INVESTIGATING CHANNEL CHANGE IN RELATION TO LANDUSE CHANGE IN THE KLEIN BERG RIVER, TULBAGH

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KEYWORDS

Klein Berg River

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Discharge

Bank erosion

Invasive alien vegetation

Geographic Information Systems

River morphology

Cross-profiles

Aerial photographs

ABSTRACT

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The Klein Berg River catchment is intensely cultivated with orchards, vineyards and wheat, while also ensuring a water supply to the main urban center, Tulbagh, and the two conservation areas (Waterval and Groot Winterhoek). The primary objective of this thesis is to determine channel change over a long and short time period, and to relate these changes to landuse change within the catchment. Assessing stability of a selected reach within the catchment was done on a short term basis with the use of erosion pins and cross profiles, while aerial photographs of over 55 years (acquired during 1942, 1967, 1987 and 1997) which were analysed using Geographic Informations Systems. Rainfall and discharge data, which were available for a period of 49-years were statistically analysed and used to determine trends. Vegetation characteristics were assessed by means of transects within the study reach. The results over the short time period (18 months) indicate noticeable channel change in the form of erosion and deposition within the channel. Bank material composition and riparian invasive alien vegetation play an important role in bank stability. Sand was the dominant grain size of the bank material, and fluvial entrainment occurred during periods of high flow. Woody alien trees prevent the growth of protective ground vegetation, and thus the soil is prone to erosion. Undercutting was also observed with the invasive woody trees, resulting in treefall. Debris dams were also common in the channel and depending on their position in the channel, either cause or prevent bank erosion. Landuse change over the 55-year period illustrated its effects on channel stability. Shrublands within the catchment has been replaced with invasive alien vegetation along the riparian zone, while shrublands along the Obiekwa

Mountains, were replaced with cultivated lands. The patterns (shape and size) of lateral and point bars within the study area changed significantly within the 55-year period, which indicates a change in the discharge and sediment dynamics within the catchment. The change in sediment dynamics may be due to agricultural activities and urbanization. The increased trend in rainfall, especially during the winter season within the catchment is also an important catchment control. The study has revealed the integrated nature of variables within the catchment. It is thus recommended that a holistic and integrated approach at a catchment scale is required in the assessment of channel change of a river.

DECLARATION

I hereby declare that my thesis entitled *Investigating channel change in relation to landuse change in the Klein Berg River, Tulbagh* is my own work, it has not been submitted before for any degree or examination in any university, and that all the information sources I have used or quoted have been indicated and acknowledged as complete references.

Mandy Esau

Signed:…………………………

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1. INTRODUCTION

1.1 Introduction

South Africa is a semi-arid country with an average annual rainfall of approximately 500 mm. However, the spatial variability of precipitation is indicated by mean annual rainfall (MAR) ranging from about 1070 mm in the east to 58 mm along the west coast (DWAF, 1986). With a limited water supply and a growing population, the development and management of water resources in South Africa requires immediate attention. Water is a scarce, and consequently valuable resource in South Africa, where approximately 12 million people do not have an adequate supply of potable water and approximately 21 million people lack basic sanitation (White paper, 1996). It is the goal of local government to ensure that every person has access to adequate water supply and sanitation. With the increasing growth in population[1] and the economy, the demand for water is ever increasing in South Africa (DWAF, 1986). What further complicates water management in South Africa is the uneven water distribution and the fact that the water demand is increasing in areas where there is not an adequate supply of water.

The Western Cape is growing in its use and demand for water, with urban and agricultural sectors being the main users. Little (1995) predicted a water demand of 250 x 10^6 m^3/annum and agricultural water demand of 4 x 10^6 m^3/annum, while DWAF (1986) predicted an increase in water demand of 3,4% per annum in the metropolitan areas of the Western Cape. Development and growth, and consequently water demand, is especially occurring in the Cape Metropolitan area in the Western Cape. In order to meet the

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[1] *Present population is growing at 2.5% annually*

demand, water is currently diverted from rivers in the Berg and Breede catchments. Since South Africa mainly depends on rivers as a source of water, our rivers are under great stress. In addition, landuse, urban development and climate change are also factors which affect our rivers. The consequence is a changing environment and in many cases degradation of ecosystems. Although environmental change is natural, humans are accelerating and/or changing the rate and nature of natural processes (Dollar and Goudie, 2000).

1.2 Problem identification

With an increase in agricultural development and urban growth, there is an increase on the stress placed on the Klein Berg River. Observation of a select reach in the Klein Berg River shows areas infested with invasive alien vegetation as well as signs of bank erosion. Research from the River Health Programme (2004) also indicates that the Klein Berg River is under stress.

1.3 Background to the problem

Historically the lower reach of the Klein Berg River was perennial, but due to agricultural and urban developments, as well as the diversion of water to the Voelvlei Dam, the lower reach of the river does not flow during the summer months (River health report, 2004). Agricultural development within the Klein Berg catchment started in 1699, with the replacement of indigenous shrubland by vineyards and orchards. Introduced by local farmers, invasive alien vegetation now infests the riparian zone of the Klein Berg River. Water demand in the Klein Berg catchment is outstripping water supply, and in dry years, water needs to be trucked into the urban center of Tulbagh (DWAF, 2004).

Catchment land use changes, weirs and changes to the riparian zone are important impacts that have geomorphological significance in South Africa (Rowntree and du Plessis, 2003). The above-mentioned factors affect the discharge and sediment dynamics within a catchment. Any change within the discharge or sediment load in a river affects channel processes and channel form.

1.4 Aims and Objectives

A predefined reach within the Klein Berg River has been chosen as a study area to ascertain the extent of channel modification. The area was chosen because of easy access and the availability of aerial photographs. The aim of the project is to determine channel change over both a medium (55 years) and short time period and to relate these changes to conditions (such as vegetation, discharge and landuse change) within the catchment.

Objectives

1. With the use of aerial photographs determine and relate long term channel change with changes in catchment conditions
2. To determine short term bank stability

Key Questions:

Channel Change

- Has the channel changed significantly over time?
- If significant changes are evident, which factors (within catchment) were responsible?

Bank stability

- Determine changes in bank stability over short time
- If bank erosion is present, what are the factors responsible for degradation?

- Determine impact of vegetation on bank stability?

Discharge

- Determine long-term pattern of discharge
- Does discharge have significant impact on bank stability?

LITERATURE REVIEW

2.1 Introduction

Rivers are one of the most sensitive and dynamic components of the physical landscape, and are influenced by a variety of interconnected factors. Major controls on channel form are outlined in Figure 2.1 (Rowntree and Dollar, 1996b). This chapter provides an overview of channel type, and the catchment and channel controls which influence the channel type. Knowledge of bank stability, vegetation, hydrology, and the impact of human activity on river systems are essential in this study and the literature review will therefore focus on these factors.

2.2 Channel type and channel adjustment

2.2.1 Channel types

River channels can be divided into two main types, namely bedrock channels and alluvial channels. The geology of the channel bed and the resistance to erosion are the main factors determining the channel form of the bedrock channel (Rowntree, 2000). The stream power during flood events has the capacity to transport all available loose sediment in the channel. Bedrock channels are termed "controlled channels, as their form is determined by bedrock controls rather than by flow" (Rowntree, 2000:413).

"A river that has formed its channels in the sediment that is being transported or has been transported by the river is termed an alluvial river" (Schumm and Winkley, 1994:1). Channel form in alluvial channels is the result of a balance between available sediment and the capacity of the flow to transport the sediment. The bank and the bed of the channel consist of sediment in temporary storage within the system (Rowntree, 2000). The bank and bed material are particularly important factors in determining the stability of the channel form and its associated habitats (Rowntree and Ziervogel, 1999).

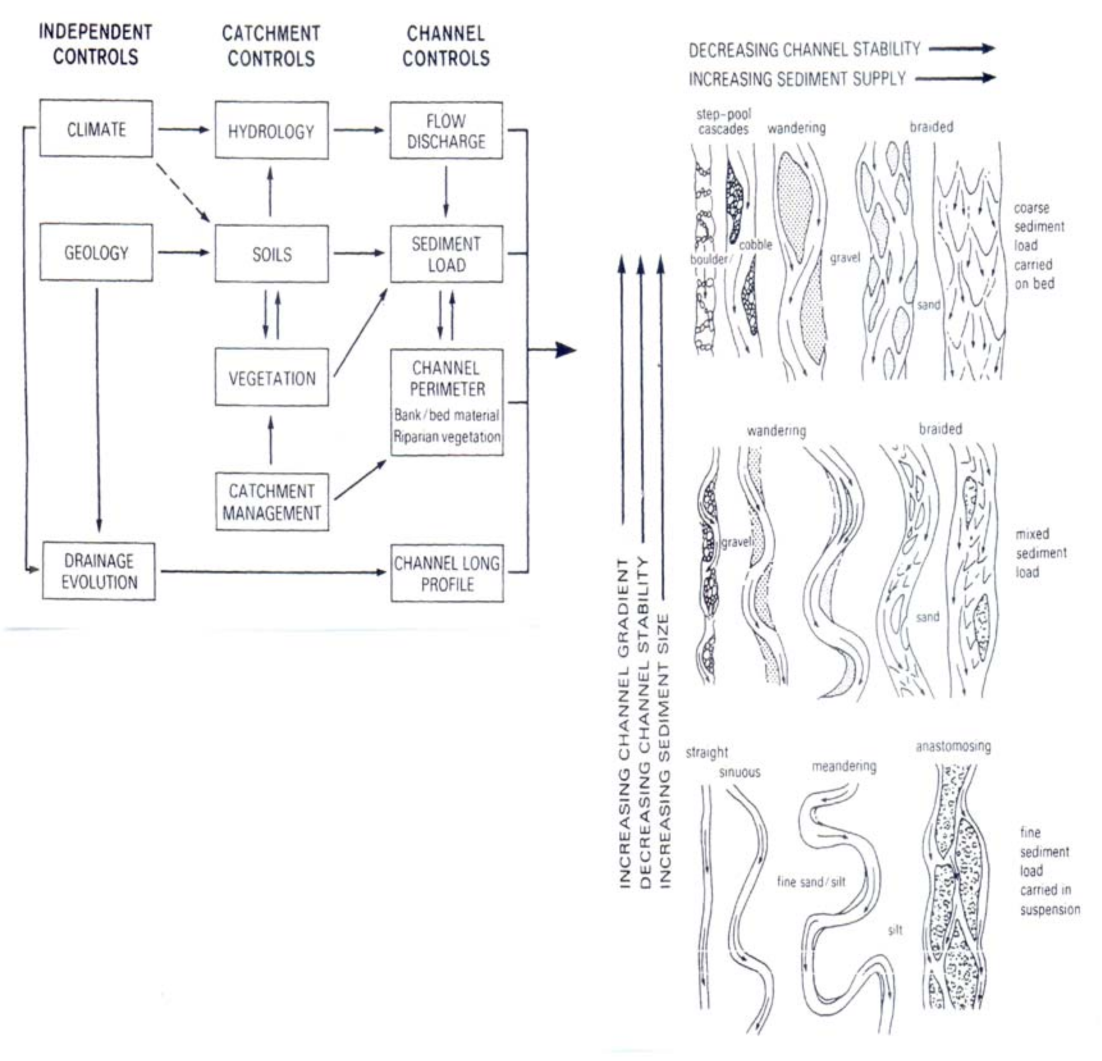

Figure 2.1 Major controls of channel type (source: Rowntree and Dollar, 1996b)

Alluvial channels are thus very dynamic, changing in response to the flow and sediment load within the channel. Figure 2.1 illustrates the different types of channel plan, namely straight, meandering and braided. The different channel plans are a result of the interaction between stream energy, sediment load and perimeter material (Rowntree and Dollar, 1996b).

Straight channels

Straight channels reflect a low sinuosity as indicated in Figure 2.1. The occurrence of straight channels is rare, with meandering channels more common due to the variability of bank material and the influence of bank vegetation (Richards, 1982). Straight channels occur in low-energy environments.

Meandering channels

The difference between straight and meandering channels is that the meandering channels are actively migratory due to bank erosion and point bar development (Richards, 1982). Meandering channels when a river is free to migrate across its floodplain (Rowntree and Dollar, 1996b). Selective bank erosion is one of the main factors for the formation of meandering channels.

Braided channels

"Braiding is favoured by high-energy fluvial environments with steep valley gradients, large and variable discharge, dominant bedload transport, and non-cohesive banks lacking stabilization by vegetation" (Richards, 1982: 211). Braiding develops when wide and shallow sections of the river have bar formations dividing the flow of water (Figure 2.1).

The creation of a particular channel pattern is dependent on the amount of energy available (Richards, 1982). A change in the channel type will occur if there is a change in any of the control variables within the catchment. "An increase in discharge or sediment load, or a reduction in bank strength due to vegetation clearance could all result in a shift from, meandering to braiding. In the longer term tectonic episodes or climatic change could have similar effects" (Rowntree and Dollar, 1996b: 39).

2.2.2 Channel adjustment

One of the major factors affecting the shape and pattern of the river is the sediment and flow regime. Any change in the supply or transport of sediment will ultimately affect the fluvial system (Dollar and Rowntree, 2003). The change in the sediment regime may be due to tectonic movement, climatic change, major floods, land use change or human modification of the fluvial system (Dollar and Rowntree, 2003). As a response to this change the occurrence of erosion and deposition will occur downstream in the valley bottoms. Any change within the catchment will thus affect the downstream channel (Figure 2.1).

2.3 Bank stability and erosion

Bank stability is an important control of equilibrium channel form (Richards, 1982), and therefore the factors that affect bank stability (both intrinsic and extrinsic), are important to consider in catchment management. In many channels, both in humid and arid regions, bank erosion is one of the principal means of sediment supply (Kirkby, 1969; Knighton, 1973; Knighton, 1984). “Bank erodibility has usually been related to the properties of the bank sediment rather than stream bank vegetation” (Murgatroyd and Ternan, 1983:367).

The role of vegetation in bank erosion has often been neglected because the effect of vegetation is so variable and it is difficult to quantify. However, the importance of riparian vegetation in catchments with respect to channel morphology has been highlighted by

Zimmerman *et al,* (1967), Mosely (1981), Rogers and van der Zel (1989), Thorne (1990), Viles (1990), and Rowntree (1991) among others.

"Streambank stability refers to a bank's resistance to change in shape or position" (Gordon *et al*, 1992:337). Petts and Foster (1985) relate the mechanics of bank failure to the (i) forces of erosion; (ii) the size, geometry and structure of the bank; as well as (iii) the properties of the bank material. According to Richards (1982), factors affecting bank erosion may be fluvial or non-fluvial in origin. Non-fluvial factors include vegetation and processes such as weathering and weakening, frost action and rainwash (Richards, 1982; Petts and Foster, 1985). Within a natural channel in an undisturbed basin, the above-mentioned factors may operate separately, or they may act together to result in bank instability.

Intrinsic

Bank erosion within a natural channel usually results when an intrinsic threshold is surpassed within the river system, thus causing adjustment or changes within the whole system. An intrinsic threshold is normally surpassed without a change in external factors, rather instability is caused when a critical threshold is exceeded within a system. Figure 2.1 depicts the interconnection of factors within a natural river system. According to Yang and Song (1979), rivers can adjust themself in order to maintain a dynamic balance between sediment load and stream power.

Extrinsic

Within a disturbed environment, man may further induce channel instability by extrinsic factors, which are normally direct changes made to the stream. These changes are normally related to engineering schemes that are planned to prevent threats of flooding, sedimentation or erosion (Park, 1977). Additional examples of human impacts can be seen in Table 2.1. Extrinsic factors normally alter the sediment load or flow characteristics of the catchment, which causes an adjustment within the river system.

2.4 Factors affecting bank erosion

2.4.1 Physical Factors

Flow Properties

The hydraulic action of the water in a channel acts directly on the bank. However, as noted above, bank erosion is a function of many interrelated factors, and therefore a threshold flow cannot reasonably be defined (Knighton, 1984). Extreme floods, i.e. high magnitude discharge, may cause extensive bank erosion as a result of channel widening (Neill and Yaremko, 1989). Apart from the magnitude of the discharge, its frequency also forms an important aspect of the erosion process.

According to Wolman and Miller (1960), discharge with a low magnitude and high frequency is more effective in entraining sediment than discharges with a high magnitude and low frequency. Consequently, “multi-peaked flows may be more effective than single flows of comparable or greater magnitude because of the increased incidence of bank wetting” (Knighton, 1984:62). Petts and Foster (1985) also noted that secondary currents associated with floods of intermediate size and high frequency cause high rates of bank erosion. According to Knighton (1984), shear stress can be the most dominant force leading to bank erosion. Shear stress can be generated: (i) near the surface of flow, and (ii) at the base of the bank which leads to undercutting.

Table 2.1 Factors influencing bank erosion (as taken from Knighton, 1984 and Neil and Yaremko 1989)

Factors		**Relevant characteristics**
Physical	*Flow properties*	Magnitude, frequency and variability of stream discharge Magnitude and distribution of velocity and shear stress Degree of turbulence
	Bank material composition	Size, gradation, cohesivity and stratification of bank sediments
	Climate	Amount, intensity and duration of rainfall Frequency and duration of freezing
	Subsurface conditions	Seepage forces, piping Soil moisture levels
	Channel geometry	Width and depth of channel Height and angle of bank Bend curvature
Biological	*Vegetation*	Type, density and root systems of vegetation
	Animals	Burrows - earthworms, termites Large grazing animals
Man	*Man-induced factors*	Urbanization, land drainage, reservoir development, boating Basin development, removal of bank vegetation Construction and obstruction of bridge crossings Local bank protection, channelizing and straightening Harvesting of sand and gravel from channels

Bank material composition

The properties of bank material have an important control on bank erosion. Bank material properties include the size, gradation, cohesivity and stratification of bank sediments.

Cohesiveness, which affects the entrainment of sediment from the banks, can be determined by the percentage of fine-grained particles such as silt and clay.

Cohesive materials consist of aggregates, which are groups of "primary particles that cohere to each other more strongly than to surrounding soil particles" (Angers and Mehuys, 1993:651). Thus entrainment takes place by the erosion of aggregates rather than separate or individual particles. Non-cohesive material consists of individual grains, which are entrained by pivoting and rolling or sliding. According to Knighton (1984:63), stability within composite banks are determined by the "strength of the weakest material since its removal will eventually produce failure in the rest of the bank".

Climate

The amount, intensity and duration of rainfall locally affect the soil moisture conditions of the banks and may, depending on other prevailing conditions, cause erosion. According to Laker (2000), soil erosion in South Africa is aggravated by the aggressive nature of rainfall. "Frost action is more important as a precondition than an erosive process" (Knighton, 1984:62). Since frost action can loosen the surface of an unvegetated bank thus making it more susceptible to erosion, water freezing in cracks or fissures can heave apart units and weaken the soil (Petts and Foster, 1985). According to Petts and Foster (1985), frost action can cause relatively high erosion rates in late winter and early spring. Frost action is especially common in tundra regions, where the formation of ice wedges can enhance erosion (Petts and Foster, 1985).

Subsurface conditions - Soil moisture conditions

The moisture content of the soil is a vital consideration in the stability of the soil mantle

(Carson, 1969; Simon *et al*, 2000). The high soil moisture conditions operate to reduce bank strength, by loosening and detaching particles or aggregates (Petts and Foster, 1985). Bank wetting and frost action reduce the strength of the bank material and thus makes it more susceptible to erosion (Knighton, 1984). Saturated moisture conditions may be due to seepage or a flow condition arising as a result of piping or pipe flow. According to Thorne (1990) the presence of riparian vegetation will have an effect on soil moisture conditions of the banks. The vegetated banks are drier than unvegetated banks for 3 reasons: (1) canopy prevents between 15 and 30 percent of precipitation reaching the ground or soil surface due to interception and evaporation into the atmosphere, (2) evapotranspiration causes a reduction in the soil moisture levels, (3) suction pressure. Other positive aspects of vegetation include the fact that vegetation reduces the rate of evaporation as compared to open channel water. Water lost through transpiration is less as compared to evaporation.

Channel geometry - Bank angle and Height

"In cohesive materials, bank stability is strongly dependent on both the bank angle and height, as well as soil properties, and failure can occur by deep, or shallow rotational slips" (Figure 2.2) (Petts and Foster, 1985:113). The undercutting of easily erodible sandy gravel may occur due to fluvial erosion which can lead to the formation of an overhang or cantilever within the upper bank. This overhang may collapse into the stream channel due to further undercutting, wetting, or cracking (Figure 2.2). Undercutting of the banks, followed by the collapse of the overhang and the erosion of fallen material, may follow a cyclic pattern. Overhangs may collapse due to the weight of the material, but may also collapse due to desiccation (Petts and Foster, 1985).

The velocity and boundary shear stress appear to be at a maximum in the lower bank region even when the flow is near bankful. Fluvial erosion thus tends to scour the base of the bank causing an increase in both the bank angle and height. This may result in gravitational failure of the intact bank (Petts and Foster, 1985). Undercutting of the banks is affected by the presence of vegetation, details of which are discussed in section 2.4.2 of this chapter.

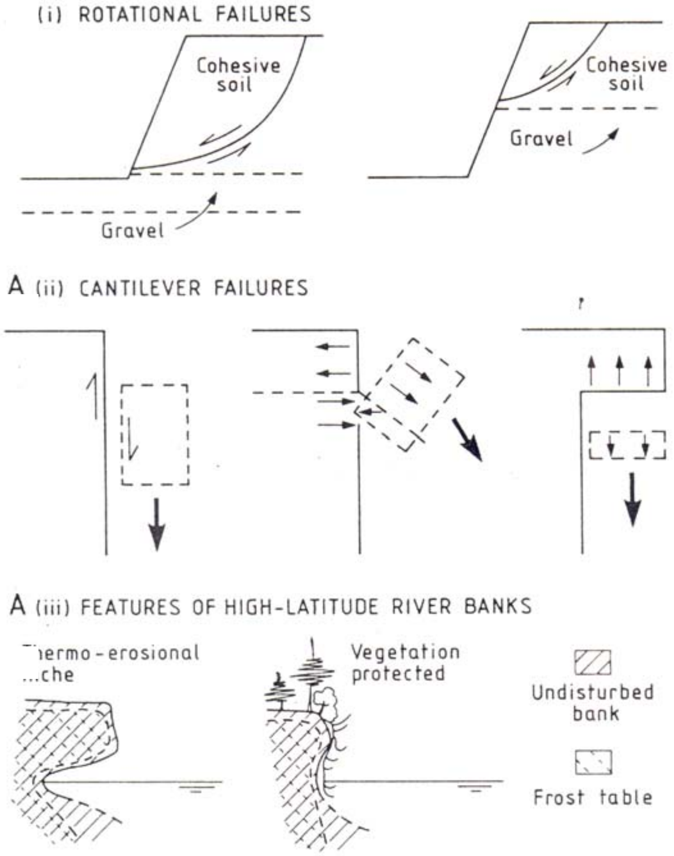

Figure 2.2 Bank failure (source: Petts and Foster, 1985)

2.4.2 Biological factors

2.4.2.1 Vegetation

Biological factors include the effect of vegetation and animals. In the study of slope stability and fluvial processes, the presence or effect of vegetation has largely been ignored due to the difficulty in quantifying vegetation characteristics (Greenway, 1987;

Rowntree, 1991). Literature relating to fluvial processes will either not give any data or information on the vegetation parameters or give a very general description of the vegetation characteristics. In the study of stability analyses, "vegetation was considered to have an indirect or minor effect on stability, and it is usually neglected" (Greenway, 1987:187). Thorne (1990), Greenway (1987) and Viles (1990) have highlighted the importance of vegetation parameters in the study of fluvial and slope processes[2]. The biological effects also include the effects of animals such as earthworms, termites and larger grazing animals which has been covered by Goudie (1988)

2.4.2.2 Effects of riparian vegetation on bank stability

A riparian zone is "that area of land between the aquatic and the terrestrial ecosystem where water availability, determined by fluctuations in the river flow, regulates plant growth and species distribution" Van Coller (1993:4). Riparian zones are extremely susceptible to invasion by alien species due to unlimited water supply.

Vegetation affects the channel bank stability and upslope resistance to erosion, while also affecting evapotranspiration and the rate of runoff (Gordon *et al*, 1992). Thus riparian vegetation through its impact on water quality and flow rate, is important in the functioning of river systems. "Indigenous riparian vegetation colonizes the source area of streams, river banks and floodplains and in these areas it retards the flow rate, improves water quality, stabilizes river banks, controls water drainage and has an important role in water use through transpiration" (Rogers and van der Zel, 1989:94).

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[2] *Banks are a type of slope.*

Bank vegetation has a localised effect and its impact on bank stability may differ due to the different vegetation characteristics. Bank vegetation may reduce near-bank velocities, decreasing the shear stress on the banks, and consequently promote sediment deposition of the channel shelf, instead of erosion. However, where large rooting systems are extruding from the bank, it may result in local bank scour around the roots. The effect of vegetation on bank stability is thus dependent on the characteristics of vegetation, the characteristics of the channel and the hydrology.

Keller and Swanson (1979) observed that streamside vegetation had an effect on the average channel width and slope. Vegetated banks are less erosive resulting in narrower and steeper channels as compared to alluvial channels with unvegetated banks which transport the same amount of sediment and water. However, Keller and Swanson (1979) also noted that different types of vegetation (i.e grasses and woody trees) may have contrasting effects of the channel.

Rooting systems

Rooting systems also have a profound effect on the stability of banks. Roots bind the soil, increasing its resistance to erosion by one or two orders of magnitude (Murgatroyd and Ternan, 1983; Petts and Foster, 1985). Smith (1976) observed that vegetated streambanks with a thick root mat of 5cm retard bank erosion up to 20 000 times more effectively than unvegetated banks. With respect to rooting depth, Murgatroyd and Ternan (1983), noted that an important distinction can be made between grassy and woody vegetation in terms of their effects on bank stability. The root systems of the woody and herbaceous vegetation differ in the depth of penetration as well as the root density. To be effective against bank erosion, the rooting system must extend way below the average low water plane, as scour takes place around the stems, snapping aerial parts and uprooting the plants. Rooting systems above the average low water plane will undercut the root zone during high flows. The roots of vegetated banks can provide an protection from the flow of water, while large root-bound blocks of soil that rests at the bank foot, may protect the slope base from further erosion (Petts and Foster, 1985). Rooting systems are thus an important control of bank erosion.

Organic Debris

In most early work the biological processes and organic debris of streams were largely ignored on the assumption that the gravel and finer sediments were the only channel forming materials in transit. The major effects that organic debris can have on sediment transport rates were confirmed by Douglas *et al,* (1982), Petts and Foster (1985), Beschta (1987) and Robinson and Beschta (1990) among others. Keller and Swanson (1979) describe the effects of organic/debris dams on stream channel development, with respect to scale, i.e size of catchments. Debris dams are normally associated with woody vegetation. Debris dams usually consisting of vegetation such as logs and twigs, form temporary storage sites within a channel, which prohibits the downstream movement of sediment within rivers. This plays an important control in the channel form. The size and location of the debris dam within the channel is very important, as it may either have an erosional or depositional effect. If debris dams restrict the normal flow of water within the stream and flow in the stream is diverted towards the bank, it may cause lateral erosion.

According to Keller and Swanson (1979), the nature and extent of the influence of large organic debris on stream channel morphology and process is primarily a function of source factors such as stream size; and hillslope and valley morphology and delivering debris to the channel. Furthermore in small to moderate size steep mountain streams, debris jams locally may control channel morphology and processes by increasing or decreasing channel bed and bank erosion and/or deposition. It can provide for significant in-channel sediment storage for long periods of time and can produce an "organic stepping" that creates a variable channel morphology analogous to pools and riffles in low gradient meandering streams or stepped-bed morphology in arid gravelly channels. Living or dead trees anchored by rootwads into a streambank may greatly retard bank erosion. Once a tree falls into the channel it may reside there for a long time and, depending on the size of the stream as well as other factors, may greatly affect channel form and processes (Keller and Swanson, 1979).

2.4.2.3 Effects of alien riparian vegetation on bank stability in South African catchments

The riparian zone is particularly susceptible to the invasion by alien plants (Rogers and van der Zel, 1989). Banks are susceptible to invasion by both herbaceous shrubs and woody trees. The degradation of our riverine habitats is mostly the result of dense infestations of alien woody trees such as the *Acacia* species for example *A.mearnsii* (black wattle), *A. longifolia,* etc (Macdonald and Jarman, 1984).

Within deep channels, woody vegetation increases boundary roughness, promotes the formation of debris dams and enhances bank stability (Rowntree, 1991). Woody species, for example black wattle, are the most important invaders of streambanks. The impact of woody aliens on bank processes depends on their growth form, above ground biomass, cover density, and density and extensiveness of root systems. Woody vegetation invading grasslands do not always enhance staibility. This is due to the dense canopy which these aliens form, prohibiting any undergrowth, thus leaving the soil surface poorly protected and susceptible to flow erosion. A few of the alien trees associated with bank erosion inlcudes *Acacia mearnsii*, *A. longifolia*, *A. saligna*, *Lantana camara* and *Pinus pinaster*. Woody aliens have shallow rooting systems which cause erosion once flash floods uproot them causing bank collapse (Rowntree, 1991). The invasion of the riverine fringes by poorly suited woody aliens, such as *Acacia mearnsii*, can lead to much increased rates of river bank erosion. On a spatial scale the degree of bank stability varies along the river channel, along with local site properties affecting bank erosion (see Table 2.1).

According to Richards (1982), vegetation conversion has several interrelated effects: the runoff and sediment yield is altered; bank stability is reduced when the anchoring effect of root networks is removed; and the stream velocity may increase if the roughness of the bank vegetation is diminished. A reduced vegetation cover may increase the discharge, increase the velocity (and erosion capacity) at a given discharge and reduce bank resistance. All of the above-mentioned factors will accelerate bed and bank erosion.

According to Rowntree (1991), the formation of debris dams are common where woody alien vegetation invades channel banks. As indicated earlier, large woody debris has an important impact on channel morphology, river hydraulics and aquatic ecosystems. In order to assess the process of bank stability, large woody debris and the effects of the debris need to be included in the assessment.

Streambank vegetation properties, and the effect of debris dams are important aspects to be considered with regards to bank stability. As mentioned above, the effect of vegetation on bank stability is localised and depends on the factors mentioned Table 2.1. In order to assess the effect of the invasion and clearing of alien riparian vegetation on bank stability, a detailed inventory of the streambank vegetation is required.

In order to assess the impact of the riparian vegetation on bank stability, a more detailed description and analysis of the vegetation parameters are required. Within this study a distinction needs to be made with regards to: (1) indigenous or alien vegetation, (2) grassy or woody vegetation (3) terrestrial or aquatic vegetation, while the presence of organic debris also needs to be included.

2.4.3 Impacts of human beings on bank stability

"Rivers have suffered the affect of human activity since society first began to impact on catchment conditions through land cover changes, to develop water resources for urban and agricultural use and to modify channel structures for flood mitigation and to improve navigation" (Rowntree and du Plessis, 2003:3). Rivers have an ability to respond rapidly to these modifications or disturbances within a catchment. The disturbances can vary considerably in character, but they generally alter the flow regime and/or sediment load of the river. A change in either the flow regime or sediment load creates disequilibrium in the channel (Petts, 1980). In response to the change in equilibrium, brought about by either intrinsic or extrinsic factors, the channel will adjust its channel form and strive to find a new state of equilibrium or quasi-equilibrium.

According to Knighton (1984) there are two types of man-induced change: direct or channel-phase changes and indirect or land-phase changes. Direct changes involve engineering works designed to alleviate the effects of flooding, erosion or deposition. Indirect changes arises due to activity within the catchment which alters discharge and load in the stream and eventually results in channel adjustment (Knighton, 1984).

Through human intervention the rate of bank erosion can be increased by several magnitudes. Land use and land management affects erosion rates and sediment yields within a catchment. Wherever vegetation is cleared or disturbed, erosion increases. Trampling by animals can also compact soils and result in erosion (Rowntree, 2000).

Human-induced factors affect the sediment and/or discharge of a channel which consequently affects the channel form. Alluvial river channels change their shape and dimensions to accommodate the discharge and the associated amount and caliber of the sediment they transport (Martin and Johnson, 1987). According to Rowntree and Dollar (1996a), the impact of riparian vegetation also plays a very important role in the controlling the channel form, which according to Martin and Johnson (1987) is ultimately determined by changes in climate and landuse.

2.5 Streamflow

2.5.1 Factors affecting streamflow

The nature of streamflow in a catchment is a function of the hydrologic input to that catchment, in terms of precipitation, as well as the physical, vegetative, and climatic characteristics. Humans, however, can have a major impact on the lag time and the peak flow of a catchment. The principal areas of human intervention in the hydrological cycle can be seen from Figure 2.3.

2.5.2 Effect of alien riparian vegetation on streamflow

The effects of alien vegetation on the streamflow/discharge have been well documented in South Africa (Dye and Jarman, 2004; Le Maitre *et al*, 1996; Van Wyk, 1987; Chapman *et al*, 1995; Manning, 1987). Le Maitre *et al*, (1996) concluded that riparian zones invaded by alien species could result in a 2 - 8 % decrease in annual runoff. The effect of invasive alien vegetation has been, and is a major concern to many scientists in South Africa, and there is abundant literature concerning the effects these aliens have on terrestrial and fluvial environments. According to Richardson *et al* (1992), invasive vegetation exerts great ecological effects on the fynbos biome. The effects of the invasive colonization include the alteration of coastal sediment movement patterns, the acceleration of river bank erosion, a reduction in streamflow, changes in fire regime, and the alteration of the composition of natural plant and animal communities (Richardson *et al*,1992; Rowntree,1991). Recent research has also highlighted the threat that these invasives pose to the endemic flora (Richardson *et al*, 1992).

Van Wyk (1987) has determined that pine forests in the Jonkershoek Forest Research Centre in the Western Cape, can reduce the streamflow by almost 50%, while Macdonald and Jarman (1984) have also highlighted that dense alien infestations impact on interception, stand transpiration, and streamflow characteristics. Bosch and Hewlett (1982) summarized the effects of vegetation changes on streamflow by reviewing 94 catchments worldwide, and concluded that (i) a reduction of forest cover increases water yield, (ii) establishment of forest cover on sparsely vegetated land decreases water yield, and (iii) the response to treatment is predictable.

The invasion of alien species also has an effect on water quality. In the fynbos biome such infestation can destabilise a catchment area, and consequently result in increased soil erosion (Le Maitre *et al*, 1996). "Most woody and herbaceous plant invaders were considered to reduce erosion rates as a consequence of their rapid invasion of disturbed sites. However, the possibility of alien plants increasing erosion rates as a consequence of increased post-fire erosion was also noted. Alien grasses are thought to increase the frequency of fires and hence of post-fire erosion events, while woody aliens are thought to increase fuel loads which can result in soil sterilization and thus enhanced periods of post-fire soil exposure." (Macdonald and Jarman, 1984:32). Soil erosion is at present one of the main problems in South Africa, not only in terms of the loss of topsoil but also in terms of its negative impact on water quality. According to DWAF (1986), soil erosion results in a decrease of 1% per annum in reservoir capacity.

It is the knowledge of the effect of invasive alien vegetation on streamflow which has led to the widespread removal of these plants in South Africa. The Reconstruction and Development Programme (RDP) in conjunction with the DWAF and the private sector, has initiated a national campaign for water conservation. Their mission is aimed at enhancing water supplies by empowering communities to carry out catchment management projects that focus on the eradication of all invasive alien plants. The programme is being implemented on a national scale throughout South Africa to improve water supply. The project is not only concerned with the mountain catchments but with the riparian zones as well.

"Mountain catchments, with an area of only 8% of the land surface, provide 49% of the total annual run-off of the country, therefore their management, for the optimum sustained yield of water, of highest possible quality, is of great importance" (Seydack and Bekker, 1995:12). The management of protected mountain catchments will increase water supply at a lower cost as compared to other projects with a similar aim. For instance, Van Wilgen *et al* (1996) estimated that, compared to optimal catchment management, direct use of sewage and desalination would be 1.8 and 6.7 times more expensive. In addition to conservation of the water resource, the diversity of the fynbos biome is conserved, fire management is made easier, increased catchment stability is achieved, there is a greater potential for ecotourism and jobs are made available through the control programmes (Le Maitre *et al*, 1996). The clearing of the riparian zones will not yield a significant increase in water quantity as compared to mountain catchments, but it will have an effect on water quality (Versfeld, 1995).

Vegetation is the chief agent of water loss through transpiration (Manning, 1987). According to Le Maitre *et al* (1996), plants in the riparian zone will have a direct effect on streamflow because soil water availability is obviously much greater in the riparian zone than any other area in the catchment.

The type and density of vegetation influences how much precipitation is intercepted above the ground and also determines how much water infiltrates the soil once the water falls to earth (Manning, 1987). Where invasive alien vegetation is concerned, the transpirational use of water by these plants is much more than indigenous vegetation. Invasive vegetation also tends to form dense thickets prohibiting the growth of indigenous vegetation and ground protection. The presence of a vegetative cover retards overland flow, giving the water more time to infiltrate the soil. This can make a substantial difference in the rate at which stream levels rise during a storm (Manning, 1987). As the alien vegetation invades an area, it inhibits the establishment of ground cover, leaving the soil bare and prone to erosion.

Vegetation and soil type are important variables affecting the runoff within an area. The soil type influences the type of vegetation growing in an area, while the vegetation also influences the soil by modifying the infiltration capacity and permeability properties (Manning, 1987).

Dye and Poulter (1995) recorded streamflow changes after the clearing of pine and wattle in a riparian zone. In an experiment conducted in Kalmoesfontein, invasive pines and wattles were cleared approximately 30m on either side of a reach on a tributary of the Crocodile river. Results by Dye and Poulter (1995) indicated that the invasive vegetation exerted a profound effect on streamflow in the following way:

i. Due to transpiration rates which fluctuated to a high during the day and low during the night, the streamflow fluctuated as well
ii. Overcast weather conditions caused a decrease in evaporation which consequently caused an increase in streamflow
iii. The clearing of the invasive vegetation caused an increase in streamflow, suggesting that the invasive vegetation utilized a significant amount of water

2.5.3 Impacts of human beings on streamflow

Components of the hydrological cycle are often influenced by human activity (Figure 2.3). According to Ward, (1975) the most important impacts on the hydrological cycle relate to:

1. Large-scale modifications of channel flow and storage by means of surface changes such as afforestation, urbanization, deforestation etc. These activities affect surface runoff and the frequency and magnitude of discharge

2. Irrigation and land drainage
3. Large-scale abstraction of groundwater and surface water

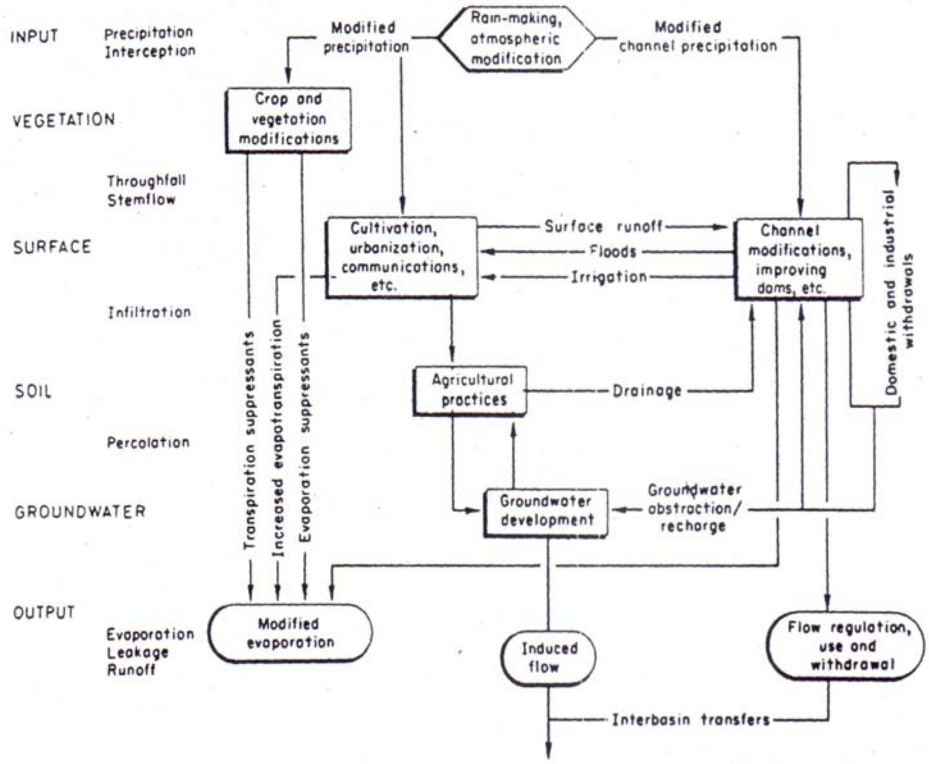

Figure 2.3 Principal areas of human intervention in the hydrological cycle (source: Ward, 1975)

2.6 Summary

According to Knighton (1984), individual effects of bank erosion cannot be separated nor an erosional threshold defined, because so many factors could be responsible (Table 2.1). Spatially, bank erosion may vary due to local site characteristics, such as bank material properties, the degree of flow asymmetry and channel geometry (Knighton, 1984). However, bank vegetation properties, and the effect of debris dams are important aspects to be considered with regard to bank stability. Bank erosion within the channel might therefore occur due to a change in any of the above-mentioned factors. As a result of the change, the channel will have to adjust to these changes, and strives towards an equilibrium or “quasi-equilibrium” state. Man-made (external) impacts on a river system, such as vegetation conversion or landuse change, may be additional factors necessary for the acceleration of bank erosion.

Bank stability is an important control in channel form, and in order to understand the processes involved in bank erosion, a detailed inventory needs to be taken of the variables affecting bank stability. The study of bank erosion and its deleterious effects have been documented for rivers in America (Antonio and Alvarez, 1989; Harvey and Sing, 1989), Britain (Jones, 1989), China (Chenjisheng *et al*, 1989), Germany (Zimmerman, 1989) and the Netherlands (Pilarczyk *et al*, 1989). The importance of predicting future sites of bank erosion and the prevention of bank erosion with, for example, riprap stability (Maynord, 1989) and other materials is a major focus of research.

3. STUDY AREA

3.1 History of the Klein Berg Catchment

Historically the Klein Berg River catchment was known as the Roodezand Valley. The valley was first discovered by Pieter Potter in 1658, and was opened to farming by Willem Adriaan van der Stel in 1699 (Ross, 2002). The Klein Berg River, one of the main tributaries of the greater Berg River catchment, is the main source supplying water to the Voëlvlei dam, a major water supply for Cape Town (Table 3.1).

Table 3.1 Principal water resources of the Cape Metropolitan Area (Little, 1995)

Source	**Available yield ($m^3 \times 10^6/a$)**
Riviersonderend Scheme (Theewaterskloof Dam)	228
Voëlvlei Dam	101
Wemmershoek Dam	52
Steenbras Dams	39
Minor sources	10
TOTAL	**430**

The Voëlvlei dam was commissioned to supply the Cape Metropolitan with water in 1952 (River Health Programme, 2004), with the Klein Berg River supplying 1.3 million cubic metres of water per day via a canal to the dam. However in 1969, with the increase in Cape Town’s water demand, the Voëlvlei dam wall was raised and more water was diverted from the Klein Berg River (1.7 million cubic metres per day) to the dam (River Health Programme, 2004). In 1971 this supply was increased by diverting an additional 0.18 million cubic metres of water per day from the Vier-en-Twintig and Leeu rivers. However, it is the Klein Berg River which is the dominant supplier to the Voëlvlei dam.

Historically, the Klein Berg River was a perennial river, but due to the diversion of water to the Voëlvlei dam, and abstraction of water for agriculture, the lower reaches of the river does not flow during the summer months (River Health Programme, 2004).

The Klein Berg River has discharge data for the catchment dated from 1954. The position of the weir (G1h008) is shown in Figure 3.1. Two rainfall gauges are located within the catchment (Figure 3.1), the details of which can be found in Table 4.2. The daily rainfall data is available from 1954 to the present.

3.2 Topography

The Klein Berg catchment has its source in the Great Winterhoek (in the north), Witzenberg (in the east) and Waterval mountains (in the south), and the Obiekwa-Voëlvlei Mountains in the west (Figure 3.1). The Klein Berg catchment drains an area of 390 km^2 (Figure 3.1) and flows through the Nuwekloof Pass before joining the Berg River.

A long profile of the Klein Berg River was compiled from the following 1: 50 000 topographical maps: 3319AA Groot-Winterhoek and 3319AC Tulbagh. The long profile is drawn from the Winterhoek Mountains before the confluence with the Berg River (Figure 3.2).

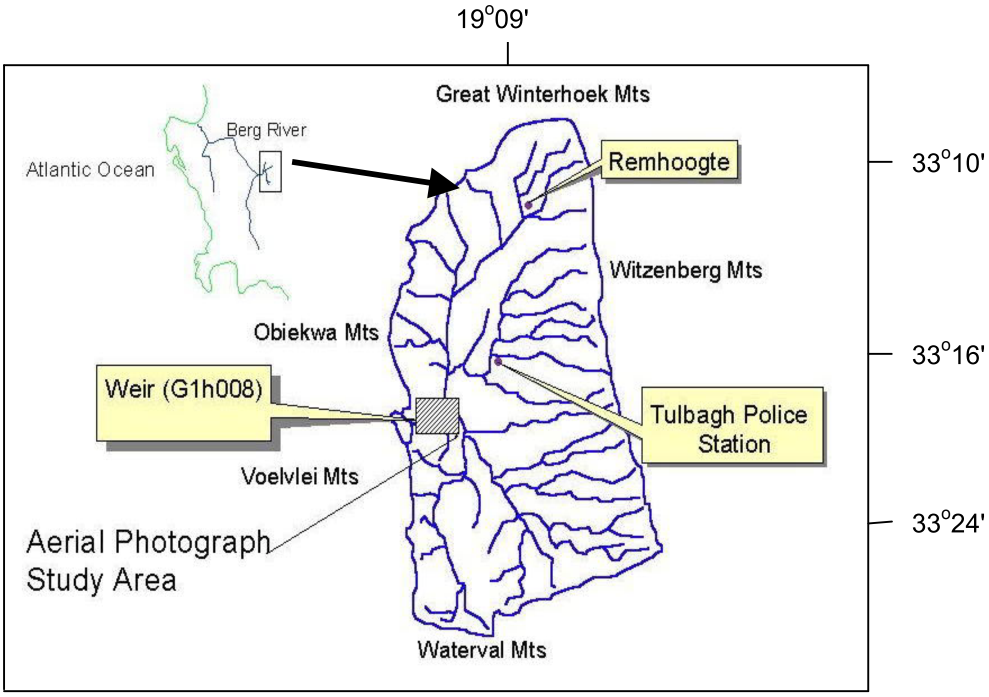

Figure 3.1 The Klein Berg Catchment

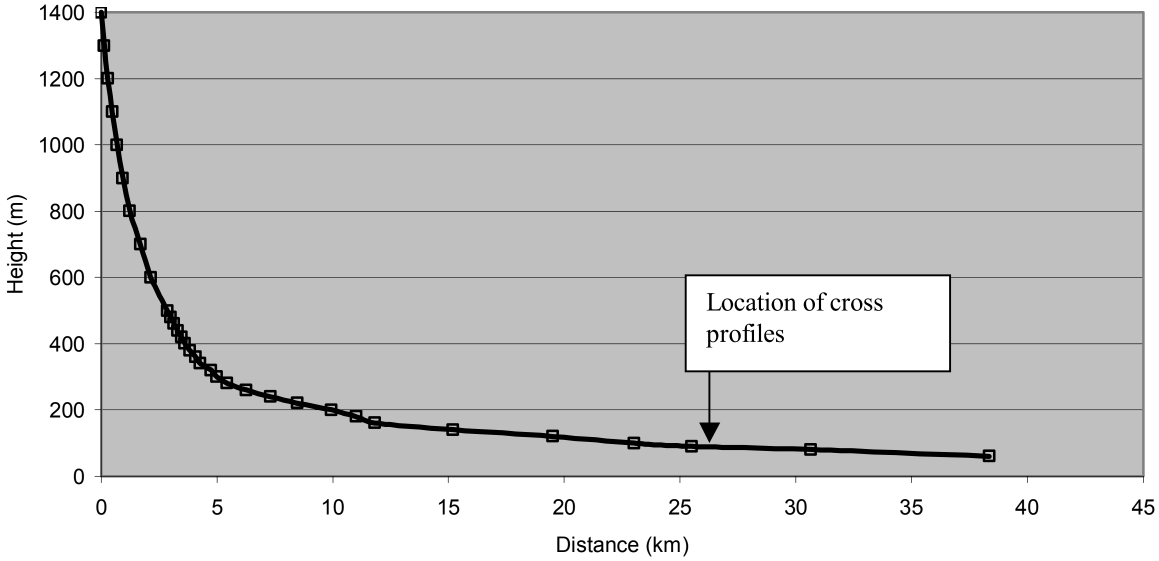

Figure 3.2 Long profile of the Klein Berg River

3.3 Geology and soils

The geology comprises quartzitic sandstones of the Table Mountain Group belonging to the Cape Super Group (Liebenberg *et al*, 1976). Old sediments of the Malmesbury Group can be found on the Obiekwa and Voëlvlei Mountains, as well as between Tulbagh and Wolseley (Gresse and Theron, 1992). The soil depth is classified as moderate to deep, while the soil texture ranges from clayey loam and sandy loam (Liebenberg *et al*, 1976).

3.4 Landuse

The Klein Berg catchment is commonly known as the Tulbagh valley, and is one of the principal agricultural regions in the South-Western Cape. Tulbagh valley is intensely cultivated with vineyards and orchards with an area of 3600 ha currently under cultivation (DWAF, 2004). Farm dams are common in the area, with many of the rivers originating from the mountain ranges dammed to provide farmers with water. Also the abstraction of groundwater to augment water supply is found in the area. The Klein Berg River catchment is also home to the Waterval and Witsenberg Nature reserves. The Suurvlak Plantation, consisting of dense stands of pine trees, is located within the Waterval nature reserve. Water uses in the catchment are thus varied.

Tulbagh is the main urban area in the catchment, and receives its domestic water supply from the Moordernaarskloof River as well as from groundwater (DWAF, 2004). The water demand in the urban area is increasing with the increase in population. During the dry years, water is trucked in to meet the local water demands (DWAF, 2004). Wastewater treatment releases 200 m^3 per day during the winter months, which is used for irrigation during summer months (River Health Programme, 2004).

3.5 Vegetation

The vegetation of the catchment is classified as West Coast Renosterveld (River Health Programme, 2004). However a huge area has been replaced by agricultural land and urban development. The Mountain fynbos is maintained in the two nature reserves and on the mountain slopes within the catchment (River Health Programme, 2004). Invasive alien vegetation such as *Acacia, Pinus* and *Hakea* species commonly occur in the catchment, especially in the mountain areas and along the stream channel.

3.6 Rainfall and Discharge

The catchment area is subjected to hot dry summers and cold wet winters, typical of the Mediterranean climate in the western Cape. The wet season is during the months of April to September. The mean annual rainfall of the catchment is 640mm (DWAF, 2004). The streamflow in the Klein Berg River imitates the rainfall in the catchment, and clearly shows seasonal variability. Figure 3.3 illustrates the discharge statistics for the months of the year. The statistical values were computed from monthly discharge data for the years 1954 to 2002. The data was made available from DWAF. Figure 3.3 shows a wet (dominant runoff) winter season (May to October) and a dry summer season (November to April). The flows during the dry season, especially from December to April, are generally low and fairly constant. The flows during the wet season are generally higher and more variable, with discharge increasing to a peak in the month of August.

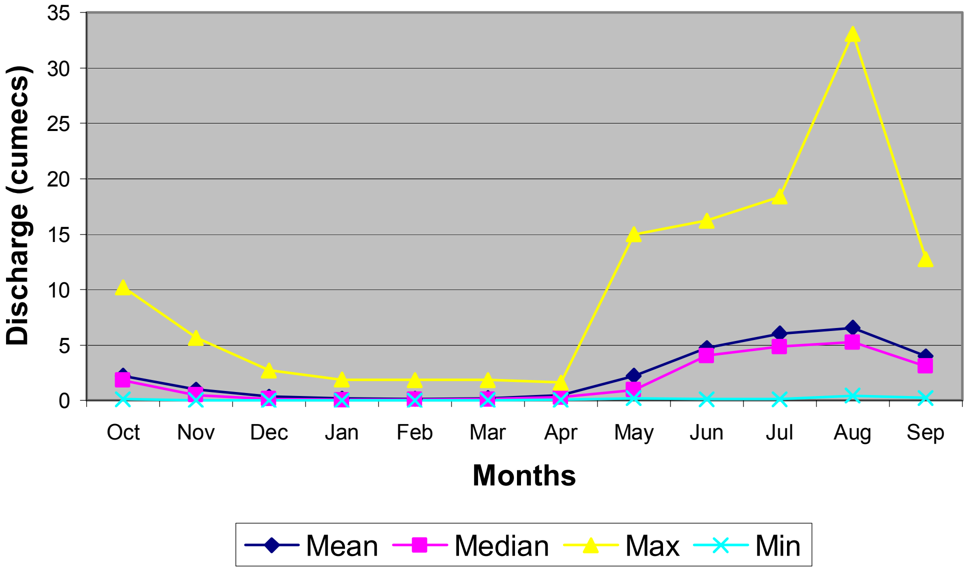

Figure 3.3 Discharge statistics for the Klein Berg River, 1954-2002 (data made available from DWAF)

3.7 Water quality

The water quality in the upper reaches of the Klein Berg River is high, while the lower reaches are of a low quality (River Health Programme, 2004). The low water quality in the lower reaches is due to poor quality effluent from Tulbagh, winery effluent discharged in the river, and pollution from informal settlements (DWAF, 2004).

3.8 Description of the study reach

The aim of the project is to determine the historical change of the Klein Berg River in a selected area of the channel. Due to the easy access and the availability of aerial photographs the area demarcated in Figure 3.1 was chosen. The aerial photograph of 1997 has been included to present the reader with the overall topography of the area (Figure 3.4).

To determine the channel changes over a short-time scale, cross-profiles were used. The reach under investigation can be found in the Nuwekloof pass, approximately 5 km to the south-west of Tulbagh. The river reach is confined between the Obiekwa mountains in the north and the Voëlvlei mountains in the south. The reach is approximately 100 m upstream from the weir (G1h008). The reach has a length of approximately 250m, and is fairly straight with the occurrence of pools and riffles. The reach has a low gradient of 0.0036 (Figure 3.2), calculated from the vertical height difference (10m) divided by the channel reach length (2.75km). The width of the river within the reach varies from very wide near the weir because of the damming impact, to a narrower reach further upstream. The Klein Berg River is an alluvial channel, consisting of sand, gravel, cobbles and boulders. The reach is invaded with alien trees that form a dense canopy in the area. Four cross-profiles were re-surveyed, the position of which can be seen on Figure 3.4

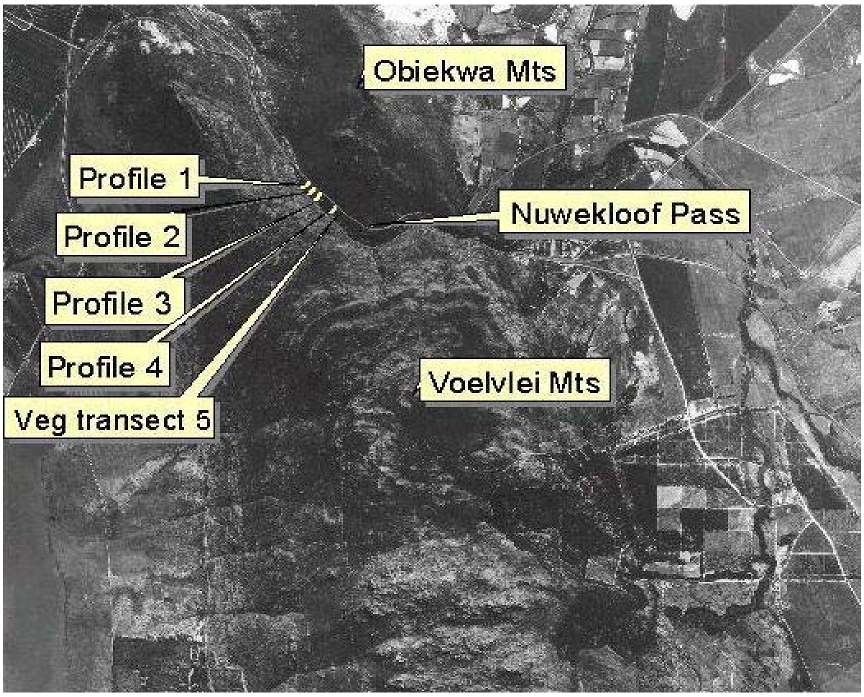

Figure 3.4 Location of cross-profiles

4. METHODS

This chapter describes the methods used to determine channel stability over both the long and short time periods; describes the procedures and methods of sampling vegetation data; and the statistical techniques used to analyse rainfall and discharge data. Within the research area the following variables were measured or determined:

- cross profile
- particle size of the banks
- particle size of the channel bed
- vegetation type
- vegetation density
- vegetation height, diameter, age and health

Selection of cross-profiles

Four cross-profiles were identified along the reach. The selection of the sites was done on a random basis. The sites were chosen by first making a visual assessment of the channel. Sites such as bends, riffles, pools, debris dams, sites where banks were colonised by alien vegetation and additional locations where bank erosion is active, were chosen.

4.1 Bank (and Bed) Parameters

4.1.1 Methods of assessing bank stability

4.1.1.1 Particle size analysis

Bank

The characteristics of the bank material are an important control on the stability of the bank. An important indicator of bank stability is the degree of cohesiveness, i.e, the percentage of silt-clay present in the bank material (Knighton, 1984). Particle size analyses of the bank material were done for each transect along the channel. This will give an indication of the cohesiveness of the soil in the reach, which is an important indicator of fluvial erosivity.

Sampling Procedure

Soil samples from the banks were collected 1m upstream and 1 m downstream of each cross- profile. The soil samples were collected with a hand-held auger. The samples were taken at a depth of 10 cm and placed in a plastic bag for further analysis in the laboratory.

Analysis in the lab:

Samples were dried in the oven for 24 hours at a temperature of 105°C. The samples mainly consisted of sand particles as aggregates were not common. Where aggregates were present in the sample they were pre-treated with hydrogen peroxide and hydrochloric acid to remove organic material, before drying. A 100 - 200 gram sample was taken and placed in the coarsest sieve (at the top of a stack of 8 sieves), on the sieve shaker. The twelve different sieve sizes used are in Appendix 1. The finest grain size was less than 0.063mm, which represents silt and clay. After 15 minutes of sieving the mass of the material held within each sieve was determined and recorded. To determine the degree of error, the material within each particle size category was added and compared to the mass of the original sample.

Bed

Bed material was measured directly in the field by the grid sample method. A quadrant of $1m^2$ was first identified on the streambed. All particles greater than coarse gravel (approximately 25mm) were measured within this quadrant. Particles were measured with both a caliper and tape measure. Measurements were taken along three axes: the A-axis, B-axis and the C-axis of each pebble.

4.1.2 Methods of measuring change

Measuring bank retreat can be achieved over different time scales by several methods.

1. Field measurement using erosion pins is appropriate over a short time scale of 1 - 10 years (Richards, 1982) and illustrates the final product of erosion and bank retreat. Steel erosion pins are usually inserted horizontally into the bank to record erosion. Markers, 1cm apart, on the pin indicate the initial position of the vertical orientated bank. As erosion progresses, more and more markers are exposed giving an indication of the amount of bank retreat. In the study site, 10 pins, 1m in length and 1.5 cm in diameter were inserted at site 4 and site 5 respectively, where bank erosion was likely to occur. The sites, which are indicated in figure 3.4, included a bank devoid of vegetation (transect 5) and sites between and beneath the roots of a black wattle tree (left bank at site 4).
2. On a short time scale, bank erosion can also be determined with the use of repeated survey profiles, which was accomplished with the use of a level and measuring stick. These cross profiles indicate the hydraulic geometry at local sites along the river. Repeated profiles show how the channel dimensions change with time. The cross profile indicates whether material has been eroded or deposited at the site. In order to gain an overall view of bank erosion of the entire channel, predefined transects need to be identified.

The above-mentioned methods have been used simultaneously to gain an understanding of the approximate volume of soil eroded, as well as an account for such changes in bank erosion. Examples where above-mentioned methods were employed in assessing bank stability can be found in Hughes (1977), Murgatroyd and Ternan (1983).

3. Comparison of variously dated maps and aerial photographs of appropriate scale is suitable for time scales of 10 - 200 years (Richards, 1982). This method indicates how the planform of a channel changes with time. According to Neill and Yaremko (1989:104), the comparison of air photographs may show a "systematic pattern of channel shift that can be extrapolated into the future." Aerial photography has wide applications in distinguishing temporal changes in fluvial landforms and controlling processes (Gilvear and Bryant, 2003).
4. Sedimentological and palaeobotanical evidence on the other hand form a suitable approach over longer periods of hundreds to thousands of years (Richards, 1982).

4.1.2.1 Erosion pins

Erosion pins were also used in conjunction with cross-profiles to assess the volume of sediment being eroded. The erosion pins consisted of thin steel rods with a diameter of 1cm and a length of 60 cm. They were also placed in locations where there were no cross sections but where visible bank erosion was occurring and were inserted into the bank to a point where only a small portion of the pins was visible. However, several erosion pins were lost (due to high streamflow events and/or vandalism). Erosion pins were placed in the study area on 7 April 1998 and retrieved in March 1999. This allowed measurement after one winter season.

4.1.2.2 Cross-profiles

The measurement of bank erosion and deposition of material in the channel was accomplished by repeating profile surveys on four pre-defined transects along the study area. This was accomplished with the use of leveling equipment, namely a dumpy level, staff and taut tape. Permanent markers were placed on either side of the bank for each cross-profile. The taut tape was then placed across the cross-section as a guide. The location of the dumpy level was also marked to ensure the readings were taken from the same location. Readings from the dumpy level were taken at a starting point (indicated with a permanent marker) from one side of the bank, through the channel to the opposite bank. An interval of 15 cm and 30 cm was used in determining the cross-profile, although in areas that were inaccessible a larger interval was used. Red paint was used as markers along the cross-profile. This was essential as the cross-profile needs to be surveyed along the same transect. Data was stored and analysed using EXCEL, a spreadsheet package. This allows graphic presentation, especially in displaying changing bank and bed properties.

4.1.2.3 Aerial photographs

A study of four sequential aerial photographs was conducted to assess channel, land use and vegetation change along the (selected) study reach of the Klein Berg River. The four panchromatic aerial photographs were dated 1942, 1967, 1987 and 1997. The scale of each of the aerial photographs were 1: 10 000. Since the photographs were not available in digital form, each of the aerial photographs were scanned and geo-referenced.

“Spatial information that pertain to a location on the earth’s surface are often termed georeferenced data” (Aronoff, 1989: 39). The location can be expressed in Cartesian coordinates or in latitude and longitude (Bernhardsen, 1992). Tatuk GIS was the package used for georeferencing in latitude and longitude. The methodology used to georeference aerial photographs is included in Appendix 2. Geo-referencing of the photographs leads to geocoding which allows for the correct orientation and thus comparison of each of the photographs becomes easier. Once the images were geocoded correctly, the georeferenced images were imported into ArcView GIS 3.3, where features such rivers, bars, landuse and riparian invasive alien vegetation were digitized using on screen digitization techniques.

4.2 Vegetation Characteristics

The impact of woody vegetation on bank stability depends on physical characteristics of the channel (bed and bank sediments, flow regime, channel slope and initial morphology), characteristics of the invasive vegetation (species, life form, age, stand density), the part of the channel which is subject to colonization, and its position in the stream network. The relationship between these variables is complex and knowledge of them inadequate (Rowntree, 1991).

Five vegetation or transect belts, with a width of 10 m and perpendicular to the channel, were used to sample the characteristics of the vegetation within the study reach. The first four vegetation belts correspond to the position of the profiles, while vegetation transect 5 corresponds with site 5 where the erosion pins were placed. The vegetation belts extended from the banks in the opposite directions to the maximum distance which could be sampled. Facing downstream, the maximum distance of the right side of the vegetation belt extended to the main road (R46), while the maximum distance on the left side was a private road.

Within each vegetation belt, zones with a length of 5m were then demarcated from the bank. Thus vegetation characteristics were determined within quadrants of $50m^2$, eventually covering the total area within each 10m wide transect belt. Vegetation sampling from the banks to the valley slopes would indicate how/if vegetation varies with distance from the bank. Nine vegetation parameters (Table 4.1) served as a guideline in sampling the vegetation.

Table 4.1 Framework for the assessment of vegetation on bank erosion and stability (Thorne, 1990)

VEGETATION PARAMETERS

Type Grasses Shrubs Trees	***Density*** Sparse Open Dense	***Position*** Bank toe Mid-bank Top bank
Diversity Mono-stand Mixed Climax-vegetation	**Age** Immature Mature Old	***Spacing*** Continuous Close Wide
Health Healthy Fair Poor	***Height*** Short Medium Tall	***Extent*** Wide Medium Narrow

All vegetation found within the belts was recorded. Samples of leaves were taken from species that could not be identified in the field. The height of species less than 4m was measured by means of a tape measure. If the species height was greater than 4m the height was estimated. The diameter of each species was measured by means of a tape measure 10 cm from the ground. The relative age of the species was identified as mature or immature species, although there were cases where categorization could only be done after the identification of the species. The health was determined by means of a visual assessment. A summary of the data collected from each transect can be found in Appendix 3.

4.3 Rainfall and discharge characteristics

Rainfall

The South African Weather Service provided data for two rainfall gauges within the Klein Berg River catchment, details of which are given in Table 4.2. Both rain gauges have 50-year records, dating from 1954 to 2003. Data was analysed using EXCEL.

Table 4.2 Details of rainfall stations

	Latitude (South)	Longitude (East)	Height above sea level (m)
Tulbagh Police station	33.283	19.13	155
Remhoogte	33.1830	19.1670	370

Discharge

The Department of Water Affairs and Forestry made available daily and monthly discharge data for the weir located on the Klein Berg River (G1h008). The weir is situated between the Obiekwa Mountains in the north and the Voëlvlei Mountains in the south (Figure 3.1). Daily and monthly streamflow data were made available from 1954 to 2002. Data was analysed using EXCEL. Data that was incomplete or not recorded was not included in the analyses.

Key questions to be answered:

- Are there significant changes in annual discharge?
- Are there significant changes in winter and summer precipitation?
- Is it possible to determine the range of flows which are geomorphologically significant?
- Are there any significant changes in the discharge within the periods corresponding to the aerial photographs (i.e 1942 – 1967; 1968 – 1987 and 1988 – 1997)?

- If any changes have occurred, can one relate it to landuse change within the catchment?

In order to answer the above-mentioned questions for rainfall and streamflow, the subsequent graphs and statistical values were calculated within Microsoft Excel:

- A **hydrograph** illustrates variability in streamflow. Hydrographs were constructed from daily streamflow data for the periods corresponding to the aerial photographs. The y-scale for these hydrographs was kept similar to make comparison easier.
- **Statistical values** such as the mean, minimum, maximum and median were calculated for the discharge data. Graphs indicating mean discharges for the winter and summer months were also constructed.
- The **moving average** is helpful in determining trends within the data set. The 5-year moving averages for the rainfall data were calculated.
- Monthly rainfall graphs were constructed to determine a linear trend. This function is available in Excel (Appendix 4).

5. RESULTS

Chapter 4 described the methods used to determine, measure and analyse the channel stability; vegetation, discharge and rainfall characteristics. This chapter will report on the results of the analyses of the above-mentioned parameters.

5.1 Measuring change to assess channel stability

5.1.1 Erosion pins

Erosion pins were used to determine the rate of bank erosion over a short period of time at two sites along the Klein Berg River. 10 erosion pins were used. The pins were inserted in the bank between and beneath the roots of a black wattle tree at site 4. There was a high loss of erosion pins, possibly due to vandalism, and only 2 of the 10 pins were recovered. The readings taken from the pins indicated a loss of sediment of 35mm and 26mm over a period of 11 months. Although the results were measured from 2 pins only - it is representative of the area beneath the tree - according to observation a site of local bank undercutting. The flow of water is diverted towards the right bank, and with the roots of the trees, eddies are produced which produce local scour.

5.1.2 Cross profiles

"Cross-sectional form adjusts to accommodate the discharge and sediment load supplied from the drainage basin…channel dimensions are not arbitrary but are adjusted, through the processes of erosion and deposition…" (Knighton, 1984:99). The following four cross-profiles show adjustment of channel dimensions over a period of twenty months. Fig 3.4 shows the position of the selected sites.

Figure 5.1 illustrates the discharge for the Klein Berg River from January 1998 to

February 2000, which thus reflects two winter seasons. The months when the river was surveyed is indicated on the figure. What is interesting to note is that the winter runoff for 1998 starts off with a peak discharge and gradually decreases, while the discharge for winter 1999 increases to the peak discharge.

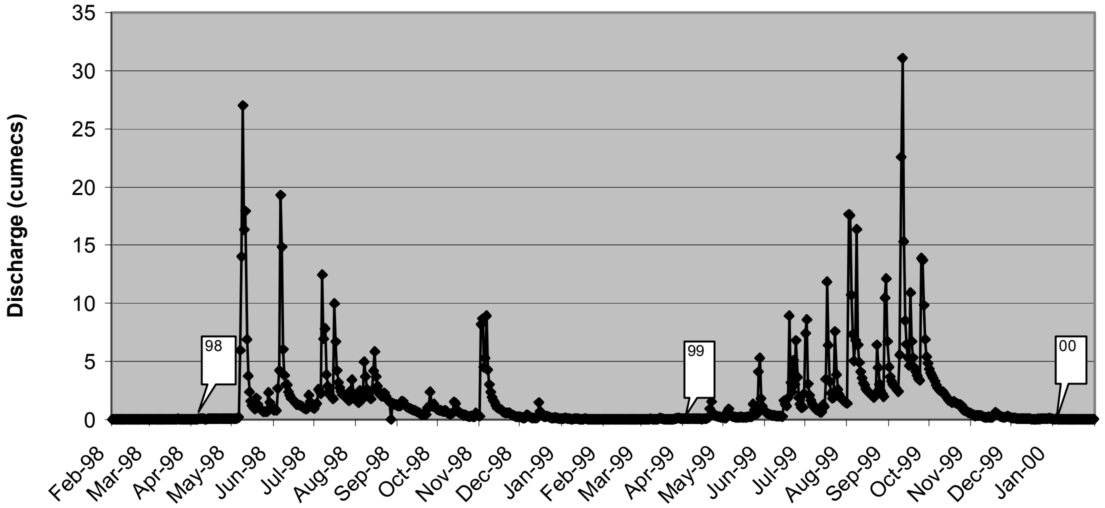

Figure 5.1 Discharge values (m^3/s) from 1 February 1998 to 31 January 2000

(Source: Department of Water Affairs and Forestry (DWAF))

Cross profile 1:

Description: Cross profile 1 (Figure 5.2) is a pool, located 50 metres upstream of the weir. Due to the proximity of the weir, the area experiences the damming effect. The river width is the highest in the reach. The vegetation transect for this cross profile is dominated with invasive vegetation, namely black wattle and blue gum. The invasive trees do not allow the development of undergrowth and thus a sparse ground layer is present. As a result the bare soil is susceptible to soil erosion especially during times of rainfall events and high flow. The bank material composition is illustrated in table 5.1, and indicates a silt and clay composition ranging from 5.5% in the left bank to a low 1.5% in the right bank.

The medium and fine sand are the dominant grain size for both banks, comprising 75% of the right bank and 58% of the left bank.

Bank erosion over the two-year period is evident on both sides of the channel. The erosion on the left bank (looking upstream) may be due to flow being diverted towards the bank around the boulder (shown as **B** on figure 5.2). As the bank is devoid of vegetation, the sandy soil is especially susceptible to erosion during high flows. Erosion of the banks is especially prominent between April 1998 and April 1999. At a depth of 2.25m, channel widening of approximately 1m occurred due to erosion (Fig 5.2). Basal scour is also prominent along the left bank (looking upstream), where approximately 0.5m^3 was eroded from 1998 to 1999. From 1999 to 2000, erosion is prominent along the right bank.

Due to the depth of this site no particle size analysis of the channel bed was done. The cross profile (Figure 5.2) shows change within the channel bed - evidence of bedload movement. Observation along the survey of the profile revealed sand to be the dominant grain size.

Table 5.1 Grain size distribution of bank material (%) for cross profile 1

	Left Bank (%)	**Right Bank (%)**
Very coarse sand	0.8	10.1
Coarse sand	15.5	15.3
Medium sand	52.6	30.9
Fine sand	22.4	27.5
Very fine sand	7.2	10.8
Silt and Clay	1.5	5.5

Plate 5.1 Left bank (profile1) Plate 5.2 Right bank (profile 1)

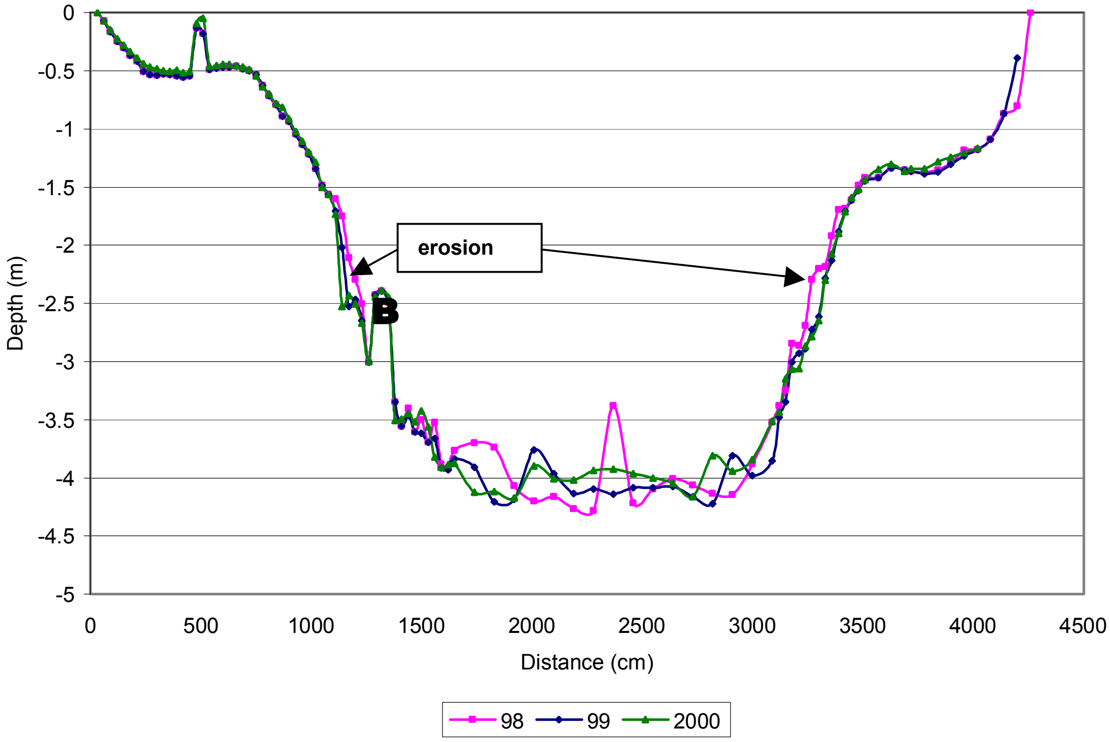

Figure 5.2 Cross Profile 1 (looking upstream)

Cross profile 2

Description: Cross profile 2 (Figure 5.3) is located across a pool. Vegetation transects show both banks to be infested with black wattle, blue gum and port jacksons. Sparse ground cover is found beneath the invasive trees. The bank material composition is illustrated in Table 5.2, and shows a higher percentage of silt and clay (4.8%) for the right bank than the left bank (3.2%). The dominant particle size for both banks is medium and fine sand. The consistent erosion along the left bank (looking upstream) from April 1998 to January 2000 is evident from Figure 5.3. Erosion from the top of the left bank (looking upstream) to the base of the slope accounts for approximately 3.5m^3 of soil. This may be attributed to the sparse ground vegetation along the banks as well as a lack of cohesion of bank material. Accretion is found on the right bank (looking upstream).

Table 5.2 Grain size distribution of bank material (%) for cross profile 2

	Left Bank (%)	**Right Bank (%)**
Very coarse sand	5.5	2.4
Coarse sand	9.3	10.0
Medium sand	48.6	35.0
Fine sand	25.9	34.1
Very fine sand	7.4	13.6
Silt and Clay	3.2	4.8

Plate 5.3 Left bank (profile 2)

Plate 5.4 Right bank (profile 2)

Accretion is evident within the channel bed, which illustrates active bedload movement. Due to the depth of this site, no particle size analysis was done. However, along the survey of the profile, sand was observed to be the dominant grain size.

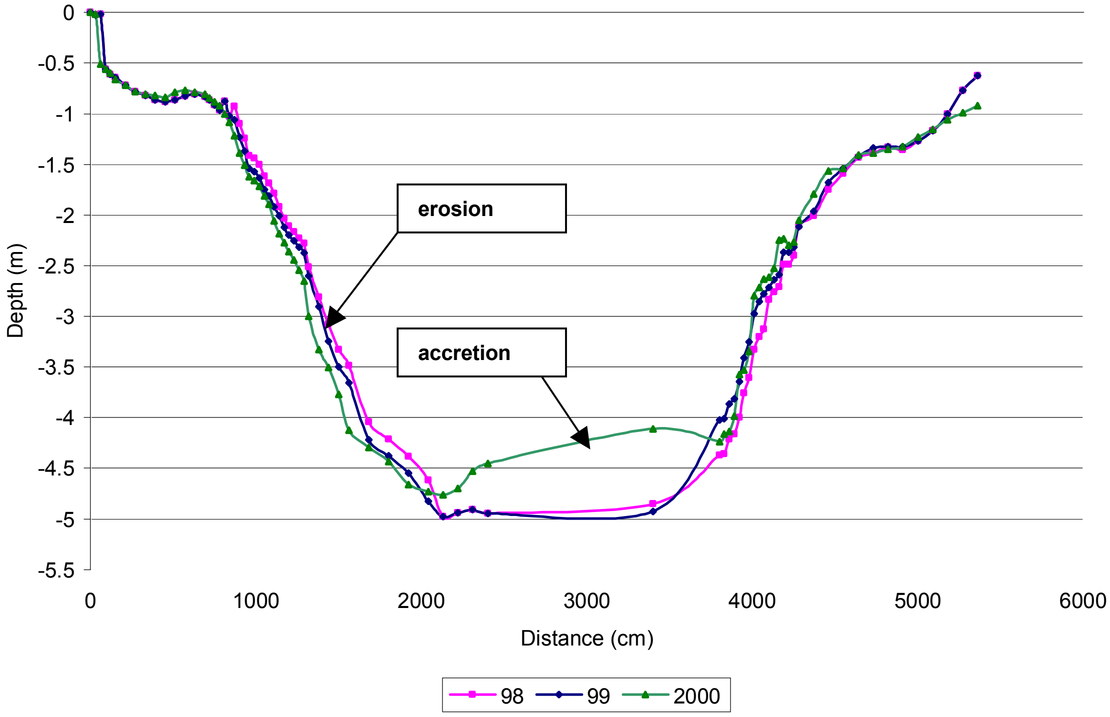

Figure 5.3 Cross-profile 2 (looking upstream)

Cross profile 3

Description: Cross profile 3 (Figure 5.4) is located across a riffle, which is dominated by black wattle and blue gum. Compared to cross profiles 1 and 2, the active channel of cross profile 3 is very narrow, with a width of 1.2m. The soil characteristics of the bank are illustrated in Table 5.3. A higher percentage of silt and clay was found for the right bank (4.5%) as compared to 0.1% for the left bank. The grain size distribution of the left bank is dominated by coarse and very coarse sand (85%), while medium and fine sand comprises 61% of the right bank. Erosion at the base of the left bank is clearly illustrated from 1998 to 1999.

A particle size count of the bed reveal a bed dominated by gravels (70%) and cobbles (30%). Bedload movement was evident as the survey indicates change along the channel bed from 1998 to 2000.

Table 5.3 Grain size distribution of bank material (%) for cross profile 3

	Left Bank (%)	**Right Bank (%)**
Very coarse sand	44.0	11.1
Coarse sand	40.5	16.2
Medium sand	13.1	40.7
Fine sand	1.9	20.6
Very fine sand	0.4	6.8
Silt and Clay	0.1	4.5

Plate 5.5 Profile 3

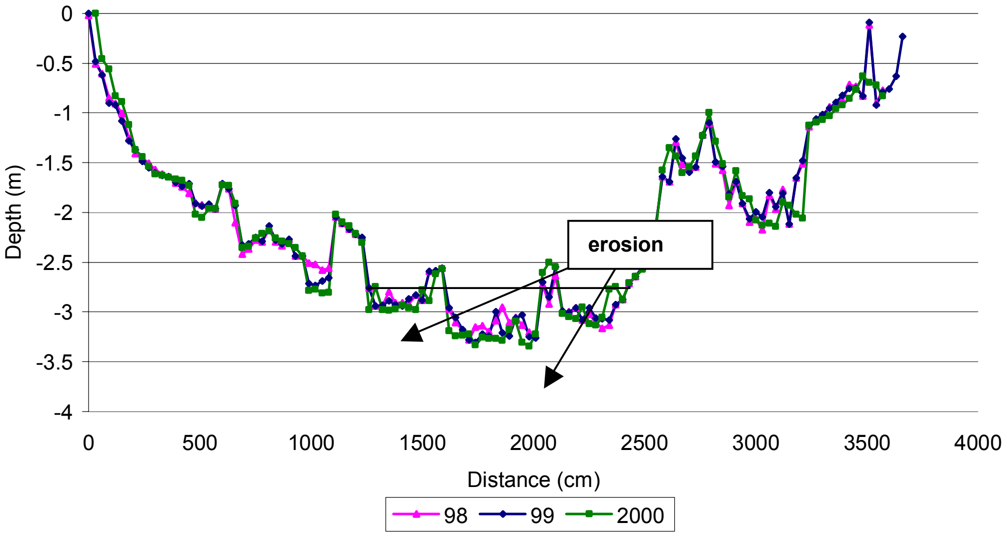

Figure 5.4 Cross-profile 3 (looking upstream)

Cross profile 4

Description: Cross profile 4 (Figure 5.5) is located along a riffle, where black wattle trees dominate the banks. The complexity of the rooting systems (Plate 5.7) has an impact on bank stability, as indicated with the use of the erosion pins (5.1.1). Soil erosion from the left bank (looking upstream) was prominent and consistent from 1998 to 2000. However, the occurrence of deposition at the base of the left bank is evident in 1999, with no change for 2000.

The composition of the right bank material shows a 5.9 percent of silt and clay content, and a 52% of medium and fine sand. The left bank shows a high percentage of medium and coarse sand (90.2% collectively), while the silt and clay comprises 0.6%. As mentioned previously, silt and clay provide cohesion to the soil, and thus impacts on bank stability.

The resurvey of the channel bed indicates bedload movement. A particle size count of bed material reveals a bed dominated by gravels (39%) and cobbles (61%). The huge boulders in the riffle remained stationary during the study period, as they need very high discharge values to initiate movement.

Table 5.4 Grain size distribution of bank material (%) for cross profile 4

	Left Bank (%)	**Right Bank (%)**
Very coarse sand	2.4	26.0
Coarse sand	43.2	7.6
Medium sand	47.0	27.6
Fine sand	5.2	24.3
Very fine sand	1.6	8.7
Silt and Clay	0.6	5.9

Plate 5.6 Left bank (profile 4)

Plate 5.7 Right bank (profile 4)

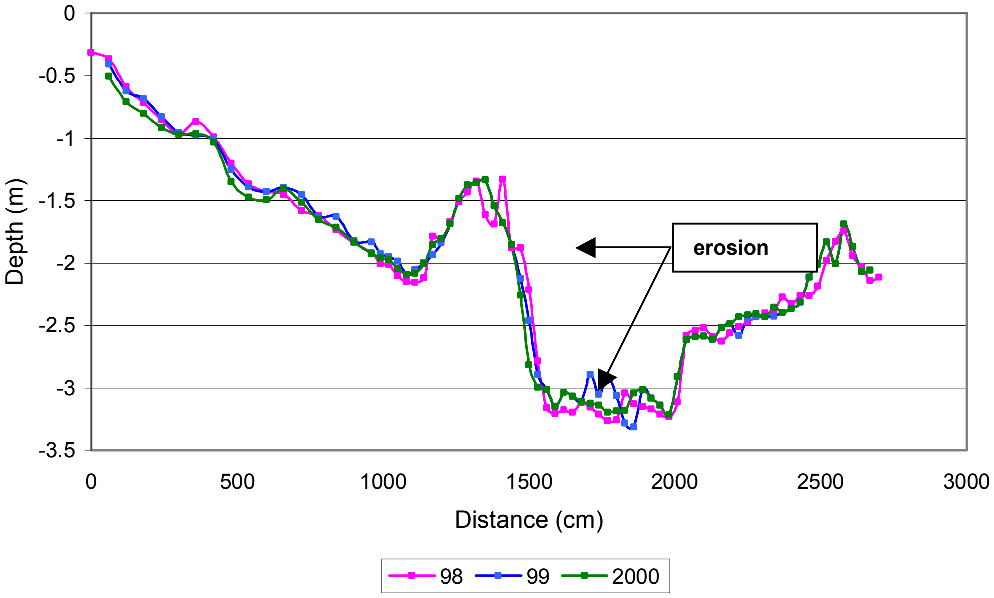

Figure 5.5 Cross-profile 4 (looking upstream)

5.1.3 Aerial Photographs

The results from the study of the aerial photographs are given in Figures 5.6 to 5.9. These illustrate the changes in riparian vegetation, channel form and landuse for the study area. As the flight line of the aerial photographs taken at different times were not exactly the same, the spatial area covered by each photograph is not identical. Due to the georeferencing package used, namely Tatuk, the final maps (Figures 5.6 – 5.9) display white stippled lines, which is a trademark of this specific package.

Figure 5.6 reveals a riparian zone dominated by indigenous vegetation with the occurrence of scattered alien vegetation along specific riparian areas along the river. The Klein Berg River displays a meandering channel pattern with associated lateral and point bars before being confined between the Obiekwa (north) and Voëlvlei Mountains (south) in the Nuwekloof Pass. A divided river channel is evident along the upper Klein Berg River

(Figure 5.6). The western part of the catchment area displayed by Figure 5.6 is dominated by indigenous shrubland, while the eastern section has clearly been developed.

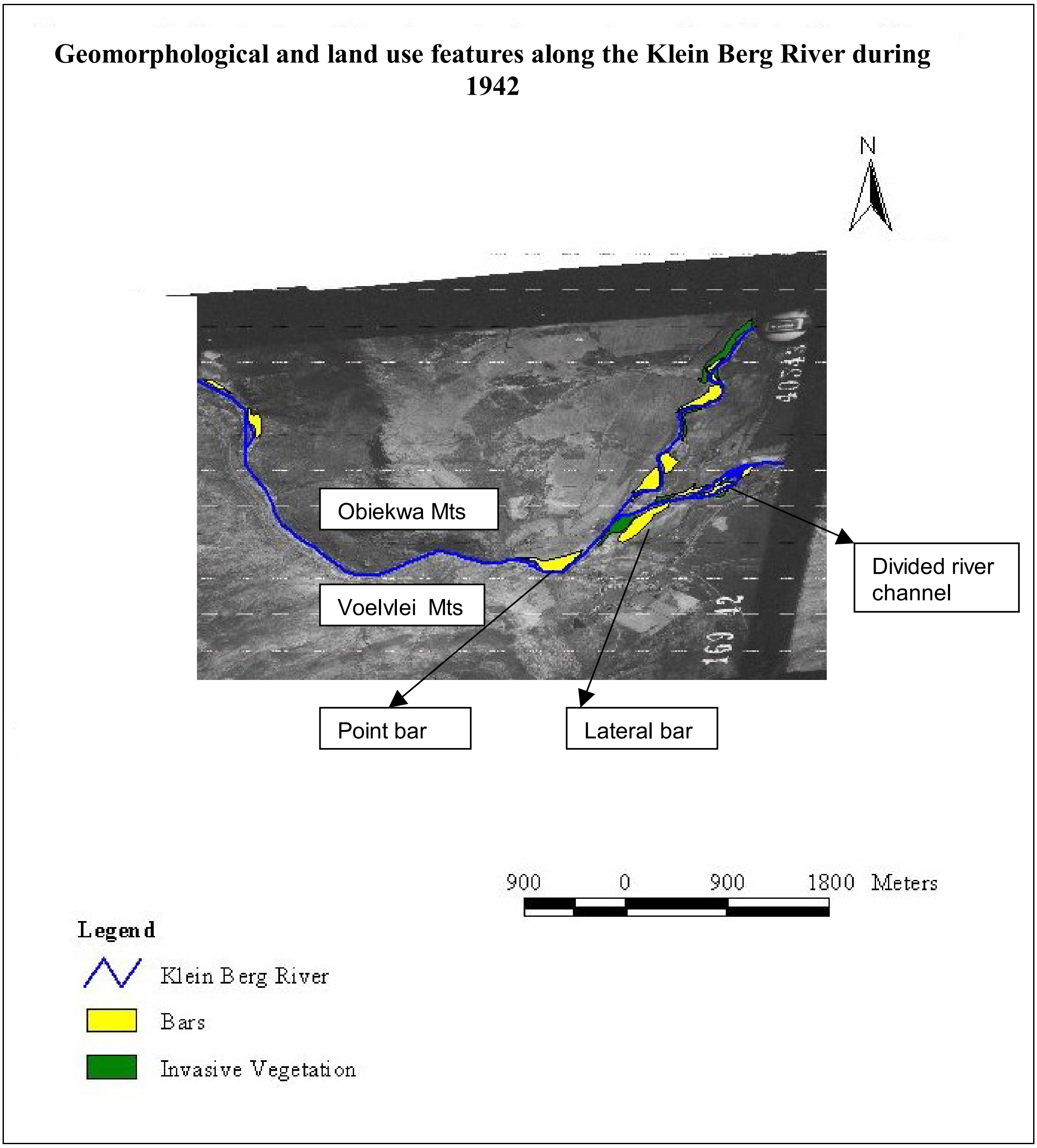

Figure 5.6 Geomorphological features captured from the aerial photograph of 1942

Figure 5.7, the map of 1967, covers a bigger area than the map of 1942. The map of 1967 shows an increase in scattered invasive alien vegetation along the riparian zone, as alien vegetation have now replaced shrubland along the banks and floodplains of the river.

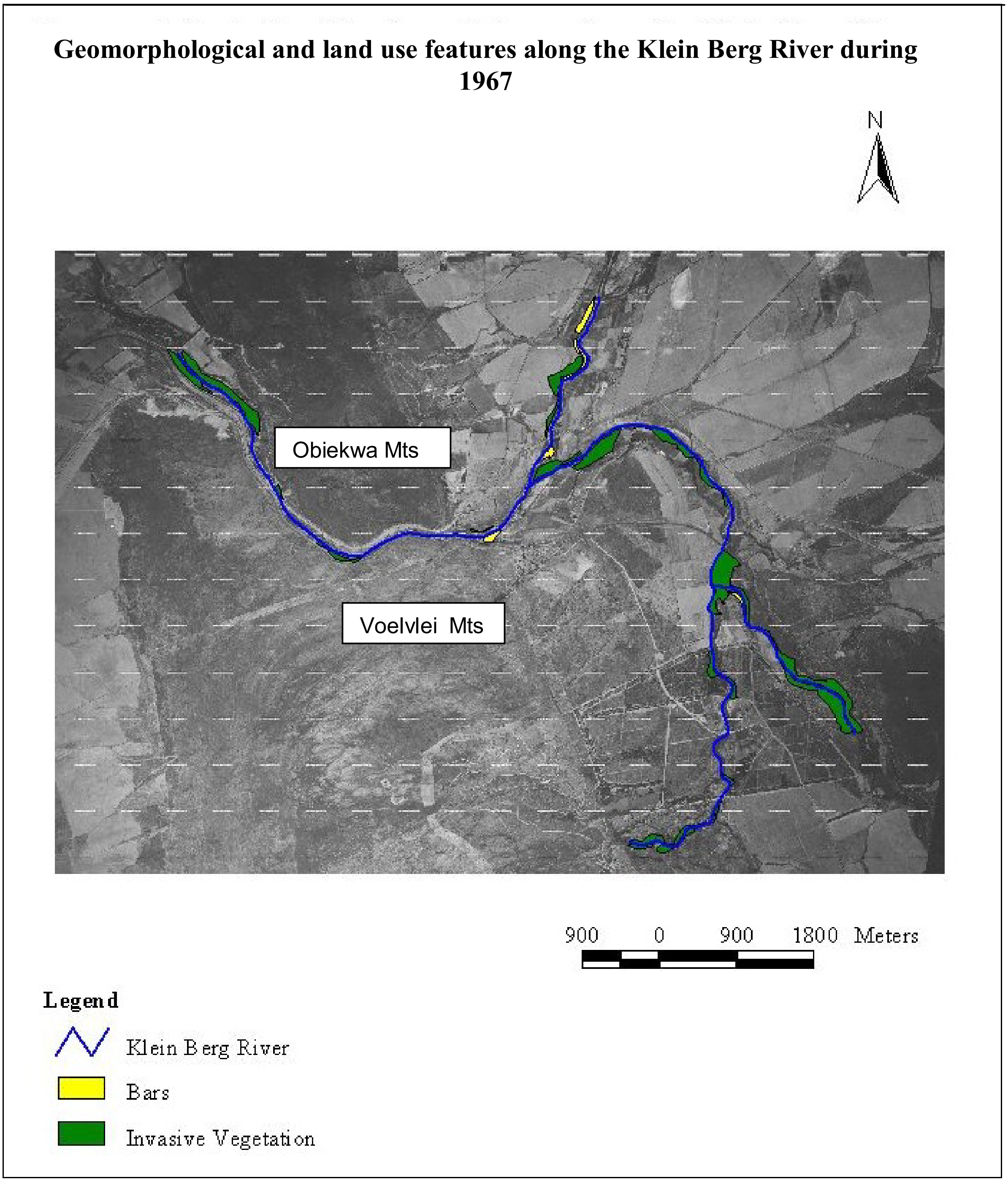

Figure 5.7 Geomorphological features captured from the aerial photograph of 1967

Although not clearly displayed on the map, an external disturbance in the form of road construction, approximately 20m north of the river, was observed from the aerial photograph. The construction of the road, completed in 1968 (Ross, 2002), has clearly resulted in the movement of materials from the steep valley slopes along the road to the river channel. Channel narrowing was also evident from the 1967 aerial photograph.

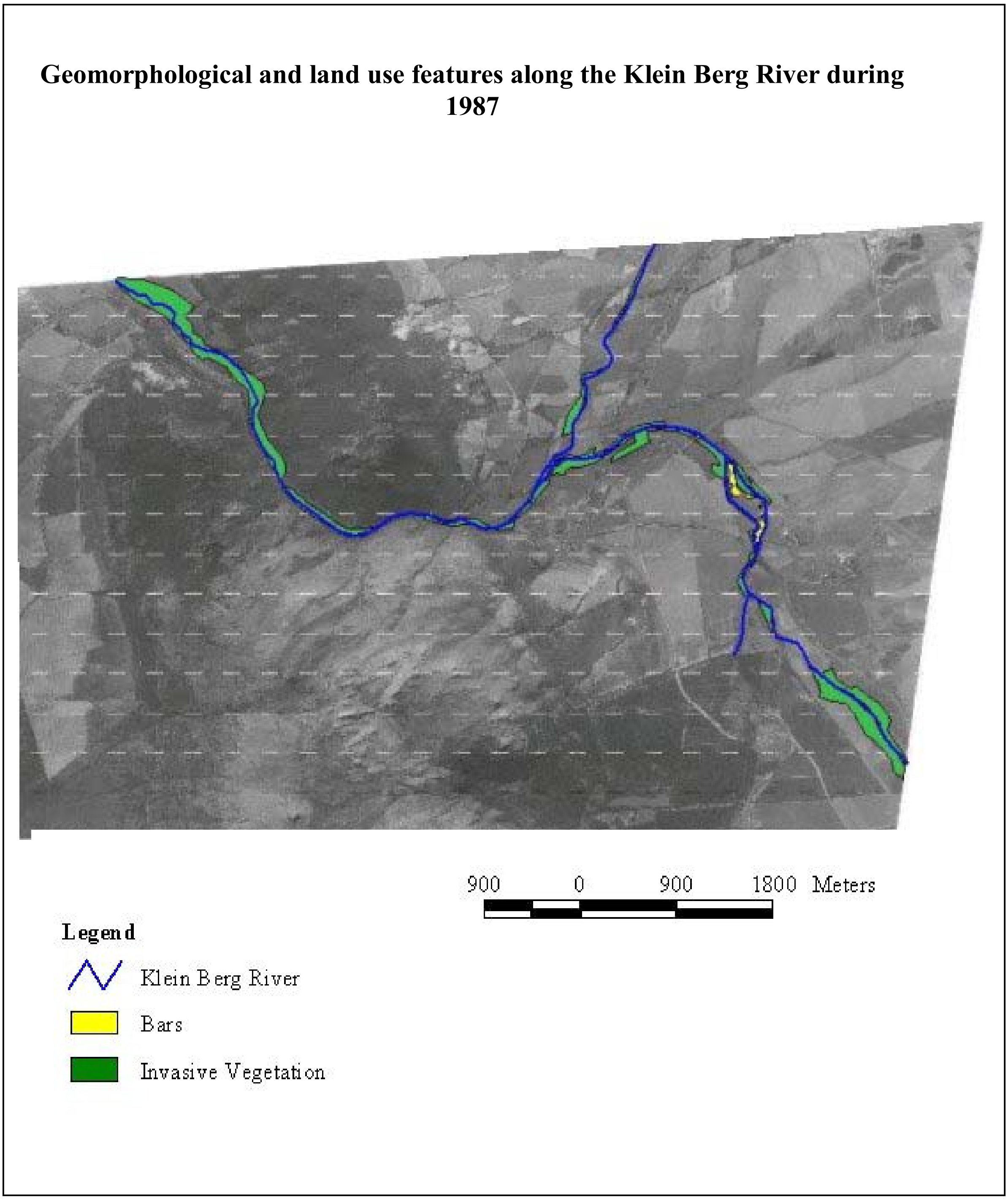

Figure 5.8 Geomorphological features captured from the aerial photograph of 1987

The map of 1987, Figure 5.8, displays the occurrence of scattered alien vegetation and dense alien infestation along the riparian zone; and in some instances the river channel is entirely obscured. The occurrence of open sandy areas disappears completely. The occurrence of agricultural land increases significantly during this period, and in many instances bars are replaced with agricultural land. This is clearly seen where the point bar in Figure 5.6 has now been replaced with agriculture. Increased agricultural development along the eastern Obiekwa Mountains is also prominent from the map. The pine plantations near the Waterval Mountains indicate mature stands of trees (as compared to scattered pine trees in 1967).

The map of 1997, Figure 5.9, shows the replacement of scattered alien vegetation with dense stands of alien vegetation. In many instances, agricultural activity extends right onto the river bank. The river channel that is so noticeable from the aerial photographs in 1942 is completely concealed by the dense stands of invasive vegetation in 1997.

From 1942 to 1997, cultivated landuse increased by approximately 10% within the study area. The substitution of shrubland with cultivated lands is a result of the fertile soils in the valley. River channel change from 1942 to 1997 displays a decrease in mobile fluvial deposits (bars). A change in the channel bar features indicates a change in the sediment and discharge dynamics within the reach and thus within the catchment. The extensiveness of the canopy cover does not allow accurate measurements of the channel width along certain locations.

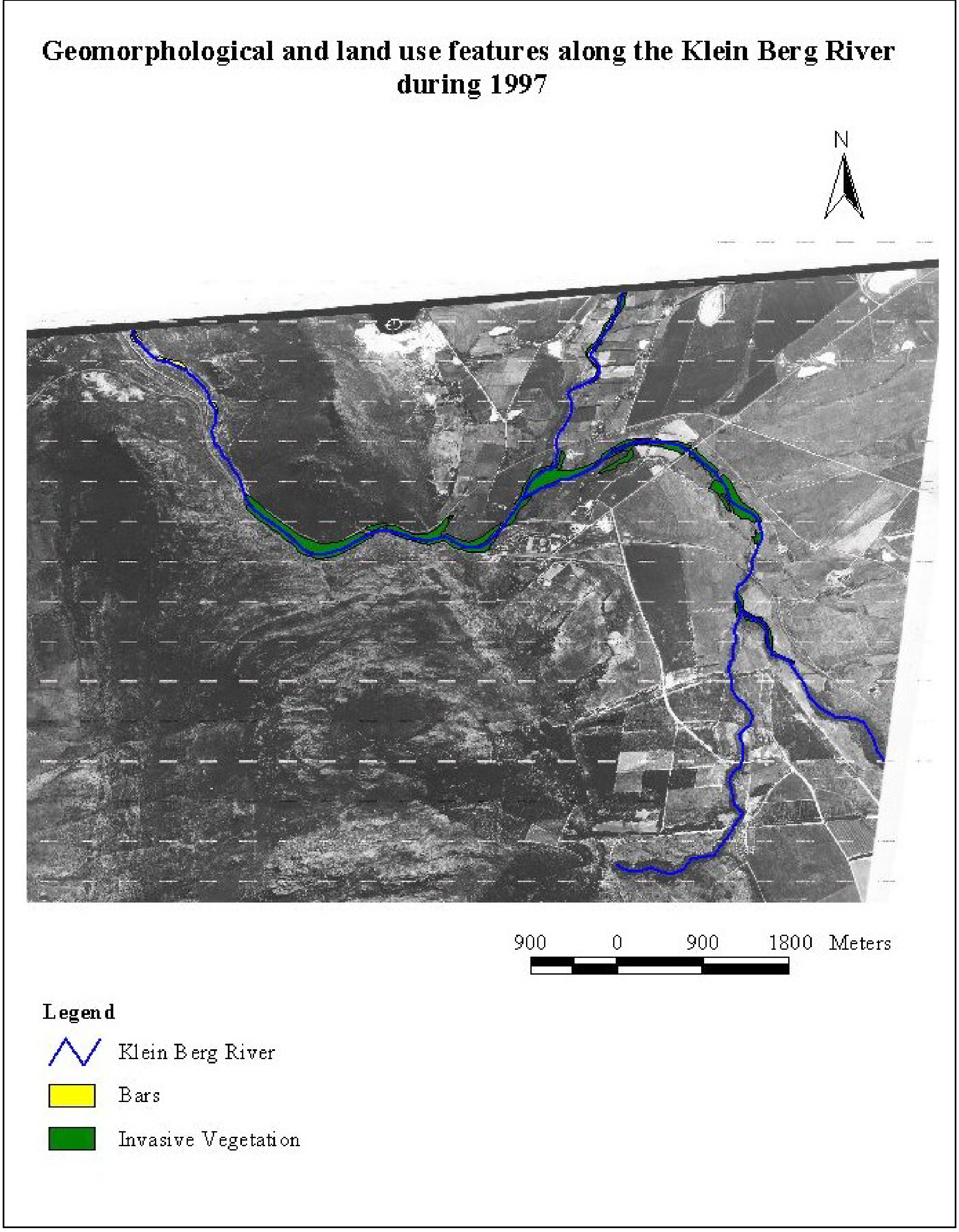

Figure 5.9 Geomorphological features captured from the aerial photograph of 1997

5.2 Vegetation

5.2.1 Introduction

The riparian vegetation in the Nuiwekloof Pass consists chiefly of trees and shrubs. The trees are primarily of alien species such as *Acacia* and *Eucalyptus*. This vegetation forms a narrow but dense, closed canopy along the watercourse (Plate 5.8).

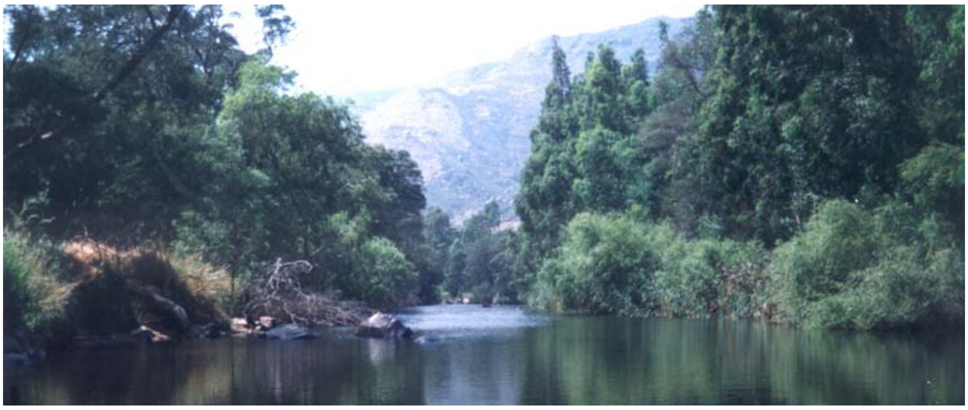

Plate 5.8 Riparian vegetation along the Klein Berg River (near Nuiwekloof Pass)

The trees extend from along the banks across the flood plains to the steep valley slopes. The invasive alien vegetation growth is only dominant from the river to the roads on either side. The trees along the banks reach impressive heights to as much as 30m and provide shade for the many organisms found in the river channel. Vegetation, such as trees and plants, was also found on bars within the river channel. The invasive woody vegetation tends to be concentrated along the banks and flood plains, and decreases in density as one moves away from the river up the valley slopes. The presence of indigenous trees and shrubs become more dense along the valley slopes. Vegetation along the mountain slopes, that is the area beyond the roads and railway line, is quite distinct from the riparian vegetation and mainly consists of Mountain fynbos (Plate 5.9). A common occurrence in rivers where the riparian zone is dominated by trees is the presence of large organic debris. Debris can be found in the river, on the banks and on the flood plain of the Klein

Berg River.

Plate 5.9 Indigenous vegetation along the mountain slopes of the Klein Berg River catchment

5.2.2 Vegetation type

Vegetation type consists of woody invasive alien vegetation, as well as the indigenous species. The invasive alien species found in the area include: *Acacia mearnsii* (black wattle), *Acacia saligna* (port jackson willow) and *Eucalyptus grandis* (saligna gum). Black wattle was found to be the dominant species within the riparian zone, especially within the first 10 m of the river channel. Figure 5.10 illustrates the frequency of all the species found within the 6 vegetation transects. No distinction was made of the different indigenous species, while the invasive alien species were divided into the three dominant invaders.

From figure 5.10 one can conclude that the presence of indigenous vegetation is extensive and thus quite relevant in the study area. However, Figure 5.10 is very misleading, because the size (height and diameter) of the species is not taken into account. A total of 136 indigenous plants were recorded. *Acacia mearnsii* is the most dominant alien invader in the area, with a total of 112 trees recorded. A total of 67 trees of the species *Saligna gum* was recorded while the Port Jackson (*Acacia saligna*) numbered 20. A list of all species found within the study area can be found in Appendix 3.

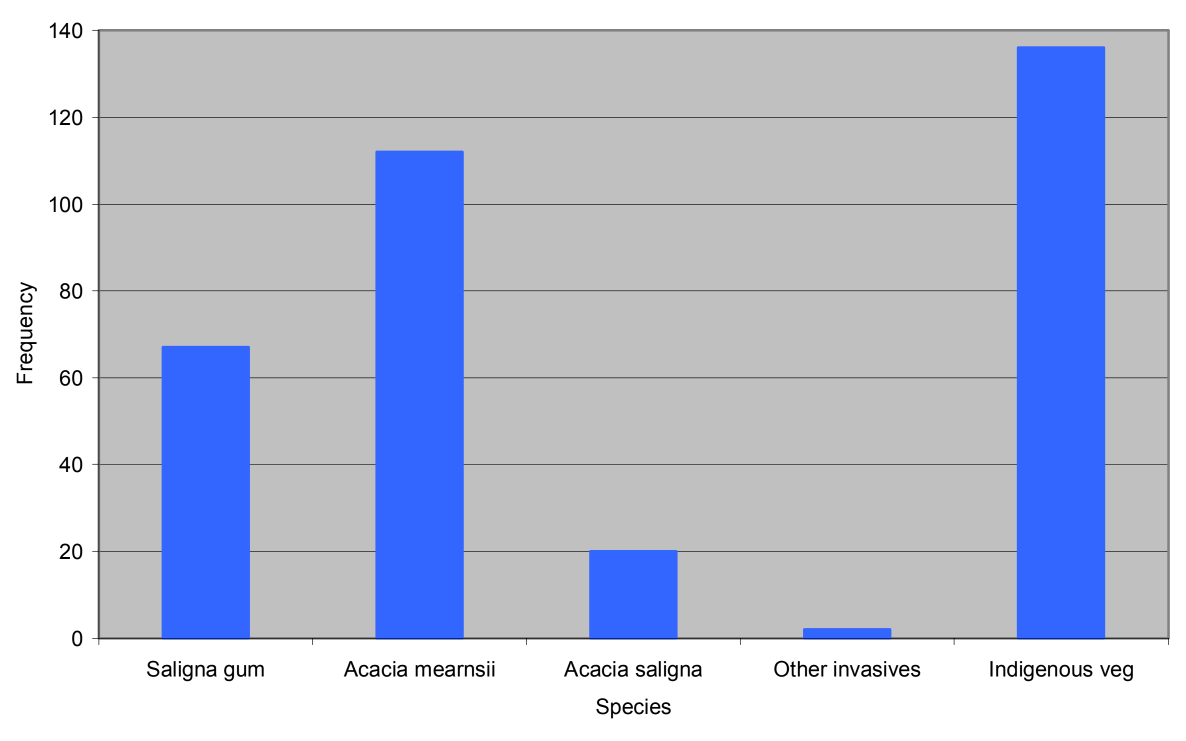

Figure 5.10 Frequency of vegetation species

5.2.3 Vegetation Density

Absolute or true density is the number of plants per unit area. Apparent density or canopy cover percentage is strongly influenced by the size of the plant and is calculated using the canopy gap width method. Observation from aerial photographs and from the field shows that the density of the vegetation is fairly similar along the river course and consists of dense stands of vegetation - the most conspicuous of which are invader species. It is apparent from field observation that the vegetation density decreases as one moves away from the riparian zones onto the steeper slopes.

The true density of the vegetation based on the frequency in figure 5.10 reveals that the invasive alien vegetation has a density of roughly 59%. The density of the vegetation as recorded from the aerial photograph of 1997 and observed in the field reveals a very dense alien vegetation. The true density is not reflective of conditions observed within the study area and thus a more realistic impression of the area will be achieved if the average height and diameter of the various species is considered.

5.2.4 Vegetation height, circumference, age and health

The measurements of height and circumference give an indication of the size of the vegetation. This data together with the frequency gives an understanding of the apparent density in the study area. Table 5.5 and Table 5.6 illustrate basic statistic values for the height and diameter variables recorded for the different species.

Table 5.5 Basic statistic values for the height (in meters) data

Species	**Mean (m)**	**Min (m)**	**Max (m)**	**Lower Quartile**	**Upper Quartile**
Black wattle	9.92	0.4	32.0	3.0	15.0
Gum	7.85	0.5	30.	3.0	10.0
Port Jackson	3.3	0.7	10.0	1.0	4.5
Indigenous	2.90	0.1	35.0	0.93	3.0

Table 5.6 Basic statistic values for the circumference (in centimeters) data

Species	**Mean**	**Min**	**Max**	**Lower Quartile**	**Upper Quartile**
Black wattle	64.97	1.0	380	16.0	85.0
Gum	47.97	2.0	280	11.0	50.0
Port Jackson	20.33	5.0	50	10.0	30.0
Indigenous	14.34	0.5	60	3.0	22.0

Tables 5.5 and 5.6 reveal that the invasive alien species as compared to the indigenous species are dominant with regards to size. The black wattle, which is the most dominant invader, is also the most mature of all the species recorded, as it dominates with regards to height and diameter recordings. 50% of all the black wattles have heights extending from 3 m to 15 m, and diameters extending from 16 cm to 85 cm. Second to the Black wattle, 50% of the gum trees reach heights of 3 m to 10 m, while the diameters extend from 11 cm to 50 cm. The Port Jacksons are much smaller in size as can be seen from Table 5.5 and Table 5.6. The indigenous vegetation consists of small shrubs and grasses as well as mature trees. Heights therefore range from 0.93 m to 3 m while the diameters are from 3 cm to 22 cm.

The maximum height recorded for the alien trees was 32m, while the maximum diameter recorded was 380 cm. According to the aerial photographs the infestation of the aliens in the study area began in the 1940's. The growth of the trees in the study area from 1940 thus testifies to the mature age of the trees.

The average health of the trees ranged from fair to healthy, with 32% of the trees being healthy and 41% fair, while 26% of the trees were classified as poor, and 2% were dead.

5.2.5 Change in vegetation distribution

A change in the distribution of species is observed as one moves away from the bank and floodplain towards the slopes of the valley. Figure 5.11 illustrates the frequency of each species within the different quadrants/intervals from the banks to the valley slopes. According to figure 5.11 the frequency of indigenous species within each quadrant is more than each of the individual alien species except in the 15 - 20 m quadrant. A comparison of indigenous and alien vegetation reveals that the first 20 m from the river channel is dominated by invasive alien species. All the species decrease in frequency as one moves from the banks to the valley slopes.

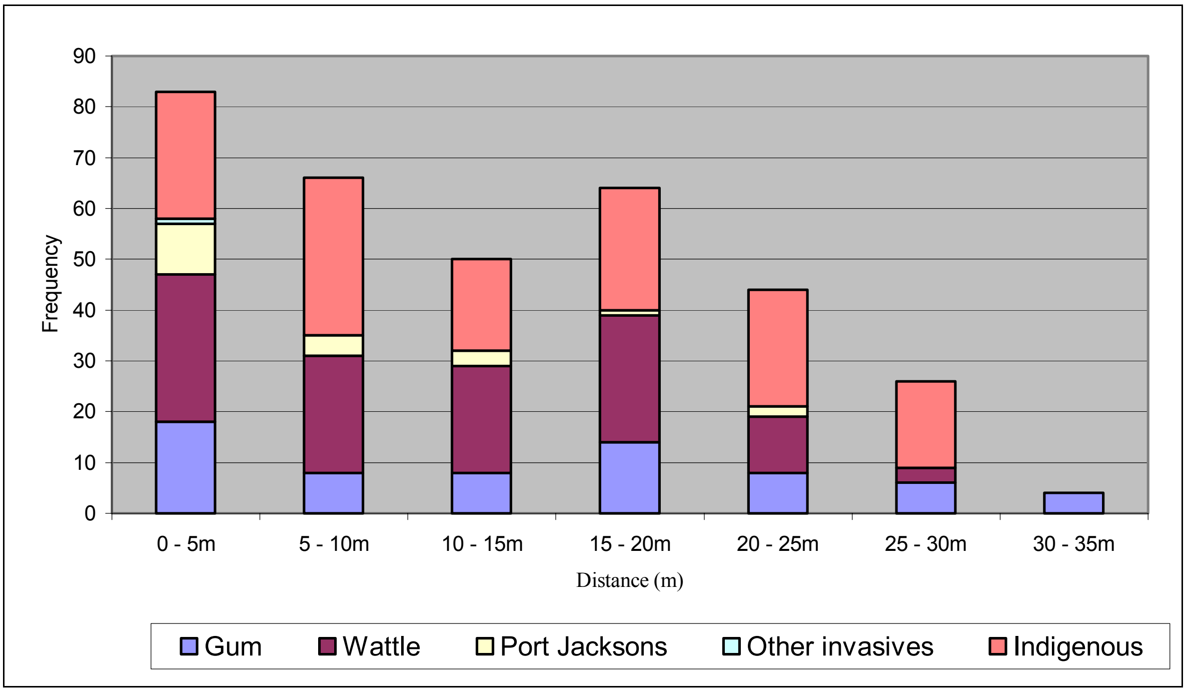

Figure 5.11 Change in vegetation distribution

5.3 Rainfall and discharge characteristics

5.3.1 Rainfall

The South African Weather Service provided data for two rainfall gauges that are located within the Klein Berg River catchment. Details of the stations are provided in Table 4.2. Both rain gauges have a 50-year record, dating from 1954 to 2003. The location within the catchments as well as an elevation difference has a marked influence on the values for the two rainfall gauges. Fig 5.12 is a bar graph showing mean rainfall from January to December for the two stations. Remhoogte, which is situated within the upper reaches of the Klein Berg River, and has a height of 370m above sea level, is close to the northern mountain range and shows a higher average rainfall than Tulbagh Police station. Tulbagh Police station is situated within the center of the catchment at a height of 155m above sea level. Despite the difference in rainfall values, figure 5.12 clearly shows a correlation between the rainfall values. A positive correlation of 0.8275 was determined for the two rainfall gauges.

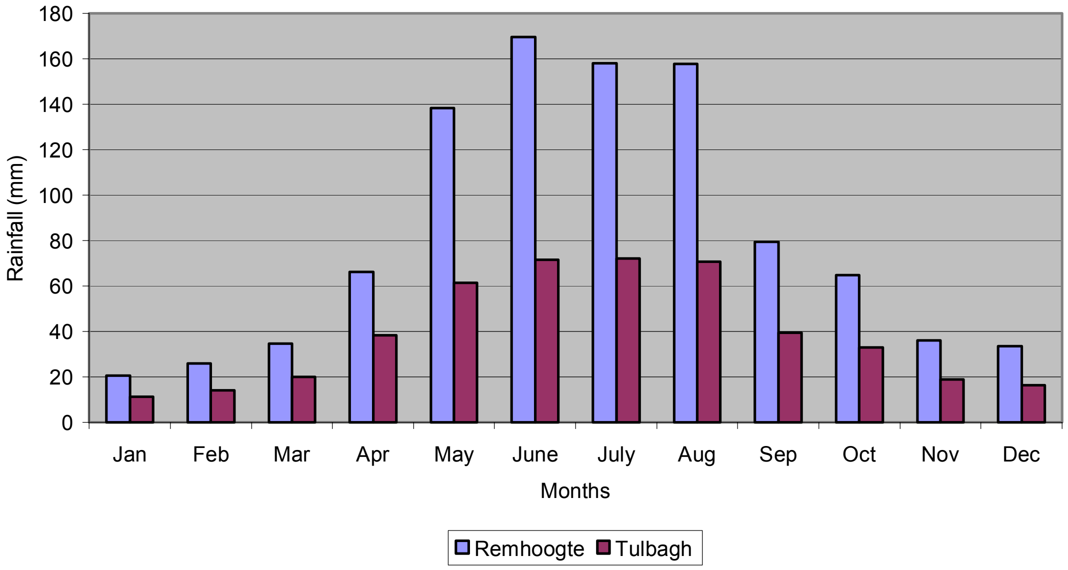

Figure 5.12 Mean monthly rainfall in mm for Tulbagh and Remhoogte (1954 – 2003). (Source: South Africa Weather Service)

Figure 5.13 illustrates the annual rainfall values for Tulbagh and Remhoogte from 1954 to

2003, as well as the 5-year moving average for both stations. Due to missing data, 1999 and 2000 were not included in figure 5.13. The 5-year moving average shows a smoother graph and depicts the varied nature of the rainfall in the area. Although no significant trends are recognized from the graph, the rainfall totals following 1976 show on average higher values for both stations. This increase is however clearly seen in the rainfall for Remhoogte and Tulbagh for the winter season (April to September) (Appendix 4).

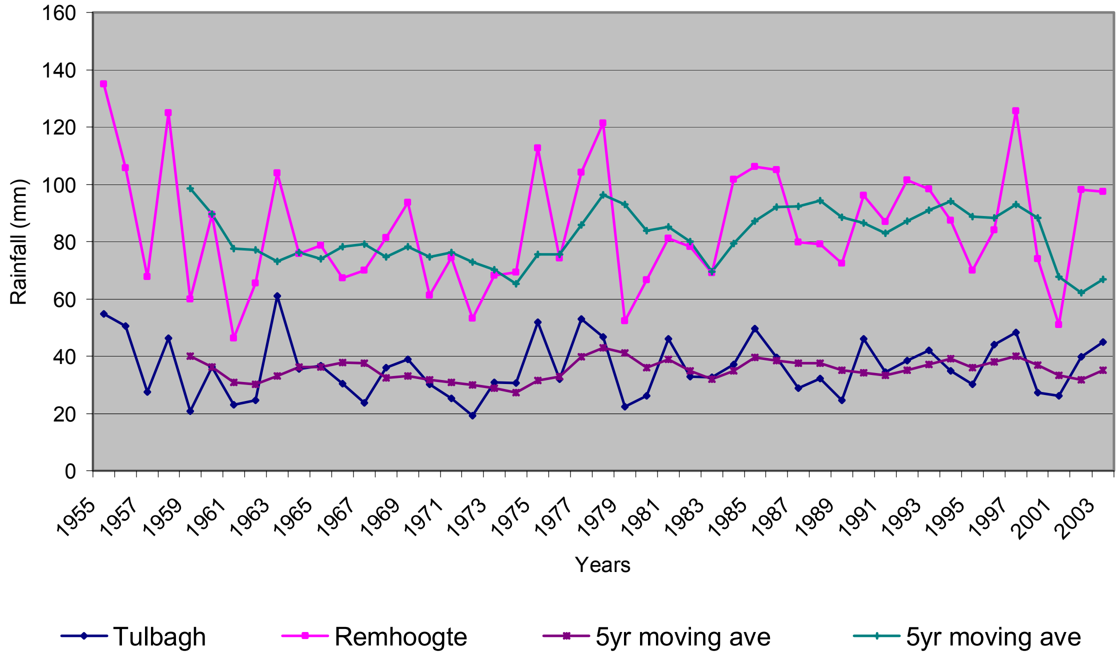

Figure 5.13 Rainfall values and 5-year moving average for Tulbagh and Remhoogte. (Source: South Africa Weather Service)

The graphs (Appendix 4) for Tulbagh and Remhoogte depict rainfall data for a 43-year period, and show a linear increase for the months of April, June, July and September. The month of May does not show any trend, while August shows a decreasing trend for both stations. With a strong positive correlation between the two stations, and an observed change in rainfall, the impact of precipitation on channel change needs to be considered.

5.3.2 Discharge

Daily and monthly discharge data were obtained for the weir located on the Klein Berg River (G1h008) from the Department of Water Affairs and Forestry. The weir is located as the river exits the Nuwekloof pass between the Obiekwa Mountains in the north and the Voëlvlei Mountains in the south. Seasonal variation of flow is illustrated in Figure 3.3, which clearly shows a winter runoff during the months from May to August.

Analyses of discharge data, prior to 1954 and corresponding to the aerial photographs were done. As a result, the statistical values reflect different periods of time, but nonetheless give an indication of conditions within the catchment during the specific periods. Table 5.7 illustrates the basic statistics for each of the periods, while hydrographs illustrates the annual variation of discharge for the periods (figure 5.14 to 5.16).

Table 5.7 Statistical values of discharge (in m^3/s) for periods corresponding to aerial photographs. (Source: DWAF)

	Years of record	**Ave**	**Max**	**Min**	**Median**
1954 – 1967	14	2.59	126.2	0	0.674
1968 – 1987	20	2.26	148.3	0	0.54
1988 - 1997	10	2.676	96.08	0	0.588

The 14-year period from 1954 to 1967 (figure 5.14), indicate that 50% of all flows (median) were higher than 0.674 m^3/s. This indicates relatively higher flows if compared to the following two periods of flow. However, a reason for this higher value could be due to the fact that the relatively drier months of January to May in 1962 were not included due to missing data.

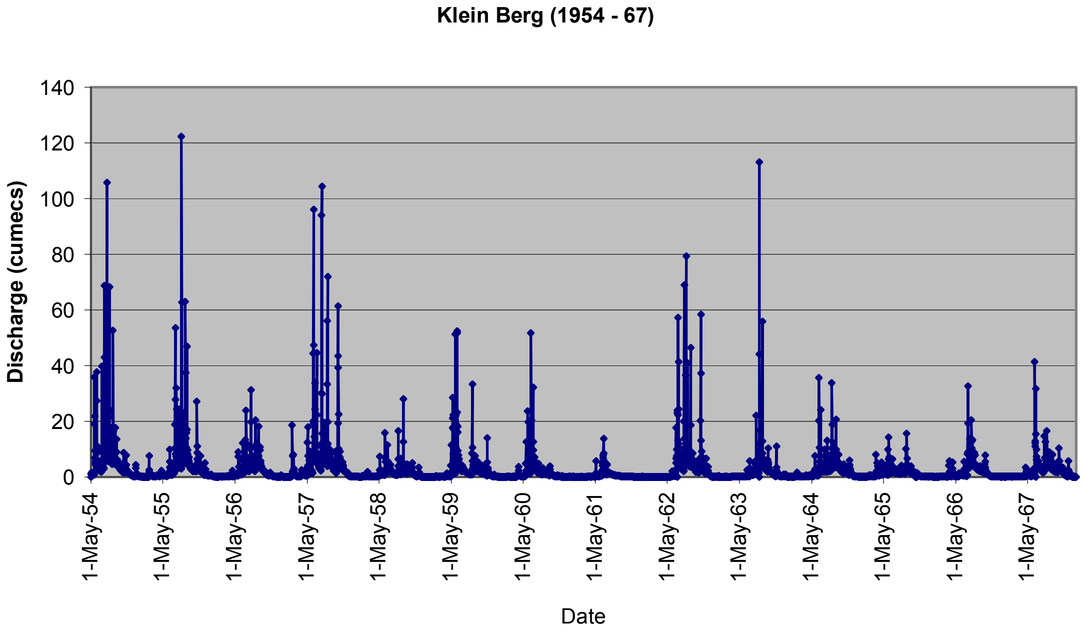

Figure 5.14 Daily discharge data for a period of 14 years from 1954 to 1967. (Source: DWAF)

It is evident from the graph (fig 5.14) that the hydrological year of 1960/61 was the lowest. For this year an average of 0.494 m^3/s and a median of 0.167 m^3/s was calculated. The low discharge for this hydrological year corresponds to the low rainfall received for Tulbagh (23.18mm) and Remhoogte (46.31mm).

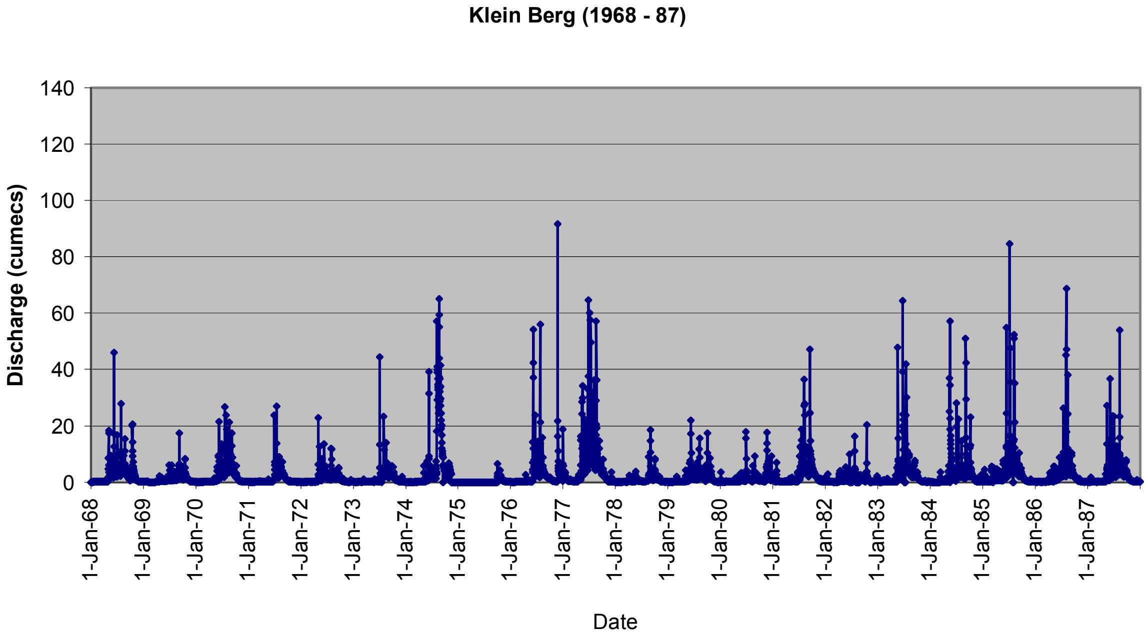

Figure 5.15 Daily discharge data for a period of 20 years from 1968 to 1987. (Source: DWAF)

The statistical values for the period 1968 to 1987 are the lowest. Reasons for this could be the longer period of measurement, as well as a lack of data for the months of November 1974 to September 1975. However, if the map of 1987 (figure 5.8) were considered, the increase of agricultural land during this time would have an impact on discharge. An increase in agricultural land means a greater demand for water, and thus greater abstraction from rivers.

Figure 5.16 reflects the shortest time period of measurement. The data set for this period contains no significant data gaps. The period 1988 to 1997 has the highest average flow of 2.676 m^3/s, although the median has a value of 0.588 m^3/s. During this period, the occurrence of invasive alien vegetation in the riparian zone is most dense. Although the study did not determine the impact of invasive alien vegetation on streamflow, research in South Africa has clearly shown that invasive alien vegetation decreases streamflow (Dye and Poulter, 1995; Le Maitre *et al*, 1996).

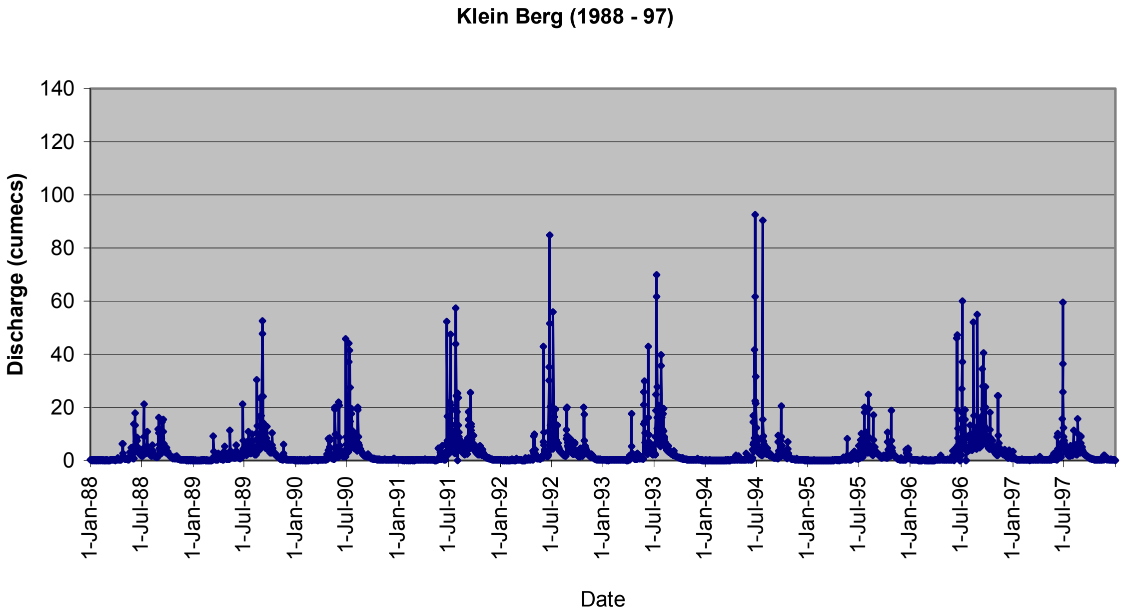

Figure 5.16 Daily discharge data for a period of 10 years from 1988 to 1997. (Source: DWAF)

The impact of urbanization is also most prominent during this period. Discharge of treated sewage into the river during the winter months needs to be factored into any changes within the discharge record.

6. DISCUSSION AND CONCLUSIONS

The aim of the project was to determine channel change over both a medium (55 years) and short time period and to relate these changes to landuse change (assessing stability), vegetation and discharge within the catchment. This chapter will provide possible explanations for the observed changes in channel stability over both the long and short time period.

6.1 Introduction

The Klein Berg catchment or Roodezand Valley is an intensely cultivated catchment as well as catering to a diverse range of water uses. At present, the Klein Berg River catchment is intensively cultivated with green orchards and vineyards as well as wheat and oat fields. The pine plantations are also prominent along the Waterval Mountains. As a result the water abstraction from the Klein Berg River has left the middle reaches of the river with no flows during the summer months (River Health Programme, 2004). This is mainly due to the abstraction of water for agriculture, domestic/urban use and the diversion of water to the Voelvlei dam. With population and economic development projected to increase within the Cape Metropolitan area, further pressure may be placed on the Berg river system (DWAF, 2004).

6.2 Assessing stability

On the short time scale, i.e from 1998 to 2000, channel change, in the form of erosion and deposition, was clearly evident from the erosion pins and the resurveying of the channel cross-profile. The composition of the bank material revealed a dominant sand content with silt and clay only constituting a very low percentage. A low percentage of silt and clay means less resistance to the shear force of flow. Coupled with the absence of protective undergrowth, due to the invasion of invasive alien vegetation, bank erosion is prominent. As a result, the widening of the channel at cross profile 1 was very noticeable.

Erosion of the sandy soil was also prominent beneath the roots of the black wattle tree, as indicated by the erosion pins. As black wattle is the dominant invader along the riparian zone, it plays an important role with regards to bank stability.

Fluvial entrainment during high flow was also observed and recorded in the study area. According to Thorne (1990), when the banks become fully saturated, the bank material strength and cohesion decreases, while the bank material weight increases, resulting in bank instability. Plate 6.1 illustrates the soil being eroded due to the dislodgement by fluvial scour.

Channel change was not only associated with widening, as deposition within the channel occurred at cross profile 2. Deposition normally occurs when the transport capacity of the channel decreases (Richards, 1982). This results in the deposition of material along selected locations within the channel.

A change in the catchment conditions means a change in the sediment and flow characteristics. Any change in the sediment or discharge in the channel results in a change in the morphology of the river through processes of erosion and deposition. A change in the channel bar features was clearly evident from 1942 to 1997. This indicates a change in the sediment and discharge dynamics within the reach and thus within the catchment. The lateral and point bars, which are clearly seen in 1942, have either been colonized by invasive vegetation in 1997, or are used for agricultural purposes.

The change in discharge and sediment dynamics within the catchment was also observed with the disappearance of the divided channel after 1942. In 1967 the divided channel is replaced with a straight channel invaded with woody alien trees. Within the study area, the increase in dense infestations has mainly been recorded in the riparian zones of the river. The density of the riparian invasive alien vegetation is especially apparent in 1997. "Invasion of streambanks by alien woody vegetation can be expected to result in a change in form" (Rowntree, 1991:38).

6.3 Vegetation

Field observation identified vegetation, treefall, large organic debris and rooting systems to be important variables affecting the stability of banks in the study area.

Plate 6.1 Erosion during high flow

Plate 6.2 Black wattle on bank

The presence of vegetation or lack thereof is very important in bank stability. The lack of vegetation along the banks allows the detachment of individual particles from the bank during high flows (Plate 6.1). The woody invasive alien species prohibits the growth of indigenous vegetation and as a result the ground is bare and susceptible to erosion especially during high flows. Plate 6.2 illustrates the growth of a black wattle on the bank of the river. Surface vegetation is sparse and thus during high flows the area is susceptible to erosion.

Plate 6.3 Treefall due to thin soil cover over bedrock

Treefall was observed in the study area and plays a very important role in soil erosion and bank stability. Within the study reach the woody alien species were especially susceptible to treefall where their rooting systems were shallow. Plate 6.3 illustrates treefall of a black wattle due to a shallow rooting system resulting from bedrock close to the surface. As a result of the shallow rooting systems, the force of the wind easily uproots the trees. As the tree is uprooted the soil is eroded. A consequence of treefall along the banks was firstly the destabilization of the banks. Within the channel, the fallen tree obstructs streamflow and also causes the deposition of sediment and debris (Plate 6.4). The weight of trees along the banks plays an important role in bank instability as bank collapse may occur if the weight reaches a critical weight.

Plate 6.4 Treefall in the river channel

Large organic debris is present within the channel and along the flood plains in the entire study area (Plate 6.5). The location of the debris relative to the channel can play a major role in bank erosion. Along the channel, huge debris loads are located along the banks of a few sites along the reach and protect the banks from the shear stress exerted by the flowing water. However, in many instances the debris diverts the flow of water to the banks and can then cause bank erosion.

Organic debris is also located on the floodplain where it was deposited by high flows occurring during the winter seasons. A measurement of one of these debris loads consisting of logs and branches revealed an area of $18m^2$ (6 metres by 3 metres) with a height of almost 2.5metres. These debris loads are mobilized during high flows (Plate 6.6). Debris within the channel can also act as a reservoir, allowing sediment deposition.

Plate 6.5 Large organic debris on floodplain

Plate 6.6 Large organic debris during high flow

Where **Rooting systems** do not fall below the water level, bank erosion is likely to occur causing undercutting (Plate 6.2). The rooting systems of the invasive alien trees observed in the study area were complex and is influenced by factors not examined in this study. Shallow but extensive rooting systems of trees subjected to treefall in the riparian zone were observed. Plate 6.7 illustrates one of the alien trees where the extensive rooting system covers the entire bank. In many examples rooting systems are very complex and basically cover the major part of the banks, thus protecting it from the force of the water. The rooting system of the large invasive trees is very prominent, and may either have a positive or negative impact on the banks depending on the position of the roots and on the flow of water.

Plate 6.7 Complex and extensive rooting system

Vegetation transects show that the riparian zone of the Klein Berg River is densely infested by invasive alien vegetation, the main species being *Acacia mearnsii* and the *Eucalyptus* species. The extensive height and diameter of these alien species confirm their mature age. However, the presence of the large numbers of indigenous shrubs and trees, shows that the invasive aliens have not totally repressed the growth of indigenous species. The invasive alien species obstructs the growth of indigenous species by not only competing for space but also for water supply. This is especially so along the riparian zone. The true density of indigenous species does not increase from the banks to the valley slopes, however, the biomass - in terms of height and diameter - increases along the valley slopes. This is the opposite to the invasive aliens, which tends to be dense along the banks. The growth of the invasives decrease as one moves away from the river channel -

its source of unlimited water.

The invasive alien species play a major role in the stability of streambanks. The invasive alien vegetation, especially the *Acacia mearnsii* and *Eucalyptus*, is concentrated along streambanks. The size of the trees is extremely substantial which may have an impact on bank stability especially if the bank is already subjected to undercutting. The invasives along the banks also prohibit the growth of any vegetation, and as a result the banks are completely bare and subject to erosion from water flow especially during high flow.

The invasion of alien vegetation is influenced by the unlimited access to water. The Klein Berg River is a perennial river and the invasion by alien vegetation has been greatly facilitated not only by the unlimited access to the water in the river, but also due to the methods of seed dispersal. This is especially true of the *Acacia* species which expands rapidly along the river as the seeds are dispersed in the water and stored within the banks. Disturbances in the environment also facilitate the spread of alien vegetation. Disturbances such as the building of the road (prior to 1946) and the earthquake (1969) should thus also be taken into account. Fires occur frequently in the Nuwekloof pass, but are mainly confined to the valley slopes adjacent to the train line.

6.4 Rainfall and discharge

The climate has an important influence on the hydrology of a catchment (Figure 2.1), and consequently on the channel itself. The precipitation within the catchment (i.e at both Remhoogte and Tulbagh) show an increasing linear trend from 1954 to 1997 for the winter rainfall months of April, June, July and September, while a negative trend was observed for August (Appendix 4). Within the summer months, the trends are all similar, except for the month of October. Although only basic statistics was used to analyse the data, the fact that the basic statistics indicate a trend, is relevant (Mr Carlton Fillis, SA Weather Bureau Service pers. comm. 2004).

The analyses of discharge in the study area do not give a true reflection of the situation in the study area, as effluent from the treatment plant in Tulbagh is discharged into the Klein Berg River, while water is also being abstracted from the river for urban, domestic and agricultural use.

6.5 Conclusion and recommendation

The variables impacting on river morphology is determined by the time scale being considered. On the medium time scale, agriculture has had a major impact on channel morphology by altering the sediment and flow dynamics, while the impact of precipitation variations (an independent control) cannot be ignored. The human-induced change within the catchment is not only due to agriculture, as urban development has had a marked influence on the hydrology of the catchment. On a short time scale the impact of invasive vegetation, as well as soil characteristics, is significant with regards to erosion. The study has indicated the dynamic nature of river systems over both a medium time scale (40 years) and a short time scale of (18 months).

The study has also revealed the importance of conducting a time series on the area or catchment which is currently under investigation, as this allows for a greater understanding of the historical factors, which have shaped the current river and its catchment. This knowledge will not only assist in the understanding of current processes, but may also be vital in predicting how the river will respond in future.

Spatially, the study area only covered a small part of the Klein Berg River catchment due to the availability of aerial photographs. The nature of water, especially with all its different components, requires a holistic approach, and thus requires research at a catchment scale – and not at a reach scale only. In addition, all aspects within the catchment (as indicated by Figure 2.1) needs to be included in the assessment of discharge and sediment movement, and thus an integrated approach is required.

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PERSONAL INTERVIEWS

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APPENDIX 1

Results of particle size analysis
Cross profile 1 Left

Weight of sample and beaker (g):	156.66
Weight of beaker (g):	1.69
Weight of sample (g):	154.97

Size mm	**ϕSize**	**Raw weight grams**	**Inidividual weight %**	**Cumulative weight %**
2000	-1	0.24	0.16	0.2
1400	-0.5	0.33	0.22	0.4
1000	0	0.62	0.42	0.8
850	0.5	0.93	0.63	1.4
500	1	21.93	14.82	16.3
355	1.5	35.66	24.10	40.4
250	2	42.20	28.52	68.9
180	2.5	22.13	14.96	83.8
125	3	11.03	7.45	91.3
90	3.5	6.77	4.58	95.9
63	4	3.83	2.59	98.5
<63	>4	2.29	1.55	**100.0**
		147.96		

Degree of error: 95.48

Cross profile 1 Right

Weight of sample and beaker (g):	150.77
Weight of beaker (g):	1.69
Weight of sample (g):	149.08

Size mm	**ϕSize**	**Raw weight grams**	**Inidividual weight %**	**Cumulative weight %**
2000	-1	5.18	3.75	3.8
1400	-0.5	3.94	2.85	6.6
1000	0	4.76	3.45	10.1
850	0.5	2.25	1.63	11.7
500	1	18.86	13.66	25.3
355	1.5	21.18	15.34	40.7
250	2	21.49	15.56	56.2
180	2.5	23.52	17.03	73.3
125	3	14.43	10.45	83.7
90	3.5	8.92	6.46	90.2
63	4	5.97	4.32	94.5
<63	>4	7.60	5.50	100.0
		138.10		

Degree of error: 92.63

Results of particle size analysis

Cross profile 2 Left

Weight of sample and beaker (g): 153.64
Weight of beaker (g): 1.69
Weight of sample (g): 151.95

Size mm	ϕSize	Raw weight grams	Inidividual weight %	Cumulative weight %
2000	-1	3.58	2.37	2.4
1400	-0.5	2.30	1.52	3.9
1000	0	2.42	1.60	5.5
850	0.5	1.71	1.13	6.6
500	1	12.41	8.22	14.8
355	1.5	25.83	17.10	31.9
250	2	47.58	31.50	63.4
180	2.5	27.86	18.45	81.9
125	3	11.28	7.47	89.4
90	3.5	6.79	4.50	93.9
63	4	4.40	2.91	96.8
<63	>4	4.88	3.23	100.0
		151.04		

Degree of error: 99.40

Cross profile 2 Right

Weight of sample and beaker (g): 151.03
Weight of beaker (g): 1.69
Weight of sample (g): 149.34

Size mm	ϕSize	Raw weight grams	Inidividual weight %	Cumulative weight %
2000	-1	0.86	0.58	0.6
1400	-0.5	1.00	0.67	1.3
1000	0	1.77	1.19	2.4
850	0.5	1.47	0.99	3.4
500	1	13.37	9.01	12.4
355	1.5	17.75	11.96	24.4
250	2	34.23	23.07	47.5
180	2.5	30.54	20.58	68.1
125	3	20.12	13.56	81.6
90	3.5	12.55	8.46	90.1
63	4	7.58	5.11	95.2
<63	>4	7.13	4.81	100.0
		148.37		

Degree of error: 99.35

Results of particle size analysis
Cross profile 3 Left

Weight of sample and beaker (g):	156.66
Weight of beaker (g):	1.69
Weight of sample (g):	154.97

Size mm	ϕSize	Raw weight grams	Inidividual weight %	Cumulative weight %
2000	-1	38.13	24.86	24.9
1400	-0.5	10.78	7.03	31.9
1000	0	18.54	12.09	44.0
850	0.5	12.92	8.42	52.4
500	1	49.17	32.06	84.5
355	1.5	13.72	8.95	93.4
250	2	6.35	4.14	97.6
180	2.5	2.12	1.38	98.9
125	3	0.82	0.53	99.5
90	3.5	0.40	0.26	99.7
63	4	0.24	0.16	99.9
<63	>4	0.17	0.11	100.0
		153.36		

Degree of error: 98.96

Cross profile 3 Right

Weight of sample and beaker (g):	155.41
Weight of beaker (g):	1.69
Weight of sample (g):	153.72

Size mm	ϕSize	Raw weight grams	Inidividual weight %	Cumulative weight %
2000	-1	10.74	7.09	7.1
1400	-0.5	2.18	1.44	8.5
1000	0	3.94	2.60	11.1
850	0.5	2.43	1.60	12.7
500	1	22.10	14.59	27.3
355	1.5	26.14	17.25	44.6
250	2	35.59	23.49	68.1
180	2.5	21.58	14.24	82.3
125	3	9.66	6.38	88.7
90	3.5	6.20	4.09	92.8
63	4	4.08	2.69	95.5
<63	>4	6.87	4.53	100.0
		151.51		

Degree of error: 98.56

Results of particle size analysis

Cross profile 4 Left

Weight of sample and beaker (g):	155.20
Weight of beaker (g):	1.69
Weight of sample (g):	153.51

Size mm	ϕSize	Raw weight grams	Inidividual weight %	Cumulative weight %
2000	-1	0.23	0.15	0.1
1400	-0.5	0.78	0.51	0.7
1000	0	2.65	1.73	2.4
850	0.5	3.99	2.60	5.0
500	1	62.35	40.62	45.6
355	1.5	48.10	31.34	76.9
250	2	24.01	15.64	92.6
180	2.5	5.91	3.85	96.4
125	3	2.13	1.39	97.8
90	3.5	1.41	0.92	98.7
63	4	1.02	0.66	99.4
<63	>4	0.91	0.59	100.0
		153.49		

Degree of error: 99.99

Cross profile 4 Right

Weight of sample and beaker	156.79
Weight of beaker (g):	1.69
Weight of sample (g):	155.10

Size mm	ϕSize	Raw weight grams	Inidividual weight %	Cumulative weight %
2000	-1	33.79	21.93	21.9
1400	-0.5	3.59	2.33	24.3
1000	0	2.62	1.70	26.0
850	0.5	1.49	0.97	26.9
500	1	10.22	6.63	33.6
355	1.5	15.57	10.10	43.7
250	2	26.99	17.51	61.2
180	2.5	23.54	15.28	76.5
125	3	13.87	9.00	85.5
90	3.5	7.93	5.15	90.6
63	4	5.42	3.52	94.1
<63	>4	9.07	5.89	100.0
		154.10		

Degree of error: 99.36

APPENDIX 2

Methodology for georeferencing using TatukGIS

Step 1

Open the AIC Project Manager module and select the *New Project* menu option under the *File* menu.

Step 2

Select the *add/insert file* button to add the file containing the topographical map (in this case the TIFF file) to the AIC project process list. After clicking on the *add/insert file* button, browse to the location of the subject map file on the PC hard disk and click to add to the AIC project process list. In this exercise, the process list will include only this one file containing the topographical map to be georeferenced.

Step 3

Double click on the file in the project list to advance with that file to the AIC Editor module.

Note at this time that the appearance of the Editor module is flexible. By using the options within the *View* menu, various parts of the Editor (such as the section for entering GCPs) can be either shown or hidden away from view. The tool bars on the form can also be repositioned at any time by simply dragging them from one location to another. Sometimes the tool bar menu items are presented in different locations in different screen shots, and not all appear in all screen shots. This is because the screen shots presented in these tutorials are not large enough to display all the AIC Edit module menu buttons in every screen shot. Sometimes the button locations are repositioned in some screen shots to force the display of the button(s) being discussed at that point of the tutorial. Likewise, the GCP entry form is sometimes displayed, sometimes not, depending on which look best presents what is being discussed. Therefore, do not overly focus on the exact locations of the menu buttons in each screen shot illustration.

Step 4

Enter GCP's at the four corners of the map. (The GCP's do not have to be entered exactly at the corners, but the goal should be to spread the GCP's out as must as reasonably possible. In this case, since the coordinates of the four corners are presented on the map, the corners are a good choice for the GCP placements.) Begin by using the *zoom* option or the mouse wheel to magnify the area near one of the four map corners. To minimize the error, zoom in close enough to be able to identify each map corner precisely.

Step 5

Identify and record the map corner with the use of the (*select*) button, which activates the (*add point*) button, and then by using the (*add point*) button. Record the location of the map corner by positioning the pointer (which now appears as a hand holding a point) exactly on the map corner and clicking.

Step 6

Enter the coordinates of the map corner via the keyboard. The AIC offers the choice of entering the GCP coordinates in decimal format or in terms of degrees, minutes, and seconds. In this case, since the coordinates are printed on the topographical map in degrees, minutes and seconds, it is easier to enter the data in the same format. Therefore, proceed to click on the (*options*) button and then choose the desired format, then click *OK*.

Then enter the x and y coordinates of one of the corners, taking the coordinate information directly off the topographical map. Click on the red *OK* button to save the data. (The z coordinate, which represents altitude, is not supported in this version of the AIC.) Note the *comment* field, which can be used to add any unique information relating to a GCP, such as the source of the coordinate data or any doubts about its accuracy, if it is felt that the comment information might be useful at a later time. Also note the *active* option, which allows the user to inactivate any specific GCP from the transformation operation, without deleting the GCP and data.

Step 7

Enter the coordinate data for the other three map corners, repeating this process each time.

Step 8

Select which rectification method to use for the transformation. Click on the *options*, identify the desired method, and select by clicking on *OK*. In this case we use the 1st order polynomial approximation method. (See Guidance for using the AIC for additional help about selecting the most appropriate rectification method for a particular project.)

Step 9

Click on the *Projection* button to advance to the Projection panel dialog box in order to select the coordinate space settings for the GCPs. Since the coordinates of this topographical map are in latitude/longitude degrees, we can be fairly certain that the coordinates reflect the AIC default settings are appropriate. The default settings are datum: *WGS 1984*, projection: *Geodetic (unprojected)*, and units: *degrees p/180*. These AIC Editor module default settings are appropriate for most situations, and should be used unless the user is i) sure that the coordinate space of the GCPs are different than the default settings and ii) the intent is to project the output image to a target coordinate space that is other than the coordinate space of the GCP points. For guidance on the *Projection panel* coordinate space settings, refer to the Projection Panel discussion and the Projection Panel Settings Guide.

From the AIC *Project Manager* module, select the (*options)* menu to open the *Project options* dialog box in order to make the necessary project settings prior to running the rectification project. Within the *Project options* dialog box select *PNG* as the PixelStore storage format. The PixelStore-PNG format option is most appropriate for scanned maps, which have limited colors, because it offers "lostless" compression. (The PixelStore-JPEG format option is most appropriate for aerial photos with limited colors.) Next check the *Use projection* option to specify the target coordinate space for the output image. The AIC supports a large number of coordinate space possibilities. In this exercise, we select World *Geodetic System 1984* as the datum and the *Universal Transverse Mercator UTM* as the projection.

Step 10
Select a *File Path* to identify the directory and file name to save the output file. If prompted that a *PixelStore* file does not exist for the project, select *Yes* to instruct the AIC to set up a supporting PixelStore file for the project.

At this time also note the *Storage*, *Compression*, and *Pixel* size settings in the *Project options* dialog box, which relate to the rectified PixelStore format output image that will be generated during the transformation process. Because *lostless* (no loss in image quality) compression is automatically applied when the PNG format is selected, the compression level setting is relevant only if the JPEG format option is selected. As a general rule, the *Pixel size* setting is best left at *0* (the default setting), which means that the pixel size of the original input image will be used for the rectified PixelStore output image, offering the best possible output image quality. (The process of customizing the pixel size is often referred to as "resampling" in photogrammetry jargon and is a relatively advanced topic.) Refer to *Project Options* in the *Guide* for more discussion on these settings.

Step 11
From the Project Manager select the (*run*) button, which will open the *Project Run* dialog box. The Project Run dialog box is similar to the Project Options box, but also presents the *Run* and *Preview* features.

Step 12
Preview the project. Preview allows the user to quickly see an outline of each of the map files (only one in this tutorial) in the project list and how the files fit (mosaic) together. This allows the user to quickly spot any obvious errors before commencing the project run calculation process. If the position or shape of a particular map appears to be wrong, simply click on that map segment to advance with that file directly to the AIC Editor module, in order to quickly check the data and make any necessary corrections. The preview option can be a significant time saver, particularly with projects incorporating a large number of files or large file sizes. (The map outline below appears crooked, but simply reflects the target projection selected for the output file, which simulates the applying of the flat map to the three-dimensional surface of the globe.)

Step 13
Click on the *Run* button to start the rectification project run. The project run for this one map might require several minutes to perform, depending on the specifications of the PC and the detail level of the map. The box at the bottom of the monitor displays the progress, in terms of the percentage of the whole rectification run that has been completed. The project run can be terminated at any time prior to completion by using the *Stop* button.

Step 14
AIC Viewer and saving the project file. The rectified and georeferenced output file

image will appear within the AIC Viewer module on the PC monitor when the project run has finished. The output image file is automatically saved to the TatukGIS PixelStore format, to the file path specified earlier in the *Project options* (or *Project Run)* dialog box.

APPENDIX 3

Vegetation characteristics for transects (belt)

Belt No: 1 **Bank: Left**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Blue gum	M	250	20	Poor
2	5	Port Jackson	M	20	3	Healthy
3	5	Black wattle	M	75	15	Healthy
4	5	Black wattle	I	10	2.5	Fair
5	5	Rubus spp	I	10	0.5	Fair
6	5	Black wattle	M	60	15	Healthy
7	10	Black wattle	M	70	15	Fair
8	10	Black wattle	M	110	20	Fair
9	10	Brabejum stellatifolium	M	30	8	Fair
10	10	Black wattle	M	75	18	Fair
11	15	Rubus spp	M	30	2	Fair
12	15	Leucadendron brunioides	I	10	1	Fair
13	15	Leucadendron	I	10	2	Poor
14	20	Leucospermum vestium	M	20	2	Fair
15	20	Eucalyptus lehmannii	M	60	12	Healthy
16	20	Port Jackson	I	12	4	Fair
17	20	Eucalptus cladocalyx	M	60	13	Healthy
18	25	Brabejum stellatifolium	M	30	6	Fair
19	25	Rubus spp	I	50	1	Fair

Belt No: 1 **Bank: Right**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Blue gum	M	82	13	Healthy
2	5	Blue gum	M	55	10	Healthy
3	5	Black wattle	I	12	3	Poor
5	5	Blue gum	I	35	4	Fair
6	5	Grass	M	3	0.7	Healthy
7	5	Giant reed	M	2	1.00	Healthy
8	5	Port Jackson	I	30	2.2	Fair
9	10	Blue gum	M	45	9	Poor
10	10	Black wattle	M	140	15	Fair
11	10	Blue gum	M	125	10	Fair

12	15	Blue gum	M	70	6	Poor
13	15	Black wattle	M	45	10	Fair
14	15	Blue gum	M	145	22	Healthy
15	15	Blue gum	M	20	8	Fair
16	20	Black wattle	M	75	15	Fair
17	20	Black wattle	M	45	10	Poor
18	20	Blue gum	M	40	10	Fair
19	20	Blue gum	M	41	12	Fair
20	20	Blue gum	M	53	8	Poor
21	20	Black wattle	I	25	2.5	Poor
22	20	Black wattle	M	65	20	Poor
23	20	Saligna gum	M	29	10	Fair
24	20	Eucalyptus lehmannii	I	2	0.2	Healthy
25	20	Port Jackson	I	14	3	Fair
26	25	Port Jackson	M	30	10	Fair
27	25	Black wattle	M	58	20	Fair
28	25	Blue gum	I	25	5	Poor
29	25	Serruria fasciflora	I	3	0.3	Healthy
30	25	Eucalyptus lehmannii	M	20	5	Fair
31	25	Rubus spp	M	25	3	Fair
32	25	Protea nitida	M	20	8	Fair
33	25	Leucadendron	I	15	1	Fair
34	25	Leucadendron	M	22	3	Fair
35	25	Leucadendrn spissifolium	M	10	1.8	Healthy
35	25	Leucadendrn spissifolium	M	10	1.8	Healthy
36	25	Leucadendron corymbosum	M	2	1.3	Fair
37	25	Rubus spp	M	23	2	Fair
38	25	Blue gum	M	33	15	Fair

Belt No: 2 **Bank: Left**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Black wattle	I	5	2	Healthy
2	5	Black wattle	M	20	3	Healthy
3	5	Port Jackson	I	5	1	Fair
4	5	Black wattle	M	40	15	Healthy
5	5	Blue gum	I	5	3	Fair
6	5	Black wattle	M	80	20	Healthy
7	10	Hypericum perforatum	I	2	0.5	Fair
8	10	Port Jackson	I	20	4	Fair
9	10	Eucalptus cladocalyx	M	50	10	Fair
10	15	Eucalptus cladocalyx	M	60	15	Healthy
11	15	Brabejum stellatifolium	M	40	5	Healthy
12	15	Leucendron brunioides	I	30	1.5	Fair
13	20	Hypericum perforatum	I	3	1	Healthy
14	20	Leucospermum vestium	I	30	1.5	Fair
15	20	Leucendron brunioides	M	20	1	Fair
16	20	Leucadendron	M	15	2	Fair
17	25	Weed	M	3	1	Fair
18	25	Thorn	M	10	2	Fair
19	25	Acacia cyclops	M	30	2	Healthy
20	30	Protea nitida	M	50	10	Fair
21	30	Leucadendrn corymboum	M	3	1	Fair

Belt No: 2 **Bank: Right**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Leucadendron spp	M	3.5	1.4	Fair
2	5	Port Jackson	M	50	8	Fair
3	5	Hypericum perforatum	M	3	0.5	Healthy
4	5	Blue gum	M	280	4	Poor
5	10	Hypericum perforatum	M	6	1.5	Fair
6	10	Black wattle	M	200	20	Healthy
7	15	Black wattle	M	105	20	Healthy
8	15	Black wattle	M	60	12	Healthy
9	15	Black wattle	M	185	14	Fair
10	15	Leucadendron spp	M	5	1.5	Fair
11	20	Blue gum	M	36	10	Fair
12	20	Black wattle	M	61	10	Fair

13	20	Black wattle	M	48	10	Fair
14	20	Leucadendron	M	5	3	Fair
15	25	Melia azedarach	I	30	6	Fair
16	25	Leucadendron spp	M	15	3	Fair
17	25	Leucospermum	M	25	3	Fair
18	30	Grass	M	0.5	2	Fair

Belt No: 3 **Bank: Left**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Blue gum	I	50	4	Healthy
2	5	Port Jackson	I	20	5	Healthy
3	5	Black wattle	M	90	20	Healthy
4	5	Black wattle	I	10	1	Healthy
5	10	Port Jackson	I	20	1.8	Healthy
6	10	Black wattle	M	100	18	Healthy
7	10	Black wattle	M	80	3	Healthy
8	15	Black wattle	I	10	0.5	Healthy
9	15	Black wattle	M	40	2	Healthy
10	15	Black wattle	I	30	2.5	Healthy
11	20	Black wattle	I	10	2	Healthy
12	20	Black wattle	M	200	10	Healthy
13	20	Black wattle	M	100	7	Healthy
14	20	Black wattle	I	10	2	Healthy
15	20	Black wattle	I	15	2	Healthy
16	25	Black wattle	M	50	3	Healthy
17	25	Black wattle	M	30	2	Healthy
18	25	Weed	M	20	0.8	Healthy
19	25	Weed	I	10	0.4	Healthy
20	25	Weed	M	15	0.8	Healthy

Belt No: 3 **Bank: Right**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Port Jackson	M	30	5	Healthy
2	5	Blue gum	M	50	15	Healthy
3	5	Black wattle	M	80	20	Healthy
4	5	Blue gum	M	100	30	Healthy
5	10	Black wattle	M	200	30	Fair
6	10	Blue gum	M	50	20	Fair
7	10	Black wattle	I	10	2	Healthy
8	10	Black wattle	M	30	25	Healthy
9	15	Black wattle	M	40	27	Healthy
10	15	Black wattle	M	80	30	Healthy
11	15	Blue gum	M	50	18	Poor
12	20	Blue gum	I	3	0.8	Healthy

13	20	Black wattle	M	100	32	Healthy
14	20	Black wattle	M	10	5	Healthy
15	20	Black wattle	I	4	3	Healthy
16	25	Black wattle	I	4	2	Healthy
17	25	Black wattle	M	30	3	Healthy
18	25	Blue gum	M	80	24	Fair
19	30	Blue gum	M	30	5	Fair
20	30	Blue gum	M	10	3	Fair
21	30	Blue gum	M	20	5	Healthy
22	30	Blue gum	M	10	3	Healthy
23	35	Blue gum	I	2	0.5	Fair
24	35	Blue gum	I	5	0.8	Fair

Belt No: 4 **Bank: Left**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Port Jackson	I	10	2	Healthy
2	5	Port Jackson	I	5	1	Fair
3	10	Port Jackson	I	10	0.8	Fair
4	10	Port Jackson	M	10	3	Fair
5	10	Port Jackson	M	10	2	Fair
6	15	Port Jackson	M	10	0.7	Healthy
7	15	Port Jackson	M	30	1	Healthy
8	15	Port Jackson	I	15	5	Fair
9	20	Blue gum	M	50	15	Fair
10	20	Blue gum	M	5	1	Fair
11	20	Blue gum	M	5	0.8	Fair
12	20	Black wattle	M	50	12	Fair
13	20	Blue gum	M	30	10	Fair
14	20	Blue gum	I	5	2	Fair
15	20	Blue gum	I	10	2	Fair
16	25	Blue gum	M	20	5	Fair
17	25	Blue gum	M	100	10	Healthy
18	25	Blue gum	M	30	4	Healthy
19	25	Blue gum	I	10	2.5	Healthy
20	25	Blue gum	I	5	2.5	Fair
21	30	Blue gum	M	30	10	Healthy
22	30	Blue gum	M	40	4	Fair
23	30	Blue gum	M	30	5	Fair
24	30	Blue gum	M	30	4	Fair
25	35	Blue gum	I	10	1.7	Fair
26	35	Blue gum	M	30	1	Fair

Belt No: 4 **Bank: Right**

Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Blue gum	M	25	5	Fair
2	5	Hypericum perforatum	I	2	1	Fair
3	5	Blue gum	I	11	4	Fair
4	5	Serruria	I	1	0.5	Healthy
5	5	Black wattle	M	170	25	Healthy
6	10	Black wattle	I	15	5	Poor
7	10	Black wattle	M	117	15	Fair

8	15	Black wattle	I	20	1.5	Fair
9	15	Lantana camara	M	4	3	Healthy
10	15	Leucadendron teretifolium	I	2	1	Healthy
11	20	Leucospermum vestium	I	5	4	Fair
12	20	Black Wattle	M	15	10	Healthy
13	25	Serruria fasciflora	I	3	0.5	Healthy
14	25	Leucadendron salicifolium	M	4	3	Fair
15	25	Leucadendron corymbosum	M	5	2	Fair

Belt No: 5 **Bank: Left**

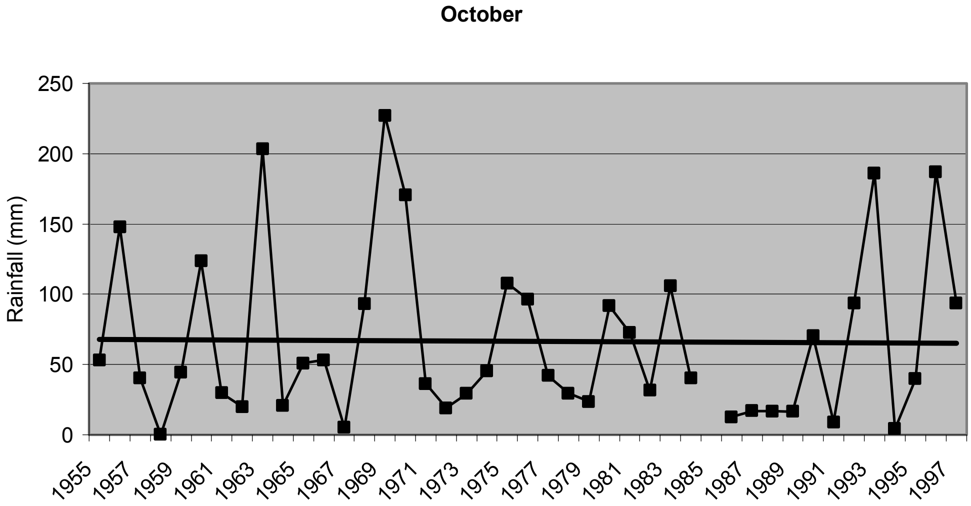
Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Port Jackson	M	37	7	Fair
2	5	Black wattle	M	25	10	Healthy
3	5	Black wattle	M	123	15	Poor
4	5	Black wattle	M	197	14	Poor
5	10	Eucalyptus cladocalyx	M	25	8	Fair
6	10	Leucadendron rubrum	M	31	2	Fair
7	10	Rubus fruticosus	I	25	4	Poor
8	10	Eucalyptus lehmannii	M	30	15	Poor
9	10	Leucadendron salicifolium	I	4	3	Poor
10	15	Rubus fruticosus	M	3	1	Poor
11	15	Eucalyptus lehmannii	M	25	5	Fair
12	15	Leucadendron	M	7	2	Poor
13	15	Port Jackson	I	4	0.5	Poor

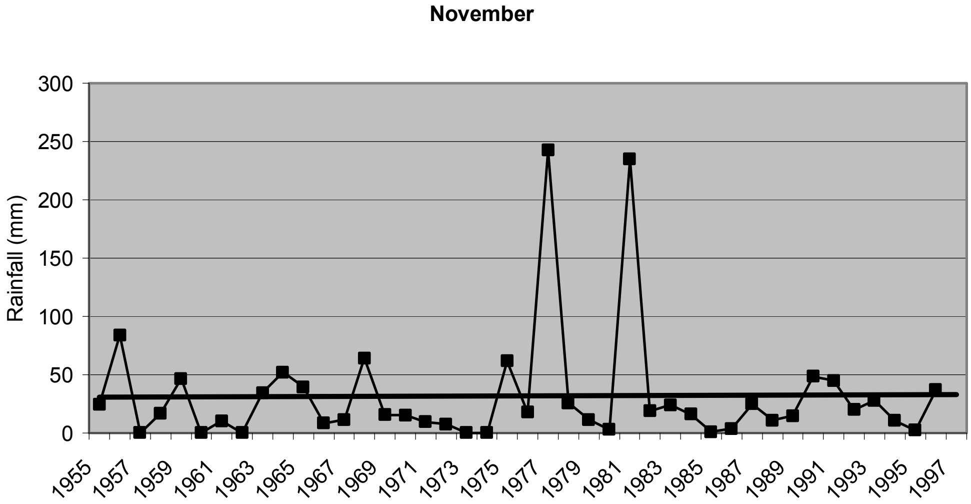
Belt No: 5 **Bank: Right**

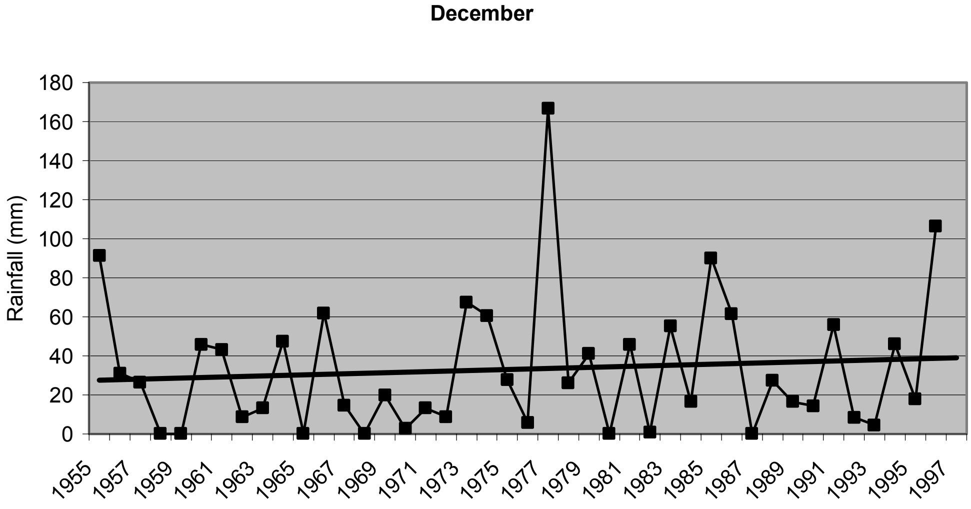
Stem No	Distance from bank	Species/Sample	Age	Diameter (cm)	Height (m)	Health
1	5	Black Wattle	M	58	15	Poor
2	5	Black Wattle	M	37	10	Poor
3	5	Serruria	M	2	0.27	Fair
4	5	Black Wattle	M	45	17	Poor
5	5	Black Wattle	I	12	2	Healthy
6	10	Blue gum	M	19	2.5	Poor
7	10	Hypericum perforatum	I	8	1	Poor
8	10	Blue gum	M	11	7	Poor
9	10	Blue gum	M	40	5	Poor
10	10	Black Wattle	M	14	9	Poor
11	15	Blue gum	M	15	3	Fair
12	15	Black Wattle	I	10	3.5	Fair
13	15	Rubus spp	M	15	4	Fair
14	20	Black Wattle	I	15	4	Fair
15	20	Black Wattle	M	230	18	Poor
16	20	Blue gum	M	24	8	Poor
17	20	Leucadendron	M	9	2	Healthy
18	20	Blue gum	M	34	3	Fair

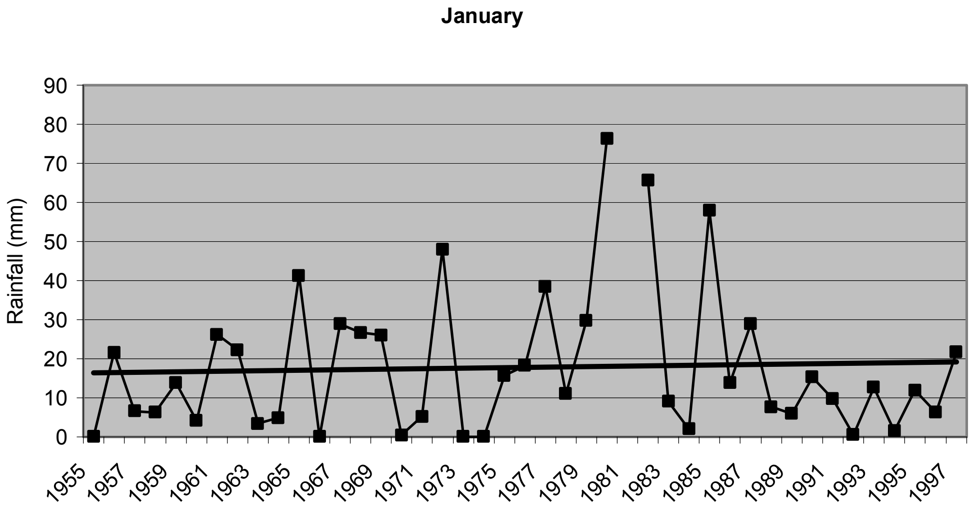
APPENDIX 4a

Monthly summer rainfall trends for Remhoogte (1955 – 1997)





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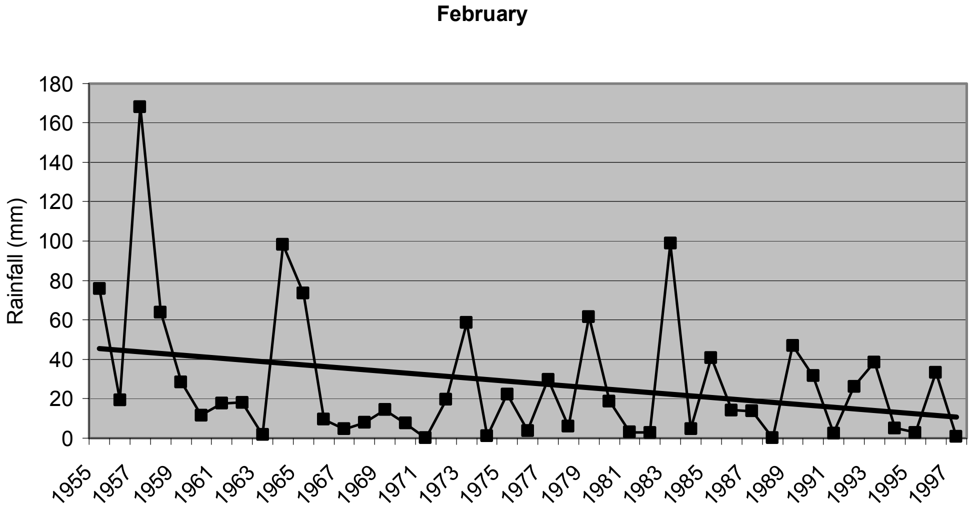
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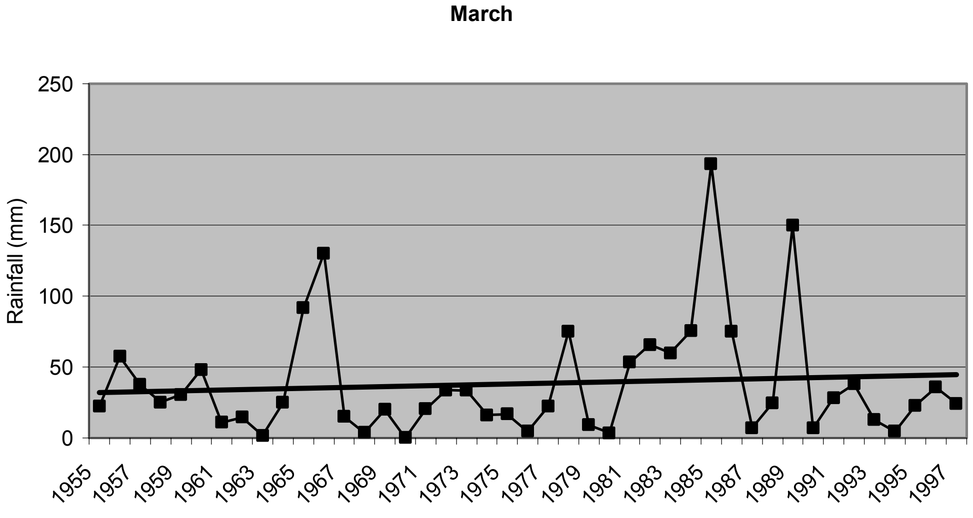
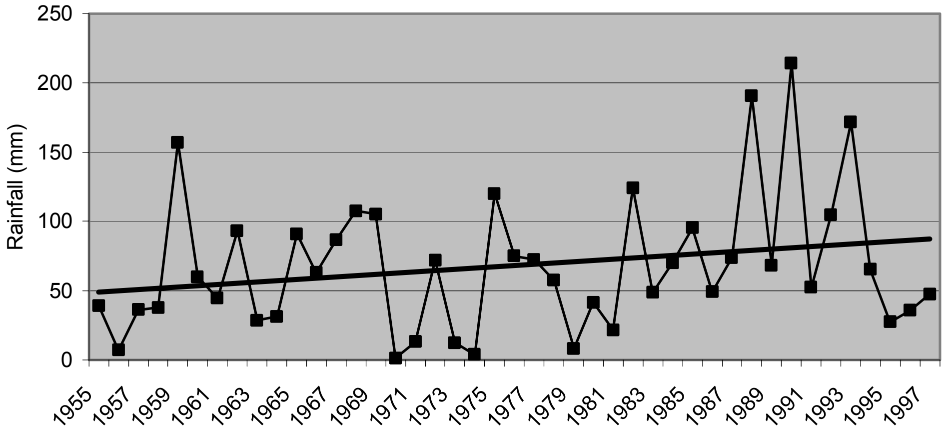

March

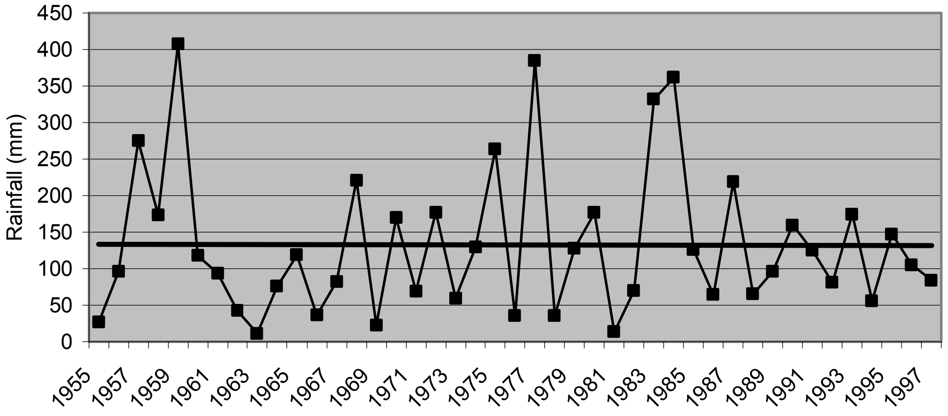
APPENDIX 4b

Monthly winter rainfall trends for Remhoogte (1955 – 1997)

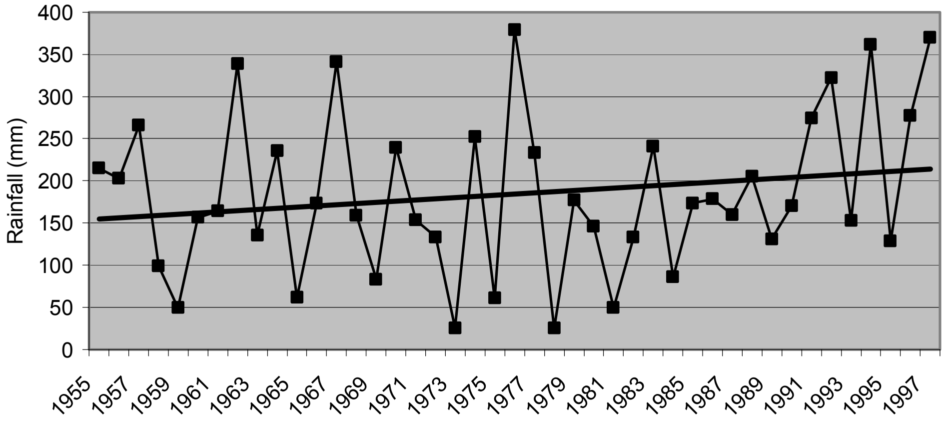
April

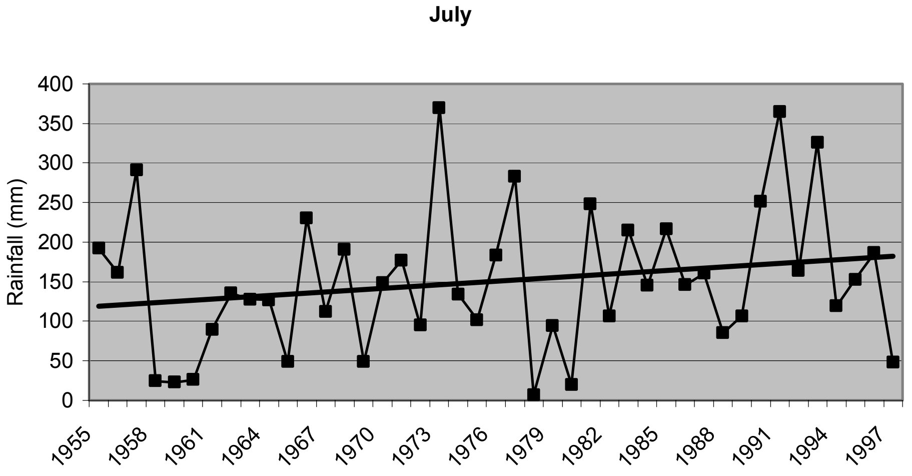


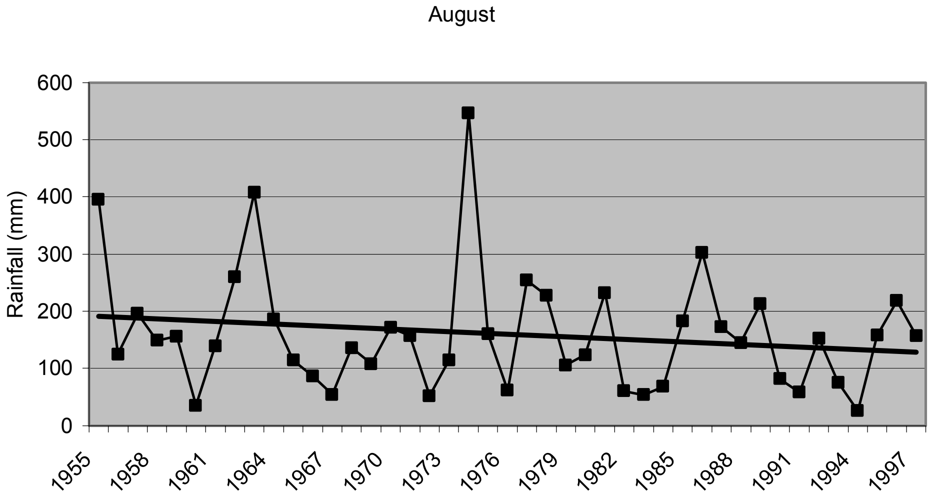
May

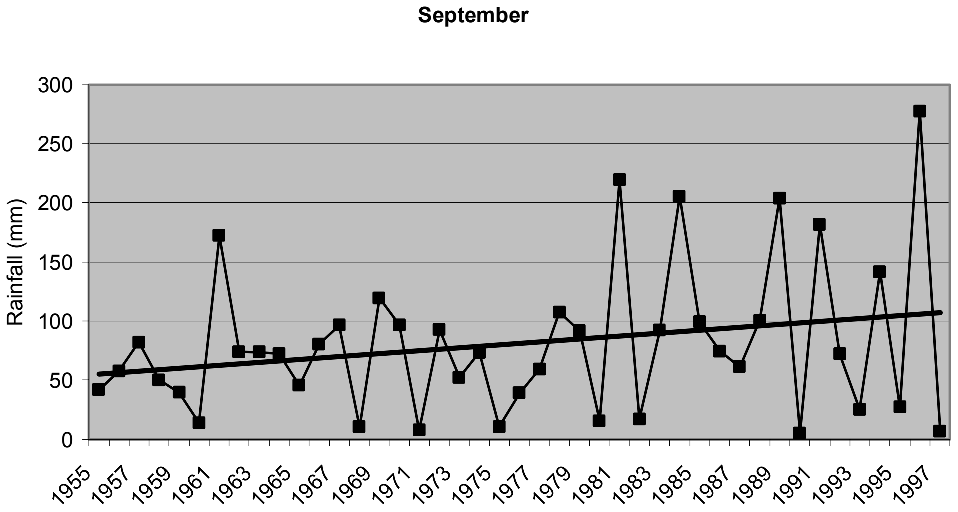


June



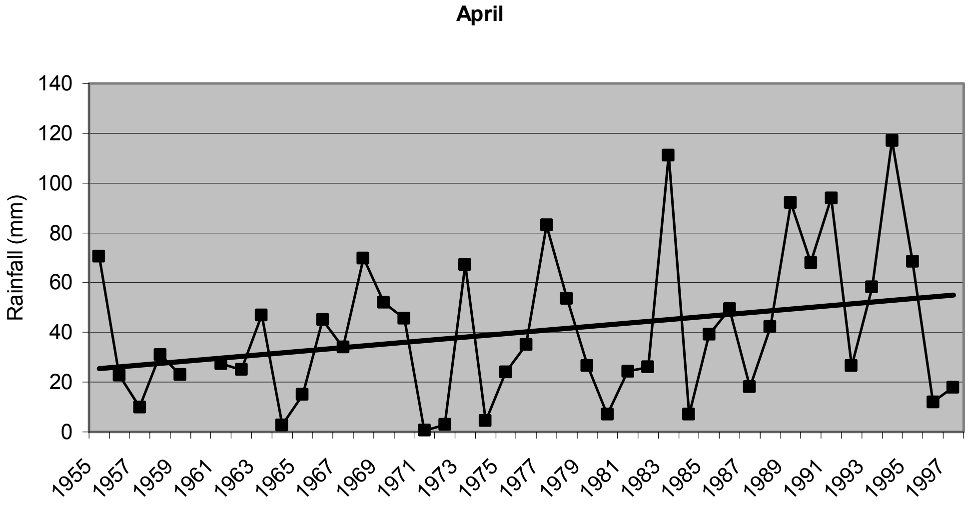

July
Rainfall (mm)
400
350
300
250
200
150
100
50
0
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997

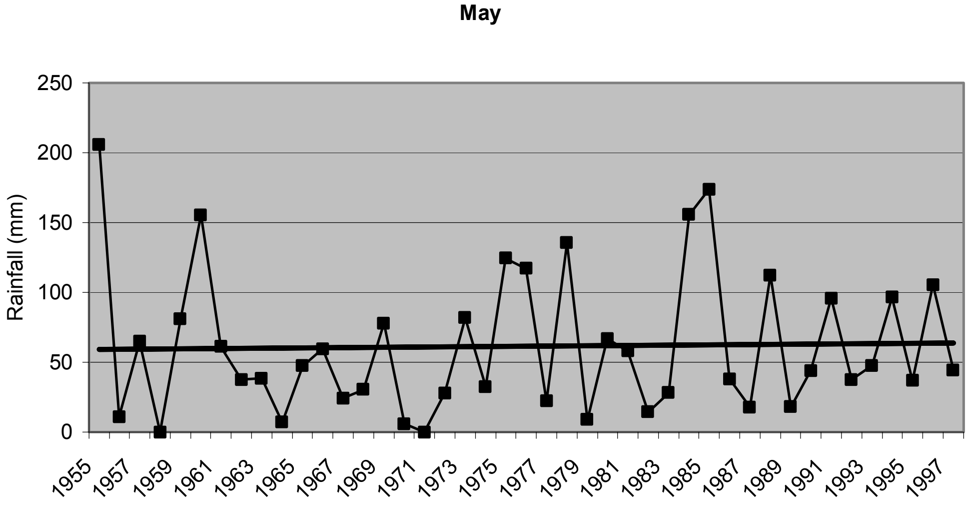

August
Rainfall (mm)
600
500
400
300
200
100
0
1955
1958
1961
1964
1967
1970
1973
1976
1979
1982
1985
1988
1991
1994
1997

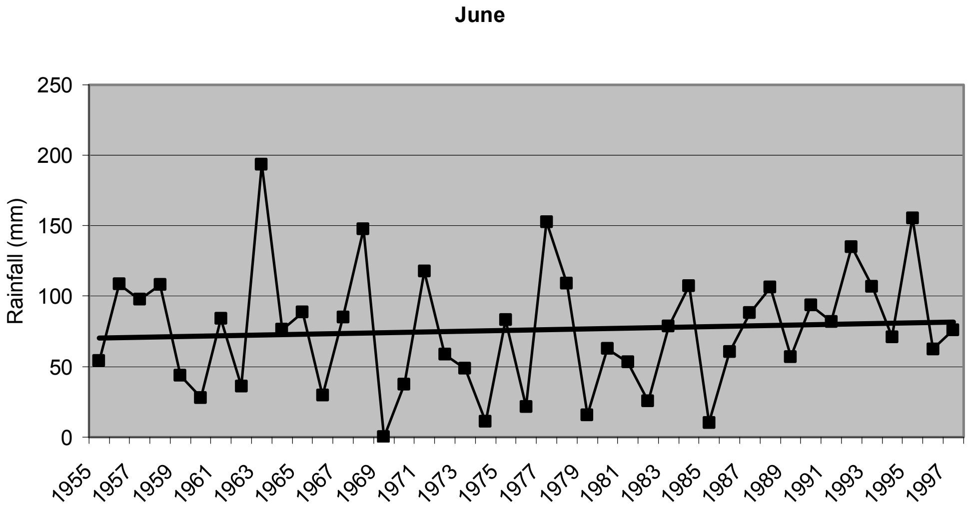

September
Rainfall (mm)
300
250
200
150
100
50
0
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

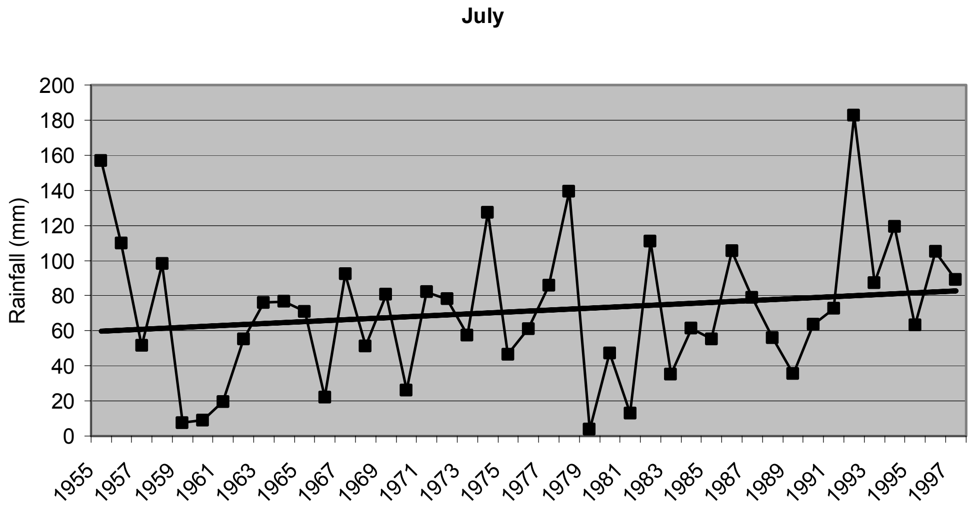
APPENDIX 4c

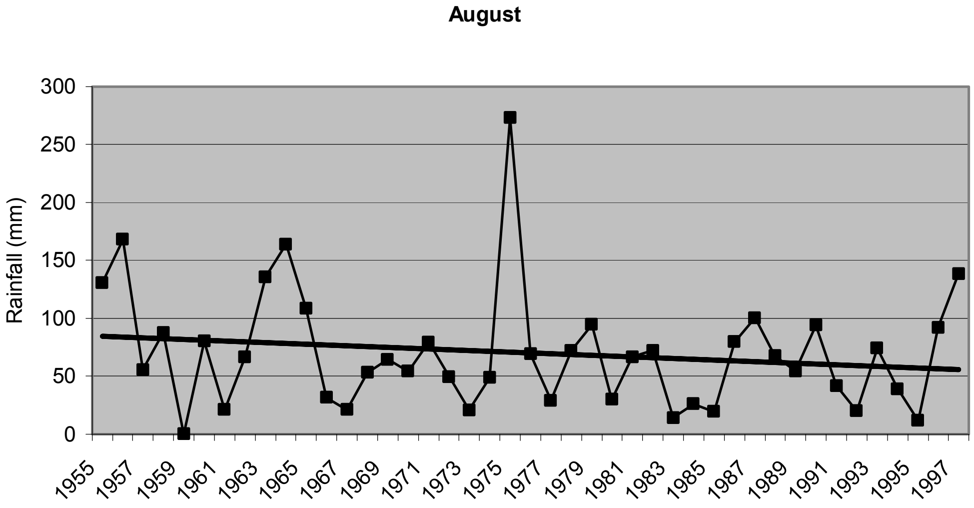
Monthly winter rainfall trends for Tulbagh (1955 – 1997)

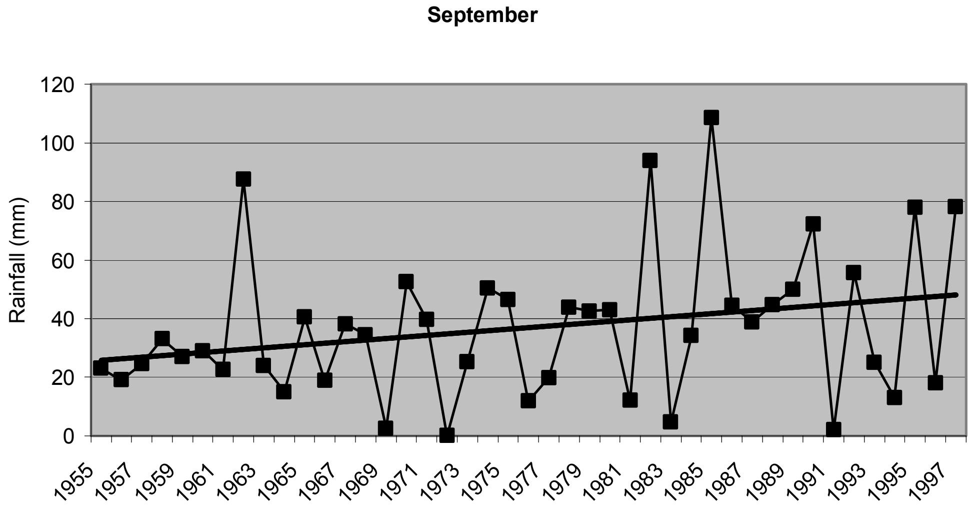






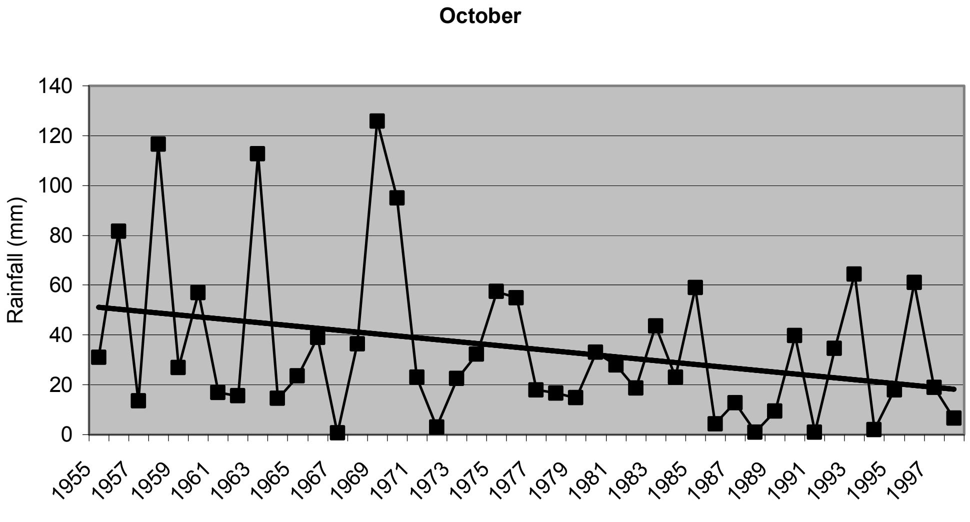

July
Rainfall (mm)
200
180
160
140
120
100
80
60
40
20
0
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

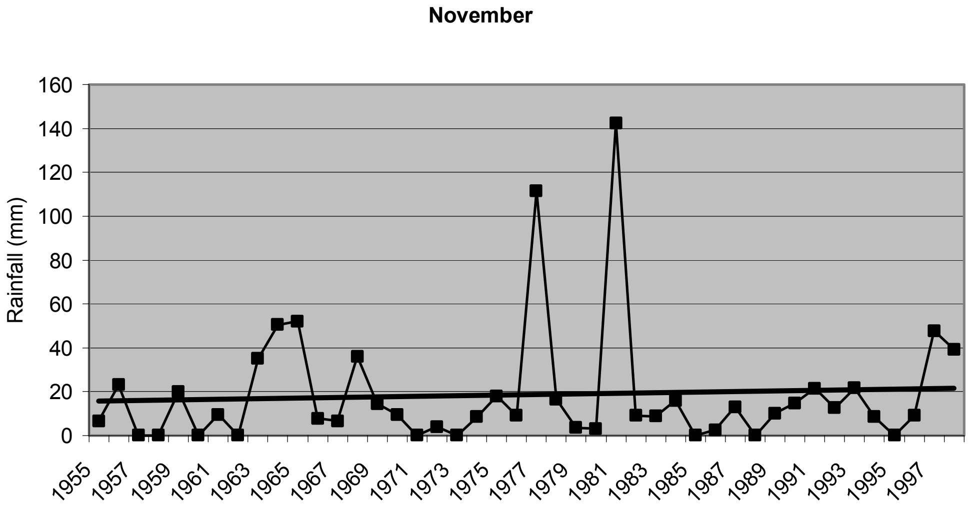

August
Rainfall (mm)
300
250
200
150
100
50
0
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

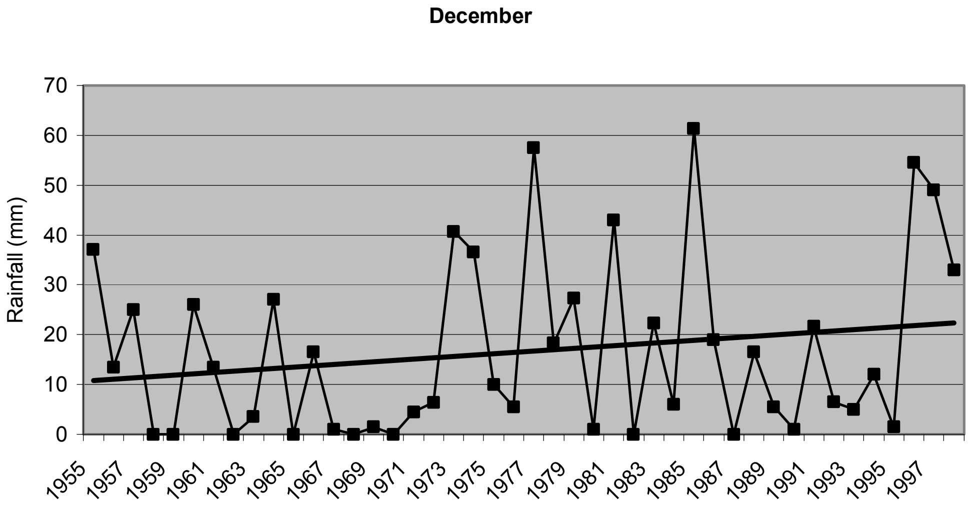

September
Rainfall (mm)
120
100
80
60
40
20
0
1955
1957
1959
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997

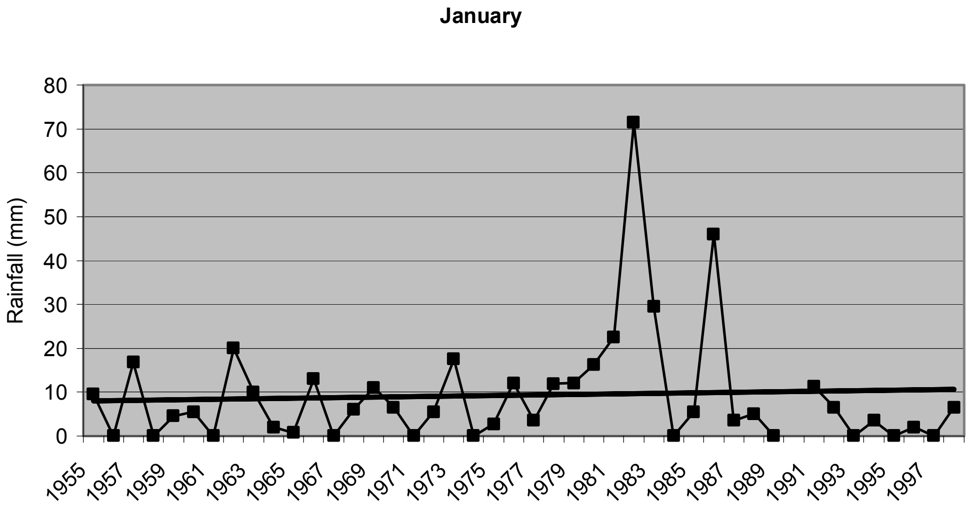
APPENDIX 4d

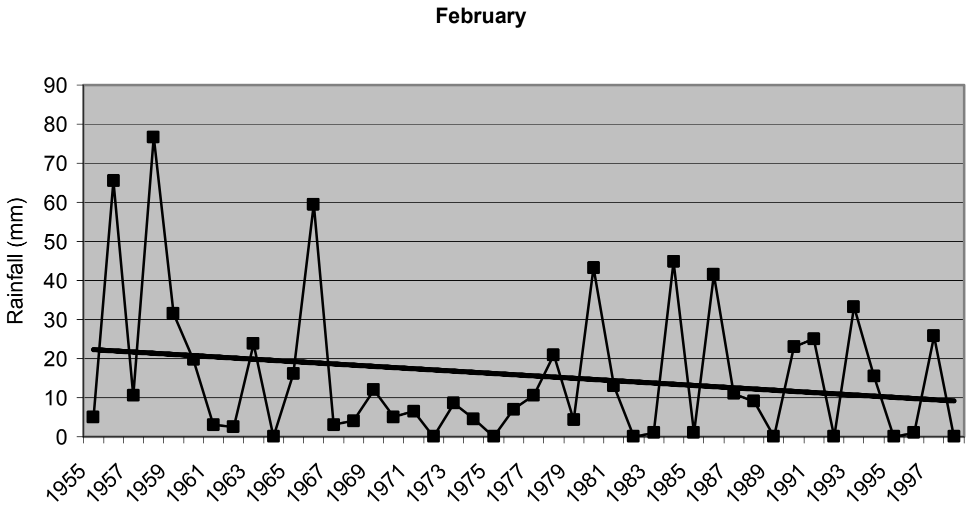
Monthly summer rainfall trends for Tulbagh (1955 – 1997)

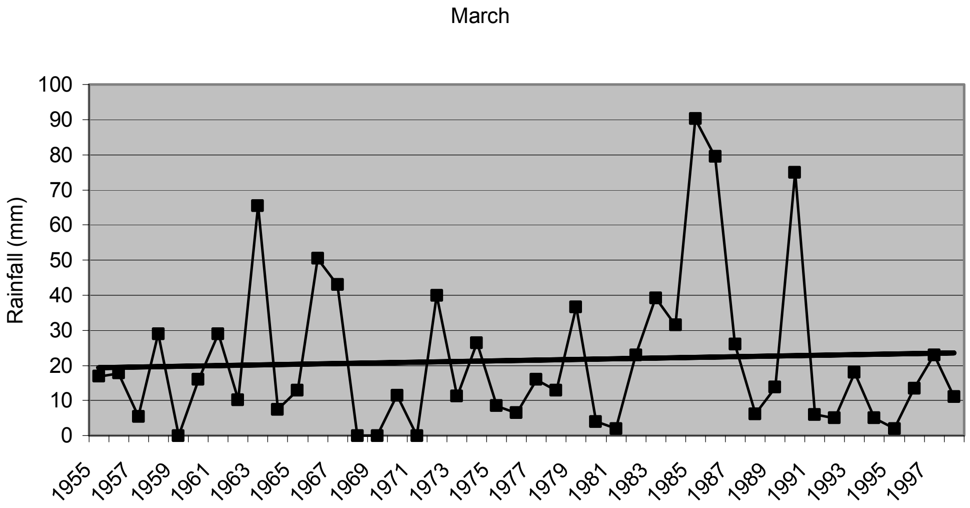












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