedimentation of the dam, when combined with the naturally occurring characteristics in the catchment, its contribution could be considerable.

CHAPTER 7

OTHER CONTRIBUTIONS TO THE SEDIMENTATION RATE

Other contributions to the sediment yields in the Mdloti Catchment are discussed in this chapter, in particular those from sand mining operations and roads. Their inclusion is relevant to the aim of this research which is to provide a full investigation of the extent to which sedimentation within the Hazelmere dam can be attributed to land use change. An examination of the findings and concerns of previous studies in the Mdloti Catchment echo observations made during field surveys (Currie, 1997; Walker, 1999; Russow & Garland, 2000). Consideration of these other contributions to the sediment yield is necessary to highlight other factors contributing to the cause of sedimentation in the dam, for the development of an ICM strategy for the catchment (objective 7, p. 4).

7.1. SEDIMENT CONTRIBUTIONS FROM SAND MINING

Sand mining or 'winning' is the extraction of fine sand, from in or near to the channel. The Minerals Act 50 of 1991 and the Department of Minerals and Energy (DME) control the mining of watercourses in South Africa. The environmental impacts of such practices on the morphology and hydraulics of the river and surrounding areas is cause for concern by many environmental researchers (eg: Jacobson, 1997; Hartfield, 1997; Walker, 1999). The complex nature of operations in the catchment and the river channel coupled with poor collection of monitoring data makes it is difficult to prove that the exact cause of changes in fluvial processes are related to sand mining. Jacobson (1997) and Hartfield (1997) highlight that, with the inevitable altering of the sediment budget, a subsequent altering of channel geometry and hydraulics are to be expected. The extent of fluvial changes is dependent on magnitude and frequency of mining, mining methods, particle size characteristics of sediment load, riparian vegetation and hydrological events after mining activities. In addition, temporal and spatial responses can vary because of thresholds, feedbacks, lags, upstream/downstream transmission disturbances and physiographic controls thus causing delayed responses that may become unnoticed by short-term studies. Such studies were, therefore, not undertaken but Walker's (1999) research provides some important considerations discussed below. Also important, yet not significant to the Hazelmere sub-catchment due to its proximity inland, but rather for the Mdloti Catchment is that of beach erosion as a result of sand mining (Dunn, 1997).

Two sites upstream of the Hazelmere Dam have been extensively used for sand mining ((a) and (b) in Figure 7.1). The first (a) is situated approximately one kilometre from the dam wall and the other (b) is a few kilometres upstream, at a shallow, wider stretch of the river. A decrease in the gradient upstream of site (b) has resulted in a slower flow causing deposition of sediment to accumulate at (b). Of particular concern in the discussion of sedimentation is the disturbance of the channel sediment at site (a). The proximity to the dam from this site would not allow, under most circumstances, the time necessary for deposition of the disturbed particles to take place before entering the dam, contributing to the sedimentation of the dam.

Walker (1999) studied the sand mining operations in the Mdloti Catchment and sectioned the negative environmental impacts of sand mining into primary, secondary and cumulative impacts for each activity involved in the operation. A complex chart of these inter-relationships is given in Figure 7.2. The primary impacts include: damage to vegetation, compaction of soils, formation of runoff channels along tracks, increased silt load, spillage of fuels, dust and noise pollution. Secondary impacts are namely: damage to soil, soil erosion, channel bank and bed erosion, damage to aquatic and terrestrial habitats, a decrease in water quality, cost of rehabilitation and aesthetic damage. Cumulative damages occur to property, decreasing land use potential and degrading sensitive environments. Health risks increase creating a negative recreational value of the river.

For the Mdloti Catchment, specific evidence of some of the above environmental impacts observed by the author and illustrated by the figures from Walker (1999) are reproduced below. Figure 7.3 shows erosion of the channel banks at mining sites as a result of damage to vegetation and soil stability. The damage to vegetation decreases its ability to bind soil and decreases the protection of the riverbank/bed promoting erosion of the riverbank or floodplain. Soil erosion subsequently impacts on the land use potential as well as the water quality. Figure 7.4 indicates, through the exposure of the bridge foundations, that scouring of the channel bed has occurred upstream of a sand mining site.

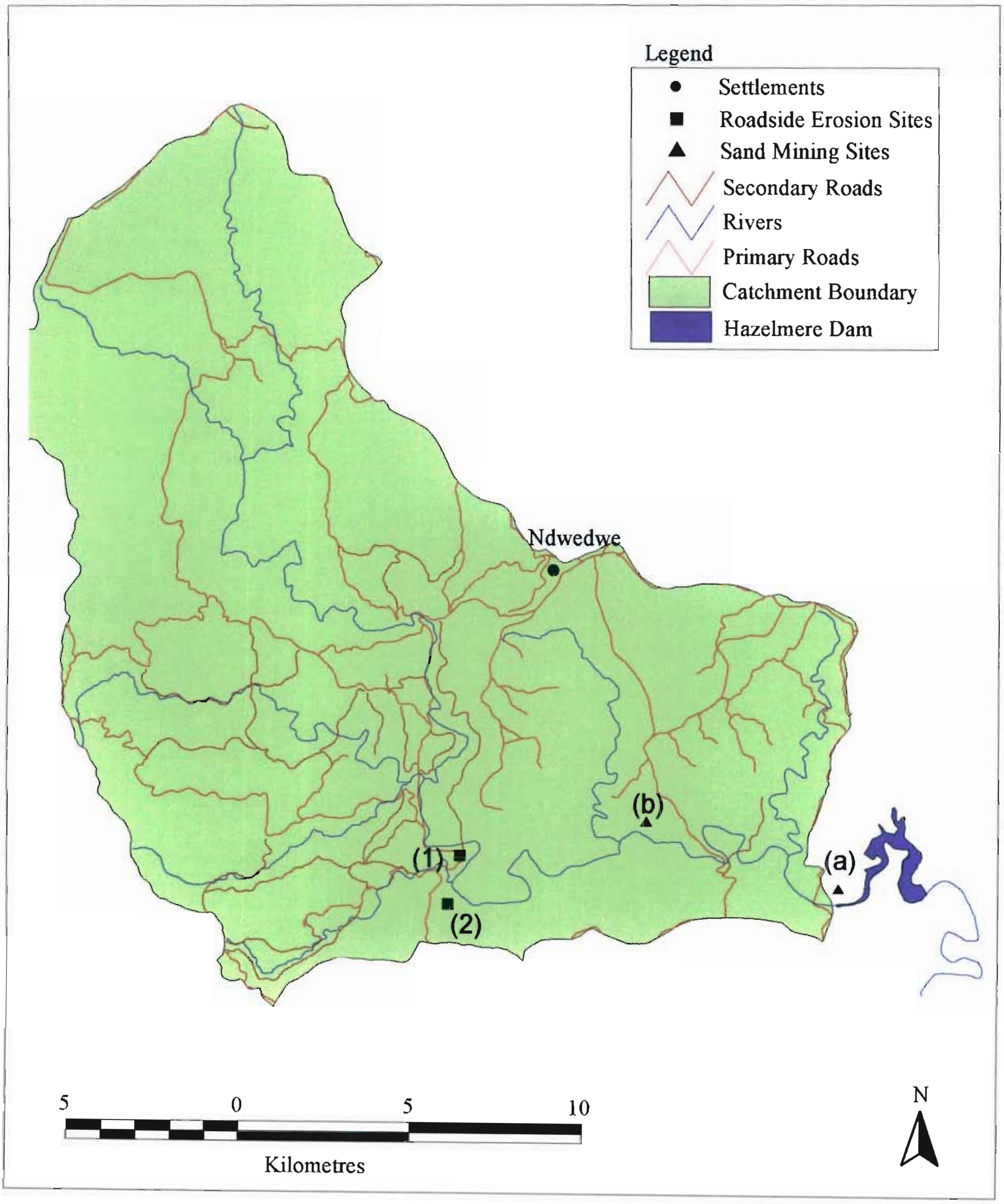


Figure 7.1: The location of sand mining sites (a & b) and roadside erosion systems (1 & 2) in the Hazelmere Catchment

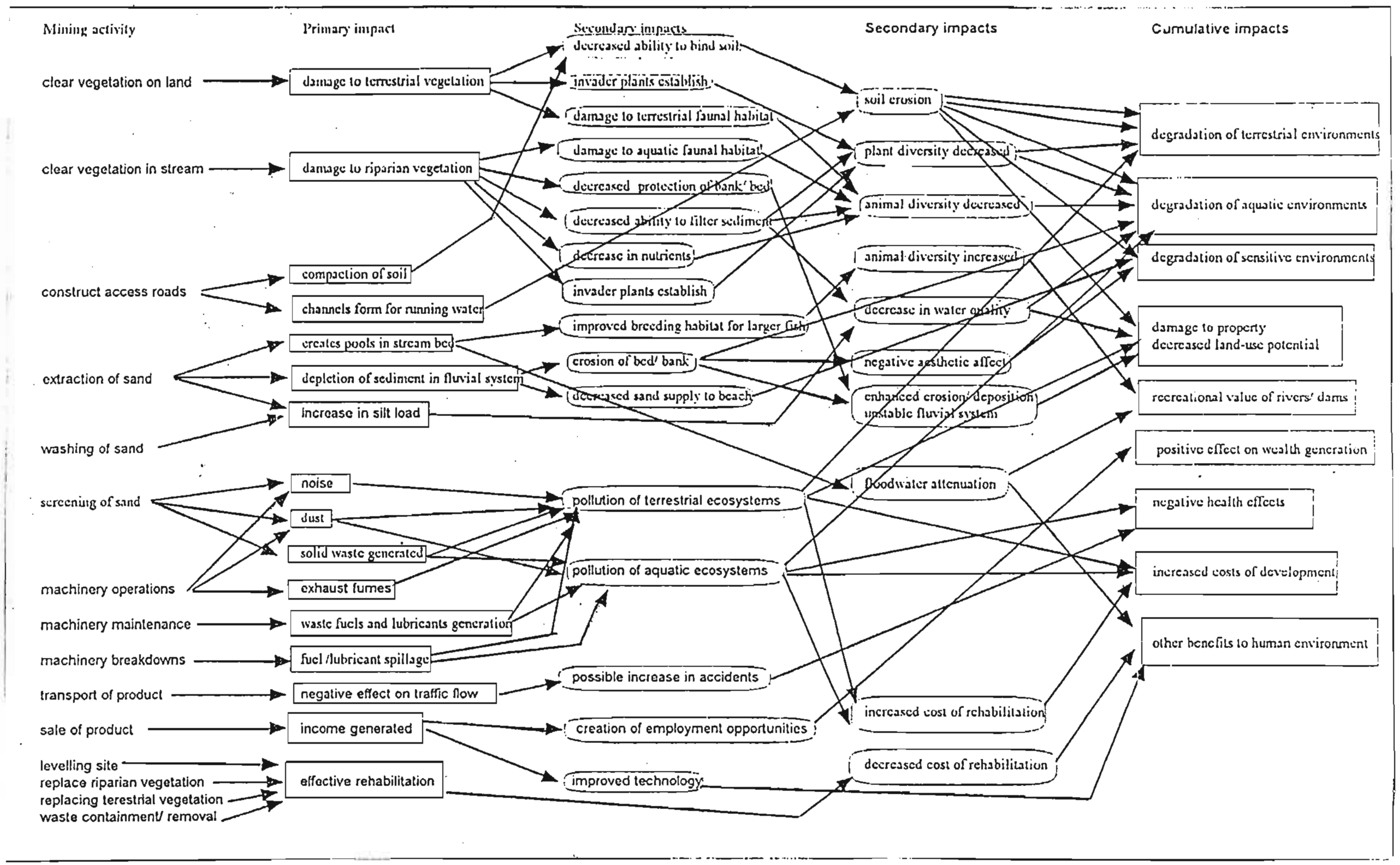


Figure 7.2: Potential environmental impacts of sand mining (Walker, 1999)

Figure 7.3: Stream bank erosion due to sand mining operations (Walker, 1999)

Figure 7.4: Streambed erosion exposing the bridge foundations (Walker, 1999)

Although this is not necessarily solely a cause of sand mining, changes to the channel gradient, velocity of flow and sediment budget brought on by sand mining practices leads to scouring of the channel bed. Complete exposure of the foundations incurs expensive structural alterations necessary for the bridge to remain stable and functional.

Figure 7.5 shows the removal of bank vegetation for an access road for sand trucks. The compaction and disaggregation by the heavy vehicles on the road as well as the lack of drainage structures ensures direct runoff from the roads into the river. Finally, Figure 7.6 shows sand mining site (a), in Figure 7.1, in both its active state (a) and once operations had been abandoned (b). Evidently little rehabilitation has taken place at this site. In an investigation of compliance to the Minerals Act in the catchment it was observed that many environmental laws have been ignored both during operation and after use has been stopped. Transgressions of the act at site (a) include: the proximity of stock piles to the flowing water, the height of stock piles (<1.5 m), the failure to flatten these piles after use and the rehabilitation of disturbed vegetation. The consequences of a lack of vegetation to the sediment yield have been discussed at length in the research (section 2.1 and 6.1). Exceeding the proximity and height limitations of the stockpiles causes sand to wash back into the river as a result of collapse, precipitation or a rise in streamflow onto the floodplain. Particles could also be carried by wind and deposited in the river or elsewhere causing numerous other concerning consequences, such as burying and sandblasting vegetation implicating on crop productivity. Interference of the flow of water has also occurred at the site through the widening of channel and by damming water in the catchment. Changing the morphology of the channel alters the flow rate and sediment budget causing deposition at the site ideal for collection of sand but also causes an increase in scouring of the channel upstream to counter balance the change in the budget. Another management concern evident at this site is the cattle grazing on the newly established vegetation. Agricultural land users should keep their cattle away from riparian zones at least until vegetation is properly established. Ideally cattle should be kept out of riparian zones permanently as this vegetation is important in filtering out sediment and other matter before it enters the river channel.

Figure 7.5: The proximity of access roads used by sand mining vehicles to the river channel (Walker, 1999)

a) The extraction stage

b) The abandoned site

Figure 7.6: A sand mining site during the extraction stage and after the termination of operations (Walker, 1999)

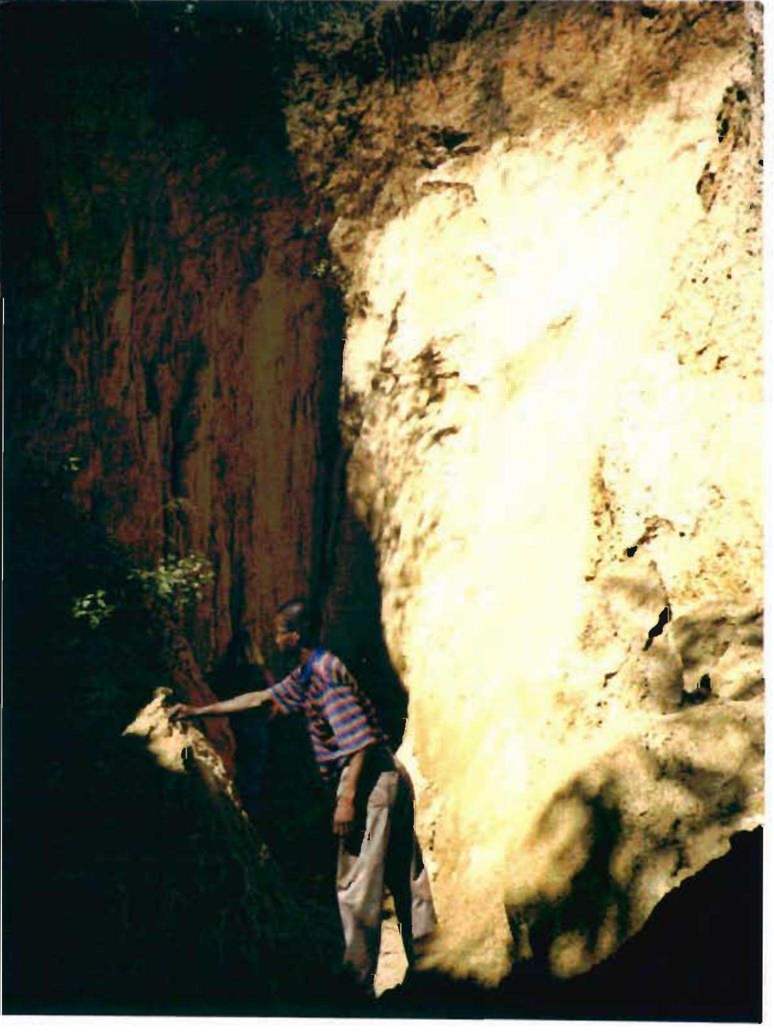
An on-going debate exists between the Department of Water Affairs and Forestry (DWAF) and Department of Minerals and Energy (DME), over whether the negative environmental impacts are significant enough to outweigh the socio-economic advantages of sand mining in the catchment. This provides evidence of the complexity of the environment and the difficulty in its management, exacerbated by the lack of co-operative governments in South Africa (Karar, 2001). Should the operations be strictly monitored and the legislation adhered to, then the socio-economic advantages should outweigh the negative environmental impacts. The lack of law enforcement and evidence given above of river channel scouring, riverbank widening, changing the flow velocity and vegetation disturbance from the riverbank clearly show that the sand mining operations are having a negative impact on the catchment. It may, therefore, be inferred that the sediment derived from these areas will ultimately be trapped in the dam, contributing to the siltation of the Hazelmere Dam. The rate at which the siltation from sand mining operations occurs has not yet been established. The Mdloti Catchment has a sediment yield of approximately 180 000 m^3/m and given correct processing 100 000 m^3/m extraction yield could easily be sustained reducing the sedimentation rate of the Hazelmere Dam (Walker, 1999). The labour needed to monitor such a small mining sector is, however, not available and offers by Umgeni Water to police the operations in the Mdloti Catchment were refused by the DME without reason (Karar, 2001). Until such time as environmental degradation resulting from sand mining is resolved, these practices will continue to contribute sediment to the river, disturbed settled particles and increase the rate of sedimentation in the dam.

7.2. SEDIMENT CONTRIBUTIONS FROM ROADS & FOOTPATHS

Many of the local inhabitants are reliant on public transport to access places of employment and commodities. Consequentially, the road network has spread extensively to provide close access to many homesteads. The extent of the road network can be seen in Figure 7.1. Many of these gravel roads were created between 1970 and 1989, evident through the comparison of 1:50 000 topographic map sheets, prior to the abolishment of the 'homelands' and apartheid laws. The consequential lack of government investment has seen many construction considerations being overlooked. Such considerations include: the rehabilitation of road cuttings to re-stabilise the steepened slope, road drainage systems and the maintenance of such systems. The lack of effective drainage systems and maintenance is apparent from the array of rill and gully systems along the side of roads. Heavy vehicles, such as overloaded taxis, buses and sugarcane trucks, are the main users of these roads. Although traffic is light in terms of the number of vehicles, as a result of the socio-economic nature of the people inhabiting the catchment, the roads are not designed for the weight of these vehicles. These vehicles are responsible for removing sediment or compacting soils under the tyres forming two concave strips running the length of the slope ultimately creating a channel of least friction for water to flow, producing high sediment output (Zieger *et al.*, 2000).

Russow and Garland (2000) carried out monitoring of road related erosion sites in the catchment estimating sediment production of such systems. Such sites are illustrated on Figure 7.1 p. 113) as (1) and (2) respectively. The first site, (Figure 7.1 (1)) a road cutting covering a slope 240 m long and designed at a gradient of 30 % was not re-vegetated or stabilised. The cutting is now riddled with deep rills and gullies along the length of the slope (Figure 7.7). Downslope, a large gully (500 m long, 20 m deep and between 1 and 20 m wide from top to base) has formed as a consequence of sediment from the cutting choking the culverts (Figure 7.8). In a comparison with descriptions and photographs of this system by Currie in 1997, and in 2000 from observations undertaken during field surveys by the author, the gully system had grown headward by approximately five metres. Volumetric determinations of this change in eroded area account for a further 1000 m^3 of sediment entering the system in 3 years. Russow and Garland (2000) made another significant comparison from aerial photographs taken in 1989, seven years prior to their investigation. A 50 m headward growth was calculated for the period between 1989 and 1997. These two observations indicate that the gully is still active and growing headward at an accelerated rate, urgently requiring control. An estimated soil loss from this system alone is calculated at 24000 m^3 by 1997 together with a further 5400 m^3 loss from the road cutting.

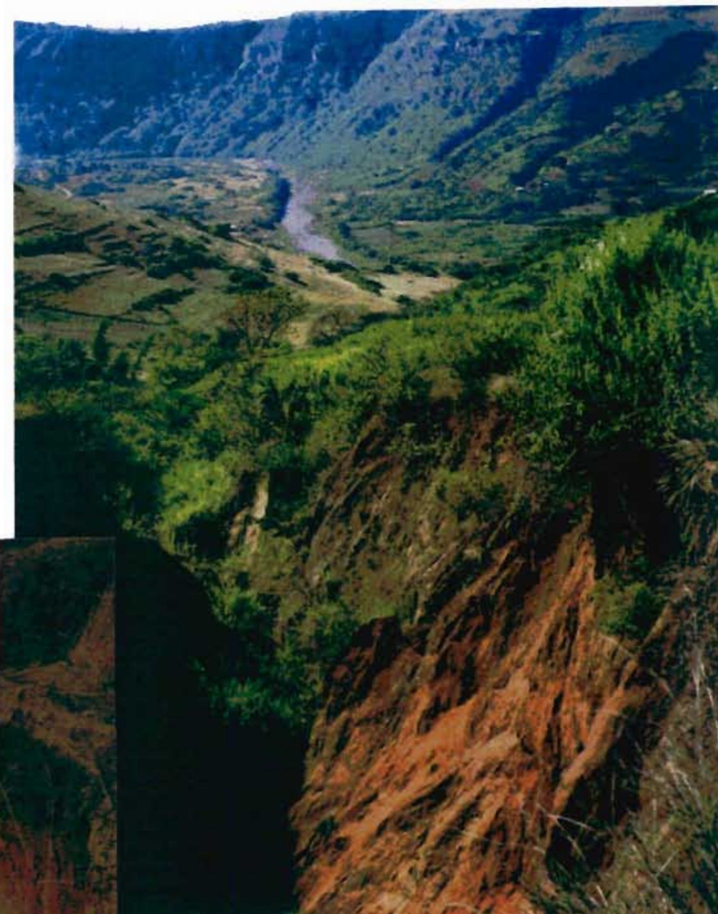
a) The extensive 240 m road cutting riddled with rill and gully systems caused from a lack of re-stabilising the slope after construction



b) A close-up of one of the gullies of the road cutting

Figure 7.7: The rill and gully erosion systems of an unvegetated road cutting at (1) in Figure 7.1 p. 113.

a) The 500 m long gully downslope of the road cutting seen in the previous figure. The river is visible in the distance indicating the distance material from the gully travels to the river.

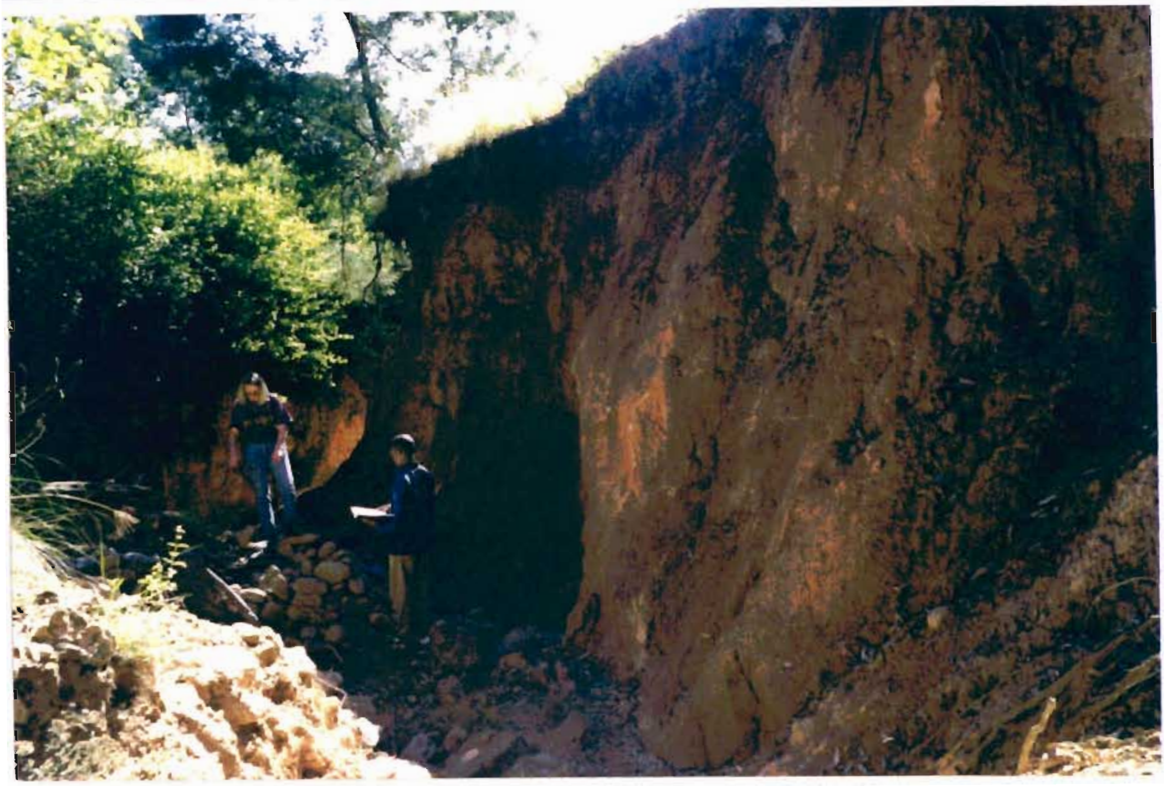


b) The head of the gully, 20 m deep. The lighter sediment is material removed from the gravel road above.

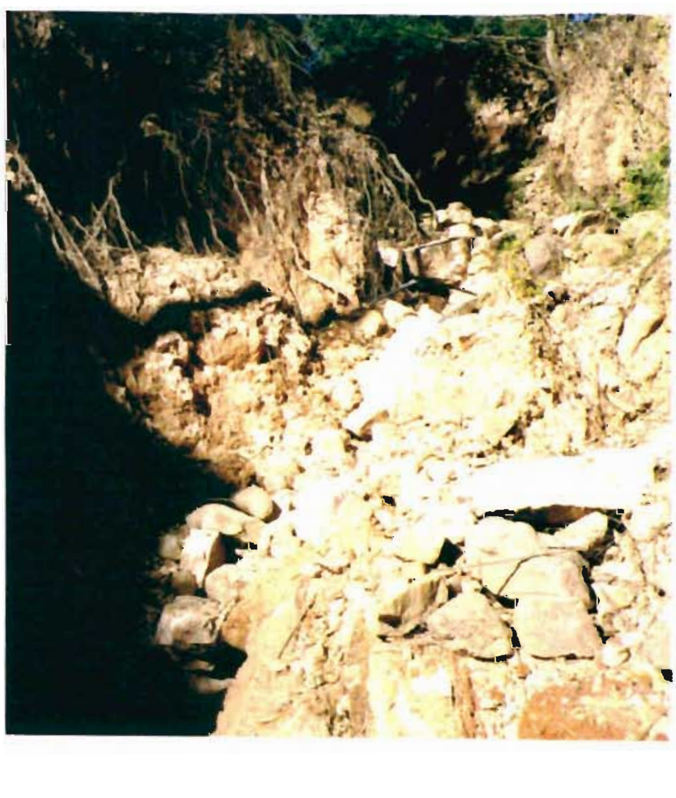
Figure 7.8: A gully formed from a chocked culvert on the road side as a result of the erosion from the unvegetated road cutting in Figure 7.7

At the second site observed (Figure 7.1 (2)), formed also as a result of poor culvert maintenance, attempts were made to remedy the problem in the past by placing rock debris in the roadside rill and the erection of a gabion at the head of a large gully system (Figure 7.9). Although the debris has prevented a deepening of the system, energy has been transferred to eroding the walls. The debris added to the system to slow the flow also adds more sediment to the system (Zieger *et al.*, 2000). The gabion has since collapsed and the system has continued to grow rapidly. Without regular monitoring and maintenance of structures, stability cannot be reached and the system remains active, removing large quantities of sediment. Although these sediment yields appear to be significant their contribution is only a fraction of the 6 million m^3 of sediment that has accumulated in the dam since its establishment. This indicates the involvement by other contributors.

In much the same way as road networks have been created to provide access, so too have footpaths been developed by people from their homes to gain access to the main transport routes and to the river for the daily collection of water. Animals also create tracks from the fields where they graze to nearby watering points. Footpaths and tracks are detrimental to the increase of erosion as they act as a channel along which water flows with reduced friction, resulting in accelerated velocity and additional erosive energy to pick up greater quantities of loose sediment. These paths become sealed and the soil compacted by the constant pounding of feet and hooves, which prevents infiltration and increases runoff. Larger gully systems are not related to these paths as with roads, but the extent of their erosional contribution is evident by the exposure of vegetation roots alongside the path and the depth of the path. Little can be done to avoid footpaths until better road networks and more basic services are provided thereby halting the need for people to collect water from the river and firewood. Education on the impact of footpaths on the productivity of the land could bring about awareness and the use of fewer paths. The maintenance of the existing paths is needed to encourage the water to run off the path rather than along its length.



a) The collapsed gabion at what was the headwall of the gully. Further deepening upstream of the gabion has taken place since the introduction of the gabion.



b) The debris packed into gully to prevent deepening upstream of (a).

Figure 7.9: A roadside gully system formed as a result of poor road drainage design layout (2) in Figure 7.1 p. 113

7.3. SUMMARY

The independent study of these two land uses in the catchment afforded their exclusion from the investigation of land use of this research as their contributing sediment yields are already known. Their inclusion here to determine the overall contributions of land use is necessary for the holistic understanding of activities contributing to the sedimentation of the dam. A holistic understanding of land use facilitates the foundation of a successful ICM strategy.

CHAPTER 8

CONCLUSION

The sedimentation problem experienced in the Hazelmere Dam has complex interrelated consequences on the social, political, economic and environmental aspects of the catchment. The environmental consequences, often overshadowed by the social, political and economic consequences, include the decline in plant and animal diversity in the river and on the land as a result of changes to their habitat conditions. Such changes have ensuing effects for the entire ecosystem. For example, sediment deposition in the river covers the spawning sites of fish thereby reducing suitable areas for laying eggs and the survival of those eggs. This in turn lowers the population of fish in the river and consequently the decline in the population of predator species feeding on these fish.

The association of micro-organisms with the sediment also has environmental consequences to the health of the ecosystem, which translates into interrelated social, political and economic consequences for the catchment. Micro-organisms can cause waterborne diseases such as cholera and bilharzia. As a result of the socio-political status of the catchment's inhabitants they are reliant on the untreated river water, which has led to cholera outbreaks being endemic in this region. The costs of treating unsafe turbid water from this dam have escalated but are necessary to eliminate sediment and associated micro-organisms in order to produce safe water for consumption. This in turn increases the cost of supplying safe drinking water to all as is required by the National Water Act 36 of 1998 for South Africa. Although the provision of piped water to these formerly disadvantaged communities would aid in alleviating the present health crisis and ultimately the costs of water treatment, this takes time and money. Therefore serious consideration is needed in the management of the catchment to develop an interim measure for reducing the health concern. Further research to develop artificial wetlands (or rehabilitate existing degraded ones) in order to purify water discharge before it enters the mainstream flow would be beneficial. Education programs to improve sanitation and purification of water could also aid in temporarily salvaging an adequate level of health in the system.

A second economic consequence emanating from the high sedimentation rate of the Hazelmere Dam is the loss of storage capacity. This comes at a time when water is considered a scarce commodity both in South Africa and globally. The demand for water is at its peak as a result of global population growth and industrial expansion as well as the increased demand in South Africa to supply piped water to previously disadvantaged communities according to the National Water Act 36 of 1998. This increase in demand incurs costs to increase the number of storage facilities and to maintain the storage capacity of existing impoundments. The loss of storage capacity in the Hazelmere Dam can only be extended by a large capital outlay to either raise the wall of the dam or to dredge the deposited sediment from the floor of the dam. These processes will, however, only slow the present rate of sedimentation and prolonging the inevitable. More expense will be needed for alterative storage facilities to meet the supply demand. In the short term the use of sediment traps and weirs along the course of the river could be beneficial in retaining sediment before it reaches the dam, as well as providing sand mining sites which would not disrupt the natural sediment budget of the stream system, yet meet the socio-economic needs of the community. Unless efforts are concentrated on determining the causes of sediment removal, transport and delivery, the problem will persist. In accordance with this reasoning, the present study was undertaken to investigate land use as a cause for the high sedimentation rate in the Hazelmere Catchment

8.1. CONCLUSIONS OF THE RESEARCH

The research presented aimed to investigate the extent to which sedimentation within an impoundment can be attributed to land use change. Although the full extent of the contributions from land use could not be comprehensively calculated due to a lack of past data and the interlinked nature of forces active on the sediment, a number of changes and trends were found. The dominant change in land use in the catchment from subsistence grazing to small-scale agriculture and subsistence cultivation can, according to literature reviewed in Chapter two, increase sediment yields by up to 900 %, from an estimated 0.06 t/ha to 0.6 t/ha. This statistically significant change in land use also coincided with areas of intense erosion features and periods of high suspended sediment values in the river. In contrast, the seasonal variation in suspended sediment values in the river indicates the association with precipitation while the erosion features coincide with highly erodible sandy soils. The erosivity of precipitation and the level of soil erodibility are further affected by vegetation cover, either in the prevention of rainsplash and overland flow or in soil fertility and aggregate stability. Regardless of how land use is viewed, it is a contributor to the sedimentation problem either as a direct implication on sediment yields from the land or as an indirect implication on other interrelated forces involved in sediment removal. Thus, it can be concluded that land use plays a definite part in the availability, removal, transport and delivery of sediment to the dam. Without further research of these interrelationships a direct analysis of the contribution of land use to sediment yields in the dam cannot, however, be calculated. It is, therefore, recommended that a multidisciplinary approach to management of the catchment as a whole be considered, such as is afforded by the Integrated Catchment Management (ICM) approach.

Eight objectives set out in the introduction were deemed necessary to achieve the aim of the research. It is necessary, therefore, to determine the extent to which these objectives have been dealt with, summarising the research. An extensive literature review, in Chapter two, identified interrelated processes responsible for availability of sediment and its transport downslope namely: erosivity of precipitation, soil erodibility, slope length and slope angle as well as the role played by vegetation cover and conservation practices. Influences that govern land uses were identified as the socio-economic and socio-political status of the inhabitants, the past land uses and availability of crop requirements. Estimates of sediment yields that can be expected from different land use and from changes between different land uses is also given in the chapter. A discussion of the processes responsible for removal and transport of sediment both on land and in the river is given to further the understanding of the causes for the sedimentation problem. A section (2.6) was also included in Chapter two defining the ICM process, its basic principles and its future role in land and water management in South Africa. A history of local and international ICM approaches identifies shortcomings to be aware of in the development of an approach for this catchment. The potential of GIS and its applied role in ICM and land management was discussed in Section 2.7. Particular mention is made of the time-series capabilities of GIS to determine change and the analytical capabilities necessary for decision-making and education, as well as the predictive capabilities of modelling management approaches to eliminate failure in reality. Chapter three describes the catchment according to the physical characteristics and socio-political and socio-economic status of the inhabitants that interact to provide a unique environment. Chapters two and three meet the requirements of objective two in affording the holistic understanding of all components in the catchment necessary for research of this kind.

Objectives three to five pertain to the methods employed in creating the land use maps and the analysis of results that have been met by Chapters four and five. A review of global structural aids, designed by Africover, FAO and UNEP in 1996, for developing classification systems was undertaken to ensure global standards were adhered to. These structural aids are also employed in the CSIR land cover database for South Africa ensuring compatibility with national systems. The scale of classification was defined by the availability and affordability of remote sensing imagery. An account of the techniques employed by the GIS in the development of the three land use maps is given in Chapter four. The tracing method of geo-correcting the distortion from the aerial photographs, the digitising process, the projection of the map to calculate area, the editing processes, error management and statistical testing to determine the accuracy of the map were methods undertaken to produce the land use maps. A time-series analysis calculated the percentage area of each land use occupied. A comparison of the area under each land use through time showed the change that had taken place. The results were statistically tested for significant change using the chi-squared test. A map of land use change was also produced by subtracting the 1996 land use map from the 1989 map to show areas that underwent significant change, according to the chi-squared test. This map was overlaid with a map showing erosion features to determine the association between land use change and the occurrence of erosion features (objective 6). This association and the integrated relationships between forces and processes identified in the catchment are discussed in Chapter six to meet the aim of the research as described above.

Chapter seven identified roadside erosion, footpath erosion and sand mining as other land uses contributing to the sedimentation rate of the Hazelmere Dam. These land uses have however been extensively researched and their contributing sediment yields known. It was therefore not necessary to include these in the classification system for determination on the land use maps but to be of aware their additional contribution in determining the overall contribution by land uses. This meets with the requirements set out in objective seven. Objective eight requires that recommendations and scope for further research be discussed. Although recommendations have been made in the discussion these need a more comprehensive discussion, which is given below.

8.2. RECOMMENDATIONS & FURTHER RESEARCH

Various conservation practices that are used in the mitigation of erosion are based broadly on covering the soil, protecting it from raindrop impacts, increasing the infiltration capacity of the soil, reducing runoff, improving the aggregate stability of the soil and increasing surface roughness to reduce velocity of runoff and wind. The conservation measures required ultimately depend on whether transport and/or detachment are the major problems. In the case of the Hazelmere Catchment the climatic characteristics assure that a large amount of water is available for the transportation of sediment while the steep slopes and low organic matter of the soil indicates the problem of detachment. It is therefore advised that no single measure is wholly effective and measures must be combined in an integrated soil conservation system, such as an ICM strategy. The role of plant cover is effective and cost-efficient in reducing sediment removal while physically altering fields to control water movement, either by reducing the velocity of runoff or increasing water storage capacity, initially disturbs the land (Morgan, 1979). Measures for the catchment must be easily implemented into existing farming systems. Costs to install and maintain measures as well as specific equipment requirements must be kept to a minimum due to the lack of capital available from subsistence, small-scale farmers to invest in conservation. Provided the conservation practices are well designed and implemented correctly, all practices are effective in combating some part of the sedimentation problem.

In small-scale agriculture and subsistence cultivation, where fertilizers and irrigation cannot be afforded, it is important that the land be rested to rejuvenate nutrient and water losses yet this is unlikely from a socio-economic perspective. Rotational cropping and multi-cropping are two alternative conservation practices that can readily be encouraged as they are historically traditional in the catchment as well as inexpensive to implement.

The natural undulating nature of the relief in the catchment has been shown to be problematic and agricultural measures, such as shortening the slope length by contour bunds or strip cropping, are required. For such conservation practices to be implemented, a percentage of land area is lost in order for long-term increases in productivity and turnover. This loss of land is a major problem facing soil conservation as both the commercial and subsistence farmers want a maximum crop yield from their land. For subsistence farmers soil conservation initiatives require an initial loss of productive land, therefore, incentives such as subsidies may be required.

To prevent overgrazing, fodder crops should be encouraged; particularly for winter-feeding when the vegetation is minimal and burning practices take place (Tiffen *et al.*, 1994). Animals should be kept from foraging on the new shoots following a burn in order to give the vegetation time to re-establish. Grazing areasshould also be rotated rather than animals being left to roam freely. This would then allow areas to rejuvenate without continuous trampling.

In terms of general agricultural practices the Conservation of Agricultural Resources Act 43 of 1983 states that it is the obligation of the land user to combat and prevent soil erosion, protect water sources and protect natural vegetation whilst combating alien vegetation (Mattison, 1998). In fact the consequences of erosion from one land user impacts both present and future users, through the depletion of resources. It should, therefore, be the responsibility of all to ensure the sustainability of our natural resources as is recommended by the ICM approach. Where land users do not have the financial or technical assistance they should be supported by all stakeholders involved as consequences will ultimately impact on them. Although the Department of Agriculture provides land users with financial and technical assistance gaining access to these can be difficult and time consuming.

Given these suggestions for management practices best suited to dealing with catchment specific issues such as steep slopes and bare ground their contribution to an ICM strategy depends on the land users' acceptance of these ideas. Changing farming techniques and convincing the farmer of the need to decrease productive land to make way for conservation structures is the ultimate challenge in the plan. Managing the population is a difficult task as each person has ideas as to the management of the land depending on their own experiences, level of education and personal requirements. Provision of education facilities will increase their knowledge of the land encouraging correct farming procedures that will ensure greater productivity for the small-scale and subsistence farmer. Skills training and education empower people increasing their chance of employment, reducing the population in the area and ultimately the intensity of land use. Addressing the needs of the people and providing the knowledge necessary to influence their needs is the first step in the plan. Staff at Umgeni Water have established a catchment forum, involving specialist parties, the local community, government and research teams (Karar, 2001). Swapping of ideas, concerns and potential solutions for the agreement by all is an essential start to improvements in the catchment. The identification in this research of problems in land use practices, concerns of land use intensity and change has been made, as have possible practices. This forum now needs to discuss these issues and suggestions and address these in the most cost effective and user-friendly way complying with all stakeholders needs. Managing and educating the people in the catchment as well as listening to their perceptions and ideas can solve many problems. An appraisal of these perceptions and ideas in the catchment could change the recommendations given above, but it is vital that the land users are supportive of the practices being suggested for the success of their implementation and management. Some essential conservation practices may need to be encouraged in terms of subsidies and incentives for implementation.

In terms of contributing towards the development of ICM strategies this research can be assessed by the five basic principles for a successful ICM. This research has identified the individual components of the catchment and their linkages with each other as is required for the systems approach. Some principle issues have been identified and researched to examine the extent of their importance in the management of the catchment as is required by the integrated approach. These issues still need to be agreed upon by the stakeholders in the catchment forum to ensure common objectives are established and that all stakeholders concerns are acknowledged. The stakeholders approach also needs to be addressed by the catchment forum to be sure that the public participates in the decision-making. The partnership approach ensures that the responsibility of the common objectives is distributed to all stakeholders. This will ensure that each stakeholder is accountable for meeting the objectives set out in the ICM. The objective should be to find a balanced management approach between economic development and resource protection while meeting social expectations. This research has shown the need to consider the environment as well as the social, political and economic consequences of land use.

This research has gone a long way toward providing a description of factors influencing the sedimentation rates in the catchment; towards understanding the processes acting on these factors as well as towards determining relationships between factors and processes. The interdependency of factors made it difficult to extract the one factor of land use to determine its individual contribution to sedimentation rates, however its relationship with other factors and processes has been considered. Land use change and practices in combination with the natural characteristics of the catchment can therefore confidently be held largely responsible for the high sedimentation rates. The knowledge of relationships and processes can be used in the setting up of an ICM strategy. This ICM strategy can only be applied once communication and co-operation with the community and other stakeholders, such as Umgeni Water, DWAF and DME, has occurred.

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APPENDICES

APPENDIX 1

INFLOW VOLUME (10^6l/day) DATA PROVIDED BY UMGENI WATER

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Mean
1989	8.6	55.7	18.2	16.1	6.2	3.1	3.8	2.5	2.1	2.9	9.7	16.9	12.2
1990	5.2	5.0	15.7	9.3	4.6	3.0	2.6	3.4	3.2	5.4	3.1	14.9	6.3
1991	9.6	19.4	18.5	9.2	5.7	3.7	3.2	2.4	3.2	5.9	8.4	4.8	7.8
1992	5.1	2.9	2.3	1.7	0.8	1.0	1.1	1.2	1.3	1.7	1.4	1.4	1.8
1993	1.7	2.0	1.2	0.8	0.7	0.6	0.8	0.7	2.6	6.6	3.2	82.3	8.6
1994	13.0	2.6	5.9	-	-	-	-	-	-	-	-	-	1.8
1995	0.9	0.4	2.2	5.7	9.0	4.5	1.9	1.2	0.8	2.0	2.6	46.9	6.5
1996	31.8	28.8	16.5	6.3	3.7	2.6	10.8	3.7	2.4	3.3	3.3	2.9	9.7
Monthly Mean	9.2	13.3	8.6	5.4	3.4	2.3	2.8	1.9	2.0	3.9	4.5	20.7	

SUSPENDED SEDIMENT (mg/l) DATA PROVIDED BY UMGENI WATER

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Mean
1989	82.8	423.0	121.9	33.5	25.2	20.3	34.0	7.2	10.8	31.2	21.8	148.0	80.0
1990	96.4	128.7	245.2	111.9	44.1	13.4	18.5	41.1	23.1	9.8	440.3	22.0	99.5
1991	125.8	68.6	628.8	33.2	45.1	10.5	12.8	7.6	41.6	34.0	148.2	66.5	101.9
1992	142.1	42.9	40.7	45.0	23.8	32.2	30.4	70.9	56.0	69.3	324.5	66.5	78.7
1993	58.3	96.3	71.1	110.1	39.4	51.9	437.1	125.8	434.1	155.9	75.8	258.8	159.5
1994	117.0	40.2	198.4	44.1	47.6	41.3	65.0	67.0	27.6	119.0	57.6	78.8	75.3
1995	13.2	69.3	360.1	39.4	42.7	23.3	25.8	24.4	29.9	371.5	40.3	251.2	107.6
1996	56.1	68.8	32.9	24.8	18.9	31.6	37.9	15.7	14.5	31.6	70.6	27.2	35.9
Monthly Mean	86.5	117.2	212.4	55.2	35.8	28.1	82.7	45.0	80.0	102.8	147.4	114.9	

TURBIDITY (NTU) DATA PROVIDED BY UMGENI WATER

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Mean
1989	116.0	266.0	108.3	110.3	88.8	245.2	41.3	72.8	52.7	36.5	54.7	2.7	99.6
1990	65.7	503.6	241.2	89.3	40.3	41.0	26.9	72.2	29.6	21.8	470.6	60.9	138.6
1991	297.6	90.1	1227.5	41.7	42.1	25.6	20.9	14.8	25.9	51.2	254.7	102.8	182.9
1992	147.8	69.2	47.7	62.2	20.6	31.5	31.3	38.7	34.4	51.1	476.8	76.0	90.6
1993	67.7	106.9	86.9	132.8	43.3	39.8	256.4	104.9	305.0	191.7	65.4	307.7	142.4
1994	117.0	54.0	356.1	101.9	79.2	128.5	131.4	113.2	74.1	116.2	60.8	90.5	118.6
1995	31.1	67.1	499.8	51.3	67.2	40.7	40.3	35.2	33.4	764.5	66.3	290.5	165.6
1996	75.4	94.9	49.9	37.9	53.1	28.9	62.4	22.2	40.0	38.6	49.1	54.7	50.6
Monthly Mean	104.0	136.6	250.4	72.7	50.3	62.0	66.3	51.2	71.9	131.2	164.4	124.5	

APPENDIX 2

RAINFALL (mm) DATA PROVIDED BY THE SOUTH AFRICAN SUGAR ASSOCIATION FROM THE TONGAAT WEATHER STATION

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual Mean
1989	42.2	352.6	12.1	86.9	19.3	4	36	15.1	53.6	81.2	344.7	98.5	95.5
1990	71.4	94.3	252.7	73	17.5	15.2	0	119.2	18.5	150.9	64.59	169.6	87.2
1991	109.6	185.1	176.2	7.7	66.5	22.7	25.5	30.9	74.6	108.7	117.4	38.2	80.3
1992	84.5	18.6	32.1	42.5	0	3.8	13.5	15.1	41.1	84.8	83.5	48.9	39.0
1993	116.6	68.6	64	56.4	31.5	0	15.5	23	93.7	146	95.9	175.3	73.9
1994	111.8	16.8	134	15.2	8.8	17	44	44.2	9.5	177.3	30.5	42.9	54.3
1995	50.9	16.3	196.1	197.4	72.6	63.7	13	12.4	4.5	135.6	100.5	273.4	94.7
1996	275.8	189.1	97.9	56.1	19	6.5	197.2	13.2	17.9	85.3	63.5	59	90.0
Monthly Mean	107.9	117.7	120.6	66.9	29.4	16.6	43.1	34.1	39.2	121.2	112.6	113.2	

APPENDIX 3

STATISTICAL CALCULATIONS:

a) Kappa Statistics

Ho = significant changes occurred between the map and ground truthing points

K = (observed – expected)/(1-expected)

Observed = ((4+16+12)/40) = 0.8

Expected = ((4/40)+(21/40)+(15/40)+(5/40)+(19/40)+(16/40)) = 0.4

K = (0.8 – 0.4)/(1 – 0.4)

K = 0.7, df = 3

Ho = reject

b) Chi-squared Statistics

Ho = no significant land use change between epochs

χ^2 = (observed – expected)^2/expected

Observed = 1989 = (6 + 5 + 56 + 29 + 4)

Expected = 1978 = (10 + 5 + 57 + 24 + 4)

$\chi^2 = (6-10)^2/10 + (5-5)^2/5 + (56-57)^2/57 + (29-24)^2/24 = (4-4)^2/4$

χ^2 = 2.7, df = 4

Ho = accept

Observed = 1996 = (7 + 5 + 37 + 48 + 3)

Expected = 1989 = (6 + 5 + 56 + 29 + 4)

$\chi^2 = (7-6)^2/6 + (5-5)^2/5 + (37-56)^2/56 + (48-29)^2/29 + (3-4)^2/4$

χ^2 = 19.2, df = 4

Ho = reject

APPENDIX 4

Ecotopes	Texture	Organic Carbon (%)	CEC (Meq/100g)	pH	EC (mS/m)	ESP (Meq/100g)	K
Bruyn's Hill (Yc21)	Loamy sand	< 0.5	0.6	5	9.8	8.8	0.3
Ozwatini (Yb13)	Sandy clay	3	0.7	4.2	14.9	43.9	0.3
Kwanyuswa (Xb10)	Sandy clay	4	1.0	4.3	9.8	38.7	0.3
EMakuluzeni (Wa6)	Sand	<0.5	0.7	4.6	11.3	13.5	0.4
Ndwedwe (Zb3)	Clay	2.5	3.0	4.5	31.2	36.2	0.4
North Coast (Ya14)	Sandy clay loam	1.8	0.8	4.1	11.1	15.6	0.5
Inanda (Yb14	Sand	<0.5	0.4	4.4	6.5	5.2	0.6