Impact of vegetation clearance on the hydrology of Luvuvhu River Basin in Soutpansberg area using Working for Water as a case study

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ABSTRACT

This dissertation focuses on the impact of vegetation clearance on hydrology of Luvuvhu River using Working for Water as a case study. Working for Water Programme (WFW) is a multi-departmental initiative led by the Department of Water Affairs and Forestry and its main aim is enhancement of water security by clearing alien vegetation. Alien vegetations are plants that do not occur naturally in an area and many are classified as weeds. Invasive alien species, particularly tree species, often have increased water usage compared with native vegetation, especially where the latter is short. The study examines how increased water use by alien tree species impact on the hydrology of a river basin.

The study attempts to determine the impacts of alien vegetation on hydrology by analyzing temporal hydrological trends up to 1995 and after 1995 when Working for Water Programme was initiated. Rainfall data, stream flow data and evaporation data have been used in the analysis of temporal trends before and after the working for water programme started their alien vegetation clearance activities. Standardized Precipitation Index (SPI) was used to analyse the rainfall data. This involved computing the SPI values for the rainfall time series data. Flow duration curves were used to determine the percentage of time flows stays in the river and changes in flow magnitudes.

The results of the study though determined from the limited hydrological data sets available indicated that the changes in stream flow were due to alien vegetation clearance and global warming. The study recommends improvement in monitoring the hydrological components in order to have accurate, reliable and continuous information that can be used to determine the hydrological impacts associated with alien vegetation.

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DECLARATION BY THE CANDIDATE

I hereby declare that the work reported in this dissertation is my original work and has not been submitted for similar degree in any other University. Sources sited have been outlined in the References.

Maumela -- 30/08/2010

Maumela Azwihangwisi Doris   Date

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ACRONYMS

CFCs	Chlouro-Fluoro Carbons
CO2	Carbon dioxide
CSIR	Council of Scientific and Industrial Research
DWA	Department of water Affairs
ENSO	El Niño-Southern-Oscillation
GCM	General Circulation Model
IAPs	Invading Aliẹn Plants
IPCC	Intergovernmental Panel of Climate Change
KNP	Kruger National Park
MAP	Mean Annual Precipitation
MAR	Mean Annual Runoff
NCWSTI	National Community Water and Sanitation Training Institute
NRF	National Research Foundation
S2	Sample variance
SA	South Africa
SADC	South African Development Community
SAWS	South African Weather Services
SOI	Southern Oscillation Index
SPI	Standardized Precipitation Index
SSTs	Sea Surface Temperatures
UNIVEN	University of Venda
WFW	Working For Water
WRC	Water Research Commission

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CHAPTER ONE: INTRODUCTION

1.1 Background of the Working for Water Programme

It is now well recognized that invasive alien species, particularly tree species, often have much increased water usage compared with native vegetation, especially where the latter is short. The reason for increased water usage is because they have a deep tap root system of which the majority of the root is situated within the first 0.55m below the soil surface. The remaining portion of the root (sinker root) penetrates into the lower soil layers. They also have millions of tiny pores (stomata) in their leaves. These let carbon dioxide into the leaves and, in the process, let water out, like opening and closing a tap (DWAF, 2002). EnviroTech (1999) defines alien as plants that do not occur naturally in an area and many are classified as weeds. These plants have been brought to South Africa from other countries and planted by man for various reasons.

It is important to examine how increased water use by alien tree species impact on the hydrology of a river basin. The answer to this question is important so that alien species control schemes and financial resources directed at eradication programmes for alien invaders can be justified (Dye et al., 1996).

DWAF (1998) indicated that about 10 million hectares of land in South Africa are infested with invasive alien plants. They out-compete and replace the natural vegetation and are undesirable because they impact on indigenous biodiversity and may use more water than the natural vegetation they replace (DWAF, 1998). The effect on runoff is similar to the deliberate planting of trees for commercial use, which is a declared stream flow reduction activity (DWAF, 1998).

Alien vegetation removal in South Africa is undertaken by the Working for Water Programme. Clearing work is undertaken by the programme on State-owned land (in nature conservation areas, for instance) and also on privately-owned land. Agreement is sought with the landowner to ensure that the land is kept free of infestations of invasive alien vegetation after initial clearing is completed. In cases where landowners are unwilling to enter into such agreements, regulations under the Conservation of Agricultural Resources Act (DWAF, 2002) are used to enforce follow-

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up work by the landowners. These regulations specify certain alien plants, which must be removed from land, others which may be grown only with a permit, and others which may not be sold or propagated. Enforcement is in co-operation with government agricultural agencies.

Working for Water Programme (WFW) is a multi-departmental initiative led by the department of Water Affairs and Forestry. When Working for Water Programme started in the then Northern Province (now Limpopo Province) in 1995, it had a total budget of 1.2 million rands. By the year 2003 the province had 42 million rands budget and 2050 employees who are responsible for clearing the Limpopo Province invading alien species (DWAF, 2002).

DWAF (2002) explains that since its inception, the WFW Programme has cleared more than 80 hectares of invading alien plants in the Limpopo Province alone. Follow up work has also been undertaken in the entire area. Almost all of the most aggressive invading alien species found in South Africa are prevalent in the Limpopo Province. The most serious of these invader species are triffid weed, *lantana*, black wattle, silver wattle, blue gum, mauritiuous thorn, syringa, bug weed, castor oil plant and polar.

The core aims of the Working for Water Programme include:

- Enhancement of water security and
- Improvement in ecological integrity.

The WFW Programme started after the realization that the alien species utilize a lot of water. Invading alien plants (IAPs) are the single biggest threat to plant and animal biodiversity. The cost of controlling IAPs in South Africa is estimated at 600 million rands a year over 20 years (DWAF, 2002). If IAPs are left uncontrolled, the problem has been projected to double within 15 years (DWAF, 2002). IAPs waste 7% of the water resources (Calder, 1992); reduce the ability to farm; cause slow recharge, reduce flooding; reduce erosion, and can cause a mass extinction of indigenous plants and animals (DWAF, 2002).

The Working for Water Programme is currently funded largely through special poverty relief funds (Calder, 1992). In the medium-term, it is intended to move to a situation in which the land

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managers (especially provincial conservation and agriculture departments, as well as private land owners) undertake alien vegetation control as a core element of their activities, with oversight and support from the national programme, and in which public sector land managers are adequately funded for this purpose (Calder, 1992). A key principle guiding the programme is that land owners, custodians and managers, both private and public, should take responsibility for the control of alien vegetation in their areas (Calder, 1992).

From a water resource management perspective, alien vegetation control in specific catchments may be prioritized by considering the level of water stress in the catchment – the balance between water availability and water requirements – and the probable increase in runoff that will result from clearance (Dye *et al.*, 1996). In these cases the costs of vegetation clearance activities contribute to improved water security. It is necessary for this study to assess the necessity of afforestation as a means of reducing erosion and providing a water catchment area versus deforestation or alien vegetation clearance as a means of increasing stream flow.

The Working for Water Programme is concentrating on clearing the alien plant species from the riparian areas. The chopping down and removal of the alien plants clear the water ways and increases flow speed and amount of water in the river (Calder, 1992).

1.2 Statement of the Problem and Motivation

A primary rationale of the Working for Water Programme is the increase in stream flow, which is considered to result from the removal of the water consuming weed species. Positive economic return will only accompany such an investment, if the volume of water increased through clearance can be beneficially utilized, and if the cost of generating water in a catchment is less than the cost of improving water security through other means such as constructing dams.

Part of the rainfall that is intercepted by the vegetation is evaporated back into the atmosphere together with the water that has transpired from the aerial parts of the plants. Since most of the water used by the alien plants is evapotranspired back into the atmosphere, they become part of the hydrological cycle. If the evapotranspired water falls back in the same catchment or

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contributes to the increase in rainfall frequency or amount then it may not be appropriate to consider it as a loss.

However, if the wind system is unfavorable and the evapotranspired water is driven out of the catchment of interest, then it constitutes a loss. The fundamental issue is on how to determine this? By studying the temporal trends of rainfall before and after the removal of alien vegetation started in the catchment of interest, it becomes possible to infer the impacts.

If the rainfall frequency or rainfall amounts have increased, it can be argued that the water loss by alien vegetation is really not a permanent loss but a temporary loss as the same water will still be available for later use in the same catchment. If the rainfall frequency or rainfall amounts have decreased then the water use by alien vegetation is a net loss to the catchment. In this case alien vegetation is undesirable. This must also recognize the fact that the El Nino and La Nina wind systems control the rainfall characteristics in South Africa.

Deforestation (clearance of alien vegetation) in principle increases flow into the streams or rivers. However, the important question here is whether this water remains in the catchment of interest or its flow towards the ocean or downstream water bodies is accelerated. Investigating the percentage of time flows of specific magnitudes last in the river (flow duration) within the catchment of interest becomes important. If there is acceleration of flow downstream on clearance of vegetation, then the big question is, is it really a worthy process? The answer to this question will depend on whether the water demand in the catchment will still be met. The study will also examine how the removal of alien vegetation impacts on ground water storage.

The increase of groundwater recharge through afforestation enhances water availability in the catchment and is therefore considered a positive contribution of vegetation to water resources availability. It is therefore important to audit water resources availability in the study catchment with and without vegetation clearance. This will indicate the hydrological response associated with introduction of alien species through afforestation programmes or clearance of the same through Working for Water Programme. In other words the current study is an integrated

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investigation of the hydrological responses and water resources availability associated with the afforesation and deforestation.

The audit should, however, take into account social and economic water demand against the water requirement for the ecosystem sustenance. For example, if it is found that the clearance of alien vegetation do not contribute to in stream flow requirements over longer percentage of time within the catchment of interest, then vegetation clearance may not be having a positive effect on the river ecology in the catchment. This is an important process as it will scientifically validate or disapprove the huge financial resources invested in the activities of the Working for Water Programme.

1.3 Research Objectives

1.3.1 Broad Objective of the Study

- Carry out an audit of vegetation clearance from the catchment and how it influences the hydrology and/or water availability in the drainage basin, physical condition of the catchment and soil erosion.

1.3.2 Specific Objectives

- To investigate the temporal trends of rainfall, stream flow, evaporation, groundwater levels and temperature before and after 1995 and links to alien vegetation clearance and climate change.
- Compare and contrast afforestation as a water catchment method and a means of reducing soil erosion against deforestation of alien species as a means of increasing surface flow and impacting negatively on catchment soil erosion, sedimentation and water quality of the river.
- To determine the percentage of time the increased flow stays in the river and the implication on social, economic and ecological water requirements.

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1.4 Research Hypotheses

1.4.1 Alien vegetation clearance has reduced rainfall amounts received in the study area

1.4.2 Alien vegetation clearance has increased streamflow in the study area

1.4.3 Alien vegetation clearance has reduced groundwater storage in the study area

1.4.4 The hydrological changes associated with alien vegetation clearance have been moderated by increase in temperature and evaporation (climate change)

1.5 Description of the Study Area

1.5.1 Location

Soutpansberg area is situated in the north eastern part of Limpopo Province of South Africa (Fig. 1.1). Working for water in the Limpopo Province carries its activities in three areas namely: Soutpansberg, Tzaneen and Groblersdal area. The study area is Soutpansberg with latitudes of 23°04'02"S and longitudes of 30°04'02''E and has four water loss control projects. These are within Luvuvhu, Mutoti, Nzhelele, and Venda areas. Luvuvhu project falls within two quaternary catchments and the main river is Luvuvhu. Mutoti project falls within four quaternary catchments and the main river is Luvuvhu. Nzhelele project falls within two quaternary catchments and the main river is Nzhelele. Venda project falls within two quaternary catchments and the main rivers are Mutale and Mutshindudi.

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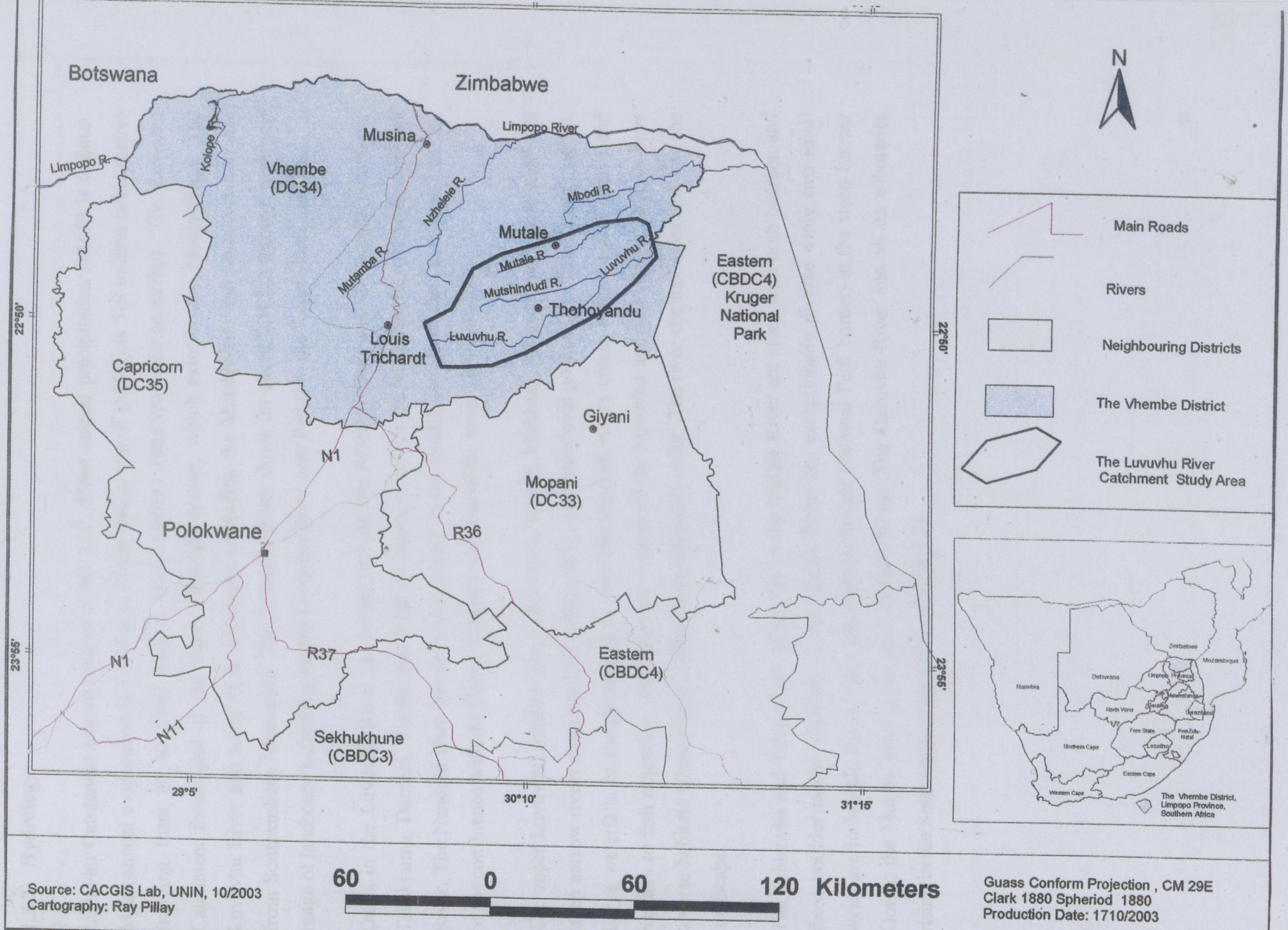

Figure 1.1: Location Of Luvuvhu River Catchment Area

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1.5.2 Hydrology

Luvuvhu Catchment has an area of 5 941 km^2. Mean annual precipitation (MAP) is 608mm. Mean annual evaporation is 1 678 mm. Mean annual runoff (MAR) is 519 million cubic metres (ranging from 85 to 1900 million cubic metres) (http:www.csir.co.za/rhp). The Luvuvhu Catchment forms part of the larger Limpopo system, which extends into Mozambique. The Luvuvhu River and some of its tributaries (including the Mutshindudi and Mutale rivers) rise from Soutpansberg Mountains. The Luvuvhu River flows for about 200 km through a diverse range of landscape before it joins the Limpopo River near Pafuri in the Kruger National Park.

Dams in the Luvuvhu River catchment include the Albasini Dam and the smaller Mambedi, Tshakhuma, Damani, Vondo, and Phiphidi Dams, of which the latter two lie in the Mutshindudi River. The Nandoni Dam has been constructed in the middle section of the Luvuvhu River east of the confluence with the Dzindi tributary and east of the town Thohoyandou.

The upper Luvuvhu, Sterkstroom, Latonyanda, Dzindi, Mukhase, Mbwedi and Mutshindudi are steep narrow rivers dominated by cobble riffles and occasional pools with a few bedrock rapids. Large waterfalls in the upper Dzindi and Mutshindudi rivers create natural reach breaks and barriers to fish migration. The Lowveld reaches of the Luvuvhu and Mutshindudi Rivers have diverse habitats where rapids, riffles, runs and pools occur. The river channel is incised into the landscape.

The Tshirovha and Tshiombedi tributaries to the Mutale River are steep with both bedrock and fixed boulder rapids. Habitats in the Mutale River are exceptionally diverse. Only two small weirs are in Mutale River. Near the western Kruger National Park border, in the steep Lanner Gorge, the Mutale River joins the Luvuvhu River. The Luvuvhu River and all its tributaries rising in the Soutpansberg are perennial (Fig 1.2).

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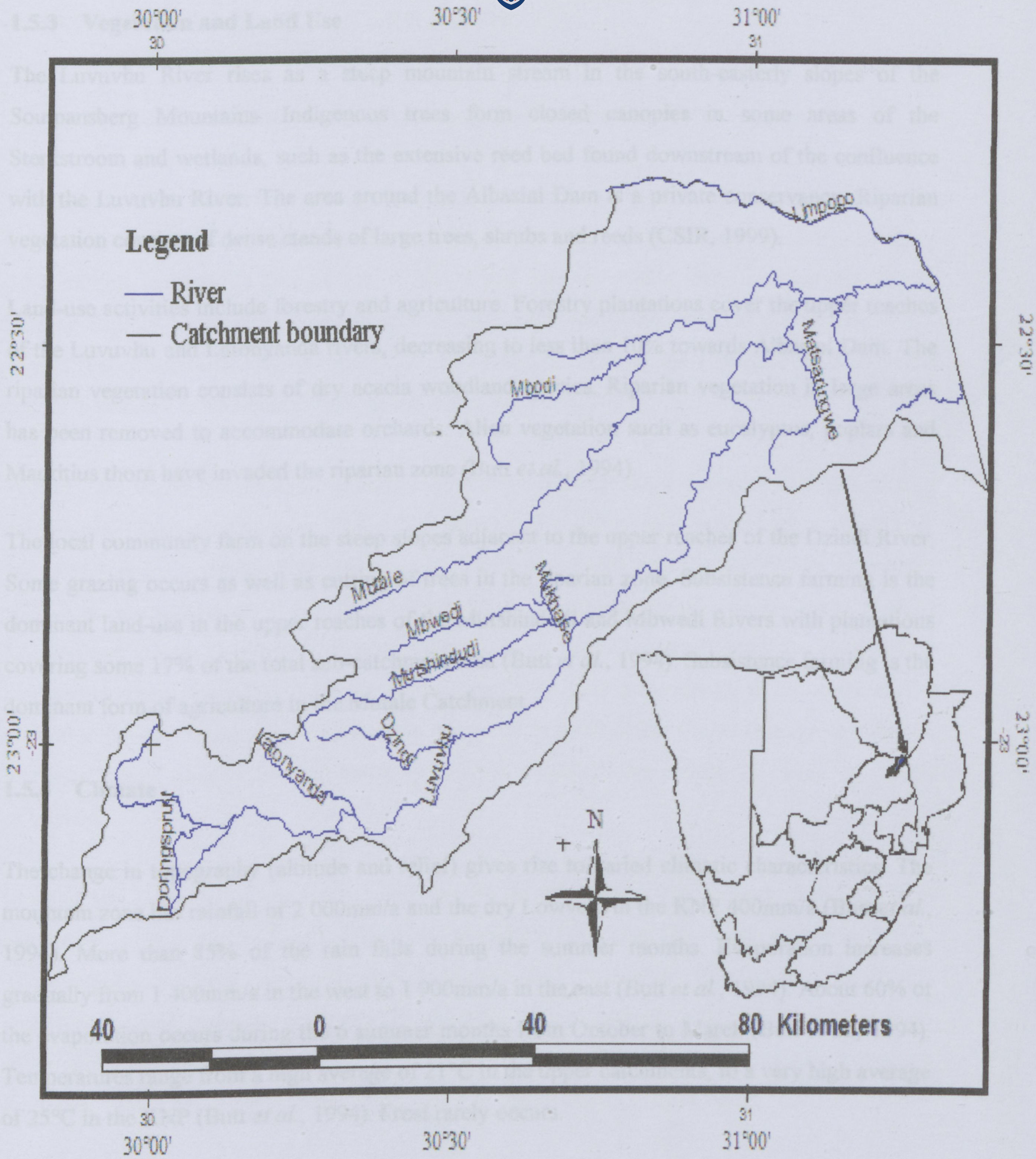

Figure 1.2: Location of Rivers within the Soutpansberg Area

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1.5.3 Vegetation and Land Use

The Luvuvhu River rises as a steep mountain stream in the south-easterly slopes of the Soutpansberg Mountains. Indigenous trees form closed canopies in some areas of the Sterkstroom and wetlands, such as the extensive reed bed found downstream of the confluence with the Luvuvhu River. The area around the Albasini Dam is a private conservancy. Riparian vegetation consists of dense stands of large trees, shrubs and reeds (CSIR, 1999).

Land-use activities include forestry and agriculture. Forestry plantations cover the upper reaches of the Luvuvhu and Latonyanda rivers, decreasing to less than 10% towards Albasini Dam. The riparian vegetation consists of dry acacia woodland species. Riparian vegetation in large areas has been removed to accommodate orchards. Alien vegetation such as eucalyptus, poplars and Mauritius thorn have invaded the riparian zone (Butt *et al.*, 1994).

The local community farm on the steep slopes adjacent to the upper reaches of the Dzindi River. Some grazing occurs as well as cutting of trees in the riparian zone. Subsistence farming is the dominant land-use in the upper reaches of the Mutshindudi and Mbwedi Rivers with plantations covering some 17% of the total sub-catchment area (Butt *et al.*, 1994). Subsistence farming is the dominant form of agriculture in the Mutale Catchment.

1.5.4 Climate

The change in topography (altitude and relief) gives rise to varied climatic characteristics. The mountain zone has rainfall of 2 000mm/a and the dry Lowveld in the KNP 400mm/a (Butt *et al.*, 1994). More than 85% of the rain falls during the summer months. Evaporation increases gradually from 1 400mm/a in the west to 1 900mm/a in the east (Butt *et al.*, 1994). About 60% of the evaporation occurs during the 6 summer months from October to March (Butt *et al.*, 1994). Temperatures range from a high average of 21°C in the upper catchments, to a very high average of 25°C in the KNP (Butt *et al.*, 1994). Frost rarely occurs.

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CHAPTER TWO: LITERATURE REVIEW

2.1 The Impact of Vegetation on Hydrology and Catchment Water Resources

A national review of potential stream-flow reduction by invading alien plants conducted by the CSIR and funded by the Water Research Commission, found in 1997 that a total area of about 10.1 million hectares (6.8%) of South Africa and Lesotho had already become invaded to varying degrees of density. These invasions were estimated to be reducing the national mean annual runoff by about 3300 million m^3 (6.7% of national runoff) and also have impacts on the runoff in primary catchments (Working for Water Research, 2003).

Working for Water Programme has been involved in alien vegetation clearance in South African catchments. Clearing of invasive alien plants along rivers, during relatively low-flow conditions, typically results in stream flow increases of 8 000 to 12 000 litres/ha per day in the winter rainfall season and up to 34 000 litres/ha per day in the summer rainfall season, regardless of location and species (Working for water, 2004). It is important to investigate if the stream flow increase by alien vegetation clearance in the river basin lasts long enough to be of social and economic benefit. Such an investigation is important in establishing the percentage of time the increased runoff stays in the river basins or flows downstream that is depleted out of catchment of interest

Most of the evidence of excessive water use by invading alien trees comes from long-term catchment experiments in South Africa and elsewhere (Working for Water Research, 2003). These experiments have been established in high-rainfall areas where shrublands or grasslands were forested with pines or eucalyptus (Working for Water Research, 2003). The results of these experiments have been used, together with crude estimates of the extent of invasion, to make a preliminary estimate of the size and significance of the problem in South Africa (DWAF, 2004).

Since invasive vegetation is in the first instance a land management issue, with strong environmental considerations due to its impact on biodiversity, its management must be approached in a co-ordinated multi-sectoral way (DWAF, 2004). The Working for Water

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Programme, which was initiated by the Department of Water Affairs and Forestry (DWAF), is now a joint programme of the Department of Environmental Affairs, the National Department of Agriculture and DWA, all of which aim to progressively clear infestations of invasive alien plants everywhere in the country, and ensure that follow-up work is undertaken so that they do not recur. Their activities protect biodiversity and catchment runoff.

Tree planting is recognized as a suitable method for reducing runoff and erosion, especially if applied to headwater catchments as a means of regulating floods (Yu, 1984). Many countries now have afforestation programmes aimed at arresting erosion (Yu, 1984). Those in India, Malagassy Republic, Philippines, Bolivia, Jamaica, Trinidad and Tobago and Mexico are briefly described by Tejwani *et al.* (1961).

Tejwani *et al.* (1961) confirms that afforestation can be used as a means of reducing erosion and as a water catchment area. Afforestation has been used in Taihang Mountains where prior to the rise of the Qing Dynasty in the sixteen century, the area was densely forested (Yu, 1984). By 1949 however only two percent remained under trees but this has now been increased to 10 % (Yu, 1984). Trees were planted along with bushes and grasses and the afforested areas closed to grazing and full gathering (Yu, 1984).

Yu (1984) explains that forests reduce the amount of water entering a stream in two ways. First, the forest canopy intercepts rainfall and evaporates it back into the atmosphere. The effect of this is the reduction of the amount of rainfall reaching the ground and generating runoff to streams. Second, tree roots also take up water from the soil and transpire this back into the atmosphere. This is called transpiration.

By intercepting rainfall, trees reduce direct runoff to streams, and replenishment of storage areas (Yu, 1984). However, some of the intercepted rainfall reach the ground surface at non erosive velocities and infiltrate to enhance groundwater recharge (Yu, 1984). By preventing water from reaching the stream, afforestation reduces stream flow, much like a direct abstraction (Yu, 1984).

Yu (1984) confirmed that trees intercept more rainfall than pasture grasses, per hectare of catchment, due to their greater leaf surface. Maximum transpiration rates for trees and pasture

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are similar, however the trees are able to maintain high transpiration rates for longer times during low rainfall because their roots can tap a greater depth of soil moisture than pasture grasses (Yu, 1984).

The interception effect of trees during rainfall is the dominant impact of trees on water storage and stream flows. Rainfall provides direct runoff to streams and supplies water to replenish storage areas that will continue to generate runoff during periods of low rainfall (Bosch and Hewlett, 1982).

Previous catchment studies of changes in land use cover have shown that coniferous and eucalyptus forests had the greatest effect on water yield, followed by deciduous hardwoods, scrub, tussock and then pasture (Bosch and Hewlett, 1982).

Bosch and Hewlett (1982) confirm that afforestation may also have important consequences for groundwater yields. Apart from reducing the rainfall intensity and increasing infiltration or deep percolation for groundwater recharge, forest cover may intercept water that formerly would have directly recharged groundwater resources. It is therefore important to assess the hydrological impacts of afforestation and alien vegetation clearance on water storage or groundwater recharge in the study basin.

Soil erosion and runoff affect water resources directly by delivering sediment, pollutants attached to sediment, and pollutants in solution to surface water; indirect effects occur through changes in stream channel dynamics and watershed functions (Bosch and Hewlett, 1982). In addition, the partitioning of precipitation between runoff and infiltration has profound effects on water budgets in watersheds (Bosch and Hewlett, 1982).

Nearing (2001) describes runoff volume, depth, and flow velocity as parameters that increase with increasing volume and intensity of precipitation. Erosion is the process of soil particle detachment and movement. Water flowing across the soil surface—surface runoff—is the most important detachment and transport mechanism. The erosive power of surface runoff is determined by the depth of flow, flow velocity, and the number and energy of particles flowing with the water.

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The capacity for surface runoff to carry soil particles increases as flow depth and velocity increases; this capacity, therefore, increases as the volume and intensity of precipitation increase (Wischmeier and Smith, 1960). Indeed, rainfall erosivity is strongly correlated to the product of total rainstorm energy and the maximum 30-minute rainfall intensity during a storm (Wischmeier and Smith, 1960). The relationship has proved to be robust and is still used in the soil erosion prediction equations that are the foundation for erosion control planning in the United States (Nearing, 2001). When WFW programme clears alien vegetation, the land remains bare with limited cover from indigenous vegetation; this creates a high chance of erosion, making it an important aspect of this study.

Soil erosion by water remains one of the most important forces of soil degradation worldwide. Environmental and ecological functions of soil are degraded by soil erosion. Accelerated erosion is the dominant cause of soil degradation globally; water erosion affects an estimated 1,094 million hectares (2,706 million acres) (Oldeman, 1994).

Sediment transported to surface water by erosion tends to carry a higher concentration of pollutants than is contained in the topsoil generally (Oldeman, 1994). This is because the heavier particles of sand and silt in runoff fall out of suspension more easily than clay and organic matter particles. Because clay and organic matter have high specific surface area and a higher proportion of cation exchange sites, eroded sediment contains a higher proportion of nutrient ions, like phosphate and ammonium, relative to the bulk soil from which it eroded—a process called enrichment (Bosch and Hewlett, 1982). Researchers have studied this process and calculated enrichment ratios for various sediment components and soil management conditions (Sharpley *et al*., 1995; Young *et al*., 1986).

Assessment of sediment status of rivers and water impoundments gives an indication of the available water storage capacity of these systems. Assessment of the water quality on the other hand indicates the pollution status of the river, which can be linked to specific causes.

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2.2 Overview of the Current South African Water Resources

South Africa is a water stressed country with an average annual rainfall of 500mm (60% of the world average). Only a narrow region along the south eastern coastline receives good rainfall, while the greater part of the interior and western part of the country is arid or semi-arid. 65% of the country receives less than 500mm per year, which is usually regarded as the minimum for dry land farming (DWAF, 1994). 21% of the country receives less than 200mm per year (DWAF, 1994).

The natural availability of water across the country is variable, and rainfall displays strong seasonality. Stream flow in South African rivers is at a relatively low level for most of the year. This feature limits the proportion of stream flow that can be relied upon for use. Moreover, as a result of the excessive extraction of water by extensive forests and sugar cane plantations in the relatively wetter areas of the country, only 9% of the rainfall reaches the rivers, compared to the world average of 31% (DWAF, 1996). Rainfall variability also has implications for water related disasters such as floods and droughts. Many urban and industrial developments, as well as some dense rural settlements, have been established in remote locations at a distance from adequate reliable water sources (DWAF, 1996). As a result, the requirement for water already far exceed the natural availability of water in several river basins, and therefore large scale transfers of water across catchments have been implemented, like the Lesotho highlands water scheme (DWAF, 1996).

Groundwater also has an important role to play in rural water supplies, but few major groundwater aquifers exist that can be utilized on a large scale due to high salinity and low water yielding fractured aquifers in most parts of the country. It is estimated that about 5 400 million cubic meters of water a year could be obtained from underground sources (DWAF, 1994).

2.3 Climate Change and Water Resources in South Africa

The potential impact of climate change on human society is through its effect on water resources (Ringuies *et al.*, 1997). The most critical factor associated with climate change impact is the

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availability of water resources. People dependent on river basins and wetlands face losses of freshwater biodiversity and a reduction in ecosystems services such as water supply, and floods control (Ringuies *et al.*, 1997).

The major effect of climate change on water systems is through changes in the hydrological cycle, the balance of temperature and rainfall (Ringuies *et al.*, 1997). Climate change may affect development directly through changes in precipitation, evaporation and hydrology, water level rise or fall in water systems and changes in the occurrence of extreme weather events (floods and droughts, storms) that would impact on primary production, ecological systems, public health and poverty (Ringuies *et al.*, 1997). Increased intensity of droughts, floods and changes in growing seasons may have significant implications on soil productivity, water supply, food security, and in turn human welfare and poverty (Ringuies *et al.*, 1997).

Water is an integral part of the ecosystem, a natural resource, a social and economic good, whose quantity and quality determines the nature of its utilization (Ringuies *et al.*, 1997). Water is a limiting resource for development in Southern Africa and a change in water supply could have major implications in most sectors of the economy, especially in the agricultural sector. Factors that contribute to the vulnerability in water systems in Southern Africa include seasonal and inter annual variations in rainfall, which are amplified by high run-off production and evaporation rates (OTA, 1993).

Climate change is expected to alter the present hydrological resources in Southern Africa and add pressure on the adaptability of future water resources (OTA, 1993). Droughts have been widespread in Africa, for example in 1986-88 and 1991-92 there were droughts which were attributed to El Nino (Chenje & Johnson, 1996). Water scarcity is a problem in many parts of the Southern African Development Community (SADC) region. Poor distribution of water resources and pollution coupled with frequent droughts and floods has led to direct hardship for many people, particularly the poor, since it has affected food security (DWAF, 1996), specifically for subsistence farmers. If the occurrence of drought becomes more frequent, the impact on water resources, and consequently agriculture, would be significant.

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In light of the above, the available literature suggests that it will be prudent to account for climate change in evaluating the hydrological components that contribute to availability of water for supply. The former minister of water Affairs and forestry, Mr. Ronnie Kasrils acknowledged that "it is possible that effects of global climate change will influence the availability of water and patterns of use during the next few decades" (Kasrils, 2002)).

El Niño is the name given to the phenomenon which occurs when sea-surface temperatures (SSTs) in the equatorial Pacific Ocean off the South American coast becomes warmer than normal. These persisting warm SSTs influence the atmospheric circulation and consequently change climate patterns globally (SA Weather Services, 2003). Amongst them were the 1997-98 events, by many measures the strongest thus far this century (SA Weather Services, 2003).

Sea-surface temperature (SST) *anomalies* are used to measure the state of the global oceans (SA Weather Services, 2003). If the ocean is warmer than usual, it will have a higher SST value than the mean and therefore a positive anomaly and a colder-than-usual ocean will give rise to a negative anomaly. El Niño events are associated with positive SST anomalies (SA Weather Services, 2003).

The Southern Oscillation Index (SOI) gives a simple measure of the strength and phase of the anomalous sea-level pressure difference in terms of standard deviations from the climatologically monthly mean (SA Weather Services, 2003). The changes in the Pacific Ocean are represented by the term "*El Niño/La Niña*", while the changes in the atmosphere are known as the "Southern Oscillation" (SA Weather Services, 2003). Because these two cannot be separated, the term ENSO (**E**l **N**iño-**S**outhern-**O**scillation) is often used (SA Weather Services, 2003). ENSO refers to both El Niño and La Niña. La Niña is the opposite of El Niño (SA Weather Services, 2003).

El Niño influences only about 30% of South Africa's rainfall during the summer rainfall season, that is October to March (SA Weather Services, 2003). Amongst others, the sea-surface temperatures around southern Africa and the atmospheric circulation over the country also play important roles in determining climate conditions (SA Weather Services, 2003).

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2.4 Greenhouse Effect and Climate Change

Global Circulation Model projections show that as a result of increasing greenhouse gas concentrations, the average global temperature will increase by 1.4–5.8°C (34.52–42.44°F) by 2100 (IPCC, 2001). With the projected global temperature increase, some scientists think that the global hydrological cycle will also intensify (OTA, 1993). GCMs indicate that global precipitation could increase by 7–15% (OTA, 1993). Meanwhile, global evapotranspiration could increase by 5–10% (OTA, 1993). The models generally show that precipitation will increase at high latitudes and decrease at low and mid-latitudes (OTA, 1993). Therefore, in mid-continent regions, evapotranspiration will be greater than precipitation and there will exist the potential for more severe, longer-lasting droughts in these areas (OTA, 1993).

OTA (1993) reported that though precipitation is likely to increase, it is not known how regional rainfall patterns will change. Some regions may have more rainfall, while others may have less (OTA, 1993). This will be influenced or moderated by local anthropogenic impacts. Furthermore, higher temperatures would probably increase evaporation. These changes would probably create new stresses for many water management systems.

2.5 Effects of Climate Change on Hydrological Systems

The hydrological cycle that operates across the climate system is being intensified (IPCC, 2005) due to apparent changes of global temperature. Thus the principal components of the hydrological cycle, such as rainfall and evaporation, exhibit increased variability.

The changes in rainfall regime have considerable impact on the natural environment and socio economic activities. The water resources systems that substantially support our daily activities are extremely sensitive to rainfall variability. The water supply systems may not provide enough water unless rainfall sufficiently replenishes surface and ground water reservoirs. Persistence of dry spells for exceptionally longer periods affect agricultural activities, water quality of streams and lakes, and even might cause wild fires. During extremely intense and prolonged flood events, the capacities of streams are increased (IPCC, 2005).

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2.6 The Standardized Precipitation Index (SPI)

The Standardized Precipitation Index (SPI) concept involves standardization of precipitation values in order to calculate the Z score for new values for normal distribution. The Z score is the difference of the values from the mean divided by the standard deviation. Kenney and Keeping (1962) defines SPI as the representation of the number of standard deviations from the mean at which an event occurs, often called a "z-score".

Technically, the SPI is the number of standard deviations that the observed value would deviate from the long-term mean, for a normally distributed random variable (Mckee *et al.*, 1993). Since precipitation is not normally distributed, a transformation is first applied so that the transformed precipitation values follow a normal distribution (Mckee *et al.*, 1993).

According to the information reviewed from Mckee *et al.* (1993), mathematically, the SPI is based on the cumulative probability of a given rainfall event occurring at a station. The historic rainfall data of the station is fitted to a gamma distribution, as the gamma distribution has been found to fit the precipitation distribution quite well (Mckee *et al.*, 1993). In simple terms, the process described above allows the rainfall distribution at the station to be effectively represented by a mathematical cumulative probability function (Mckee *et al.*, 1993). The cumulative probability gamma function is transferred into a standard normal random variable Z with mean of zero and standard deviation of one, which is the SPI.

In summary therefore, the SPI can effectively represent the amount of rainfall over a given time scale, with the advantage that it provides not only information on the amount of rainfall, but that it also gives an indication of what this amount is in relation to the normal distribution, thus leading to the definition of whether a station is experiencing drought or not (Kenney and Keeping, 1962). It gives output in units of standard deviation from the average based on as-long-a-rainfall-distribution-as-there-is-data-for (Hayes *et al.*, 1999). The longer the period used to calculate the distribution parameters, the more likely you are to get better results (e.g. 50 years better than 20 years) (Kenney and Keeping, 1962).

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The SPI was designed to state that it is possible to simultaneously experience wet conditions on one or more time scales, and dry conditions at other time scales (Hayes *et al.*, 1999). Hayes *et al.* (1999) developed a SPI classification system shown on Table 2.1 below.

Table 2.1: SPI classification (Hayes *et al.*, 1999)

SPI Value	Drought Category
2.00 and above	Extremely wet
1.5 to 1.99	Very wet
1. to 1.49	moderately wet
-0.99 to 0.99	near normal
-1.00 to -1.49	moderately dry
-1.50 to -1.99	severely dry
-2.00 and less	extremely dry

2.7 Discharge Fluctuations in the River with Time

Flow hydrograph gives discharge in a river cross section over a given time. It therefore shows a temporal trend of discharge in the river. A hydrograph can therefore be used to show discharge fluctuations in the river with time (Kesgrave, 1998).

The hydrograph behavior varies with a number of catchment conditions including the land cover type, soil texture, antecedent moisture conditions and magnitude and intensity of rainfall (Kesgrave, 1998). Therefore the hydrological response in the river is a function of these variations.

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2.7.1 Typical Hydrograph Response under Different Rainfall Conditions

When rainfall is heavy and lasts for a long time, a lot of run-off is generated. Thus water reaches the river quickly, making the time lag short and discharge high (Fig 2.1) (Kesgrave, 1998)

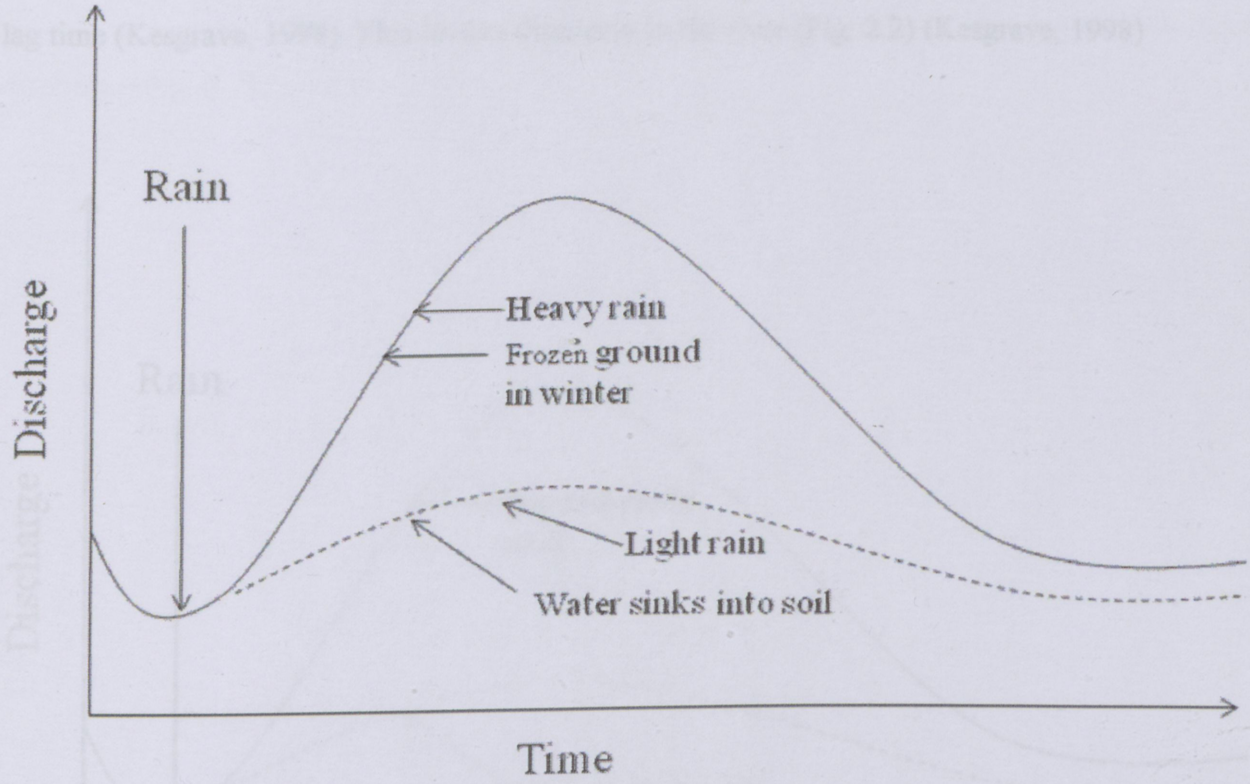

Figure 2.1: Typical hydrograph response under different rainfall conditions

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2.7.2 Typical Hydrograph Response under Different Catchment Surfaces

Impermeable rock does not allow water to infiltrate through it, making a catchment surface area made of impermeable rock to generate a lot of run-off (Kesgrave, 1998). A catchment surface made from permeable rock allows infiltration to occur, thus reducing run-off and increasing the lag time (Kesgrave, 1998). This lowers discharge in the river (Fig. 2.2) (Kesgrave, 1998)

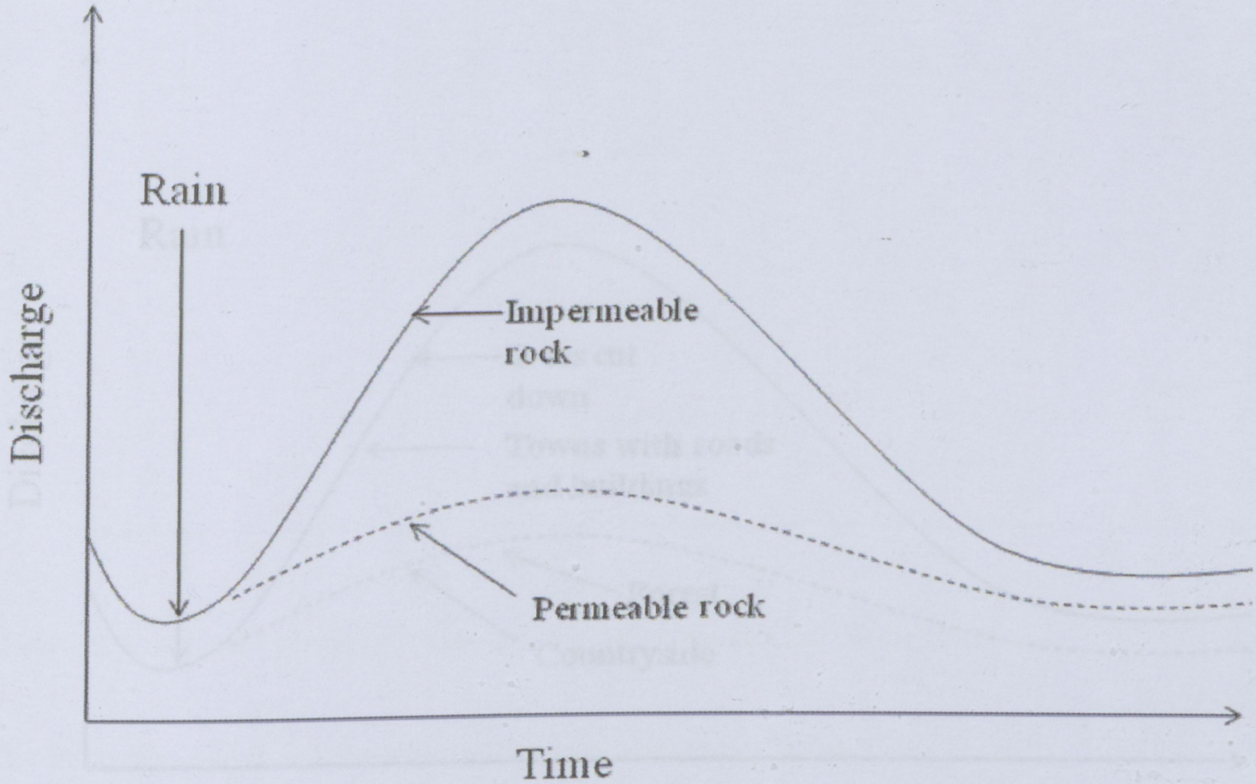

Figure 2.2: Typical hydrograph response with different catchment surface

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2.7.3 Typical Hydrograph Response under Different Land Use Types

Trees in a river catchment area delay water by intercepting it. This reduces run-off and therefore time lag and river discharge (Fig. 2.3) (Kesgrave, 1998). Where land has been built on by humans, the time lag is shortened due to the covering of the ground by impermeable surfaces (tarmac and concrete for example) (Kesgrave, 1998). This decreases the time lag and increases discharge (Fig. 2.3) (Kesgrave, 1998).

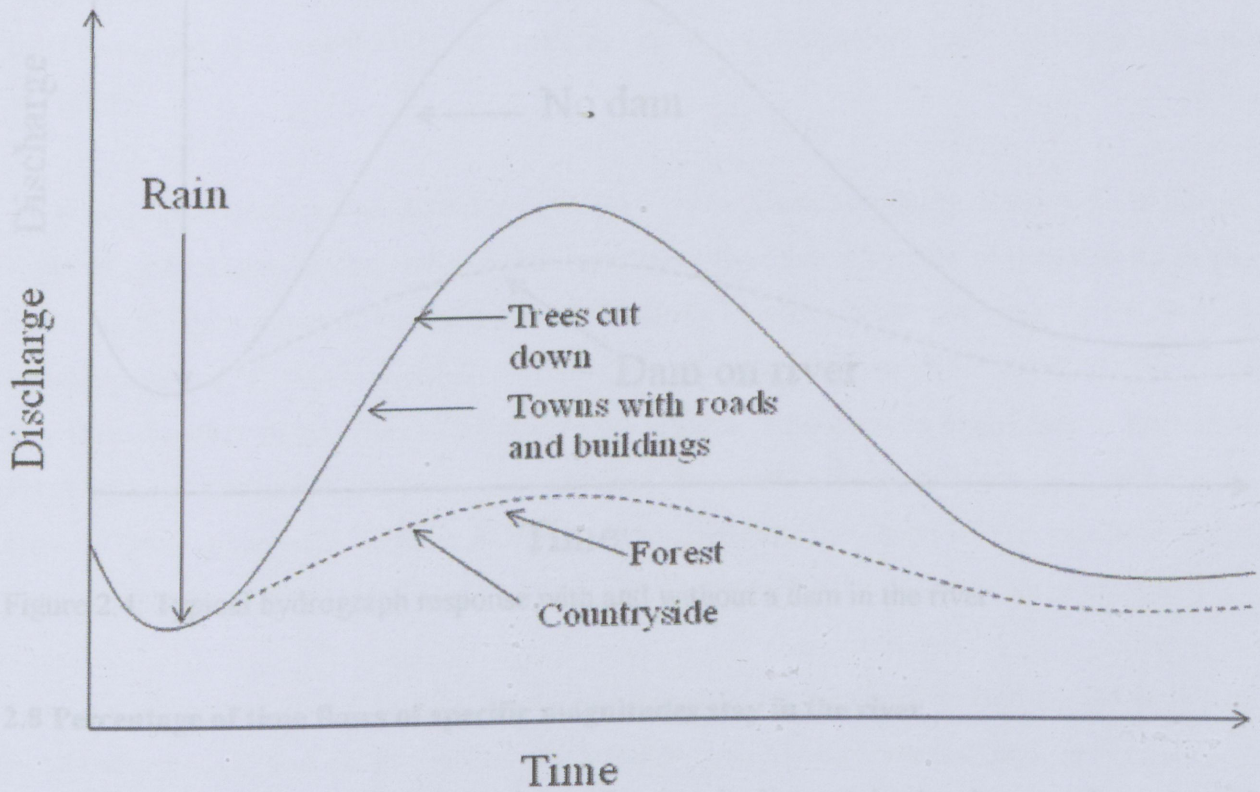

Figure 2.3: Typical hydrograph response under different land use types

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2.7.4 Typical Hydrograph Response With and Without a Dam in the River

Dams built across rivers hold floodwaters back, therefore increasing the time lag and reducing peak discharge (Fig 2.4) (Kesgrave, 1998).

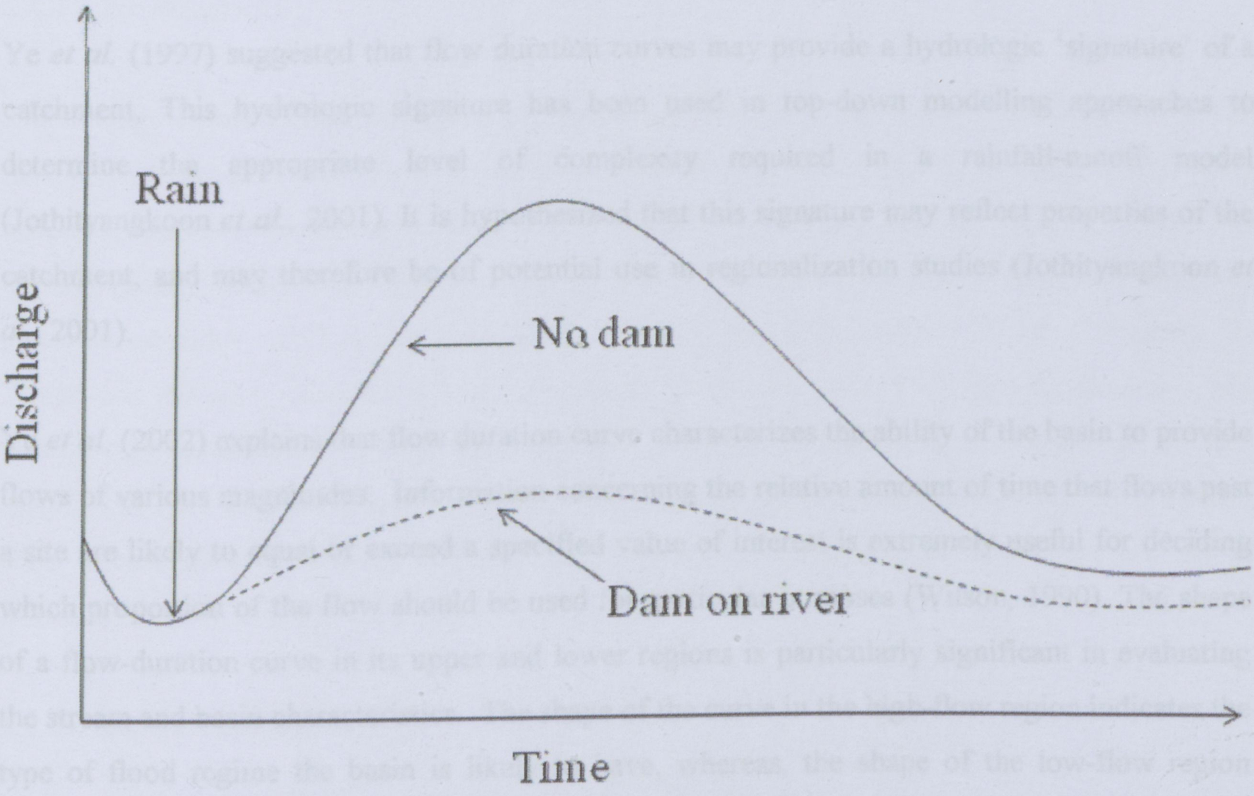

Figure 2.4: Typical hydrograph response with and without a dam in the river

2.8 Percentage of time flows of specific magnitudes stay in the river

The length of time for which flows of specific magnitudes stay in the river can be estimated using the flow duration curve concept. Flow duration curve is a percentage of time flows of specific magnitudes stay in the river. The flow duration curve concept can therefore be used to show whether the increased flow by vegetation clearance stays in the river for a long time at the drainage basin of interest to be of social, economic and ecological value.

Hansen *et al.* (1996) explained that flow duration curve provides information about the percentage of time that a particular streamflow was equalled or exceeded over some historical period. Generally it is represented on a log-normal scale with exceedence probability on the x-

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axis and discharge (or some function of discharge) on the y-axis. Flow duration curves have long been used as means of summarizing catchment hydrologic response. More recently, they have been used to validate the outputs of hydrologic models and/or compare observed and modelled hydrologic response.

Ye *et al.* (1997) suggested that flow duration curves may provide a hydrologic 'signature' of a catchment. This hydrologic signature has been used in top-down modelling approaches to determine the appropriate level of complexity required in a rainfall-runoff model (Jothityangkoon *et al.*, 2001). It is hypothesized that this signature may reflect properties of the catchment, and may therefore be of potential use in regionalization studies (Jothityangkoon *et al.*, 2001).

Yu *et al*. (2002) explains that flow duration curve characterizes the ability of the basin to provide flows of various magnitudes. Information concerning the relative amount of time that flows past a site are likely to equal or exceed a specified value of interest is extremely useful for deciding which proportion of the flow should be used for particular purposes (Wilson, 1990). The shape of a flow-duration curve in its upper and lower regions is particularly significant in evaluating the stream and basin characteristics. The shape of the curve in the high-flow region indicates the type of flood regime the basin is likely to have, whereas, the shape of the low-flow region characterizes the ability of the basin to sustain low flows during dry seasons (Yu *et al*., 2002).

A very steep curve (high flows for short periods) would be expected for rain-caused floods on small watersheds (Yu *et al*., 2002). Snowmelt floods, which last for several days, or regulation of floods with reservoir storage, will generally result in a much flatter curve near the upper limit (Yu *et al*., 2002). In the low-flow region, an intermittent stream would exhibit periods of no flow, whereas, a very flat curve indicates that moderate flows are sustained throughout the year due to natural or artificial streamflow regulation, or due to a large groundwater capacity which sustains the base flow to the stream (Yu *et al*., 2002).

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CHAPTER THREE: DATA AND METHODS OF ANALYSIS

3.1 Data

3.1.1 Rainfall Data

The average monthly rainfall data for 52 years from 1952-2004 has been used in this study. The rainfall data was obtained from South African Weather Services (SAWS) in Pretoria. The rainy season in the Soutpansberg area starts in October and ends in March of the following year. The average monthly rainfall data for the entire period, rainfall peaks, data on computed standardized precipitation index, rainfall data nine years up to and nine years from 1995 when Working for Water was initiated are presented in appendices A1-A3 and A4 (a) –A4 (b) respectively. The rainfall data presented is for one station (A9E002) which is Goedehoop at Albasini Dam. This station was used because it has long period of data. Other stations like A9E001 and A9E003 had short period data with many missing data points and could therefore not provide useful information for this study.

3.1.2 Stream flow data

The data on stream flow was obtained from the Department of Water Affairs (DWA) in Limpopo. The data presented are for three gauging stations in Luvuvhu River namely: Weltevreden station (A9H001), Nooitgedatcht station (A9H005) and Goedehoop station (A9H020). Average monthly stream flow data for Luvuvhu River at Weltevreden, Nooitgedatcht and Goedehoop are presented in Appendices B1to B2 (a) and B2(b), B3 to B4(a) and B4(b) and B5 to B6(a) and B6 (b) respectively. For all these stations, the data presented includes average monthly stream flow for the period 1952 to 2003, average monthly discharges eight years before and eight years after 1995 when working for Water was initiated.

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3.1.3 Evaporation data

The data on evaporation was obtained from DWA. The data is presented in Appendix C1 and Appendix C2. Appendix C1 represents the average monthly evaporation data of Soutpansberg for the period 1952-2003 while Appendix C2 represents the peak average annual evaporation in millimeters (mm). The data presented is for Goedehoop station at Albasini Dam of station number A9E002. Evaporation was recorded from an S class pan in millimeters. The data was used in the analysis of the temporal trends of evaporation in order to determine the impact of alien vegetation removal before and after 1995 and/or the impact of climate change on hydrology.

3.1.4 Groundwater levels

Groundwater levels station A7N019 for February and March of each year are presented in Appendices D1 and D2 respectively. The available data covered only a short period, from 1985-2003. Station A7N019 was used because it was the only station that had the data required for the period 1985-2003. The reason for using February and March data was to compare the behavior of groundwater level trend with the behavior of rainfall and streamflow fluctuations.

3.1.5 Temperature data

The minimum and maximum temperature data for Goldeville at Luvuvhu station number: 0723485A0 was obtained from South African Weather Services (SAWS) in Pretoria and is presented in Appendices E (a) and E (b). Average yearly temperature data eight years up to 1995 and eight years from 1995 was used so that the study could investigate the behavior of minimum and maximum temperatures in the study area. The study investigated the relationship between rainfall and evaporation and how it could be linked to the behavior of streamflow and temperature changes.

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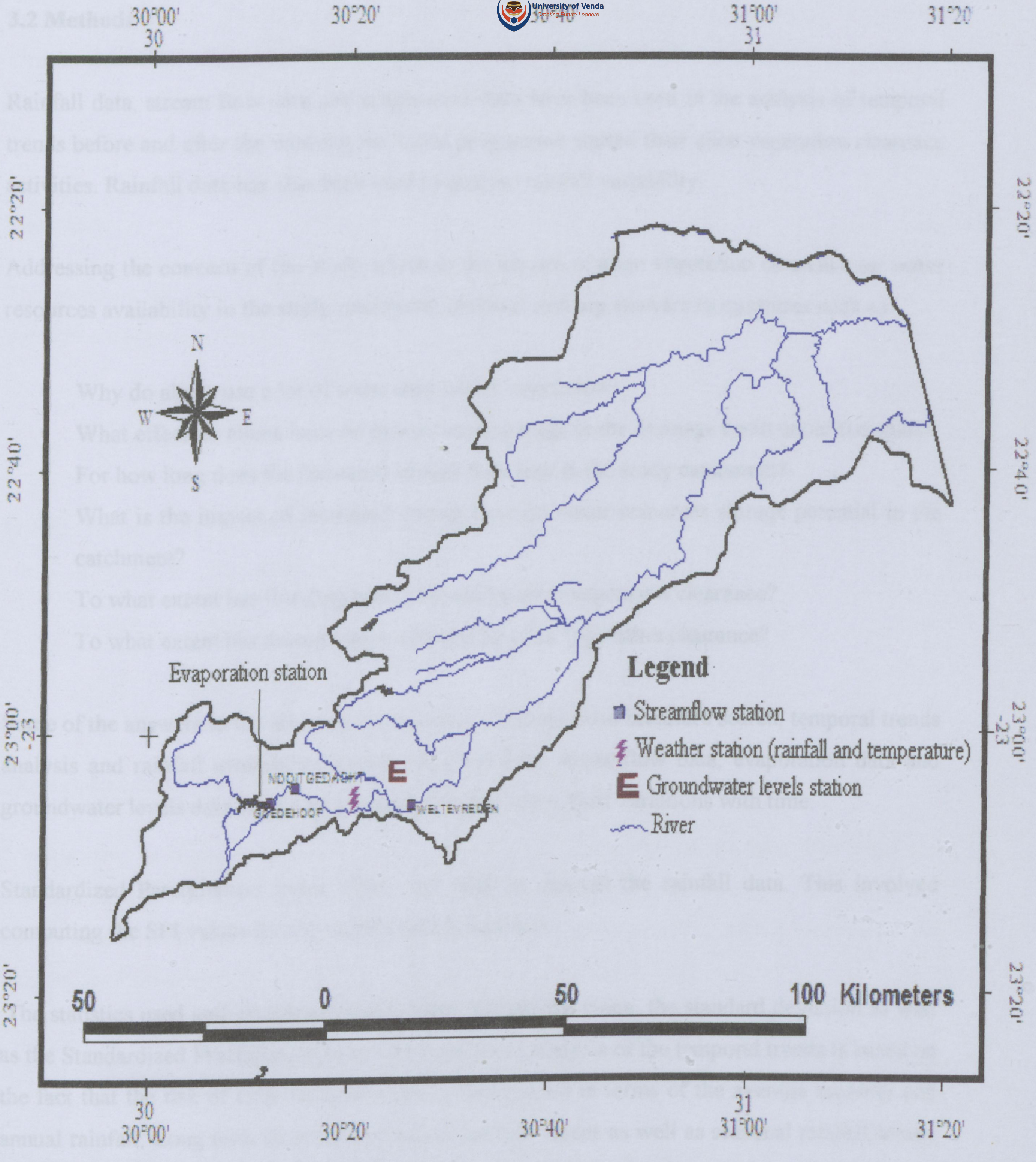

Figure 3.1: Data Stations for Streamflow, Weather Station and Groundwater Level.

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3.2 Methods

Rainfall data, stream flow data and evaporation data have been used in the analysis of temporal trends before and after the working for water programme started their alien vegetation clearance activities. Rainfall data has also been used to analyse rainfall variability.

Addressing the concern of the study which is the impact of alien vegetation clearance on water resources availability in the study catchment, includes seeking answers to questions such as:

- Why do aliens use a lot of water than native vegetation?
- What effect do aliens have on groundwater storage in the drainage basin under the study?
- For how long does the increased stream flow stay in the study catchment?
- What is the impact of increased stream flow on water resources storage potential in the catchment?
- To what extent has flooding been affected by alien vegetation clearance?
- To what extent has drought been affected by alien vegetation clearance?

Some of the answers to the above questions were obtained from literature search, temporal trends analysis and rainfall availability studies. Rainfall data, streamflow data, evaporation data and groundwater levels data were plotted against time to show their variations with time.

Standardized Precipitation Index (SPI) was used to analyse the rainfall data. This involved computing the SPI values for the rainfall time series data.

The statistics used and calculated in this study include the mean, the standard deviation as well as the Standardized Precipitation Index. The statistical analysis of the temporal trends is based on the fact that the risk of extreme events can be understood in terms of the average monthly and annual rainfall. Long term monthly and annual rainfall means as well as seasonal rainfall means were computed using the statistical data described in Section 3.1. The standard deviation was calculated from the long term monthly and annual means for the period 1952-2004 using the

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formula provided in sub-section 3.3. The standardized departures were also calculated using the formula provided in sub-section 3.5

3.2.1. Statistical analysis methods

The mean

The mean or the average, which is the sum of the individuals divided by their number, was computed from the following formula:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \tag{3.1}$$

Where i = Position of each individual data in the sample

n = number of individuals

$\bar{x}$ = Sample mean

$\sum x_i$ = Sum of individuals

The standard deviation

The standard deviation serves as a basic measure of the variability of the data. The larger the standard deviation, the larger is the spread of the data. It is the average deviation from the mean, and is obtained by computing the square root of the variance, which is also a measure of the variability of the data. The sample variance (S^2) is computed from:

$$S^2 = \frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2 \tag{3.2}$$

Where S^2= sample variance, and the rest of the parameters are as defined in Eq. 3.1.

The square root of the sample variance of a set of *N* values is the sample standard deviation:

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$$s_N = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2} \quad (3.3)$$

The square root of the bias-corrected variance gives standard deviation as,

$$s_{N-1} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2} \quad (3.4)$$

The quotient of N-1 instead of N is used to correct the bias in the variance and the standard deviation equation (Eq. 3.3) and has been used to compute this parameter in this study.

3.2.2 Standardization procedure

Temporal trends at each station were standardized by taking the difference between individual monthly values and long term monthly mean and dividing this difference by the standard deviation for each month. This standardization procedure should ensure a zero mean value and a unit variance for each series. The temporal trends data has been standardized using the following equation:

$$Z = \frac{x_i - \bar{x}}{s} \quad (3.5)$$

Where $\bar{x}$ = the historical mean

Z = the standardized departure

x_i = the sum of the individuals

S = the historical sample standard deviation

Since the standardization of data ensures a zero mean, there are years that peak below the mean and those that peak above the mean. Those that peak below the mean are negative values of

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standardized departures and are said to be associated with El Nino events. While positive values of standardized departures peak above the mean and are associated with LA Nina events.

3.2.3 Percentage of Time Flows of Specific Magnitudes Stays In the River

Following the procedure defined by Best *et al.* (2003), streamflow (in cumecs) was standardized by dividing it by the median discharge of the non-zero flow days. This ensures that the log of the standardized streamflow crosses the axis at the median streamflow of the non-zero flow days (since *log* (1) = 0). It is impossible to standardize by the median streamflow over all days because some of the ephemeral catchments in the Burdekin flow for less than 50% of the time (making the median streamflow zero). Streamflow data for Weltevreden, Nooitgedacht and Goedehoop was arranged and used in order to draw the flow duration curve. The following steps were taken:

1. Column 1 - Arrange monthly totals in Excel (for an FDC for a selected month) or annual total (for the annual FDC) in ascending order (starting with the smallest value) and ignoring the dates/years.
2. Column 2 - Next to the totals, insert another column in order to give the entries some numbers. Start with 1 and increment by 1.
3. Column 3 - If the last number in column (3) is n, then insert another column which divides each of the numbers in column 2 by (n+1) and this was expressed as a percentage.
4. Plot the values in column (1)- y value and column (3) - x value on a graph so that an exceedence curve can be created and able to read the off values.

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CHAPTER FOUR: PRESENTATION, ANALYSIS OF DATA AND DISCUSSION OF RESULTS

4.1 Rainfall data

The results of this study show that there are months or years that receive maximum and minimum inputs of rainfall. From September the rain increases progressively until November when it starts to peak and continue to increase in December to February when it peaks (Appendix A1 and Fig. 4.1). Fig. 4.1 below shows two seasons, which are dry season (April to September) and wet season (October to March). Most rainfall is received during wet season while little rain is experienced in dry season (if any). Depending on the amount of rainfall received, a hydrological year can be classified as normal or abnormal. A normal year is a year, which receives rainfall devoid of destructive impacts of abnormal rainfall such as extremely high rainfall, resulting in floods or extremely low rainfall resulting in drought.

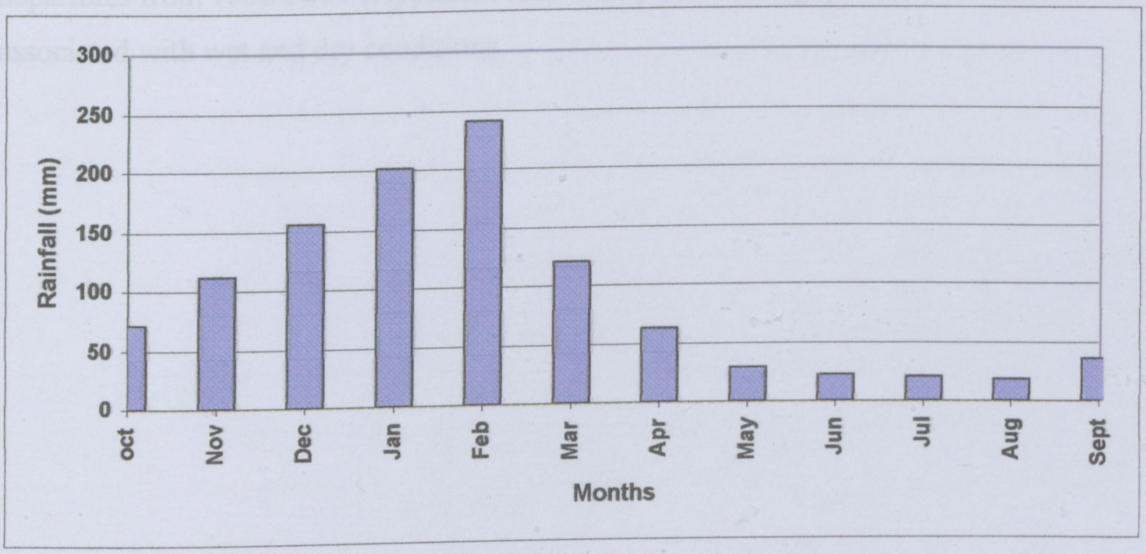

Figure 4.1: Average monthly rainfall for the period 1952-2004

Significant flooding can result during the wet season depending on the amount of rainfall received. The dry months are transitional months; sometimes they can be wet and at times dry. This can happen as a result of natural variability of rainfall as well as other climatic factors

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(Kabanda, 2004). The other climatic factors include temperature, wind velocity and pressure that characteristically prevail in a particular region (Waugh, 1990). It can be seen from Fig. 4.1 and Appendix A1 that the lowest rainfall is in August with an average amount of 18.4mm followed by July with an average amount of 20.9mm. Dry period (April-September) shows significant rainfall deficiency.

4.1.1. Standardized Time Series/ Departures

Monthly rainfall data for the rainfall season (wet season) was standardized and normalized to produce a standardized rainfall time series. This involved computing rainfall indices given in Appendix A2.

Rainfall for the wet months was standardized with respect to yearly mean, long term monthly mean and standard deviation. The long term monthly mean for the wet season (October –March) was found to be 150.4mm and the standard deviation was 71.6mm. The data for the rainfall departures from 1952-2004 (Appendix A2) were plotted in Fig. 4.2. The SPI values are normally associated with wet and dry conditions.

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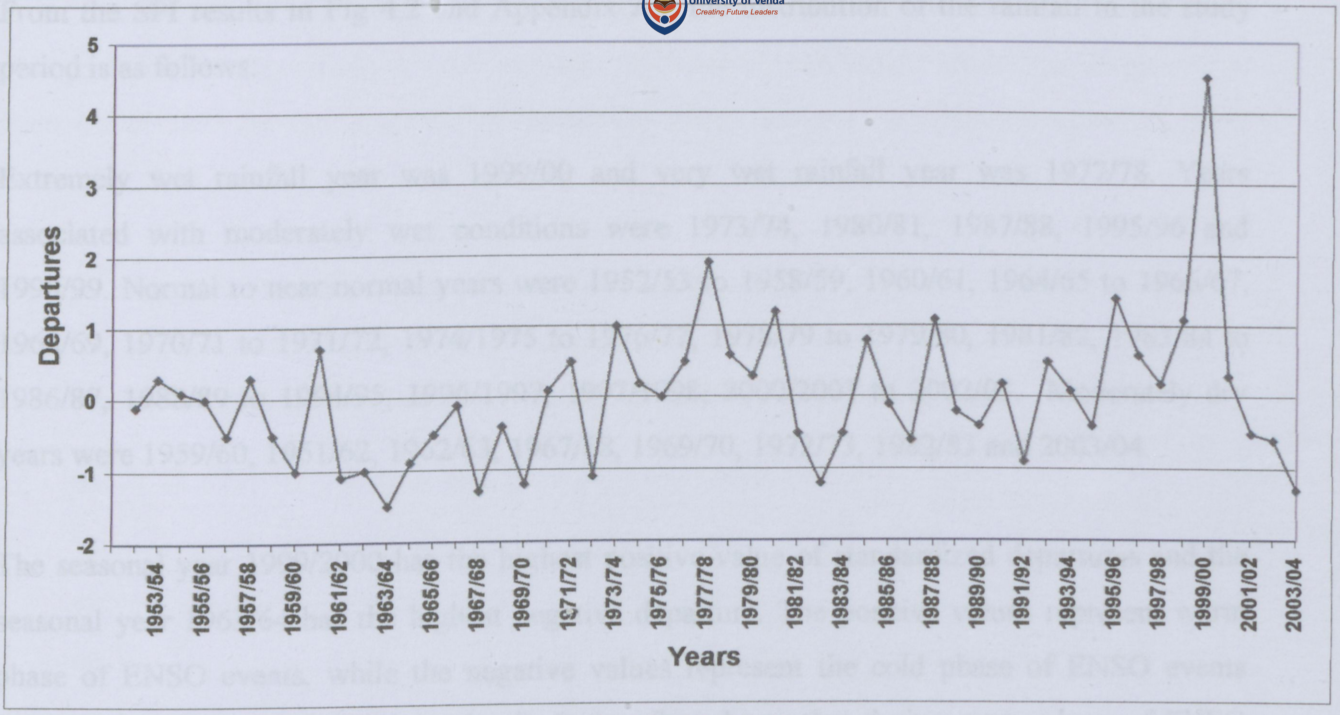

Figure 4.2: Standardized departures for the period 1952-2004

From Appendix A2, the overall mean for the standardized departures was found to be zero. Fig. 4.2 shows that there are years that peak above the mean and those that peak below the mean. There are years of above normal rainfall, normal rainfall, near normal rainfall as well as below normal rainfall. The classification according to Hayes *et al.*, 1999) is presented in Table 4.1.

Table 4.1: SPI classification (Hayes *et al.*, 1999)

SPI	Drought Category	Occurrence
2.00 and above	Extremely wet	1.9%
1.5 to 1.99	Very wet	1.9%
1. to 1.49	Moderately wet	9.6%
-0.99 to 0.99	Near normal	69.2%
-1.00 to -1.49	Moderately dry	15.4%
-1.50 to -0.99	Severely dry	1.9 %
-2.00 and less	Extremely dry	0

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From the SPI results in Fig 4.2 and Appendix A2, the distribution of the rainfall in the study period is as follows:

Extremely wet rainfall year was 1999/00 and very wet rainfall year was 1977/78. Years associated with moderately wet conditions were 1973/74, 1980/81, 1987/88, 1995/96 and 1998/99. Normal to near normal years were 1952/53 to 1958/59, 1960/61, 1964/65 to 1966/67, 1968/69, 1970/71 to 1971/72, 1974/1975 to 1976/77, 1978/79 to 1979/80, 1981/82, 1983/84 to 1986/87, 1988/89 to 1994/95, 1996/1997, 1997/1998, 2000/2001 to 2002/03. Moderately dry years were 1959/60, 1961/62, 1962/63, 1967/68, 1969/70, 1972/73, 1982/83 and 2003/04.

The seasonal year 1999/2000 has the highest positive value of standardized departures and the seasonal year 1963/64 has the highest negative departure. The positive values represent warm phase of ENSO events, while the negative values represent the cold phase of ENSO events (www.Science.gmu.edu/~Zli/elnino.html). It therefore shows that during warm phase of ENSO the area received high rainfall that possibly resulted in flooding while little or no rainfall contributed to drought. Rainfall being the considerable factor that controls the increase or decrease of stream flow, these fluctuations in rainfall amounts received must have contributed to streamflow fluctuations.

Figure 4.3 and Appendix A3 (a) and A3 (b) show the monthly rainfall depth in mm up to and from 1995 respectively when Working for water activities was initiated. It can be seen from Fig 4.3 below that there are fluctuations in terms of rainfall depth received. Before 1995, the highest average rainfall depth of 239.7mm and the lowest average rainfall depth of 12.7mm were received in February and July respectively. The highest average rainfall depth of 443.4mm and lowest average rainfall depth of 10.9mm were also received in February and August after 1995 when Working for water activities was initiated.

It can be observed from Fig 4.3 that there was a general increase in rainfall after 1995 than before 1995. Rainfall played a major role in increasing the amount of water available in the catchment. Vegetation generally has positive influence on rainfall. Thus clearance of vegetation through Working for Water Programme would have been expected to reduce the rainfall. The

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fact that the averaged rainfall generally increased after the clearance started, means that climate change could be responsible for the increase. Alternatively the impact of deforestation has not been outweighed by the impact of afforestation which has continued in the Luvuvhu River catchment.

Climate plays a major role in determining the amount of rainfall received and the availability of water in the catchment. During dry months, less or no rainfall is received in the area while during rainy season a significant amount of rainfall can be received in different areas.

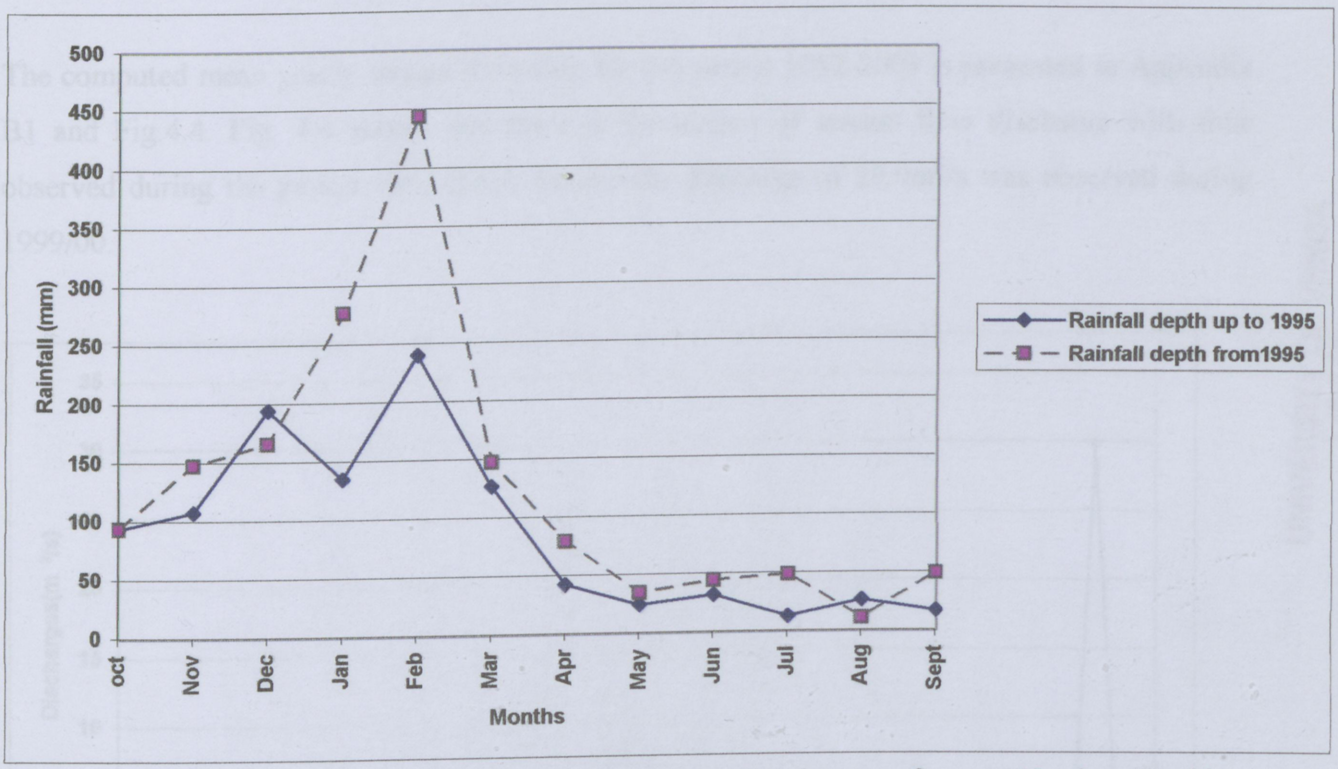

Figure 4.3: Average monthly rainfall eight years up to and eight years from 1995 when Working for Water activities was initiated

Since the observed rainfall data sets indicate an increase in rainfall after vegetation clearance started, there is therefore positive contribution to the amount of water received in the catchment. This signifies potential increase of streamflow as response to rainfall after alien vegetation clearance. Thus alien vegetation clearance has the potential to contribute to positive water security in the Luvuvhu River catchment.

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4.2 Stream Flow Data

Stream flow data was obtained from the Department of Water Affairs for the period 1952-2003. The data used was for three stations namely Weltevreden, Nooitgedacht and Goedehoop. Monthly stream flow data was used to compute the long term monthly mean and annual mean for the period 1952-2003 for all the stations.

4.2.1 Stream Flow Data for Luvuvhu River at Weltevreden.

The computed mean yearly stream flow data for the period 1952-2003 is presented in Appendix B1 and Fig.4.4. Fig. 4.4 shows that there is fluctuation of stream flow discharge with time observed during the period 1952-2003. Maximum discharge of 29.9m^3/s was observed during 1999/00.

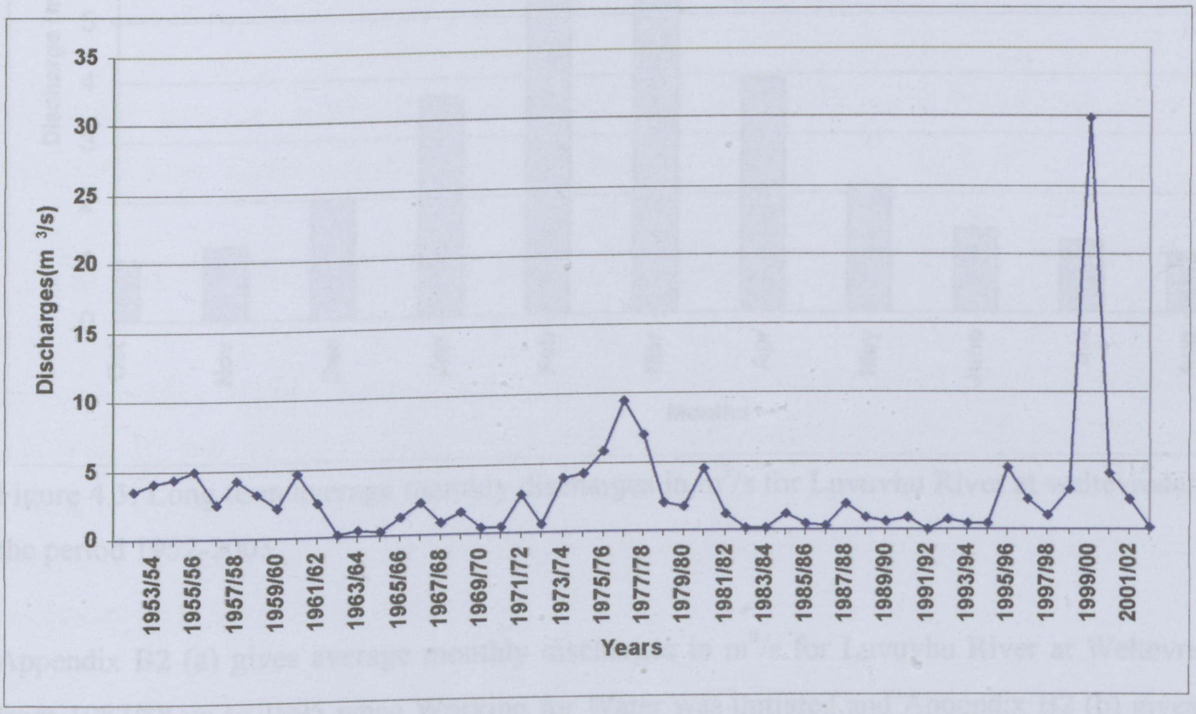

Figure 4.4: Mean yearly discharges in m^3/s of Luvuvhu River at weltevreden for the period 1952-2003.

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Figure 4.5 shows long term average monthly stream flow for the period 1952-2003. It shows that there are months that receive maximum or minimum discharges. Maximum discharge of 7.82 m^3/s was received in March and minimum discharge of 0.96m^3/s was received in September. This data helps in inferring the response of stream flow to rainfall. The main reason is to check if the increase in stream flow is due to alien vegetation removal or amount of rainfall received. It can be noted from Fig. 4.5 that discharges are generally higher during the wet season (Oct-Mar) than dry season (April-Sept). The maximum and the minimum discharges given in Fig. 4.5 correspond to wet and dry seasons respectively.

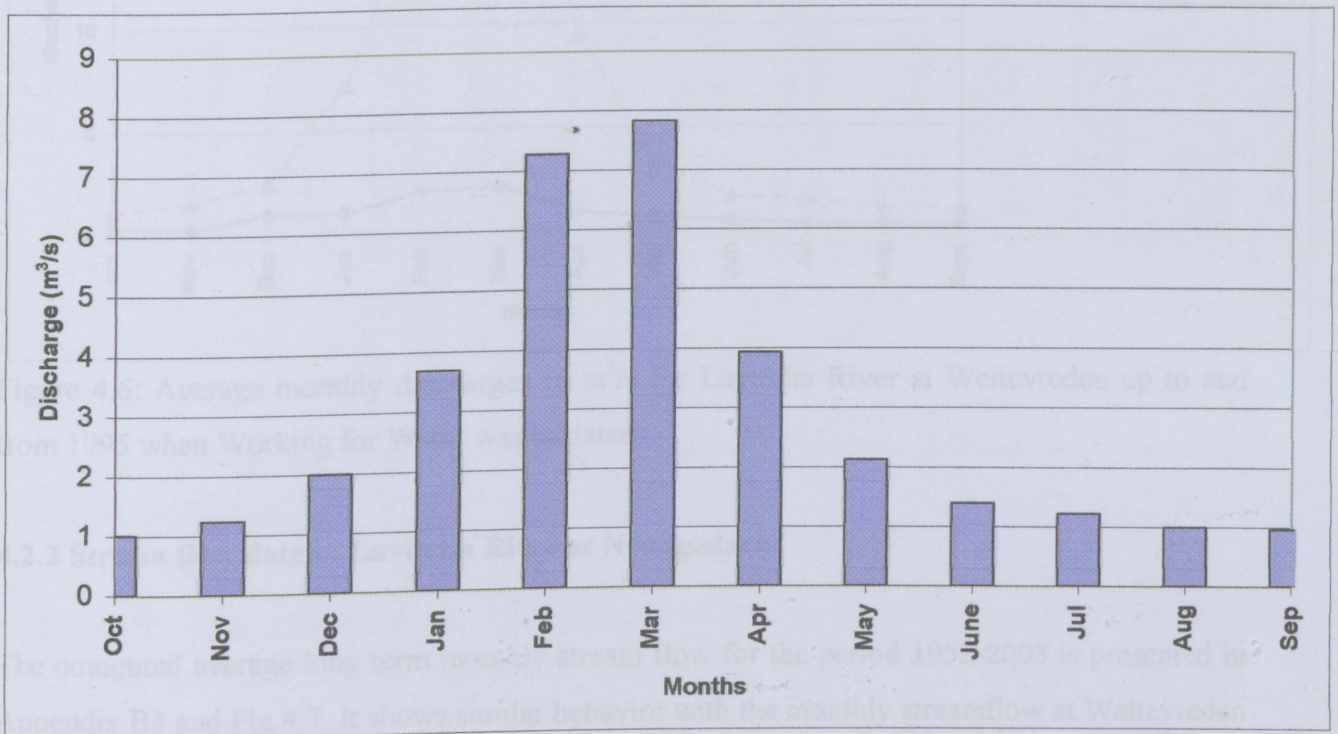

Figure 4.5: Long term average monthly discharges in m^3/s for Luvuvhu River at weltevreden for the period 1952-2003.

Appendix B2 (a) gives average monthly discharges in m^3/s for Luvuvhu River at Weltevreden from 1987/88 up to 1995 when Working for Water was initiated and Appendix B2 (b) gives the average monthly discharges in m^3/s for Luvuvhu River at Weltevreden from 1995. The data of Appendix B2 (a) and B2 (b) are presented in Fig. 4.6. It can be observed that higher discharges were received from 1995 during the wet period compared to before 1995. This indicates that Working for water activities and increase in rainfall as shown in Fig. 4.3 have positive

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contributions towards increased stream flow and water security. It is important to note from Fig. 4.6 that before and up to 1995 the river discharges were very low.

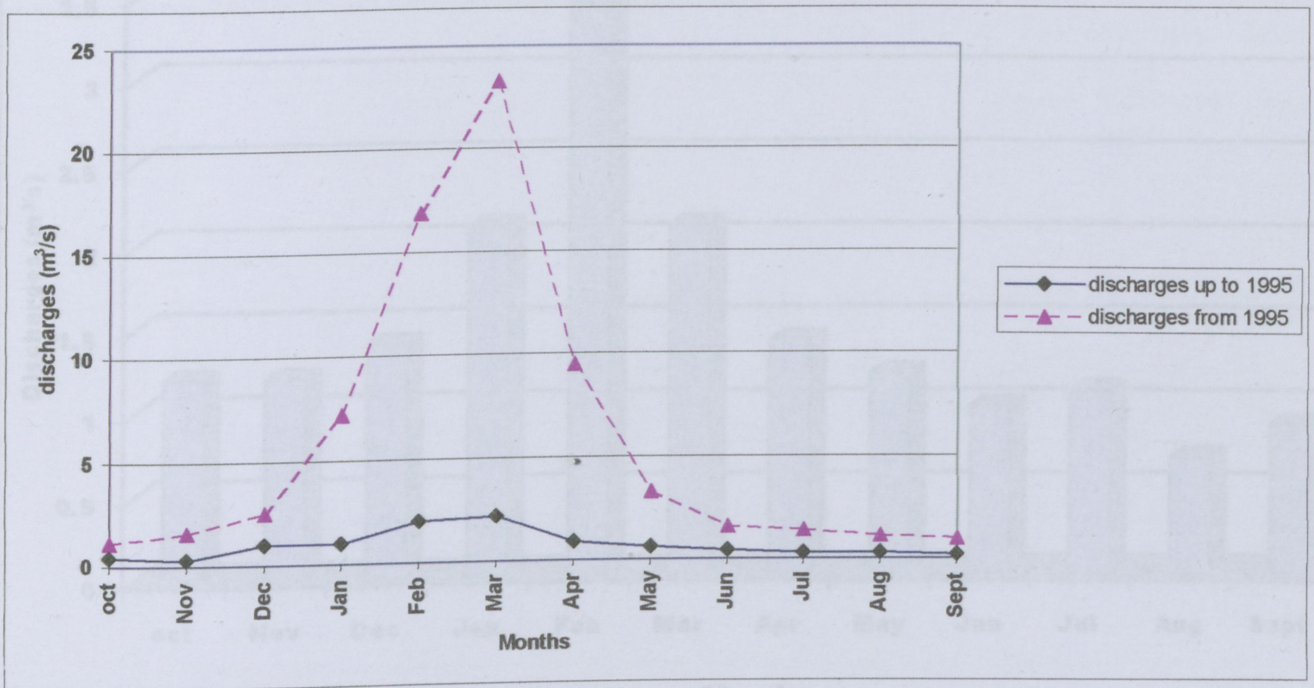

Figure 4.6: Average monthly discharges in m^3/s for Luvuvhu River at Weltevreden up to and from 1995 when Working for Water was initiated.

4.2.2 Stream flow data of Luvuvhu River at Nooitgedacht

The computed average long term monthly stream flow for the period 1952-2003 is presented in Appendix B3 and Fig.4.7. It shows similar behavior with the monthly streamflow at Weltevreden (Fig 4.5) except for the fact that the maximum and the minimum discharges occurred in the months of February and August respectively. The magnitudes of discharges at Nooitgedacht are also much less than those at Weltevreden.

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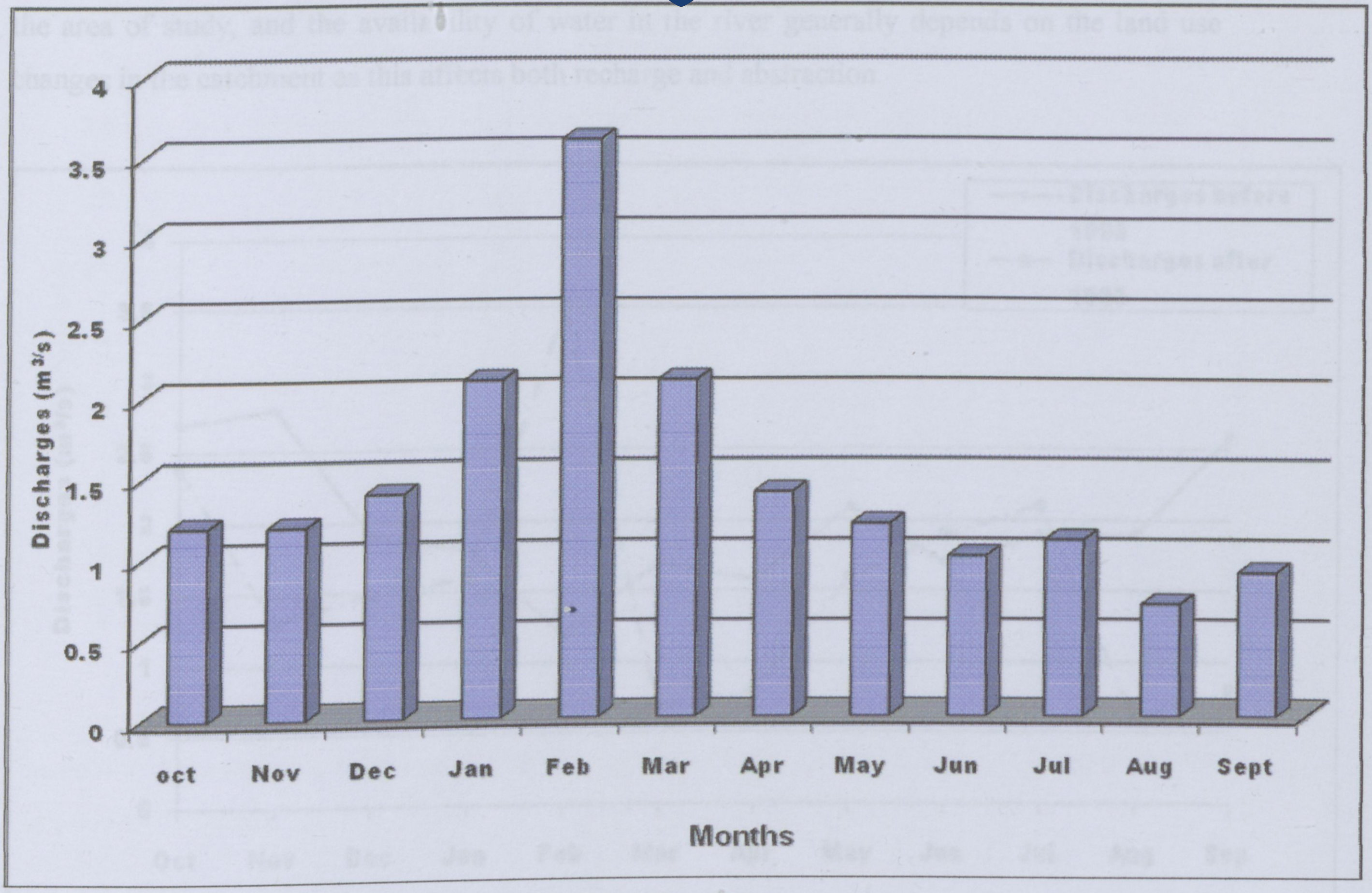

Figure 4.7: Average long term monthly discharges in m^3/s for Luvuvhu River at Nooitgedacht for the period 1952-2003.

Appendix B4 (a) gives average monthly discharges in m^3/s for Luvuvhu River at Nooitgedacht up to 1995 when Working for Water was initiated and Appendix B4 (b) gives the average monthly discharges in m^3/s for Luvuvhu River at Nooitgedacht from 1995. The data of Appendix B4 (a) and B4 (b) are plotted in Fig. 4.8. It can be observed that there were differences in discharges received from and up to 1995 during the wet period. Higher discharges were received after 1995 during the wet period compared to before 1995. This indicates that Working for Water activities and increase in rainfall shown in Fig 4.3 have positive contributions towards increased stream flows and water security, similar to what has been observed at Welteverden Station. It is important to note that activities of Working for Water form part of land use changes in the area of study and the availability of water in the river generally depends on the land use changes in

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the area of study, and the availability of water in the river generally depends on the land use changes in the catchment as this affects both recharge and abstraction.

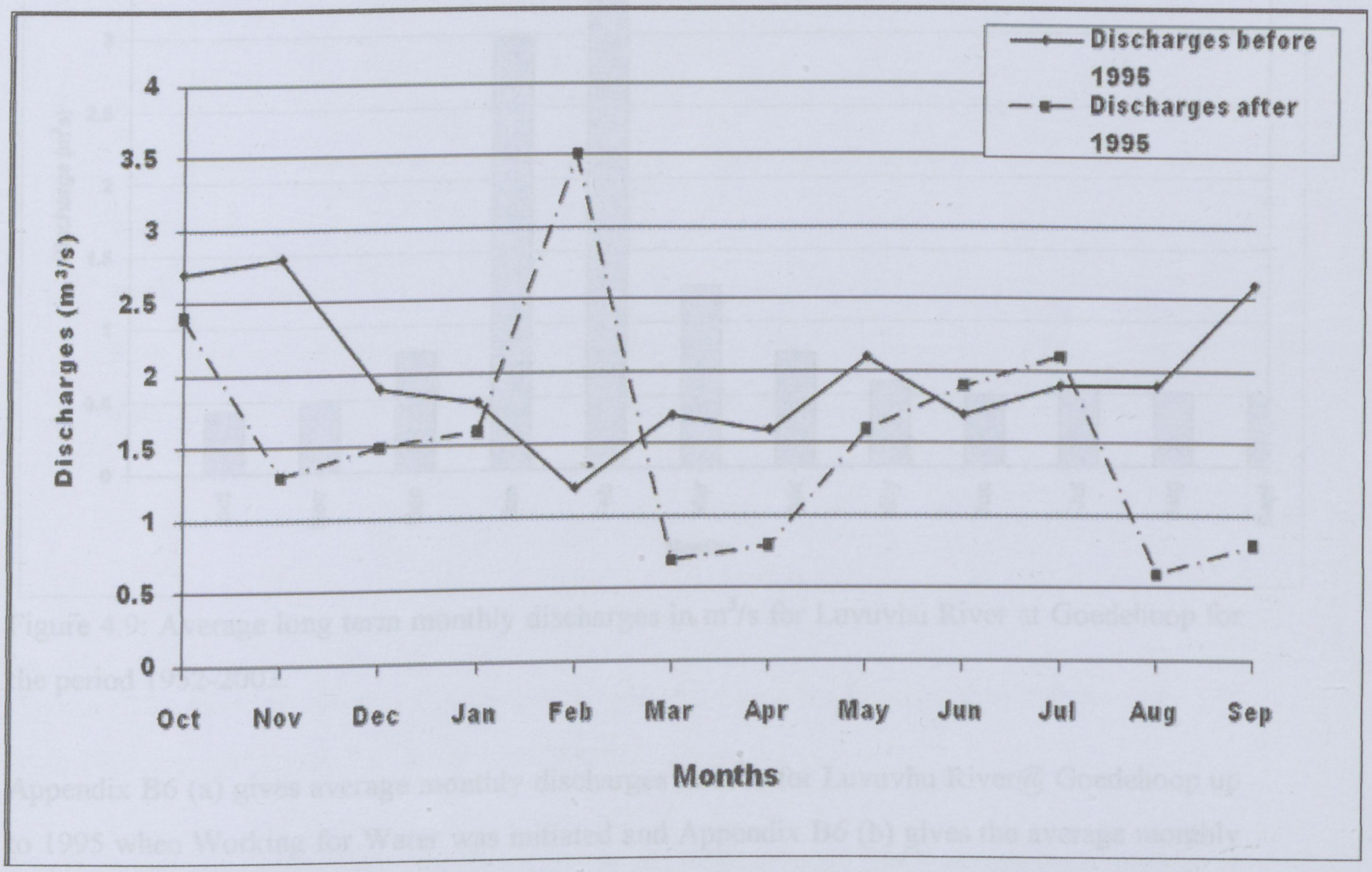

Figure 4.8: Average monthly discharges in m^3/s for Luvuvhu River at Nooitgedacht up to and from 1995 when Working for Water was initiated

4.2.3 Stream flow data for Luvuvhu River at Goedehoop

The computed average long term monthly stream flow for the period 1952-2003 is presented in Appendix B5 and Fig.4.9. It shows almost similar behavior with the monthly streamflow time series for Nooitgedacht. This is because they are in the same quaternary catchment with the same hydrological parameters.

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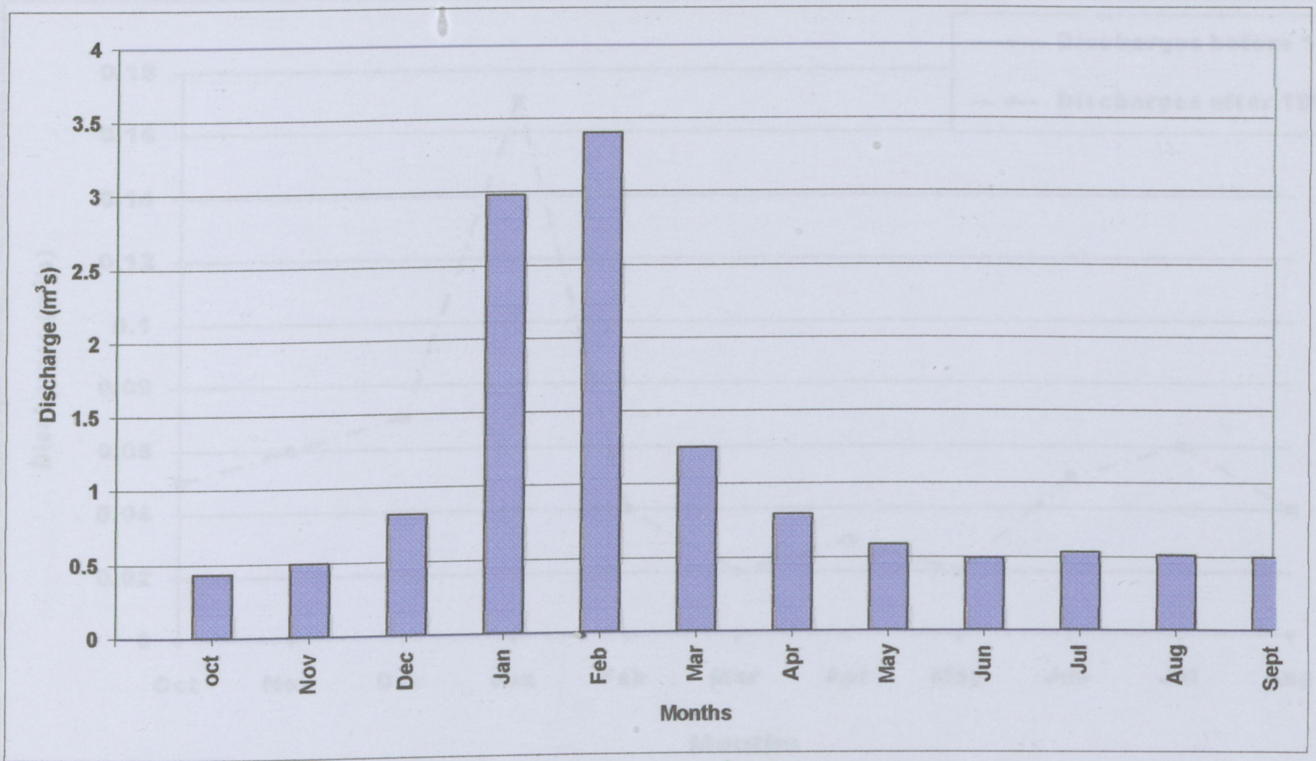

Figure 4.9: Average long term monthly discharges in m^3/s for Luvuvhu River at Goedehoop for the period 1952-2003.

Appendix B6 (a) gives average monthly discharges in m^3/s for Luvuvhu River@ Goedehoop up to 1995 when Working for Water was initiated and Appendix B6 (b) gives the average monthly discharges in m^3/s for Luvuvhu River at Goedehoop from 1995. The data of Appendix B6 (a) and B6 (b) are plotted in Fig. 4.10. It can be observed that there were differences in discharges received from and up to 1995 during the wet period and higher discharges were received from 1995 during the wet period than before 1995. This indicates that Working for water activities and increase in rainfall shown in Fig 4.3 have positive contributions towards increased streamflow availability and water security. The results show that this stretch of Luvuvhu River was mostly dry before the clearance of alien vegetation started. The increase in streamflow was also not very significant.

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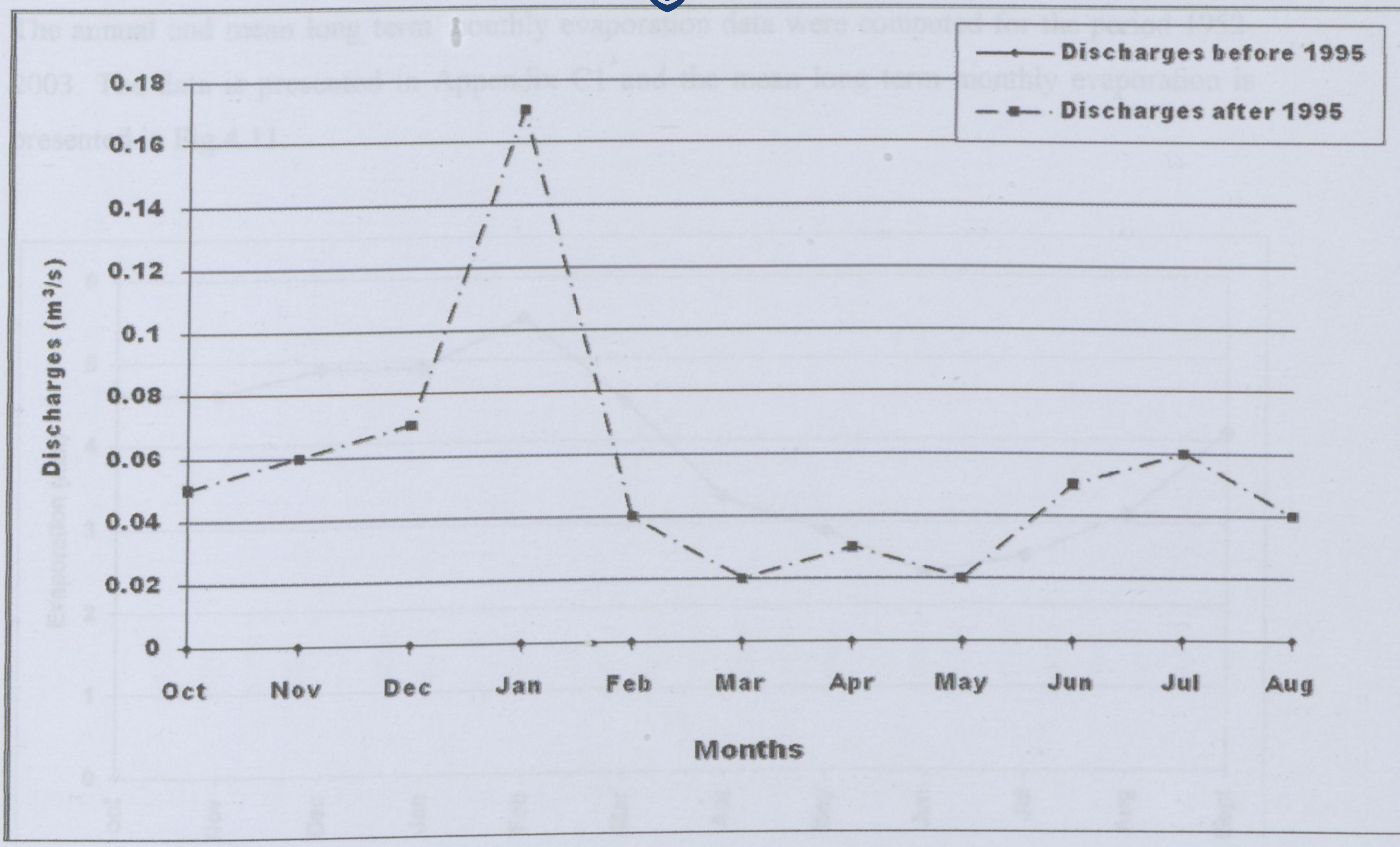

Figure 4.10: Average monthly discharges in m^3/s for Luvuvhu River at Goedehoop up to and from 1995 when Working for Water was initiated

The observed streamflow behavior (Fig 4.6, 4.8 and 4.10) indicate that there has been increase in streamflow. This has been interpreted by considering the general increase in rainfall since 1995 (Fig 4.3) and the potential impact of alien vegetation clearance. Rainfall just like alien vegetation clearance contributes to increase in availability of water in the river.

4.3. Evaporation data of Luvuvhu River at Goedehoop

Evaporation was recorded from an S class pan in millimeters. The data was used in order to analyze the temporal trends to show the impact of alien vegetation clearance and/or climate change on hydrology. There is only one evaporation station in Luvuvhu River Basin.

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The annual and mean long term monthly evaporation data were computed for the period 1952-2003. The data is presented in Appendix C1 and the mean long term monthly evaporation is presented in Fig.4.11.

Figure 4.11: Average annual and mean long-term monthly evaporation of Luvuvhu River at Goedehoop for the period 1952-2003

Figure 4.11 shows fluctuations in monthly evaporation rate. Maximum evaporation rate of 5.5 mm per month was received during February and minimum evaporation rate of 2.4mm was received in June.

Appendix C2 and Fig. 4.12 show annual peak evaporation rates for Luvuvhu River at Goedehoop for the period 1952-2003. Fig. 4.12 shows that there are fluctuations in peak annual evaporation rates. The maximum evaporation rate was in 1967/68 with a peak of 19mm. Minimum evaporation peak of 4.4mm was in 1973/74. There have been fluctuations in the annual evaporation peaks in different years; this may have been partly due to the amount of rainfall received or water available in the catchment and influence received from temperature changes, sunshine hours and windy weather and others.

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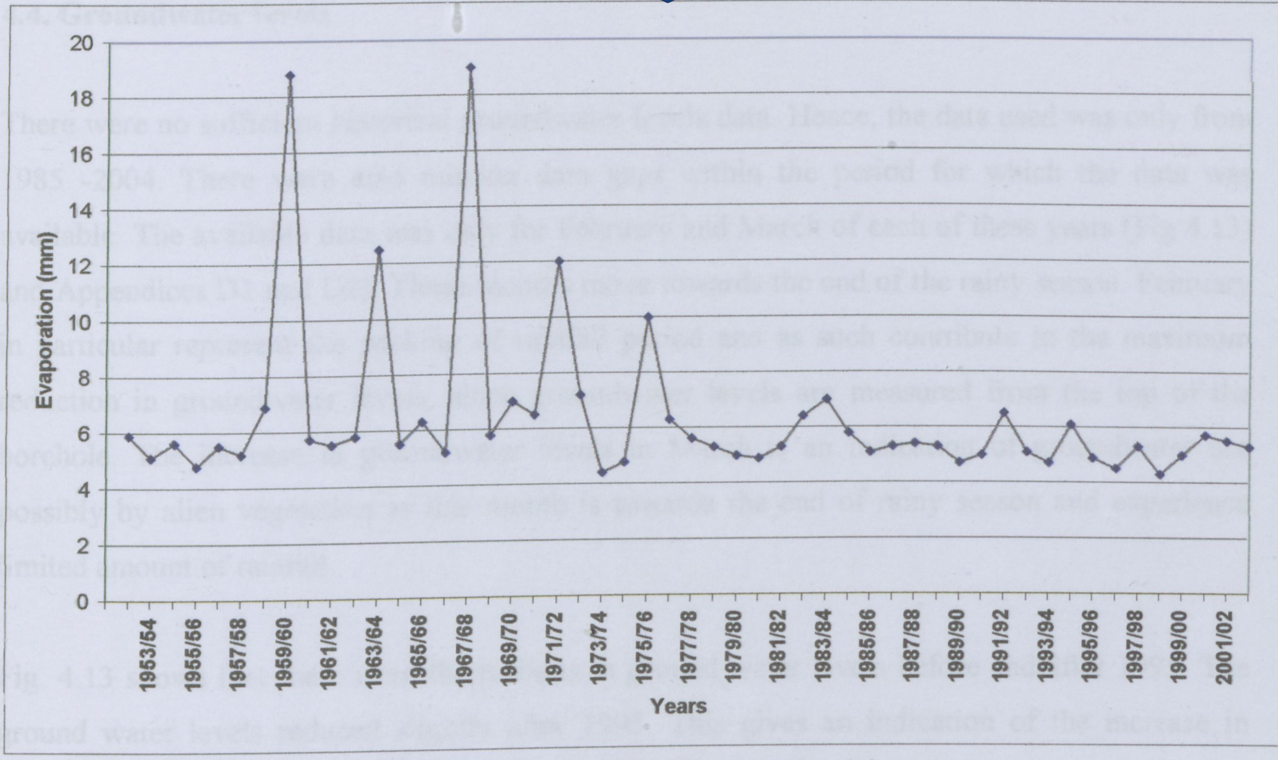

Figure 4.12: The peak evaporation rate for Luvuvhu River at Goedehoop

The observed evaporation data sets show that there have been changes in evaporation amounts in dry and wet seasons. Fig. 4.12 shows that an increase in evaporation amounts is observed during wet months and low evaporation rate was observed during dry months. This might be closely related to the amount of water available in the catchment. Since the changes in evaporation rates are linked directly to changes in temperature it became necessary to study temperature changes in order to explore behavioral trends that may be linked to climate change.

The peak evaporation rates show that before 1985 particularly there were high amount of evaporation in the area. The behavior of annual evaporation peak graphs in the 60's and 70's can partly be explained by the fact that the area was covered with vegetation (alien vegetation) with high evapotranspiration rate. After 1994 when working for water started its operation, a gradual decrease of evapotranspiration was experienced which had started in the 80's possibly due to earlier deforestation (alien vegetation clearance) or less availability of open water surfaces. It can be concluded that evaporation, streamflow, rainfall and alien vegetation clearance affect water availability in the catchment.

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4.4. Groundwater levels

There were no sufficient historical groundwater levels data. Hence, the data used was only from 1985 -2004. There were also missing data gaps within the period for which the data was available. The available data was only for February and March of each of these years (Fig 4.13) and Appendices D1 and D2). These months move towards the end of the rainy season. February in particular represent the peaking of rainfall period and as such contribute to the maximum reduction in groundwater levels, since groundwater levels are measured from the top of the borehole. The increase in groundwater levels in March is an indication of groundwater use possibly by alien vegetation as this month is towards the end of rainy season and experience limited amount of rainfall.

Fig. 4.13 shows that there were fluctuations in ground water levels before and after 1995. The ground water levels reduced slightly after 1995. This gives an indication of the increase in recharge with the clearance of high water consuming alien vegetation. The increase in rainfall (Fig 4.3) could also have contributed to increase in ground water recharge. Thus more water would be available to recharge the rivers through surface runoff and interflow. Thus the reduction of groundwater level after 1995 can possibly be explained in terms of the activities of Working for Water and /or climate change.

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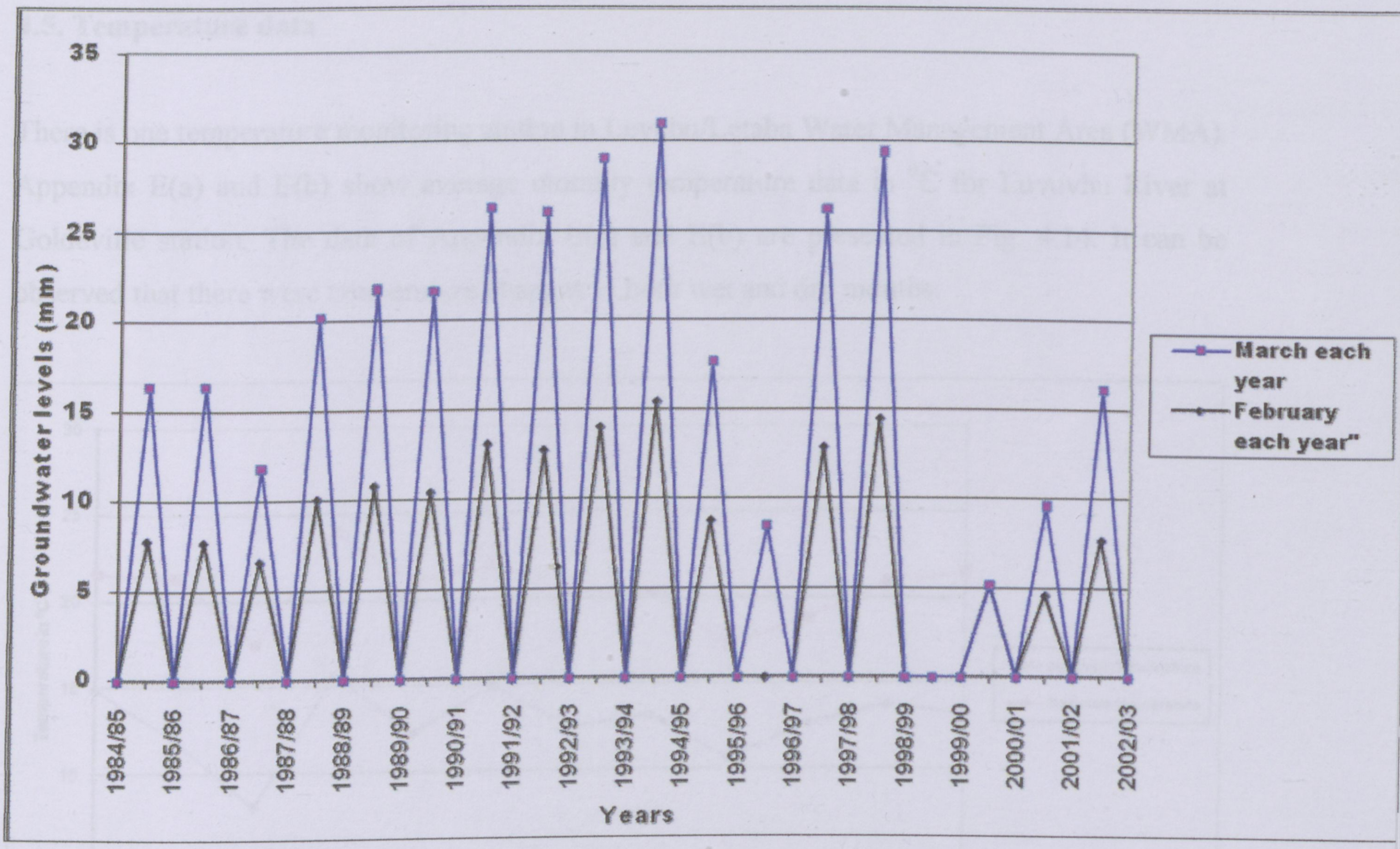

Figure 4.13: Annual groundwater flow for February and March each year for the period 1985-2004

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4.5. Temperature data

There is one temperature monitoring station in Levubu/Letaba Water Management Area (WMA). Appendix E(a) and E(b) show average monthly temperature data in ^{0}C for Luvuvhu River at Goldeville station. The data of Appendix E(a) and E(b) are presented in Fig. 4.14. It can be observed that there were temperature changes in both wet and dry months.

Figure 4.14: Minimum and Maximum monthly average temperature in ^{0}C for Luvuvhu River at Goldeville station

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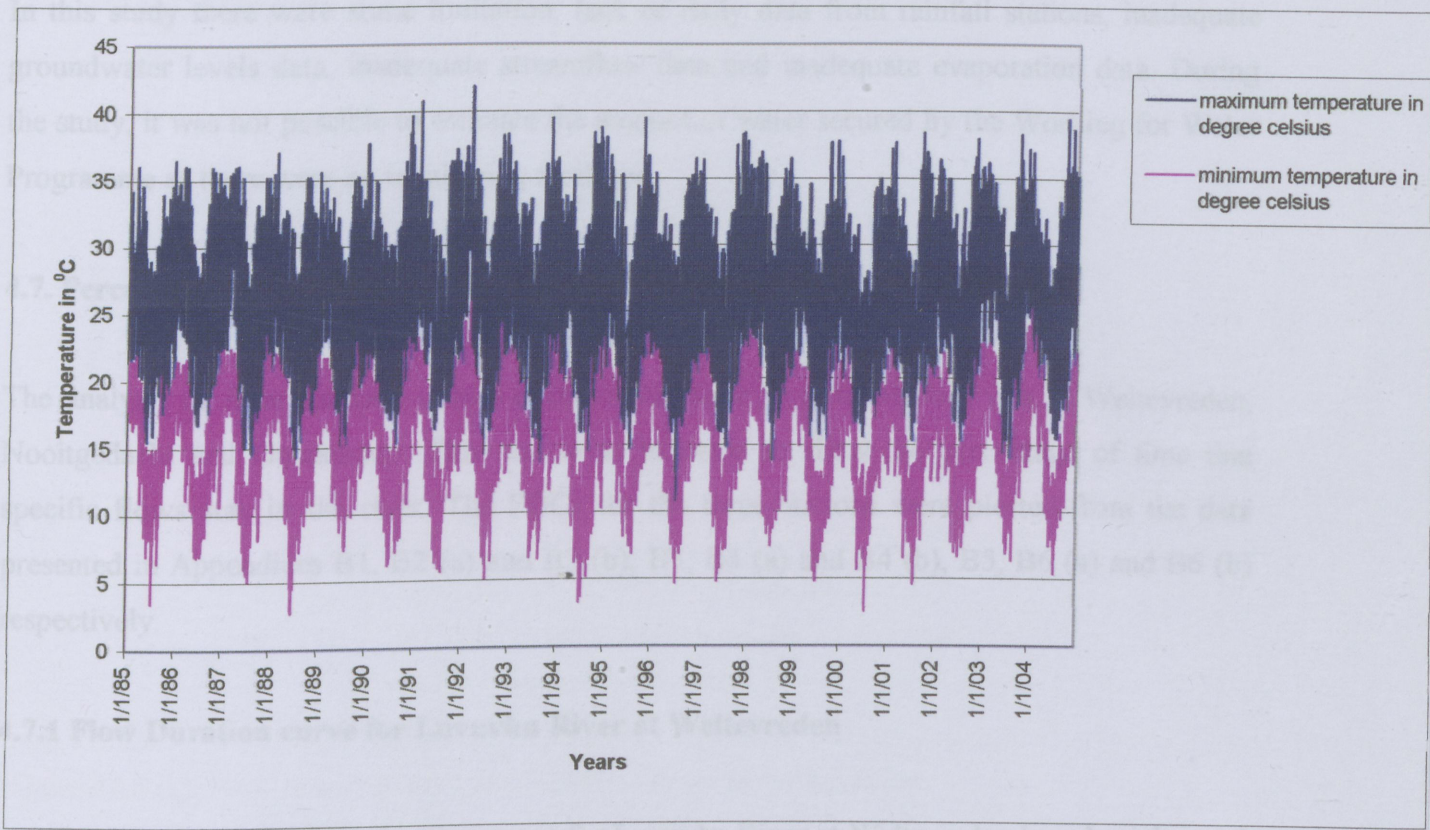

Figure 4.15: Daily Minimum and Maximum temperatures in ^{0}C for the period 1985 to 2004

Fig. 4.15 shows the minimum and maximum daily temperatures for the period 1985 to 2004. Temperature fluctuations remained stable with only slight increases since 1990's. This indicates that global warming contributes to only slight temperature increase indicating that climate change may play some role in influencing hydrological changes in the area of study. Hence the changes in streamflow can be attributed to the activities of Working for Water (land use changes and to some extent climate change).

4.6 Summarized results of the hydrological data analysis

The results of the temporal trends of the hydrological data set from the observed graphs show that there have been changes in rainfall amounts and streamflow received before and after 1995 when Working for Water was initiated. Rainfall had a significant contribution in groundwater recharge and hence stream flow increase. Working for Water Programme added value by increasing the amount of water in the water sources.

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In this study there were some limitation, lack of daily data from rainfall stations, inadequate groundwater levels data, inadequate streamflow data and inadequate evaporation data. During the study, it was not possible to estimate the amount of water secured by the Working for Water Programme as there were no monitoring facilities.

4.7. Percentage of time flows of specific magnitudes stays in the river

The analysis of flow duration curves (FDCs) was done in three stations that is Weltevreden, Nooitgedacht and Goedehoop. This was done in order to show the percentage of time that specific flows stay in the river. The FDCs for the three stations were plotted from the data presented in Appendices B1, B2 (a) and B2 (b), B3, B4 (a) and B4 (b), B5, B6 (a) and B6 (b) respectively.

4.7.1 Flow Duration curve for Luvuvhu River at Weltevreden

Fig. 4.16 (a) shows the flow duration curve for Luvuvhu River at Weltevreden based on the total flow for each year and the data is presented in Appendix F1. The figure shows that high magnitude flows stay in the river for a very short time. Thus the higher the flow magnitude in the river the quicker it will take to flow downstream. The low flows, however, stay in the river for much longer time.

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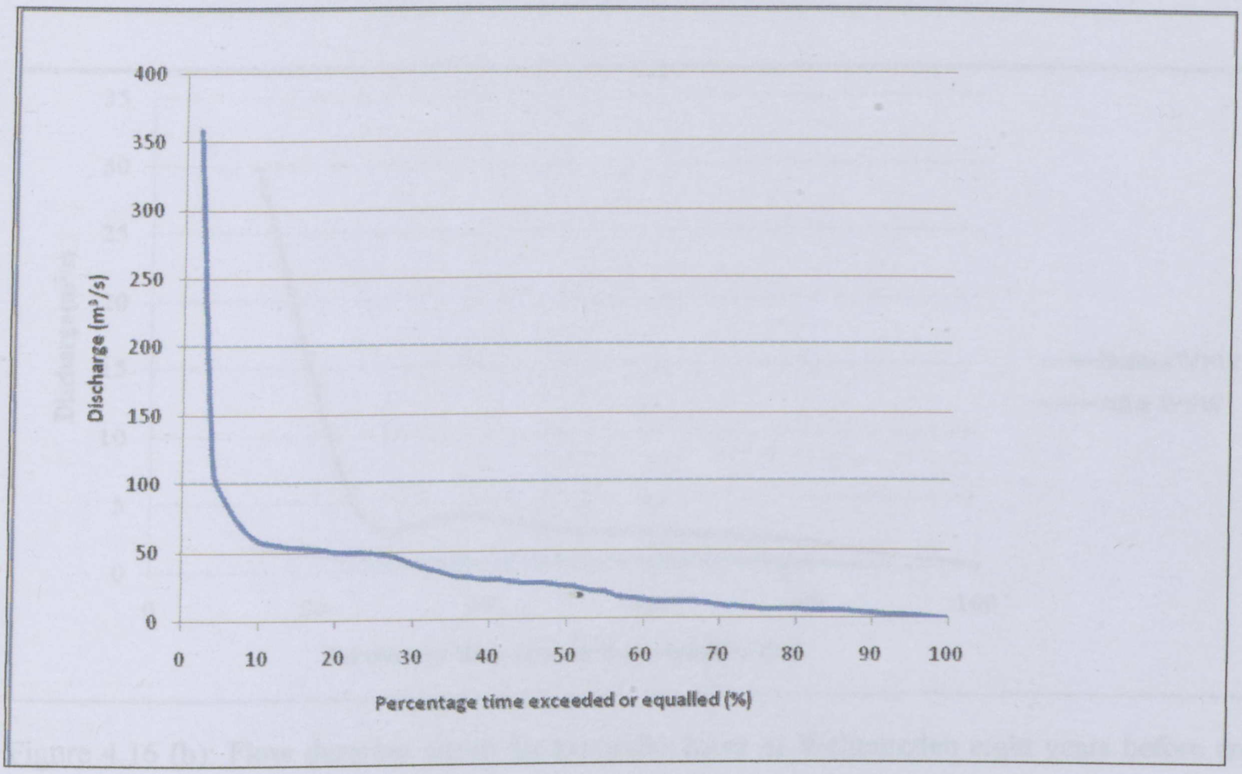

Figure 4.16 (a): Flow duration curve for Luvuvhu River at Weltevreden

Fig. 4.16 (b) represented by data in Appendix F1 (a) based on mean flows for each year before and after Working for Water was initiated shows the percentage time the flow was exceeded or equaled at Weltervreden eight years before and eight years after the Working for Water Programme started. The figure shows that the flow increased in the river after the Working for Water Programme started removing alien vegetation as compared to before, but this was not the case with discharge after the Working for Water Programme was started. Thus the removal of alien species along the Luvuvhu River has increased flow in the river. However, the high flows achieved after the Working for Water Programme started removing alien vegetation only stay in the river for a short time compared to low flows as observed in Fig. 4.16 (b).

Thus in terms of water resources availability at the point of interest, the increase in flow of the river from the removal of alien vegetation does not play a positive role in ensuring that the water remains in the river for a long time. This water, however, would have remained in the catchment of origin for a long time as part of the groundwater in the aquifers that also sustains the base (low) flows in the river.

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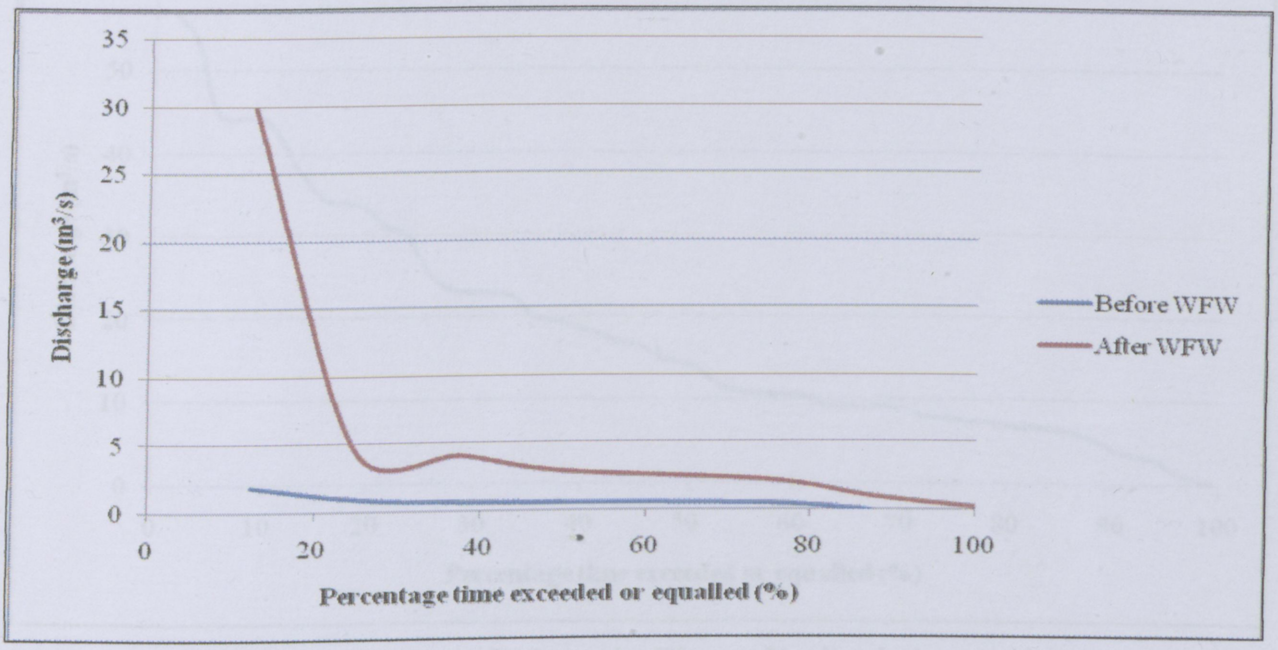

Figure 4.16 (b): Flow duration curve for Luvuvhu River at Weltevreden eight years before and eight years after Working for water was initiated

4.7.2 Flow duration curve for Luvuvhu River at Nooitgedacht

Fig. 4.17 (a) shows the flow duration curve for Luvuvhu River at Nooitgedacht based on the total flow for each year and the data is presented in Appendix G1. The figure shows that high magnitude flows stay in the river for a short time. Thus the higher the flow magnitude in the river the quicker it will take to flow downstream. The low flows, however, stay in the river for a long time.

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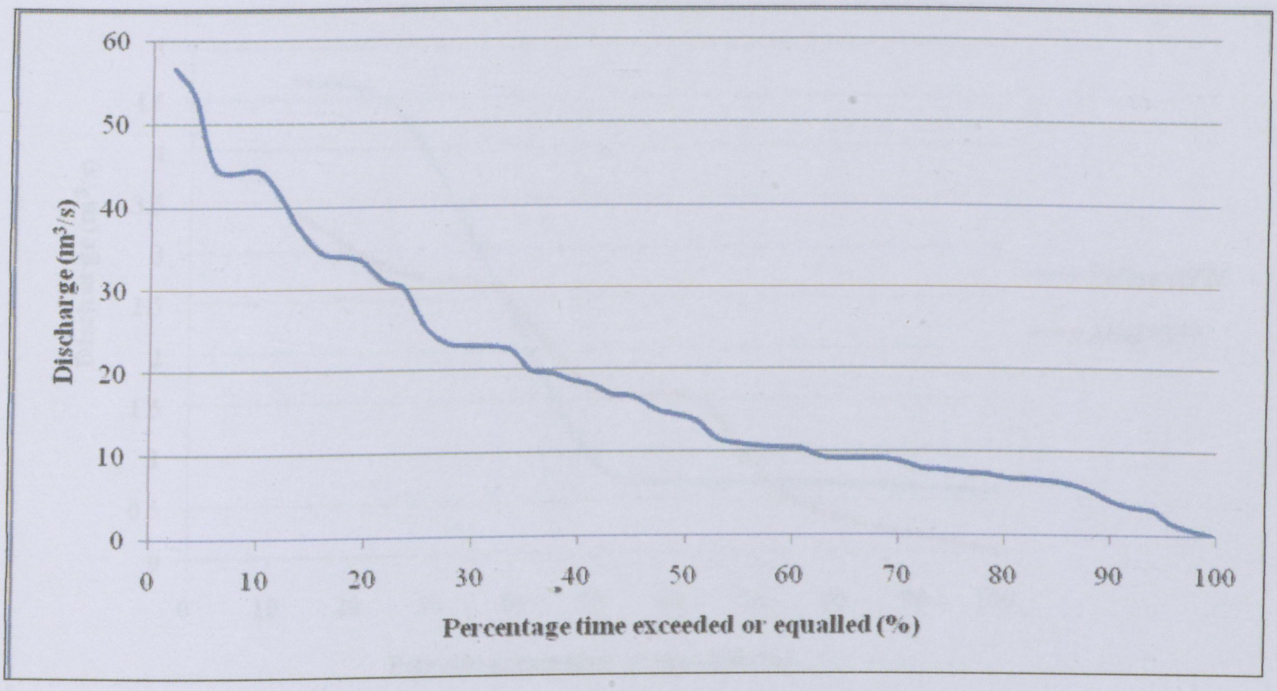

Figure 4.17 (a): Flow duration curve for Luvuvhu River at Nooitgedacht

Fig. 4.17 (b) presented by data in Appendix G1 (a) based on mean flows for each year before and after Working for Water was initiated shows the percentage of time the flow was exceeded or equaled at Nooitgedacht eight years before and eight years after the Working for Water Programme was initiated. The results do not show a general increase in flow after the Working for Water Programme initiated their activities. Instead the relatively high mean flows before the Working for Water initiated their programmes moved out of the river reach relatively faster indicating that even then the high flows never stayed in the river for a long time. After the Working for water programme initiated their activities, the water still flows out of the reach relatively faster. The effect of vegetation removal is not clear in this reach, What is clear however, is that very little storage of water takes place in the reach.

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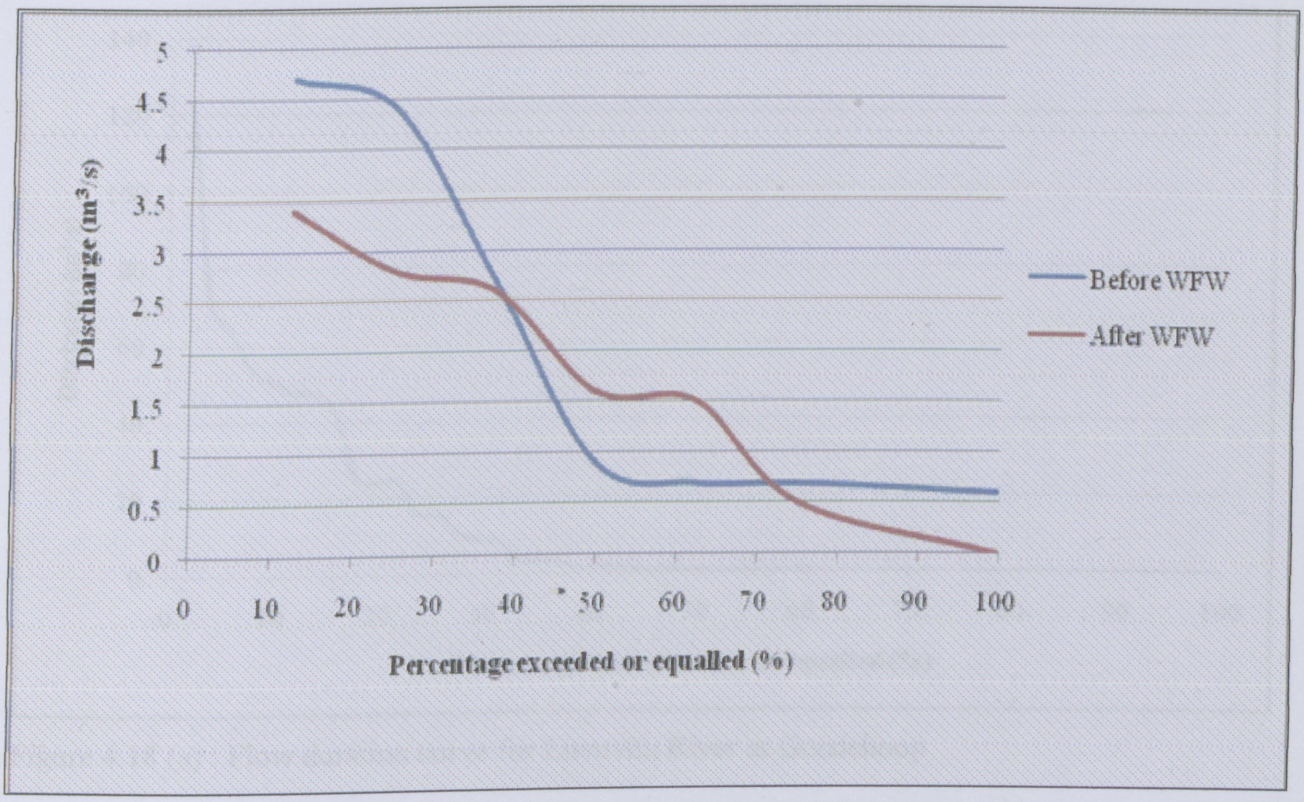

Figure 4.17 (b): Flow duration curve for Luvuvhu River at Nooitgedacht eight years before and eight years after Working for Water was initiated

4.7.3 Flow duration curve for Luvuvhu River at Goedehoop

Figure 4.18 (a) shows the flow duration curve for Luvuvhu River at Goedehoop based on the total flows for each year and the data is presented in Appendix H1.

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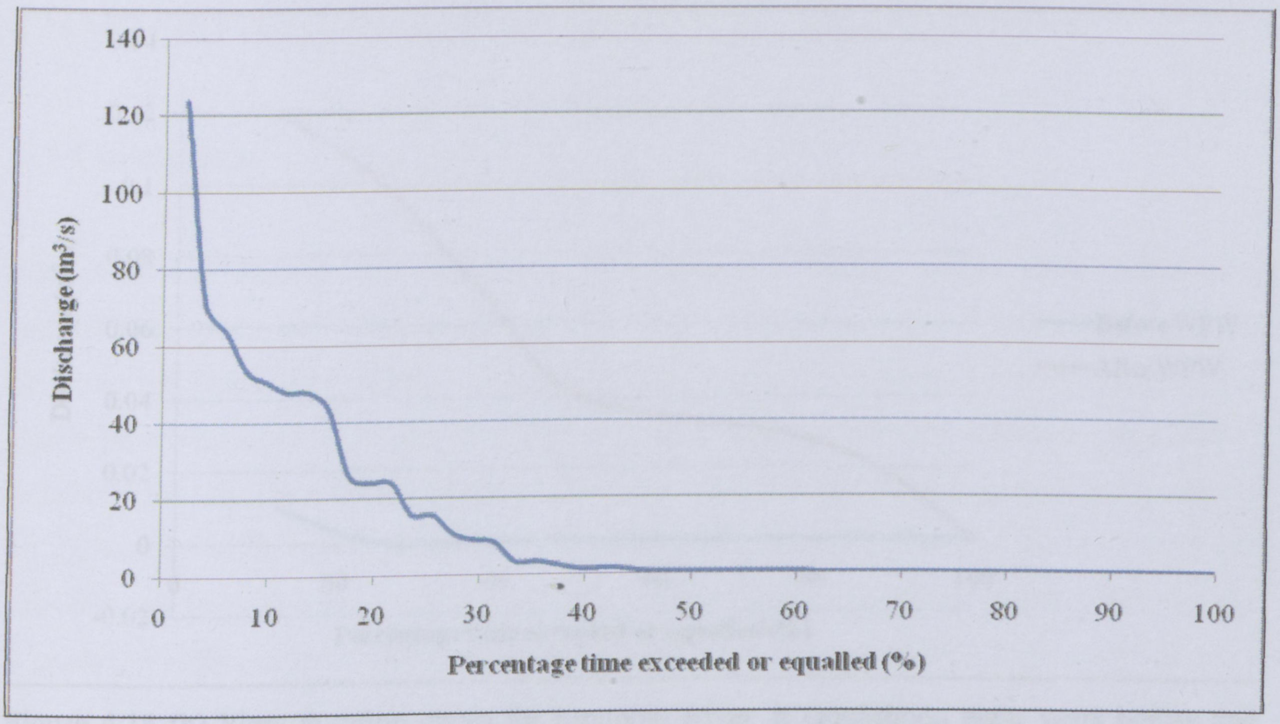

Figure 4.18 (a) : Flow duration curve for Luvuvhu River at Goedehoop

Figure 4.18 (a) shows that high discharges stay in the river for only a short time. Since the flows are relatively low as compared to those of Weltevreden, most of them stay in the river at Goedehoop for a relatively long time. Thus after the high flows are gone, the water is available as baseflow for environmetal purposes for elongated time. Thus in this context alien vegetation removal contributes to increased availability of most of the low flows in the river at the point of interest. It should however be noted that the low flows here are very low that they are almost insignificant.

The flows of eight years before and eight years after the Working for Water Programme initiated the clearance of alien vegetation is presented in Fig. 4.18 (b). This figure is based on the data presented in Appendix H1 (a). The flows eight years before Working for Water was initiated is very small and there is minimum contribution to streamflow staying in the river. The flow eight years after Working for Water was initiated shows that flows have increased in the river at Goedehoop since inception of alien vegetation removal. However, most of the relatively high flows move out of the river reach quickly.

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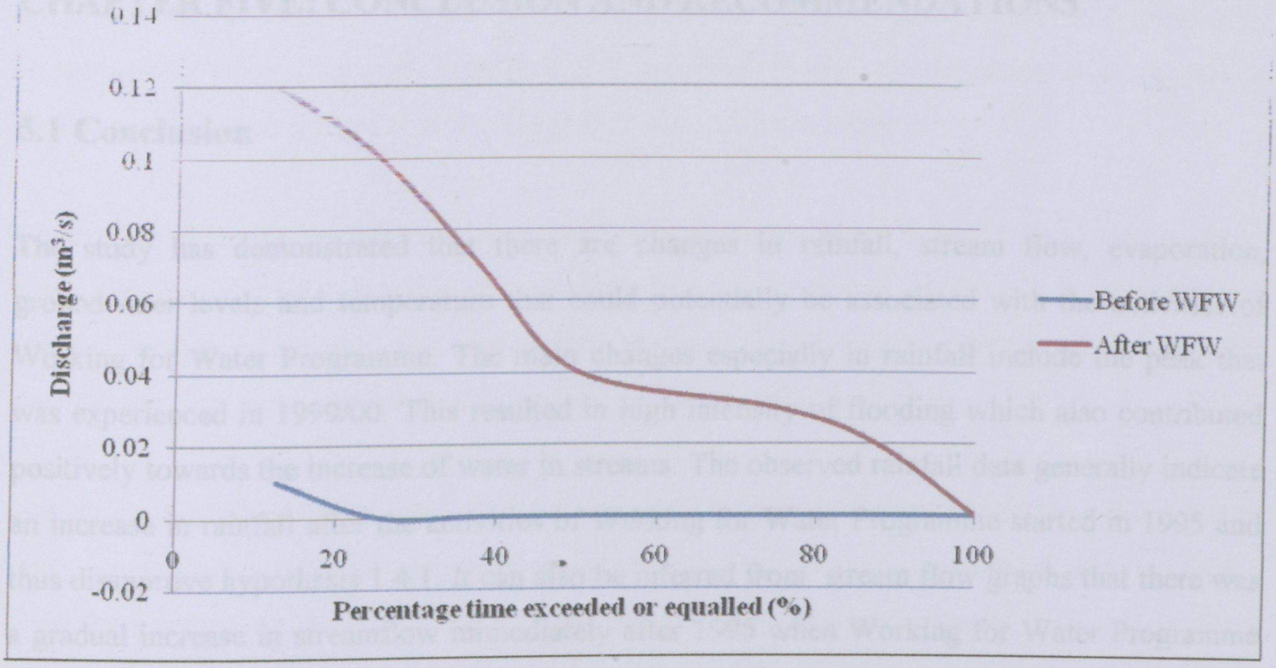

Figure 4.18 (b) Flow duration curve for Luvuvhu River at Goedehoop eight years before and eight years after Working for water was initiated

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CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study has demonstrated that there are changes in rainfall, stream flow, evaporation, groundwater levels and temperature that could potentially be associated with the activities of Working for Water Programme. The main changes especially in rainfall include the peak that was experienced in 1999/00. This resulted in high intensity of flooding which also contributed positively towards the increase of water in streams. The observed rainfall data generally indicate an increase in rainfall after the activities of Working for Water Programme started in 1995 and thus disapprove hypothesis 1.4.1. It can also be inferred from stream flow graphs that there was a gradual increase in streamflow immediately after 1995 when Working for Water Programme started to operate, though the magnitude varied from streamflow station to the other. The increase in streamflow is also linked to the rainfall amount received, which also contributed positively to the decrease in groundwater levels or increase in groundwater recharge and storage.

The increase in streamflow after clearance of alien vegetation started indicates the approval of hypothesis 1.4.2. The increase in groundwater recharge or storage disapproves hypothesis 1.4.3. Temperature changes also revealed possible impact of climate change on hydrology. However, hypothesis 1.4.4 requires further investigation to disapprove. These factors have a close link to each other in determining the amount of water be available in the catchment and the duration in which the percentage flow of specific magnitudes stay in the river.

The aim of this research was to carry out an audit of vegetation clearance from the catchment and how it influences the hydrology and/or water availability in the drainage basin. The temporal hydrological trends are reported in the above paragraph indicate the scope to which the aim was achieved.

The first specific objective has been achieved by analyzing the rainfall patterns, behavior in streamflow, changes in temperature, groundwater levels and evaporation amounts. The results show that Working for Water Programme is contributing positively in securing water in streams

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by increasing streamflow, through alien vegetation clearance. The increase in rainfall after implementing alien vegetation clearance also indicated possibilities of either alien vegetation clearance or climate change contributing to increased water availability.

The second objective has been achieved through literature review and hydrological data analysis. It has been shown that alien vegetation afforestation cannot serve as an effective water catchment method because of the amount of water they consume. Indigeneous vegetation with less water demand can, however, provide protective land cover against soil erosion.

The third objective has been achieved by showing that increased flows of high magnitudes due to alien vegetation removal stay in the river for a short time. However, the low flows stay in the river for a long time, which is not different from if these flows originated from groundwater aquifers that will ensure minimal loss of water to the ocean. Hence there should be mechanisms of securing the increased flow in streams where Working for Water is operating.

5.2 Recommendations

The study has recommended the following:

(1) Post clearing recovery

Once alien vegetations are cleared, they must be replaced by indigenous vegetation so that the indigenous vegetation can serve as water catchment. This will minimize problems of soil erosion, run-off, sedimentation and others. Rehabilitation methods must also be investigated.

(2) Data availability and monitoring

Monitoring devices must be installed in all areas where Working for water is operational. These will assist in monitoring the quantity of water, extent of alien invasion in the area, and water quality monitoring after the application of herbicides and chemical adsorption in sediments. This

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will assist planners, hydrologists, water quality specialists, environmentalist to come up with more strategies of securing safe water in the drainage basin.

(3) Efficient storage of water

Flow duration curve analysis shows that the flow of water in the stream stays for a short time, therefore there must be a mechanism for harvesting the increased flow before it flows to the ocean. That can be achieved by providing efficient storage of the increased flow.

Attempts should be made to raise the yields by planned siting of dams. A purposeful programme should be launched for the investigation of all possible sites where dams can be built in order to determine with confidence the maximum utilization of runoff of our rivers. In the selection of dam sites, special attention should be given to the reduction of evaporation losses. This can also be beneficial in storing the increased flow generated by alien vegetation clearance and this is to keep the increased flow within the drainage basin.

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Appendix A1

The monthly rainfall data in mm for the Soutpansberg area for the period 1952-2004

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1952/53	151.1	73.7	118.9	331.0	147.1	45.8	88.3	0.0	0.0	45.5	6.4	2.0	1009.8	84.2
1953/54	49.0	140.2	247.2	382.3	121.9	88.9	83.8	13.2	6.4	0.0	22.1	26.2	1181.2	98.4
1954/55	29.3	33.7	142.2	305.4	364.5	73.7	76.2	11.2	42.7	4.1	4.8	13.2	1101.0	91.8
1955/56	51.8	146.3	207.5	62.0	353.8	93.7	10.4	24.1	0.0	3.1	0.0	42.9	995.6	83.0
1956/57	14.0	35.6	67.3	241.5	237.8	88.9	57.6	38.1	18.0	36.1	24.9	32.8	892.6	74.4
1957/58	123.9	48.8	95.0	648.2	98.5	25.4	53.5	0.1	12.4	0.3	3.6	54.1	1163.8	97.0
1958/59	37.6	56.6	219.5	255.0	59.9	41.4	7.4	3.3	1.3	44.7	1.5	9.4	737.6	61.5
1959/60	55.0	40.6	174.2	33.4	131.1	37.9	95.2	7.9	34.5	3.2	4.7	10.4	628.1	52.3
1960/61	26.4	157.5	308.9	163.5	439.7	93.3	45.4	0.5	27.2	12.2	13.7	4.6	1292.9	107.7
1961/62	22.9	41.9	61.5	160.8	64.5	66.6	162.8	8.4	0.0	1.0	0.0	22.6	613.0	51.1
1962/63	6.1	121.4	169.7	62.7	54.4	70.3	79.0	91.7	54.4	6.6	0.0	5.1	721.4	60.1
1963/64	25.9	19.3	61.7	89.2	54.6	22.4	3.3	1.8	0.5	0.0	8.4	2.8	289.9	24.2
1964/65	85.1	137.2	100.1	88.9	49.5	36.8	52.8	2.0	12.7	0.0	14.5	20.3	599.9	50.0
1965/66	17.0	86.1	70.6	86.1	394.5	33.3	21.0	13.5	11.9	0.8	8.1	40.9	783.8	65.3
1966/67	65.0	48.8	79.4	367.1	221.5	62.3	123.5	3.1	10.2	10.4	4.8	1.3	997.4	83.1
1967/68	56.1	166.6	32.3	10.9	58.9	19.6	53.6	53.1	15.7	8.1	8.12	0.8	483.82	40.3
1968/69	18.2	176.1	126.9	70.9	30.0	327.2	43.7	13	5.1	1.8	2.3	31.3	846.5	70.5
1969/70	117.0	52.1	118.1	8.9	61.2	27.7	8.6	21.6	18.8	6.6	0.0	2.8	443.4	37.0
1970/71	75.4	179.3	183.9	347.5	48.3	105.7	79.3	57.2	8.6	0.0	0.0	29.7	1114.9	92.9
1971/72	76.8	156.8	98.0	288.4	245.2	240.0	27.2	40.4	2.8	0.5	10.2	2.3	1188.6	99.1
1972/73	91.2	72.1	80.0	56.6	80.3	68.2	93.9	6.0	14.1	31.2	2.8	150.6	747.0	62.3
1973/74	112.0	48.0	233.7	258.3	565.7	106.1	36.1	20.6	2.0	7.1	4.6	76.7	1470.9	122.6
1974/75	14.0	147.0	98.9	222.5	288.5	197.4	89.1	17.5	26.4	0.0	5.6	5.3	1112.2	92.7
1975/76	23.1	67.0	194.2	253.9	246.6	131.6	97.8	97.3	9.1	1.3	2.6	10.7	1135.2	94.6
1976/77	27.7	106.2	81.0	243.1	385.8	280.1	20.8	12.4	2.3	0.0	40.8	95.8	1296.0	108.0
1977/78	57.5	123.2	443.1	405.9	473.2	234.9	45.3	14.0	0.0	49.6	5.7	71.5	1923.9	160.3
1978/79	40.6	209.9	316.9	165.5	160.3	248.7	26.7	26.6	34.4	43.4	81.7	15.8	1370.5	114.2
1979/80	78.1	129.5	192.9	220.7	227.7	193.4	36.6	18.2	1.8	7.6	71.6	100.1	1278.2	106.5
1980/81	52.1	174.4	80.1	455.2	405.9	266.9	40.3	169.2	0.0	10.2	54.5	73.7	1782.5	148.5
1981/82	114.2	126.2	81.5	86.8	263.2	18.0	69.3	79.6	6.1	6.2	2.8	29.1	883.0	73.6
1982/83	64.2	33.7	44.2	103.9	48.3	108.1	4.4	10.0	29.6	58.4	151.1	16.1	672.0	56.0
1983/84	58.0	90.9	75.9	41.1	136.7	274.9	100.2	8.4	17.2	156.2	13.2	37.6	1010.3	84.2
1984/85	171.8	262.2	127.0	313.3	219.3	147.6	30.0	128.0	4.3	16.4	13.4	169.4	1602.7	133.6
1985/86	77.5	105.7	294.0	139.2	180.0	51.7	261.6	9.5	11.6	17.6	9.1	28.8	1186.3	98.9
1986/87	96.3	168.2	123.7	160.1	50.3	53.5	46.5	23.7	38.6	0.0	29.3	100.3	890.5	74.2
1987/88	93.3	78.4	440.9	127.7	363.6	251.2	39.9	78.0	140.8	0.0	78.3	39.8	1731.9	144.3
1988/89	271.3	100.6	136.6	31.9	253.4	16.3	32.8	14.9	23.9	10.6	5.3	5.9	903.5	75.3
1989/90	122.7	87.3	186.4	164.0	119.4	70.7	51.4	6.8	3.8	0.9	36.6	9.8	859.8	71.7
1990/91	45.0	65.6	137.5	232.5	183.9	317.6	7.6	31.2	5.7	0.0	0.0	30.9	1057.5	88.1
1991/92	10.7	95.6	105.3	110.8	61.0	127.7	16.8	0.0	54.3	6.7	13.0	8.5	610.4	50.9
1992/93	38.7	100.0	251.5	120.5	529.9	73.3	38.9	9.0	20.4	68.7	20.7	1.0	1272.6	106.1
1993/94	61.1	234.5	227.2	245.4	117.4	46.0	18.4	13.6	3.6	4.3	10.0	25.1	1006.6	83.9

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Appendix A1 Continued

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1994/95	108.3	100.2	69.4	50.5	288.8	112.8	133.3	38.7	0.4	10.3	45.1	13.0	970.8	80.9
1995/96	28.6	88.8	163.9	691.9	478.7	59.1	186.4	162.2	43.8	137.2	22.8	9.9	2073.3	172.8
1996/97	35.8	132.8	112.4	433.0	228.8	209.0	27.2	20.7	0.0	28.7	0.0	197.1	1425.5	118.8
1997/98	194.3	277.4	124.3	217.4	106.4	64.2	78.5	1.8	0.0	41.5	35.5	40.1	1181.4	98.5
1998/99	161.8	116.5	357.7	154.5	368.9	194.9	77.1	36.7	30.3	71.2	10.0	17.6	1597.2	133.1
1999/00	55.5	142.3	198.0	402.0	1785.3	267.2	111.7	9.3	87.4	43.5	0.0	77.3	3179.5	265.0
2000/01	114.8	122.8	100.8	69.4	433.6	191.0	118.9	19.5	8.0	53.0	10.0	16.0	1257.8	104.8
2001/02	51.8	249.4	161.0	132.0	47.5	31.2	24.0	0.0	100.0	8.5	7.0	9.2	821.6	68.5
2002/03	107.5	50.4	111.1	109.8	97.8	166.6	13.0	24.3	86.8	5.0	1.8	28.2	802.3	66.9
2003/04	38.2	37.0	49.9	35.1	90.5	100.2	74.5	0.1	10.8	10.3	37.1	12.6	496.3	41.4
Average	71.6	112.7	155.5	201.1	240.8	120.8	62.0	29.0	21.2	21.0	18.5	36.1	1090.3	90.9

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Appendix A2 Continued

The data for Standardized departures for the wet season

Years	Departures
1952/53	-0.1
1953/54	0.3
1954/55	0.1
1955/56	0.0
1956/57	-0.5
1957/58	0.3
1958/59	-0.5
1959/60	-1.0
1960/61	0.7
1961/62	-1.1
1962/63	-1.0
1963/64	-1.5
1964/65	-0.9
1965/66	-0.5
1966/67	-0.1
1967/68	-1.3
1968/69	-0.4
1969/70	-1.2
1970/71	0.1
1971/72	0.5
1972/73	-1.1
1973/74	1.0
1974/75	0.2
1975/76	0.0
1976/77	0.5
1977/78	1.9
1978/79	0.6
1979/80	0.3
1980/81	1.2
1981/82	-0.5
1982/83	-1.2
1983/84	-0.5
1984/85	0.8
1985/86	-0.1
1986/87	-0.6
1987/88	1.1
1988/89	-0.2
1989/90	-0.4
1990/91	0.2
1991/92	-0.9
1992/93	0.5
1993/94	0.1
1994/95	-0.4
1995/96	1.4
1996/97	0.6
1997/98	0.2

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Appendix A2 Continued

Years	Departures
1998/99	1.1
1999/00	4.5
2000/01	0.3
2001/02	-0.5
2002/03	-0.6
2003/04	-1.3

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Appendix A3 (a)

Monthly rainfall depth in mm before 1995 when Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1987/88	93.3	78.4	440.9	127.7	363.6	251.2	39.9	78	140.8	0	78.3	39.8	1731.9	144.3
1988/89	271.3	100.6	136.6	31.9	253.4	16.3	32.8	14.9	23.9	10.6	5.3	5.9	903.5	75.3
1989/90	122.7	87.3	186.4	164	119.4	70.7	51.4	6.8	3.8	0.9	36.6	9.8	859.8	71.7
1990/91	45	65.6	137.5	232.5	183.9	317.6	7.6	31.2	5.7	0	0	30.9	1057.5	88.1
1991/92	10.7	95.6	105.3	110.8	61	127.7	16.8	0	54.3	6.7	13	8.5	610.4	50.9
1992/93	38.7	100	251.5	120.5	529.9	73.3	38.9	9	20.4	68.7	20.7	1	1272.6	106.1
1993/94	61.1	234.5	227.2	245.4	117.4	46	18.4	13.6	3.6	4.3	10	25.1	1006.6	83.9
1994/95	108.3	100.2	69.4	50.5	288.8	112.8	133.3	38.7	0.4	10.3	45.1	13	970.8	80.9
Average	93.9	107.8	194.4	135.4	239.7	127.0	42.4	24.0	31.6	12.7	26.1	16.8	1051.6	87.7

Appendix A3 (b)

Monthly rainfall depth in mm from 1995 when Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1995/96	28.6	88.8	163.9	691.9	478.7	59.1	186.4	162.2	43.8	137.2	22.8	9.9	2073.3	172.8
1996/97	35.8	132.8	112.4	433	228.8	209	27.2	20.7	0	28.7	0	197.1	1425.5	118.8
1997/98	194.3	277.4	124.3	217.4	106.4	64.2	78.5	1.8	0	41.5	35.5	40.1	1181.4	98.5
1998/99	161.8	116.5	357.7	154.5	368.9	194.9	77.1	36.7	30.3	71.2	10	17.6	1597.2	133.1
1999/00	55.5	142.3	198	402	1785.3	267.2	111.7	9.3	87.4	43.5	0	77.3	3179.5	265
2000/01	114.8	122.8	100.8	69.4	433.6	191	118.9	19.5	8	53	10	16	1257.8	104.8
2001/02	51.8	249.4	161	132	47.5	31.2	24	0	100	8.5	7	9.2	821.6	68.5
2002/03	107.5	50.4	111.1	109.8	97.8	166.6	13	24.3	86.8	5	1.8	28.2	802.3	66.9
Average	93.8	147.6	166.2	276.3	443.4	147.9	79.6	34.3	44.5	48.6	10.9	49.4	1542.3	128.6

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Appendix B1

The monthly stream flow in m^3/s for Luvuvhu River at Weltevreden for the period 1952-2003.

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1952/53	1.8	1.5	2.0	8.0	8.9	6.5	5.0	2.9	0.0	2.3	2.1	1.4	42.4	3.5
1953/54	1.4	2.8	5.3	7.1	7.8	7.6	4.9	3.2	2.6	2.1	2.0	1.9	48.7	4.1
1954/55	1.4	1.8	1.9	4.3	8.6	8.6	7.0	5.9	4.7	3.4	2.7	2.3	52.6	4.4
1955/56	2.3	3.3	5.3	5.9	7.1	8.6	8.3	5.3	4.0	3.2	2.4	2.8	58.5	4.9
1956/57	2.0	2.1	2.1	3.1	2.5	5.6	3.6	2.1	1.9	2.1	1.8	1.6	30.5	2.5
1957/58	2.1	1.8	2.6	7.7	8.6	7.8	5.5	3.7	3.1	2.6	2.4	2.9	50.8	4.2
1958/59	2.4	2.1	4.1	7.6	5.9	4.4	2.8	1.9	1.7	2.1	1.6	1.4	38	3.2
1959/60	1.5	1.4	4.1	2.2	5.0	2.0	2.2	2.1	2.0	1.4	1.2	1.2	26.3	2.2
1960/61	1.0	1.0	4.8	6.6	12.0	9.4	6.6	3.9	3.3	2.8	2.5	1.8	55.7	4.6
1961/62	1.6	2.0	2.0	3.1	2.4	9.4	1.8	1.5	1.2	1.1	1.0	1.9	29	2.4
1962/63	0.8	1.0	1.6	1.2	1.1	0.0	0.0	1.4	1.4	1.1	0.7	0.6	10.9	0.1
1963/64	0.5	0.4	0.6	0.6	1.2	0.3	0.1	0.1	0.1	0.2	0.2	0.2	4.5	0.4
1964/65	0.2	0.8	0.8	0.7	0.4	0.3	0.3	0.2	0.1	0.1	0.1	0.1	4.1	0.3
1965/66	0.1	0.4	0.1	0.3	8.9	2.8	0.8	0.6	0.5	0.4	0.4	0.5	15.8	1.3
1966/67	0.6	0.6	0.7	3.6	10.0	2.9	4.1	1.9	1.4	1.1	0.9	0.7	28.5	2.3
1967/68	0.7	2.5	1.2	0.5	0.8	0.5	0.4	0.6	0.6	0.5	0.5	0.2	9	0.8
1968/69	0.1	1.2	2.4	1.5	0.8	6.4	2.6	1.3	0.9	0.7	0.8	0.6	19.3	1.6
1969/70	1.3	1.4	1.6	0.5	0.7	0.2	0.1	0.1	0.2	0.2	0.1	0.1	6.5	0.5
1970/71	0.1	0.2	0.4	1.5	1.1	0.7	0.7	0.4	0.2	0.2	0.1	0.2	5.8	0.4
1971/72	0.2	0.4	0.7	2.8	8.0	8.9	4.4	2.5	1.5	1.1	0.8	0.8	32.1	2.7
1972/73	1.2	0.7	0.8	0.3	0.3	0.6	1.0	0.6	0.4	0.3	0.4	0.3	6.9	0.6
1973/74	1.5	0.9	2.8	4.8	12.8	10.1	4.8	2.6	1.8	1.6	1.2	1.6	46.5	3.9
1974/75	0.9	1.9	2.9	2.3	14.5	8.7	7.4	3.8	2.9	1.9	1.4	1.3	49.9	4.2
1975/76	1.1	0.9	3.0	10.2	16.7	10.4	10.3	5.9	4.3	2.9	1.8	1.3	68.8	5.8
1976/77	1.6	2.4	1.5	2.6	39.9	34.3	11.4	6.3	4.2	3.3	3.1	3.0	113.6	9.5
1977/78	3.1	1.6	5.7	16.9	13.1	14.1	9.9	5.9	4.6	4.0	2.8	2.4	84.1	7.0
1978/79	2.0	3.3	4.0	1.9	2.0	4.5	1.5	1.2	1.0	1.1	1.0	1.1	24.6	2.1
1979/80	1.1	1.3	1.5	2.4	2.4	4.8	2.3	1.2	1.0	0.9	1.0	1.1	21	1.8
1980/81	0.8	1.7	1.9	8.5	11.0	11.7	5.4	4.2	2.6	2.0	2.0	2.3	54.1	4.5
1981/82	1.9	2.2	2.4	1.6	1.4	1.0	0.9	1.2	0.7	0.6	0.5	0.4	14.8	1.2
1982/83	0.7	0.4	0.2	0.2	0.1	0.3	0.1	0.0	0.1	0.1	0.1	0.1	2.4	0.2
1983/84	0.1	0.2	0.0	0.0	0.0	0.1	0.4	0.0	0.0	0.2	0.1	0.1	1.2	0.1
1984/85	0.1	1.4	1.8	1.1	2.6	1.3	0.6	0.6	0.8	0.9	0.4	1.2	12.8	1.1
1985/86	0.5	0.4	0.9	0.7	0.7	0.3	0.7	0.6	0.3	0.1	0.1	0.1	5.4	0.5
1986/87	1.1	0.2	0.4	0.2	0.1	0.1	0.3	0.1	0.1	0.1	0.1	0.2	3	0.3
1987/88	0.3	0.2	2.5	1.3	3.7	8.7	2.2	1.2	0.8	1.2	0.7	0.9	23.7	1.9
1988/89	2.5	1.6	1.5	0.7	1.8	1.5	0.6	0.5	0.4	0.2	0.3	0.1	11.7	0.9
1989/90	0.1	0.5	1.4	1.4	1.5	0.6	0.6	0.3	0.3	0.2	0.2	0.2	7.3	0.6
1990/91	0.1	0.0	0.3	2.0	1.6	3.3	1.9	1.0	0.7	0.5	0.3	0.2	11.9	0.9

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Appendix B1 Continued

1991/92	0.1	0.0	0.1	0.0	0.2	0.0	0.0	0,0	0.0	0.0	0.0	0.0	0.4	0.0
1992/93	0	0.0	1.3	0.8	3.4	1.8	0.5	0.3	0.2	0.2	0.2	0.1	8.8	0.7
1993/94	0.0	0.2	0.9	1.4	2.2	0.6	0.3	0.2	0.1	0.1	0.1	0.1	6.2	0.5
1994/95	0.1	0.1	0.1	0.2	1.6	0.7	0.7	0.8	0.4	0.2	0.6	0.1	5.6	0.5
1995/96	0	0.2	0.4	7.5	22.0	7.4	3.8	3.7	2.3	2.8	2.5	1.5	54.1	4.5
1996/97	1.3	1.2	1.6	2.9	4.8	4.5	3.4	2.0	1.4	1.1	0.8	1.2	26.2	2.2
1997/98	1.0	0.7	0.9	2.9	2.5	0.9	1.0	0.5	0.4	0.5	0.5	0.2	12	1
1998/99	1.0	1.3	4.2	4.8	8.3	4.6	3.1	2.6	1.8	1.8	1.2	0.7	35.4	2.9
1999/00	0.6	0.9	1.8	33.6	88.4	156.7	56.8	12.4	2.3	1.9	0.8	2.4	358.6	29.9
2000/01	3.5	3.8	2.7	1.3	6.8	11.0	6.7	4.4	3.0	2.5	1.9	1.5	49.1	4.1
2001/02	1.0	3.2	8.6	4.7	2.7	1.5	1.1	0.8	1.3	0.8	0.7	0.5	26.9	2.2
2002/03	0.5	1.3	0	0	0	0	0	0	0	0	0	0	1.8	0.2
Average	1.01	1.24	2.00	3.68	7.27	7.82	3.93	2.13	1.40	1.22	1.00	0.96	33.68	

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Appendix B2 (a)

Average monthly discharges in m^3/s for Luvuvhu River at Weltevreden from 1987/88 up to 1994/95 before Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1987/88	0.3	0.2	2.5	1.3	3.7	8.7	2.2	1.2	0.8	1.2	0.7	0.9	23.7	1.9
1988/89	2.5	1.6	1.5	0.7	1.8	1.5	0.6	0.5	0.4	0.2	0.3	0.1	11.7	0.9
1989/90	0.1	0.5	1.4	1.4	1.5	0.6	0.6	0.3	0.3	0.2	0.2	0.2	7.3	0.6
1990/91	0.1	0	0.3	2	1.6	3.3	1.9	1	0.7	0.5	0.3	0.2	11.9	0.9
1991/92	0.1	0	0.1	0	0.2	0	0	0,0	0	0	0	0	0.4	0
1992/93	0	0	1.3	0.8	3.4	1.8	0.5	0.3	0.2	0.2	0.2	0.1	8.8	0.7
1993/94	0	0.2	0.9	1.4	2.2	0.6	0.3	0.2	0.1	0.1	0.1	0.1	6.2	0.5
1994/95	0.1	0.1	0.1	0.2	1.6	0.7	0.7	0.8	0.4	0.2	0.6	0.1	5.6	0.5
Averages	0.4	0.3	1.0	1.0	2.0	2.2	0.9	0.6	0.4	0.3	0.3	0.2	9.5	0.8

Appendix B2 (b)

Average monthly discharges in m^3/s for Luvuvhu River at Weltevreden from 1995/96 up to 2002/03 after Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1995/96	0	0.2	0.4	7.5	22	7.4	3.8	3.7	2.3	2.8	2.5	1.5	54.1	4.5
1996/97	1.3	1.2	1.6	2.9	4.8	4.5	3.4	2	1.4	1.1	0.8	1.2	26.2	2.2
1997/98	1	0.7	0.9	2.9	2.5	0.9	1	0.5	0.4	0.5	0.5	0.2	12	1
1998/99	1	1.3	4.2	4.8	8.3	4.6	3.1	2.6	1.8	1.8	1.2	0.7	35.4	2.9
1999/00	0.6	0.9	1.8	33.6	88.4	156.7	56.8	12.4	2.3	1.9	0.8	2.4	358.6	29.9
2000/01	3.5	3.8	2.7	1.3	6.8	11	6.7	4.4	3	2.5	1.9	1.5	49.1	4.1
2001/02	1	3.2	8.6	4.7	2.7	1.5	1.1	0.8	1.3	0.8	0.7	0.5	26.9	2.2
2002/03	0.5	1.3	0	0	0	0	0	0	0	0	0	0	1.8	0.2
Average	1.1	1.6	2.5	7.2	16.9	23.3	9.5	3.3	1.6	1.4	1.1	1	70.5	5.9

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Appendix B3

Monthly streamflow in m^3/s for Luvuvhu River at Nooitgedacht for the period 1952-2003.

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1952/53	0.3	0.1	0.3	4.8	3.3	2.3	3.3	0.4	0.0	0.9	0.9	0.5	17.1	1.4
1953/54	1.1	2.2	4.2	7.4	3.2	2.9	1.8	1.2	0.7	0.4	0.3	0.1	25.5	2.1
1954/55	0.0	0.0	0.3	2.6	16.9	4.5	2.8	2.5	2.1	1.4	0.8	0.6	34.5	2.9
1955/56	0.8	1.8	2.7	2.5	10.3	8.4	4.0	2.2	1.0	1.4	1.0	1.28	37.4	3.1
1956/57	0.9	1.2	1.5	1.6	1.9	3.1	1.7	0.1	0.1	1.0	0.4	0.4	13.9	1.2
1957/58	1.1	0.8	1.7	19.0	10.3	3.82	2.6	0.9	1.2	0.9	0.8	1.7	44.8	3.7
1958/59	1.5	1.1	3.1	6.7	3.7	2.3	1.3	0.4	0.1	1.1	0.8	0.5	22.6	1.9
1959/60	0.5	0.7	1.3	0.8	2.3	0.2	0.6	0.7	0.3	0.5	0.1	0.0	8	0.7
1960/61	0.1	0.8	1.7	1.9	9.5	3.0	2.1	0.9	0.5	1.2	0.8	0.6	23.1	1.9
1961/62	0.5	0.9	1.3	1.3	0.9	1.1	1.1	0.7	0.3	0.4	0.4	0.4	9.3	0.8
1962/63	0.4	0.8	1.1	0.5	0.3	0.2	0.8	0.6	0.5	0.6	0.2	0.2	6.2	0.5
1963/64	0.2	0.0	0.2	0.4	0.7	0.1	0.0	0.0	0.1	0.0	0.0	0.0	1.7	0.1
1964/65	0.0	1.4	0.9	0.7	0.2	0.0	0.1	0.0	0.1	0.0	0.0	0.0	3.4	0.3
1965/66	0.0	0.3	0.0	0.1	7.7	1.5	0.1	0.4	0.9	0.2	0.2	0.3	11.7	0.9
1966/67	0.5	0.4	0.6	1.9	4.7	1.3	2.7	1.2	0.5	0.6	0.4	0.4	15.2	1.3
1967/68	0.2	1.1	0.7	0.1	0.0	0.0	0.1	0.4	0.3	0.1	0.0	0.0	3	0.3
1968/69	0.0	0.8	0.9	0.5	0.6	4.6	0.8	0.3	0.4	0.3	0.1	0.2	9.5	0.8
1969/70	0.8	1.2	0.9	0.1	0.2	0.0	0.0	0.3	0.0	0.6	0.0	0.0	4.1	0.3
1970/71	0.2	1.0	0.26	1.2	1.3	0.4	0.6	0.4	0.0	0.0	0.0	0.0	5.4	0.4
1971/72	0.3	0.8	0.9	0.8	2.5	3.6	1.5	1.1	0.8	0.8	0.8	0.8	14.7	1.2
1972/73	1.0	0.7	0.7	0.2	0.7	0.7	0.9	0.4	0.4	0.4	0.4	0.28	6.78	0.6
1973/74	1.0	0.6	1.1	2.2	7.6	4.3	1.5	1.2	1.0	0.8	0.6	0.7	22.6	1.9
1974/75	0.4	1.3	1.2	0.9	4.1	3.6	3.0	1.7	1.3	1.0	0.6	0.6	19.7	1.6
1975/76	0.6	0.6	4.0	3.4	6.9	3.1	3.3	2.3	1.9	1.6	1.3	1.1	30.1	2.5
1976/77	1.1	1.5	0.9	1.3	13.1	13.9	4.3	2.8	1.9	0.0	1.8	1.8	44.4	3.7
1977/78	1.8	0.0	2.1	7.8	17.5	8.7	2.9	1.0	0.8	0.5	0.7	0.6	44.4	3.7
1978/79	0.7	1.5	1.9	1.0	1.2	2.0	1.8	1.4	1.0	1.1	1.3	1.9	16.8	1.4
1979/80	2.5	2.8	3.2	2.7	2.4	2.5	1.8	1.1	0.2	0.2	0.3	0.4	20.1	1.7
1980/81	0.7	0.7	0.9	2.3	9.0	3.6	1.6	1.7	1.2	1.0	0.67	0.0	23.4	1.9
1981/82	0.9	0.9	1.0	1.0	0.4	0.3	0.2	0.5	0.6	0.4	0.4	0.3	6.9	0.5
1982/83	0.8	0.0	0.2	0.5	0.3	0.4	0.4	1.0	1.1	1.0	1.0	1.2	7.9	0.6
1983/84	1.2	1.2	0.8	1.0	0.8	0.8	1.0	0.8	0.8	0.8	0.8	0.7	10.7	0.8
1984/85	0.8	1.2	1.2	1.0	1.4	1.2	0.9	0.6	1.0	0.7	0.5	0.0	10.5	0.8
1985/86	0.9	0.4	1.2	1.2	1..8	1.0	0.9	0.0	0.2	0.8	0.6	0.2	7.4	0.6
1986/87	0.6	0.8	0.6	0.5	0.5	0.6	0.8	0.8	1.1	1.1	0.9	0.9	9.2	0.7
1987/88	1.1	0.6	1.1	1.1	1.0	1.1	1.1	0.9	0.6	0.8	0.8	0.9	11.1	0.9
1988/89	1.3	0.9	0.9	0.7	0.9	0.9	0.6	0.6	0.7	0.6	0.6	0.5	9.2	0.7
1989/90	0.7	0.8	1.2	1.3	0.9	0.6	0.7	0.6	0.5	0.5	0.5	0.5	8.8	0.7
1990/91	0.6	0.6	0.6	1.5	1.7	1.4	1.1	0.8	0.7	0.5	0.5	0.6	10.6	0.9

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Appendix B3 Continued

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1991/92	0.5	0.5	0.5	0.5	0.7	1.7	0.5	0.5	0.5	0.5	0.5	0.6	7.5	0.6
1992/93	0.5	0.5	0.5	0.7	1.2	1.5	3.0	5.4	4.8	6.1	5.8	3.4	33.4	2.8
1993/94	9.4	12.2	3.3	1.6	1.3	1.0	3.3	6.7	4.6	3.3	4.2	5.8	56.7	4.7
1994/95	7.8	5.9	7.0	7.0	1.7	5.0	2.5	0.9	1.2	2.9	2.6	8.8	53.3	4.4
1995/96	10.2	5.7	6.2	4.1	3.7	1.9	1.5	1.9	1.6	1.7	1.7	1.4	41.6	3.5
1996/97	1.1	1.4	1.3	1.6	2.0	2.1	1.9	1.5	1.5	1.3	1.3	1.2	18.2	1.5
1997/98	1.0	1.1	1.0	1.3	1.3	0	1.7	7.6	6.8	10.1	0.7	1.4	34	2.8
1998/99	0.9	1.0	1.7	1.8	2.1	1.9	1.4	1.5	1.4	1.45	1.1	2.5	18.8	1.6
1999/00	5.9	0.6	1.6	3.9	19.0	0.0	0	0	0	0	0	0	31	2.6
2000/01	0	0.2	0.1	0	0	0	0	0.3	3.6	2.4	0	0	6.6	0.6
2001/02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	1.2	1.2	1.4	2.1	3.6	2.1	1.4	1.2	1.0	1.1	0.7	0.9	18.3	

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Appendix B4 (a)

Average monthly discharges in m^3/s for Luvuvhu River at Nooitgedacht from 1987/88 up to 1994/95 before Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1987/88	1.1	0.6	1.1	1.1	1	1.1	1.1	0.9	0.6	0.8	0.8	0.9	11.1	0.9
1988/89	1.3	0.9	0.9	0.7	0.9	0.9	0.6	0.6	0.7	0.6	0.6	0.5	9.2	0.7
1989/90	0.7	0.8	1.2	1.3	0.9	0.6	0.7	0.6	0.5	0.5	0.5	0.5	8.8	0.7
1990/91	0.6	0.6	0.6	1.5	1.7	1.4	1.1	0.8	0.7	0.5	0.5	0.6	10.6	0.9
1991/92	0.5	0.5	0.5	0.5	0.7	1.7	0.5	0.5	0.5	0.5	0.5	0.6	7.5	0.6
1992/93	0.5	0.5	0.5	0.7	1.2	1.5	3	5.4	4.8	6.1	5.8	3.4	33.4	2.7
1993/94	9.4	12.2	3.3	1.6	1.3	1	3.3	6.7	4.6	3.3	4.2	5.8	56.7	4.7
1994/95	7.8	5.9	7	7	1.7	5	2.5	0.9	1.2	2.9	2.6	8.8	53.3	4.4
Average	2.7	2.8	1.9	1.8	1.2	1.7	1.6	2.1	1.7	1.9	1.9	2.6	23.8	2.0

Appendix B4 (b)

Average monthly discharges in m^3/s for Luvuvhu River at Nooitgedacht after 1995

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1995/96	10.2	5.7	6.2	4.1	3.7	1.9	1.5	1.9	1.6	1.7	1.7	1.4	41.6	3.4
1996/97	1.1	1.4	1.3	1.6	2	2.1	1.9	1.5	1.5	1.3	1.3	1.2	18.2	1.5
1997/98	1	1.1	1	1.3	1.3	0	1.7	7.6	6.8	10.1	0.7	1.4	34	2.8
1998/99	0.9	1	1.7	1.8	2.1	1.9	1.4	1.5	1.4	1.45	1.1	2.5	18.75	1.6
1999/00	5.9	0.6	1.6	3.9	19	0	0	0	0	0	0	0	31	2.6
2000/01	0	0.2	0.1	0	0	0	0	0.3	3.6	2.4	0	0	6.6	0.5
2001/02	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2002/03	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Average	2.4	1.3	1.5	1.6	3.5	0.7	0.8	1.6	1.9	2.1	0.6	0.8	18.8	1.6

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Appendix B5

Monthly stream flow data in m^3/s for Luvuvhu River at Goedehoop for the period 1952-2003.

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1952/53	1.27	0.88	0.76	18.36	5.43	2.82	4.92	1.91	1.29	1.51	2.14	1.91	43.2	3.6
1953/54	1.61	3.19	5.24	17.8	6.31	3.59	1.14	1.71	1.57	1.73	1.68	2.11	47.68	3.97
1954/55	1.64	1.34	1.16	7.74	30.67	9.79	4.42	4.26	3.09	2.36	2.26	2.48	71.21	5.93
1955/56	2.03	2.02	3.59	3.53	20.63	8.68	8.31	4.07	2.72	2.79	2.71	2.58	63.66	5.30
1956/57	2.21	1.88	1.97	2.37	1.42	4.08	1.19	1.46	1.57	2.08	2.00	1.95	24.18	2.01
1957/58	1.88	1.72	4.89	58.78	24.15	9.05	4.97	3.95	3.80	3.88	3.23	3.37	123.67	10.30
1958/59	2.93	2.21	6.20	17.72	6.29	3.93	2.97	2.26	2.04	2.46	2.38	1.99	53.38	4.44
1959/60	1.88	1.79	3.45	2.35	2.97	1.64	1.30	1.97	1.59	1.61	1.81	1.65	24.01	2.0
1960/61	1.41	1.41	3.50	3.46	19.47	5.41	3.44	2.06	1.52	2.09	2.04	2.00	47.81	3.98
1961/62	1.69	1.26	1.35	2.01	1.29	0.97	0.82	1.38	1.25	1.43	1.29	1.21	15.95	1.32
1962/63	0.79	2.46	2.32	1.38	0.90	0.96	0.92	1.08	0.88	1.33	1.37	1.25	15.64	1.30
1963/64	1.10	0.90	0.90	0.78	0.74	0.74	0.65	0.59	0.55	0.56	0.55	0.48	8.54	0.71
1964/65	0.55	2.07	0.70	0.74	0.65	0.79	0.56	0.69	0.68	0.63	0.63	0.53	9.22	0.76
1965/66	0.51	0.56	3.32	7.83	29.73	2.90	0.77	0.87	0.92	0.98	1.05	1.05	50.49	4.20
1966/67	0.0	0.0	0.02	0.1	2.5	0.1	0.5	0.1	0.1	0.0	0.0	0.0	3.42	0.28
1967/68	0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.02	0.02	0.02	0.02	0.02	0.26	0.02
1968/69	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.23	0.01
1969/70	0.02	0.02	0.02	0.02	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.22	0.01
1970/71	0.02	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.25	0.02
1971/72	0.02	0.02	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.08	0.00
1972/73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1973/74	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1974/75	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1975/76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.32	0.12	0.12	0.56	0.04
1976/77	0.01	0.01	0.01	0.01	0.79	0.00	0.00	0.00	0.00	0.32	0.12	0.12	1.39	0.11
1977/78	0.00	0.50	0.91	5.43	9.43	5.36	1.79	0.81	0.70	0.63	0.29	0.23	26.08	2.17
1978/79	0.09	0.62	0.92	0.06	0.08	0.48	0.05	0.03	0.06	0.03	0.02	0.01	2.45	0.20
1979/80	0.01	0.03	0.03	0.03	0.03	0.05	0.03	0.03	0.03	0.03	0.03	0.03	0.36	0.03
1980/81	0.03	0.03	0.03	0.04	7.15	2.27	0.50	0.45	0.08	0.06	0.05	0.06	10.75	0.89
1981/82	0.07	0.08	0.11	0.06	0.06	0.06	0.04	0.04	0.03	0.02	0.03	0.01	0.61	0.05
1982/83	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.13	0.01
1983/84	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.12	0.01
1984/85	0.02	0.02	0.02	0.06	2.46	0.13	0.55	0.06	0.10	0.02	0.02	0.02	3.48	0.29
1985/86	0.02	0.02	0.05	0.09	0.05	0.06	0.07	0.03	0.02	0.01	0.01	0.01	0.44	0.03
1986/87	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
1987/88	0.00	0.03	0.03	0.01	0.04	0.03	0.01	0.02	0.02	0.00	0.00	0.00	0.19	0.01
1988/89	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
1989/90	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
1990/91	0.00	0.01	0.01	0.07	0.02	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.21	0.01
1991/92	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00

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Appendix B5 Continued

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1992/93	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994/95	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
1995/96	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.03	0.09	0.09	0.05	0.30	0.02
1996/97	0.05	0.09	0.07	0.07	0.01	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.38	0.03
1997/98	0.02	0.03	0.00	0.08	0.08	0.01	0.03	0.02	0.03	0.03	0.02	0.01	0.36	0.03
1998/99	0.07	0.01	0.02	0.06	0.06	0.01	0.03	0.02	0.03	0.08	0.05	0.08	0.52	0.04
1999/00	0.10	0.24	0.17	0.33	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.07
2000/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001/02	0.00	0.00	0.16	0.64	0.00	0.00	0.00	0.00	0.19	0.21	0.09	0.16	1.45	0.12
2002/03	0.15	0.13	0.16	0.14	0.10	0.11	0.09	0.10	0.10	0.10	0.07	0.05	1.30	0.10
Average	0.43	0.50	0.82	2.98	3.40	1.25	0.79	0.58	0.49	0.53	0.51	0.50	12.84	0.00

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Appendix B6 (a)

Average monthly discharges in m^3/s for Luvuvhu River at Goedehoop from 1987/88 up to 1994/95 when Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1987/88	0.00	0.03	0.03	0.01	0.04	0.03	0.01	0.02	0.02	0.00	0.00	0.00	0.19	0.01
1988/89	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
1989/90	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
1990/91	0.00	0.01	0.01	0.07	0.02	0.05	0.04	0.01	0.00	0.00	0.00	0.00	0.21	0.01
1991/92	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
1992/93	0.00	0.00	0.00	0.01	0.03	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.00
1993/94	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
1994/95	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
Average	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix B6 (b)

Average monthly discharges in m^3/s for Luvuvhu River at Goedehoop from 1995/96 up to 2003/04 when Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1995/96	0.00	0.00	0.00	0.01	0.02	0.01	0.00	0.00	0.03	0.09	0.09	0.05	0.30	0.02
1996/97	0.05	0.09	0.07	0.07	0.01	0.01	0.08	0.00	0.00	0.00	0.00	0.00	0.38	0.03
1997/98	0.02	0.03	0.00	0.08	0.08	0.01	0.03	0.02	0.03	0.03	0.02	0.01	0.36	0.03
1998/99	0.07	0.01	0.02	0.06	0.06	0.01	0.03	0.02	0.03	0.08	0.05	0.08	0.52	0.04
1999/00	0.10	0.24	0.17	0.33	0.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.92	0.07
2000/01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2001/02	0.00	0.00	0.16	0.64	0.00	0.00	0.00	0.00	0.19	0.21	0.09	0.16	1.45	0.12
2002/03	0.15	0.13	0.16	0.14	0.10	0.11	0.09	0.10	0.10	0.10	0.07	0.05	1.30	0.10
Average	0.05	0.06	0.07	0.17	0.04	0.02	0.03	0.02	0.05	0.06	0.04	0.04	0.65	0.05

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Appendix C1

The average monthly evaporation of Soutpansberg for the period 1952-2003

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1952/53	4.2	4.7	5.9	3.3	3.9	3.5	3.3	3.5	3.2	3.4	3.1	4.1	46.1	3.8
1953/54	5.1	4.3	4.4	4.2	4.0	4.2	3.9	3.7	2.3	3.7	3.5	4.0	47.3	3.9
1954/55	5.3	4.2	5.6	3.2	3.3	3.2	3.2	2.8	2.4	3.0	3.7	4.6	44.5	3.7
1955/56	4.1	4.5	3.6	4.8	3.2	3.7	3.0	2.9	2.7	3.0	4.6	4.1	44.2	3.6
1956/57	5.5	5.4	4.6	5.3	4.5	2.9	3.4	3.0	2.7	3.6	3.8	3.8	48.5	4.0
1957/58	4.3	4.8	5.2	3.0	3.9	3.5	3.5	3.9	3.2	3.1	3.9	4.2	46.5	3.8
1958/59	5.4	6.9	3.9	4.1	4.6	4.0	3.6	4.2	3.2	3.3	4.5	5.4	53.1	4.4
1959/60	6.5	5.7	5.1	5.2	18.8	11.6	3.4	3.2	2.2	2.8	3.4	4.6	72.5	6.0
1960/61	5.7	4.9	4.8	5.3	3.9	3.4	2.9	2.7	2.0	2.2	2.8	4.2	44.8	3.7
1961/62	5.3	4.0	3.9	4.5	5.5	4.0	3.5	2.5	2.7	2.8	3.7	4.6	47	3.9
1962/63	5.8	4.3	4.7	4.4	4.9	4.2	2.9	2.6	2.2	2.3	3.6	4.5	46.4	3.8
1963/64	4.1	5.6	6.0	5.6	20.1	12.5	4.1	2.7	3.3	2.6	3.7	5.2	75.5	6.2
1964/65	5.5	5.3	3.9	4.8	5.4	5.0	3.7	3.3	2.7	3.1	3.6	4.9	51.2	4.2
1965/66	6.2	4.2	6.2	6.3	3.2	4.0	3.1	3.4	2.4	3.2	3.6	4.1	49.9	4.1
1966/67	4.6	5.2	4.8	4.4	3.7	4.3	3.2	2.8	2.7	2.6	2.9	4.3	45.5	3.7
1967/68	4.4	4.5	5.5	7.2	19.0	10.9	3.2	2.7	2.6	2.4	3.2	5.2	70.8	5.9
1968/69	5.8	4.8	5.0	5.3	5.3	3.4	2.8	2.8	2.3	2.5	3.2	4.2	47.4	3.9
1969/70	3.9	5.3	4.9	7.0	6.1	6.0	4.6	4.0	2.5	3.3	4.3	5.8	57.7	4.8
1970/71	5.2	5.3	6.5	3.9	4.7	5.3	3.7	3.0	2.4	3.1	3.9	4.7	51.7	4.3
1971/72	4.6	4.1	5.8	4.2	12.0	6.6	3.7	2.9	2.8	2.9	3.3	4.8	57.7	4.8
1972/73	4.7	5.4	6.5	7.2	5.7	4.7	3.4	3.1	2.3	3.0	3.6	5.0	54.6	4.5
1973/74	4.4	4.3	3.7	4.1	3.8	3.6	2.9	3.1	2.8	2.7	3.7	4.3	43.4	3.6
1974/75	4.8	3.9	4.8	5.3	3.5	3.4	2.8	2.8	2.1	3.0	3.3	4.0	43.7	3.6
1975/76	4.4	5.1	4.4	4.1	10.0	5.7	3.1	2.4	2.5	2.5	3.1	3.9	51.2	4.2
1976/77	4.6	4.6	6.0	6.3	4.0	2.4	3.2	3.2	2.6	2.8	2.9	3.6	46.2	3.8
1977/78	4.9	5.6	4.4	3.7	3.7	3.8	3.6	3.1	2.6	2.3	3.2	4.0	44.9	3.7
1978/79	3.4	0.0	5.3	5.3	4.6	4.4	3.6	2.9	2.6	2.6	2.6	3.6	40.9	3.4
1979/80	3.7	3.8	4.9	5.0	3.7	3.6	3.2	3.2	2.7	2.4	2.8	3.5	42.5	3.5
1980/81	4.1	4.3	4.9	4.1	3.8	3.9	3.4	2.3	2.6	2.4	2.5	3.2	41.5	3.4
1981/82	3.3	5.0	5.3	4.9	5.1	4.6	3.4	2.7	2.5	2.4	3.5	4.4	47.1	3.9
1982/83	4.1	4.8	6.1	6.4	5.8	4.6	4.1	3.6	2.7	2.8	3.3	5.0	53.3	4.4
1983/84	4.4	5.4	6.1	7.0	5.1	4.2	3.3	3.4	2.3	2.2	2.9	3.9	50.2	4.1
1984/85	4.4	3.7	5.8	4.8	4.5	3.8	3.6	2.5	2.3	2.7	3.2	3.5	44.8	3.7
1985/86	4.9	5.8	4.9	5.1	5.0	5.4	3.2	2.9	2.7	2.7	3.4	4.1	50.1	4.1
1986/87	4.2	5.2	5.3	4.9	6	4.7	3.8	3.2	2.7	2.9	2.7	3.2	48.8	4.0
1987/88	3.8	4.9	3.7	5.4	4.3	3.4	3	2.6	2.6	2.5	2.7	3.6	42.5	3.5
1988/89	3.9	4.4	4.2	5.3	4.1	4.2	3.5	2.6	2.2	2.4	3.3	4.6	44.7	3.7
1989/90	4.7	3.9	5	4	4.4	3.6	2.8	2.6	2.6	2.3	3	4.1	43	3.5
1990/91	5.0	5.0	4.3	4.5	4.8	3.7	3.5	2.7	2	2.7	3.4	3.5	45.1	3.7
1991/92	5.3	5.7	5.4	5.9	6.5	4.6	4.3	3.6	2.6	2.7	3.2	3.8	53.6	4.4

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Appendix C1 Continued

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1992/93	5.1	4.6	6	5.3	4	3.6	3.2	2.7	2.2	2	2.6	4.3	45.6	3.8
1993/94	4.3	3.7	4.6	3.8	3.6	4.3	3.5	3.1	2.8	3	3.2	4.7	44.6	3.7
1994/95	5.1	6.1	5.4	5.5	5.4	4	3	1.7	2.1	2.4	3	4.3	48	4
1995/96	4.9	4.4	4.4	4	3.2	3.5	2.6	1.8	1.9	1.8	2.3	3.6	38.4	3.2
1996/97	4.4	4.4	4.5	3.9	3.6	3.1	3.5	2.5	2.6	2.2	3.3	3.2	41.2	3.4
1997/98	4.2	5.1	5.3	4.3	4.4	5	3.4	3.1	2.4	2.1	3.1	3.6	46	3.8
1998/99	2.7	3.8	3.7	4.3	3.1	3.5	2.7	2.3	2	2	3	3.8	36.9	3.0
1999/00	4.4	3.9	5	3.6	2.8	2.5	2.6	2.3	1.7	2.1	2.7	3	36.6	3.0
2000/01	3.7	4.5	5.1	5.7	3.4	2.8	2.8	2.2	1.9	2.2	2.5	3.5	40.3	3.3
2001/02	4.0	3.5	3.6	5.5	4.6	4.5	3.5	2.8	2.3	2.4	2.7	3.7	43.1	3.5
2002/03	3.6	5.3	5	5.2	5.3	4.9	3.5	3.1	1.6	0	0	3.5	41	3.4
Average	4.6	4.6	4.9	4.9	5.5	4.5	3.3	2.9	2.4	2.6	3.1	4.1	47.8	3.9

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Appendix C2

The peak average annual evaporation in mm (1952-2004)

Years	Evaporation peaks (mm)
1952/53	5.9
1953/54	5.1
1954/55	5.6
1955/56	4.8
1956/57	5.5
1957/58	5.2
1958/59	6.9
1959/60	18.8
1960/61	5.7
1961/62	5.5
1962/63	5.8
1963/64	12.5
1964/65	5.5
1965/66	6.3
1966/67	5.2
1967/68	19.0
1968/69	5.8
1969/70	7.0
1970/71	6.5
1971/72	12.0
1972/73	7.2
1973/74	4.4
1974/75	4.8
1975/76	10.0
1976/77	6.3
1977/78	5.6
1978/79	5.3
1979/80	5.0
1980/81	4.9
1981/82	5.3
1982/83	6.4
1983/84	7.0
1984/85	5.8
1985/86	5.1
1986/87	5.3
1987/88	5.4
1988/89	5.3
1989/90	4.7
1990/91	5.0
1991/92	6.5
1992/93	5.1
1993/94	4.7
1994/95	6.1
1995/96	4.9
1996/97	4.5
1997/98	5.3

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Appendix C2 Continued

Years	Evaporation peaks (mm)
1998/99	4.3
1999/00	5
2000/01	5.7
2001/02	5.5
2002/03	5.3
2003/04	5.5

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Appendix D1

Groundwater levels for station A7N019 for February each year for the period 1985-2004

Years	Groundwater levels
1984/85	5.18
1985/86	7.83
1986/87	7.73
1987/88	6.63
1988/89	10.1
1989/90	10.8
1990/91	10.44
1991/92	13.09
1992/93	12.74
1993/94	14.02
1994/95	15.42
1995/96	8.79
1996/97	0.0
1997/98	12.88
1998/99	14.47
1999/00	0.0
2000/01	5.16
2001/02	4.6
2002/03	7.69

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Appendix D2

Groundwater levels for station A7N019 for March of each year for the period 1985-2004

Years	Groundwater levels
1984/85	5.19
1985/86	8.55
1986/87	8.68
1987/88	5.24
1988/89	10.08
1989/90	10.98
1990/91	11.23
1991/92	13.19
1992/93	13.3
1993/94	15.05
1994/95	15.57
1995/96	8.87
1996/97	8.53
1997/98	13.32
1998/99	14.94
1999/00	0.00
2000/01	0.00
2001/02	5.01
2002/03	8.48

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Appendix E (a)

Minimum Average monthly temperature data in ^{0}C for Luvuvhu River at Goldeville station from 1986/87 up to 1994/95 when Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1987/88	17.6	15.3	10.6	18.4	15.2	17.7	15.3	15.6	12.9	15.3	16.6	16.2	186.6	28.7
1988/89	17.4	14.8	9.9	18.2	14.8	17.3	14.7	15.3	12.6	14.9	16.2	15.9	181.9	28.0
1989/90	17.0	14.2	9.4	17.8	14.2	16.9	14.4	15.0	12.1	14.5	15.6	15.3	176.4	27.1
1990/91	16.6	13.7	8.8	17.3	13.8	16.6	14.1	14.6	11.8	14.0	15.1	14.8	171.2	26.3
1991/92	16.1	13.0	8.0	17.0	13.4	16.2	13.6	14.3	11.6	13.6	14.7	14.3	165.7	25.5
1992/93	15.5	12.5	8.2	16.6	12.8	15.9	13.2	14.0	11.3	13.1	14.4	13.7	161.3	24.8
1993/94	15.2	12.0	8.5	16.3	12.5	15.5	13.0	13.8	10.9	13.0	14.3	13.5	158.4	24.4
1994/95	15.0	11.3	8.8	15.9	12.2	15.1	12.6	13.4	10.6	12.9	14.0	13.1	155.0	23.8
Average	14.9	12.1	8.1	15.7	12.3	15.0	12.6	13.2	10.7	12.7	13.8	13.3	154.2	23.7

Appendix E (b)

Maximum Average monthly temperature data in ^{0}C for Luvuvhu River at Goldeville station from 1995/96 up to 2003/04 after Working for Water was initiated

Years	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Total	Mean
1995/96	22.1	22.0	19.0	24.9	21.6	22.4	21.0	21.0	17.8	18.8	21.9	21.6	254.0	39.1
1996/97	22.0	21.9	18.5	24.6	21.5	22.4	20.8	20.9	17.5	18.9	21.6	21.7	252.2	38.8
1997/98	22.1	21.6	18.0	24.4	21.5	22.2	20.6	20.7	17.3	18.9	21.2	21.6	250.2	38.5
1998/99	21.9	21.5	17.8	24.1	21.3	22.1	20.4	20.5	17.2	18.9	21.0	21.5	248.3	38.2
1999/00	21.5	21.5	17.5	23.8	21.2	21.9	20.1	20.4	17.1	18.8	20.7	21.6	246.2	37.9
2000/01	21.2	21.4	17.1	23.5	20.9	21.6	20.1	20.2	17.0	18.7	20.7	21.5	244.1	37.6
2001/02	21.0	21.0	16.5	23.3	20.5	21.7	20.0	20.0	16.9	18.6	20.7	21.2	241.3	37.1
2002/03	20.7	20.7	15.9	23.0	20.2	21.7	20.0	19.6	16.7	18.3	20.4	21.0	238.4	36.7
Average	21.6	21.4	17.5	24.0	21.1	22.0	20.4	20.4	17.2	18.8	21.0	21.5	246.8	38.0

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Appendix F1

Flow Duration curve data for Luvuvhu River at Weltevreden

Total Annual flow (x10^6 m^3)	Rank	Percentage of exceedence (%)
358.6	1	2.0
113.6	2	3.9
84.1	3	5.9
68.8	4	7.8
58.5	5	9.8
55.7	6	11.8
54.1	8	15.7
52.6	9	17.6
50.8	10	19.6
49.9	11	21.6
49.1	12	23.5
48.7	13	25.5
46.5	14	27.5
42.4	15	29.4
38	16	31.4
35.4	17	33.3
32.1	18	35.3
30.5	19	37.3
29	20	39.2
28.5	21	41.2
26.9	22	43.1
26.3	23	45.1
26.2	24	47.1
24.6	25	49.0
23.7	26	51.0
21	27	52.9
19.3	28	54.9
15.8	29	56.9
14.8	30	58.8
12.8	31	60.8
12	32	62.7
11.9	33	64.7
11.7	34	66.7
10.9	35	68.6
9	36	70.6
8.8	37	72.5
7.3	38	74.5
6.9	39	76.5
6.5	40	78.4
6.2	41	80.4
5.8	42	82.4

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Appendix F1 Continued

Total Annual flow (x10^6 m^3)	Rank	Percentage of exceedence (%)
5.6	43	84.3
5.4	44	86.3
4.5	45	88.2
4.1	46	90.2
3	47	92.2
2.4	48	94.1
1.8	49	96.1
1.2	50	98.0
0.4	51	100.0

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Appendix F1 (a)

Flow Duration curve data for Luvuvhu River at Weltevreden eight years before and eight years after Working for Water was initiated

Before WFW			After WFW		
Mean Flow (m^3/s)	Rank	Percentage of exceedence (%)	Mean Flow (m^3/s)	Rank	Percentage of exceedence (%)
1.9	1	12.5	29.9	1	12.5
0.9	3	37.5	4.5	2	25
0.7	4	50	4.1	3	37.5
0.6	5	62.5	2.9	4	50
0.5	7	87.5	2.2	6	75
0	8	100	1	7	87.5
			0.2	8	100

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Appendix G1

Flow Duration curve data for Luvuvhu River at Nooitgedacht

Total Annual flow ($x10^6$ m^3)	Rank	Percentage of exceedence (%)
56.7	1	2.0
53.3	2	3.9
44.8	3	5.9
44.4	5	9.8
41.6	6	11.8
37.4	7	13.7
34.5	8	15.7
34	9	17.6
33.4	10	19.6
31	11	21.6
30.1	12	23.5
25.5	13	25.5
23.4	14	27.5
23.1	15	29.4
22.6	17	33.3
20.1	18	35.3
19.7	19	37.3
18.8	20	39.2
18.2	21	41.2
17.1	22	43.1
16.8	23	45.1
15.2	24	47.1
14.7	25	49.0
13.9	26	51.0
11.7	27	52.9
11.1	28	54.9
10.7	29	56.9
10.6	30	58.8
10.5	31	60.8
9.5	32	62.7
9.3	33	64.7
9.2	35	68.6
8.8	36	70.6
8	37	72.5
7.9	38	74.5
7.5	39	76.5
7.4	40	78.4
6.9	41	80.4
6.8	42	82.4
6.6	43	84.3
6.2	44	86.3

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Appendix G1 Continued

Total Annual flow (x10^6 m^3)	Rank	Percentage of exceedence (%)
5.4	45	88.2
4.1	46	90.2
3.4	47	92.2
3	48	94.1
1.7	49	96.1
0	51	100.0

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Appendix G1 (a)

Flow Duration curve data for Luvuvhu River at Nooitgedacht eight years before and eight years after Working for Water was initiated

Before WFW			After WFW		
Mean Flow (m^3/s)	Rank	Percentage of exceedence (%)	Mean Flow (m^3/s)	Rank	Percentage of exceedence (%)
4.7	1	12.5	3.4	1	12.5
4.4	2	25	2.8	2	25
2.7	3	37.5	2.6	3	37.5
0.9	5	62.5	1.6	4	50
0.7	7	87.5	1.5	5	62.5
0.6	8	100	0.5	6	75
			0	8	100

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Appendix H1

Flow Duration curve data for Luvuvhu River at Goedehoop

Total Annual flow ($x10^6$ m^3)	Rank	Percentage of exceedence (%)
123.67	1	2.0
71.21	2	3.9
63.66	3	5.9
53.38	4	7.8
50.49	5	9.8
47.81	6	11.8
47.68	7	13.7
43.2	8	15.7
26.08	9	17.6
24.18	10	19.6
24.01	11	21.6
15.95	12	23.5
15.64	13	25.5
10.75	14	27.5
9.22	15	29.4
8.54	16	31.4
3.48	17	33.3
3.42	18	35.3
2.45	19	37.3
1.45	20	39.2
1.39	21	41.2
1.30	22	43.1
0.92	23	45.1
0.61	24	47.1
0.56	25	49.0
0.52	26	51.0
0.44	27	52.9
0.38	28	54.9
0.36	30	58.8
0.30	31	60.8
0.26	32	62.7
0.25	33	64.7
0.23	34	66.7
0.22	35	68.6
0.21	36	70.6
0.19	37	72.5
0.13	38	74.5
0.12	39	76.5
0.08	40	78.4
0.04	42	82.4
0.02	44	86.3

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Appendix H1 Continued

Total Annual flow (x10^6 m^3)	Rank	Percentage of exceedence (%)
0.01	46	90.2
0.00	51	100.0

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Appendix H1 (a)

Flow Duration curve for Luvuvhu River at Goedehoop eight years before and eight years after Working for Water was initiated

Before WFW			After WFW		
Mean Flow (m^3/s)	**Rank**	**Percentage of exceedence (%)**	**Mean Flow (m^3/s)**	**Rank**	**Percentage of exceedence (%)**
0.01	2	25	0.12	1	12.5
0.00	8	100	0.1	2	25
			0.07	3	37.5
			0.04	4	50
			0.03	6	75
			0.02	7	87.5
			0.00	8	100

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