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SCHOOL OF ENVIRONMENTAL SCIENCES

ASSESSMENT OF THE IMPACTS OF SELECTED LIMPOPO PROVINCE DAMS ON THEIR DOWNSTREAM RIVER ECOSYSTEMS USING REMOTE SENSING TECHNIQUES

By
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A dissertation submitted to the Department of Geography and GeoInformation Sciences in fulfillment of the requirements for the Degree of Master of Environmental Sciences in Geography (MEnv.Sc)

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August 2012

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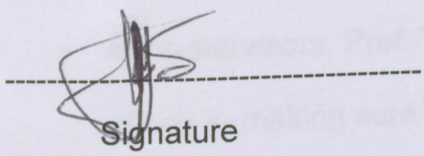
DECLARATION

I, **Matjutla John Mokgoebo (11583238)**, declare that this dissertation for the award of Masters in Geography at the University of Venda has not been previously submitted for a degree in this or other institutions, and the sources of information contained in this study have been acknowledged



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ACKNOWLEDGEMENT

I would like to thank everyone who has helped me in the drafting and compilation of research data into one comprehensive document. Special thanks can be directed to the following:

- My supervisors, Prof. T.A. Kabanda and Dr. J. Gumbo for their tireless efforts in making sure that the research is completed successfully.
- My children Vhuhwavho and Moloko for being with me in all field trips around the study area
- My wife Tendani, for the full support and inspiration she displayed during the research.
- Khodani Nemukondeni, for fully assisting me during fieldwork data collection.
- My parents Moloko and Molatela for the support they gave me, as well as Kabelo (newphew) for the academic assistance rendered during the research.
- All those who gave me support during the research.

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Abstract

The impacts of dams on their downstream river ecosystems have been associated with a decrease in stream flow, species biodiversity, water quality, altered hydrology and colonization of the area by invasive alien plant species. The impacts normally interfere with the ecosystem functioning of riparian and aquatic environments, thereby leading to decreased biodiversity. In this study, the main aim was to assess the impacts of dams on downstream river ecosystems using aerial photography. Aerial photographs and orthophotos data were supplemented by field work. Aerial photographs and orthophotos data of different years were used to assess the impacts of the five selected dams (Albasini, Damani, Mambedi, Nandoni and Vondo) on their downstream catchments. The area devoid of tree species both downstream and upstream of the dams was calculated using grids of predetermined square-sizes on each available photograph. The nearest neighbour method was used in the field to determine tree density between identical tree species. Rainfall and discharge data were also used to determine whether the upstream presence of the dams altered streamflow, thus leading to a reduction in vegetation density downstream of the dams. The results from all studied dams indicated that vegetation density decreased downstream of the dam while rainfall remained constant over a period of more than twenty years. The presence of terrestrial vegetation (*Acacia Karroo, Acacia ataxacantha and Bauhinia galpinii*) along downstream riparian zones indicated that the environments downstream of the dams have been occupied by obligate terrestrial vegetation instead of obligate riparian vegetation. Results also revealed a shortage of water downstream of the dams in winter (May, June, July) and these dry conditions are worsened during low rainfall periods . Mambedi and Vondo dam areas showed bigger treeless areas, showing their low resilience and higher fragility than in all other studied dam areas (Albasini, Damani and Nandoni).

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GLOSSARY

***Dam*:** Any structure that is placed across a flowing body of water to stop or divert the flow

Downstream impacts: Any impact that occurs away from the location of a dam or barrier, but in the direction of flowing water or downriver.

Flow regime: The pattern of flow in a river that can be described in terms of quantity and variability of water flows.

***pH*:** A measure of acidity and alkalinity on a logarithmic scale on which seven is neutral, lower values are more acid and higher values are more alkaline.

Remote sensing: The collection and interpretation of information about any geographical phenomenon by utilizing airborne techniques like aerial photography and satellite imaging.

Riparian ecosystem: Ecosystems around or next to water areas that support unique vegetation and animal communities as a result of the influence of water.

Upstream impacts: Any impact that occurs away from the location of a dam or barrier, but in the opposite direction of flowing water or upriver.

Water quality: The biological, chemical and physical conditions of water that determine its ability to support beneficial uses, such as ecosystem functioning.

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CHAPTER ONE: INTRODUCTION

1.1 Background to the problem

Dams across the world have been associated with many negative environmental, social and economic impacts. Damshave also been associated with downstream vegetation species reduction, due to less water quantities associated with the upstream presence of dams. Many dammed rivers around the world have been characterised by decline in species diversity, increase in invasive alien plants and pollution. Mumba and Thompson (2005) argue that flow disturbance provides stimulus for the establishment of opportunistic plants, particularly alien invasive species. In Limpopo, the most northerly Province of South Africa, the impacts of dams have also been accelerated by the alternating wet and dry climatic conditions that greatly affect the flow regimes of rivers. This is because dams create barriers of natural waterflow and interfere with ecological processes of riparian zones that influence vegetation composition, richness and diversity (Malik and Richardson, 2009). Dams have been associated with water pollution generated from industries and agricultural sectors such as the release of litter, hot water, pesticides and fertilizers into streams and rivers (Kney and Brandes, 2007).

The decrease in downstream flow is strongly associated with negative impacts on downstream riparian ecosystems. The decrease in water quality and quantity downstream alters the vegetation composition, natural irrigation of floodplains and microclimates. These downstream impacts are associated with a decrease in biological diversity, changes in successional stages, altered biogeochemical cycles and alteration of downstream natural ecosystems. Toxins that accumulate in dams can be released during flush periods and this is accompanied by an irreparable damage to the downstream environment. This supports Wohl *et al.* (2007) conclusion that any landscape modification and subsequent changes in hydrology, channel morphology and physiochemical properties result in the dramatic decrease in biological diversity in riparian and aquatic ecosystems. About half of South Africa's

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rainfall is stored in dams (DWAF, 2004b). There are about 550 government dams that carry about approximately 37 million m^3 of water. There are about 25 registered dams in LimpopoProvince (DWAF, 2004a).

1.2 Statement of the problem

In the past years more focus was put on conservation of water in reservoirs and dams for agricultural irrigation and hydropower generation without considering the impacts that are associated with dams. The greatest impact is usually manifested downstream, along large parts of floodplains and areas away from the dam and river banks.

The dams of Limpopo, with much of the Province characterized by wet-dry climatic cycles have remarkable and sometimes irreversible impacts on downstream ecosystems. These dams usually change vegetation composition, reduce species diversity, alter flow characteristics and encourage alien species invasion that alter the ecosystem functioning of rivers downstream. Changes in vegetation structure and composition may also alter microclimate of areas in the vicinity of dams. The impact of dams on downstream riparian ecosystems may be accompanied by decrease in water quality and quantity both downstream and upstream of the dams. Such changes in chemical and physical properties of water in dams have the potential to alter various riparian ecosystems and may deny many indigenous species of their habitats, species diversity and some rare and endangered species might start to disappear from Luvuvhu River catchment. However, it is not known whether these impacts of dams on their downstream river ecosystems have been studied and reported for the Luvuvhu River catchment. This study is therefore the effort to undertake such a study

1.3 Research Objectives

1.3.1 Aim

To assess the impacts of the selected dams that are located in the Luvuvhu River catchment on their downstream river ecosystems with the use of remote sensing.

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1.3.2 Objectives

i. to study the nature of vegetation changes along downstream river courses;
ii. to compare upstream and downstream vegetation species richness using remote sensing techniques;
iii. to assess water quality upstream and downstream of the dam;
iv. to study the flow regimes of the Luvuvhu/Mutale rivers with respect to rainfall variation; and
v. to develop effective mitigation strategies to improve ecosystem functioning and water management strategies.

1.3.3 Research questions

i. Is there a relationship between changes in vegetation density and altered stream flow?
ii. Are there significant differences between upstream and downstream vegetation richness?
iii. Does the presence of dams alter downstream and upstream water quality?
iv. Do rainfall variability and dams alter flow regimes of downstream reaches?
v. What strategies can be implemented to minimise the environmental impacts of dams?

1.4 Delimitation of the study area

LimpopoProvince is one of the nine provinces of South Africa and is characterized by alternating wet-dry climatic cycles that determine the amount of water available as runoff and making its way to the river systems (Singo, 2008). The study area falls under the Luvuvhu River catchment which forms part of the Luvuvhu/Letaba Water Management Area (WMA) of Limpopo Province (Figure 1.1). This WMA is located adjacent to and shares watercourses with Mozambique and Zimbabwe. The Luvuvhu river catchment covers a total area of 3 800km^2 andthe MutaleRiver catchment 2 150km^2. The dams under study are located in the Luvuvhu river catchment are: Albasini and Nandoni on the Luvuvhu River, Vondo on the

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Mutshindudi River, Damani on the Mbwedi River andthe Mambedi on the Mambedi River (DWAF, 2004a).

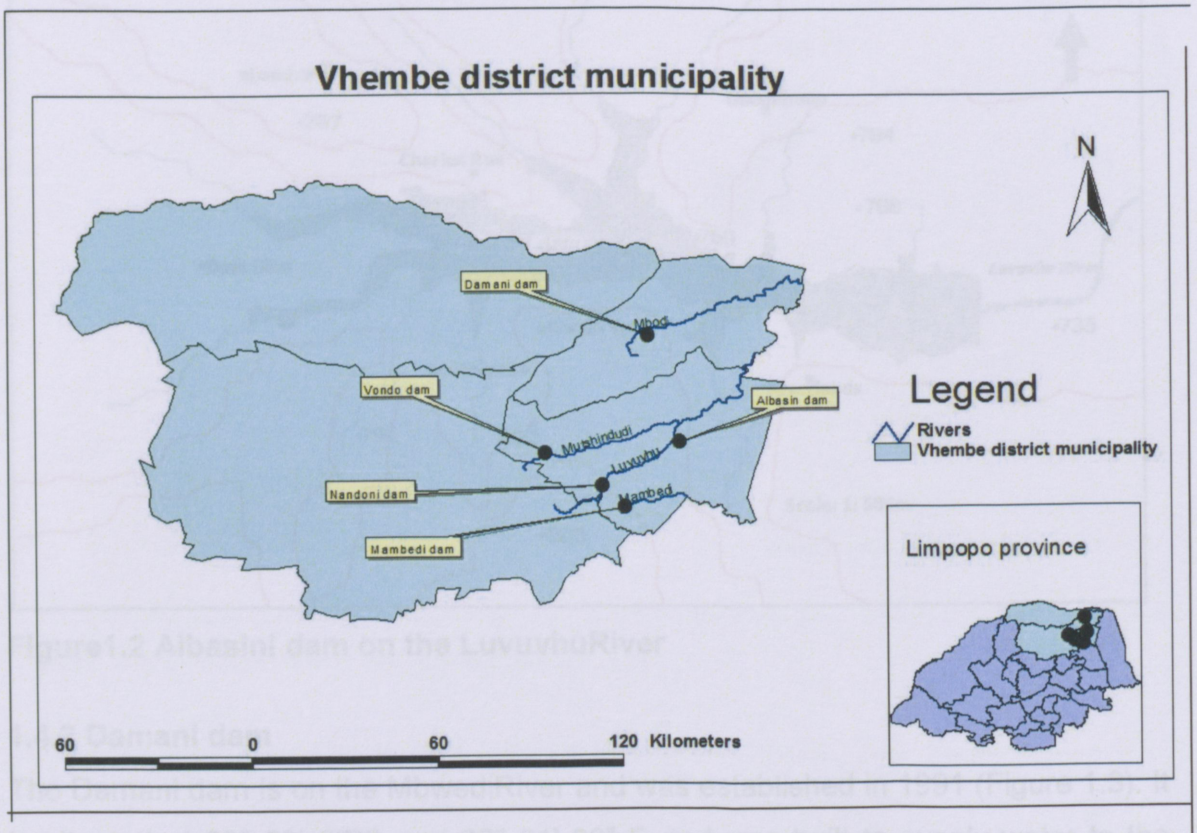

Figure 1.1The locations of the five dams under study

1.4.1 Albasini dam

The dam is situated at 23° 06' 25" S and 30° 07' 30"E and was built on the LuvuvhuRiver in 1952 and was raised by means of spillway gate in 1970/71 (Figure 1.2). The dam was built to supply water to the Levubu Irrigation Scheme to irrigate tropical fruits such as bananas, litchis, mangos, avocados and macadamia nuts. Its maximum water carrying capacity is 25.6 x 10^6 m^3 (DWAF, 2004b). It lies 22km south-east of Makhado (formerly Louis Trichardt) and approximately 45 km west (upstream) of the Nandoni dam, which also lies on the Luvuvhu River. The rainfall station in the vicinity of the dam is Goedehoop. Its average annual rainfall is 800mm and receives much of its rainfall between October and April. The lowest rainfall is recorded from May to September (Singo, 2008).

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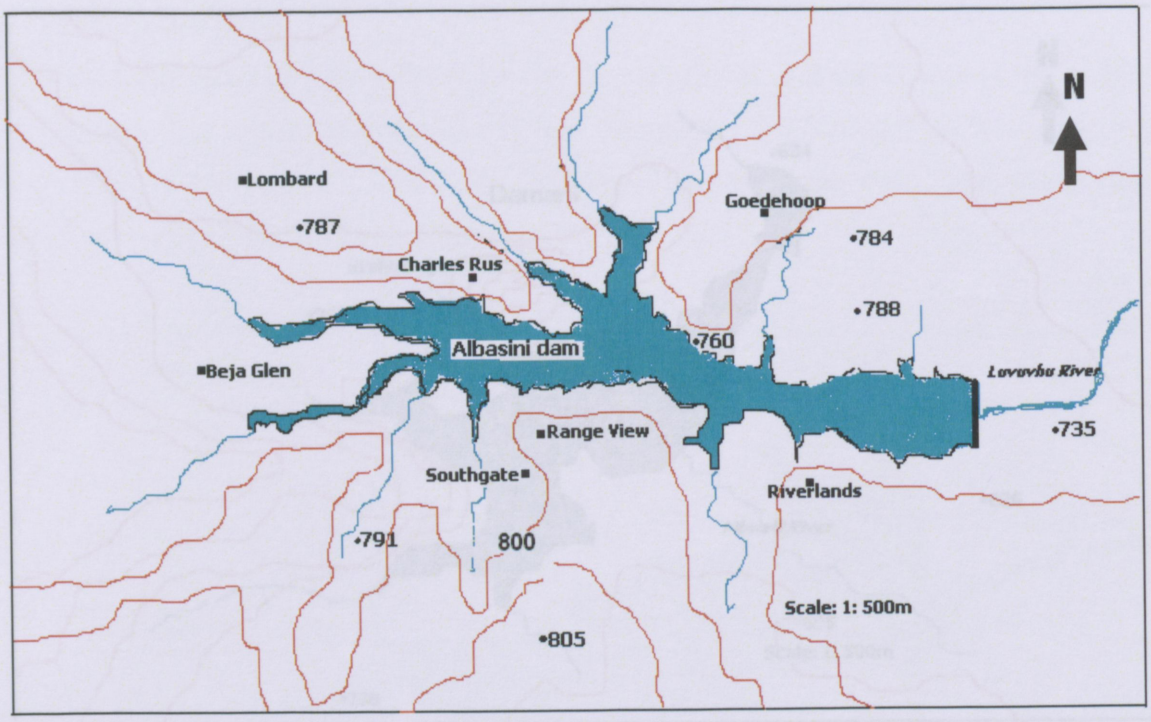

Figure1.2 Albasini dam on the LuvuvhuRiver

1.4.2 Damani dam

The Damani dam is on the MbwediRiver and was established in 1991 (Figure 1.3). It is situated at 22º 50' 07"S and 30º 31' 22" E and was built to supply water to the former Damani Coffee Estate which required 4.08mil.m^3 per annum. It is still used to supply irrigation water to the surrounding commercial farms owned by local community members. Its maximum water carrying capacity is 12.4 x 10^6 m^3 and has a surface area of 13ha (DWAF, 2004b).

1.4.3 Mambedi dam

The dam was built on the Mambedi River (Figure 1.4) to supply water to the Sapekoe Tea Company. The dam collapsed in the year 2000 after its wall failed to contain an increase in flow during the heavy downpour caused by cyclone Eline; this left the dam dysfunctional, even up to now (2012). It is situated at 23º 07' 27"S and 30º 13' 13" E. (DWAF, 2004b).

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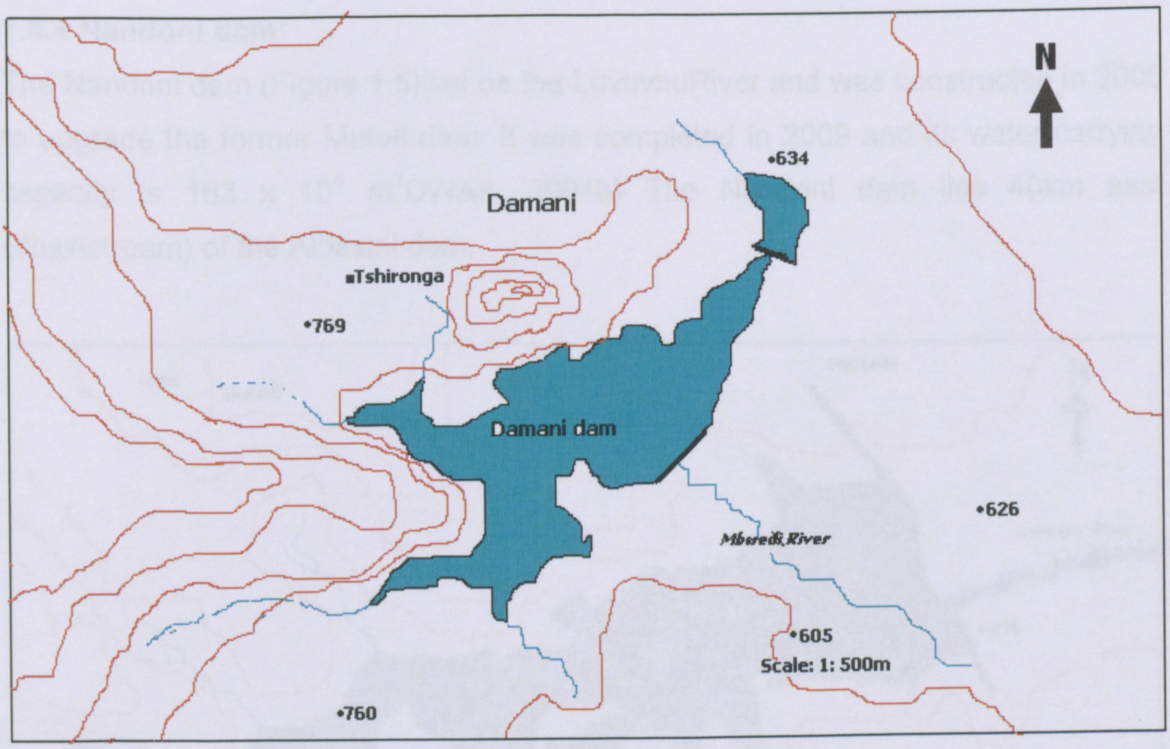

Figure 1.3 Damani dam on the MbwediRiver

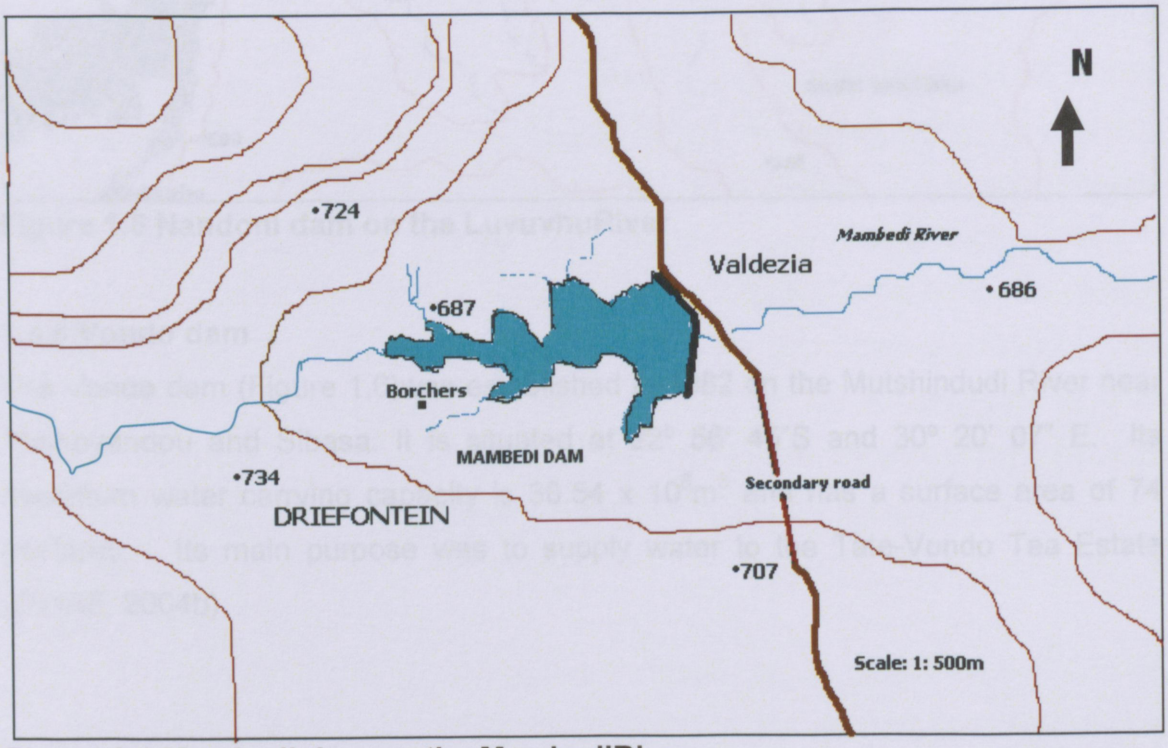

Figure 1.4 Mambedi dam on the MambediRiver

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1.4.4 Nandoni dam

The Nandoni dam (Figure 1.5)lies on the LuvuvhuRiver and was constructed in 2005 to upgrade the former Mutoti dam. It was completed in 2009 and its water carrying capacity is 163 x 10^6 m^3DWAF, 2004b) The Nandoni dam lies 40km east (downstream) of the Albasini dam.

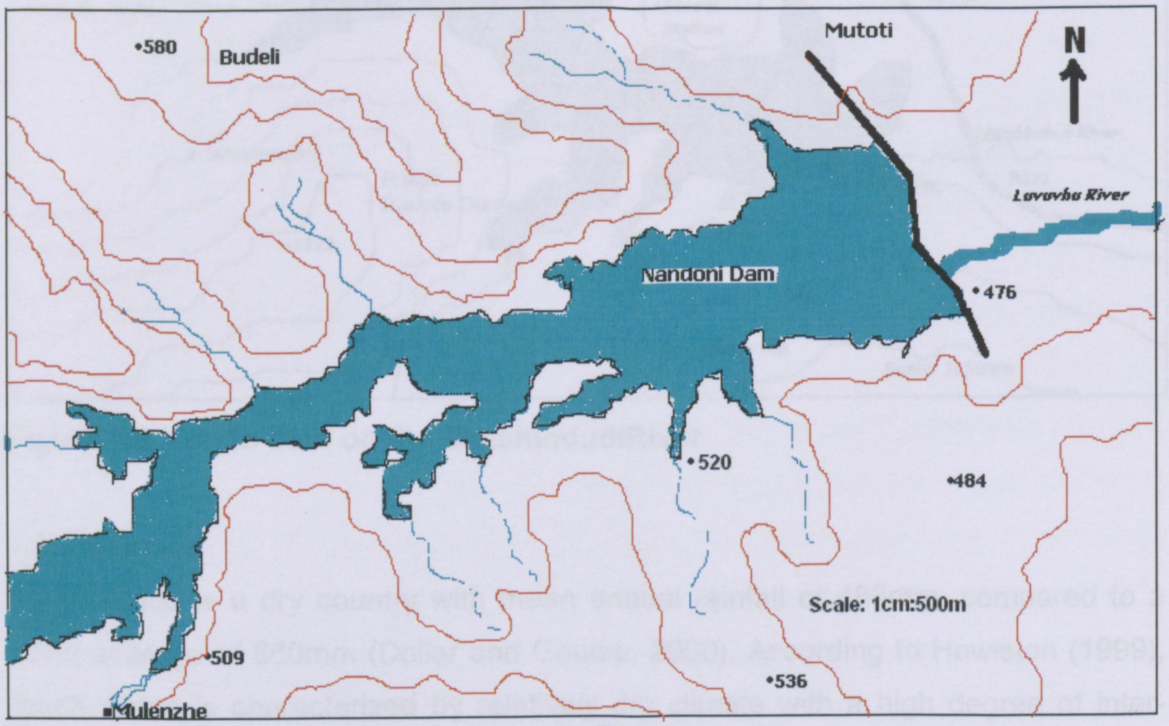

Figure 1.5 Nandoni dam on the LuvuvhuRiver

1.4.5 Vondo dam

The Vondo dam (Figure 1.6)was established in 1982 on the Mutshindudi River near Thohoyandou and Sibasa. It is situated at 22º 56' 45"S and 30º 20' 07" E. Its maximum water carrying capacity is 30.54 x $10^6 m^3$ and has a surface area of 74 hectares. Its main purpose was to supply water to the Tate-Vondo Tea Estate (DWAF, 2004b).

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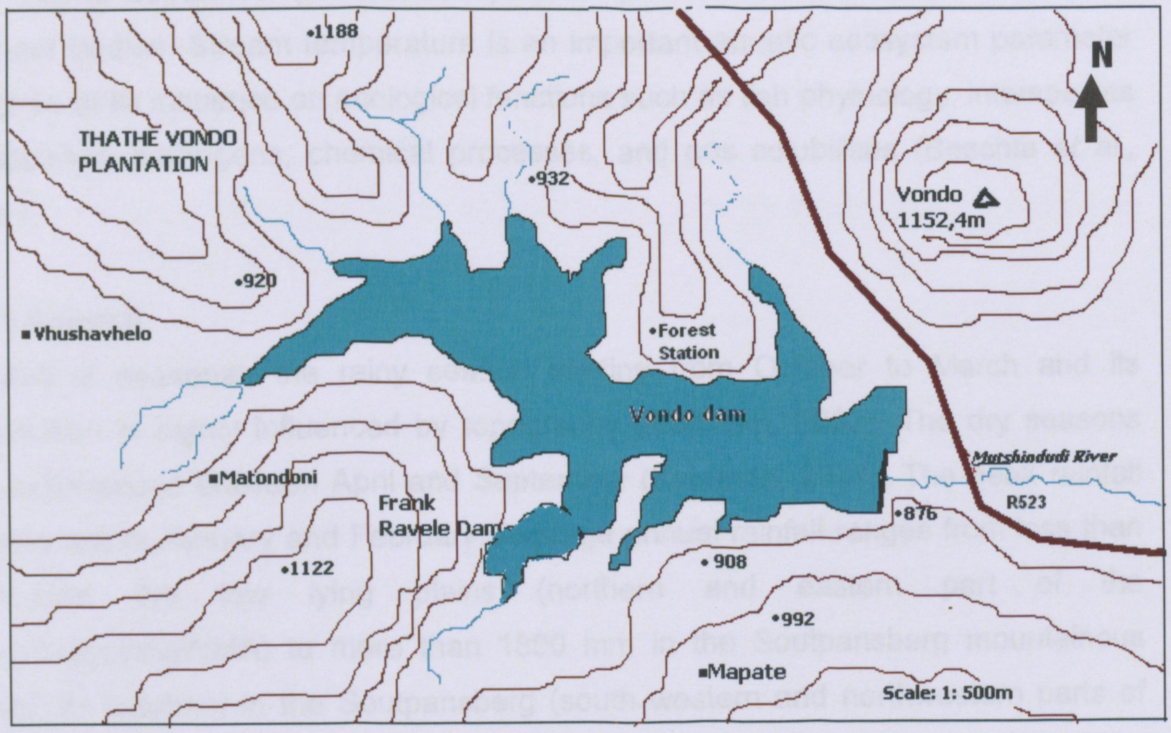

Figure 1.6 Vondo dam on the MutshindudiRiver

1.4.6 Climate

South Africa is a dry country with mean annual rainfall of 483mm, compared to a world average of 860mm (Dollar and Goudie, 2000). According to Hewiston (1999), South Africa is characterized by relatively dry climate with a high degree of inter-annual and intra-seasonal variability,this implies that it has a high degree of vulnerability to change in the climate system which might affect species composition along river systems. The climate of the Luvuvhu River catchmentis generally semi-arid and becomes arid as it progresses eastward to the Kruger National Park (Mudau, 2002). Climate also plays a major role in the determination of rainfall amount that is necessary for stream flow during wet and dry seasons.

1.4.7 Temperature

The mean annual temperature of the Luvuvhu/Mutale region ranges from 18°C in the mountainous areas of the Soutpansberg,to 40°C in the northern and eastern low lying areas. Maximum temperatures are experienced in January while minimum

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temperatures occur on average in July. Minimum temperatures are experienced from May to September (Mudau, 2002). Air temperature determines the evaporation of water bodies. Stream temperature is an important aquatic ecosystem parameter because of its influence on ecological functions such as fish physiology, interspecies competition, pathogens, chemical processes, and gas solubilities (Beschta *et al.*, 2006).

1.4.8 Rainfall

Rainfall is seasonal; the rainy season starting from October to March and its distribution is highly influenced by topography (Maluleke, 2003). The dry seasons are experienced between April and September (Kabanda, 2004). The peak rainfall months are in January and February. Average annual rainfall ranges from less than 300mmon the low lying plains (northern and eastern part of the Luvuvhu/LetabaWMA) to more than 1800 mm in the Soutpansberg mountainous areas. At Entabeni in the Soutpansberg (south western and northwestern parts of the WMA) rainfall amounts to more than 2300 mm per annum (Maluleke, 2003). Rainfall is important in determining mean river discharge flows and mean spillway discharges of dams. Interannual rainfall variability determines spatial and temporal patterns of vegetation distribution. This has also been observed by Fernandez-Illescas and Rodriguez-Iturbe (2004) when they stated that interannual rainfall fluctuation extends the range of dispersal distances that result in spatial organization (e.g., clustering,self-similarity) and proportional abundances of vegetation different from those expected for the globally dispersing case.

1.4.9 Evaporation

The mean annual gross evaporation ranges between 1400 mm per annum in the west to 1900 mm per annum in the eastern areas. Sixty percent of evaporation occurs between October and January and the lowest in June (Munyathi and Kabanda, 2009). The higher evaporation rates between October and January are due to high air temperature during summer periods. More solar energy due to longer days in summer is expended on water bodies making the upper water surface

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warmer than the rest of the water body (Tyson and Preston-Whyte, 2000). This heated water becomes less dense and evaporates. Evaporation rates help in the determination of the amount of water loss from dams and are a function of temperature of the environment, and evaporation tends to be higher during dry summer months (Vogel, 1989). Therefore, high evaporation rates during dry seasons, together with reduced water quality and quantity downstream of the dams, alter vegetation distribution and composition.

1.4.10 Topography

The Soutpansberg mountain range forms the northern boundary of the Luvuvhu River Basin. Its highest points and steepest slopes are situated in the upper portion of the catchment. The topography has an effect on the hydrology of the rest of the catchment, with higher rainfall occurring as a result of topographic influence. (Maluleke, 2003). According to Singo (2008), during times of floods the river may overtop its bank and drop eroded materials such as alluvium to form floodplains which help to reduce the velocity and peak flow. Flooding along floodplains helps in watering the riparian zone, thus feeding it with moisture from time to time to sustain riparian ecosystems.

1.4.11 Geology

The geology is varied and complex and consists of sedimentary rocks in the north and metamorphic and igneous rocks in the south. High quality coals are found near Tshikondeni and in the northern part of the Kruger National Park. The eastern limb of the mineral rich Bushveld Igneous Complex touches on the southern parts of the water management area (Maluleke, 2003). Geology also determines water quality of rivers as dissolved solid concentrations emanate from weathering and dissolution of minerals from local soil and bedrock (Kney and Brandes, 2007). Therefore, polluted streams do not reflect their actual water quality derived from bedrock and these water quality parameters are elaborated further in the preceding chapters to determine whether they have been influenced by natural or anthropogenic factors. This means that altered pH values that are derived from the underlying bedrock will

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impact negatively on riparian vegetation, which may lead to a proliferation of low or high pH-tolerant organisms which will replace the indigenous ones (Department of Environment and Tourism, 2007).

1.4.12 Vegetation

The vegetation of the Luvuvhu/ Mutale area is of Savanna type characterized by a mixture of trees, shrubs and grasses. In some areas, invasive alien species are prevalent in the upper reaches of the study area where the area of vegetation is estimated to be 168 km^2 (Le Roux *et al.,* 2004). Some parts of the former Venda Republic, where the Nandoni and Vondo dams are found are characterised by exotic eucalyptus, and pine plantations (Munyathi and Kabanda, 2009). Table 1.1 shows common tree and grass species found in the Luvuvhu/Mutale River Catchment.

Riparian vegetation along small streams strongly influences heat energy transfer processes (e.g., solar radiation flux, wind speed, air temperature) at the water surface (Beschta *et al.,* 2006). Riparian vegetation helps in improving water quality and infiltration of the soil (Almeida, *et al.*, 2010). The recovery of a stream ecosystem after disturbance is governed largely by the recovery rate of riparian vegetation and the magnitude of the disturbance (D'Sousa *et al.,* 2011). Another role of the riparian vegetation zone, as noted by Maluleke (2003), is that it helps prevent the river from down-cutting or cutting a straight path, thus promoting the meandering nature of channels, increasing groundwater discharge and maintaining an elevated water level.

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Table 1.1 Common vegetation species found in the Luvuvhu/ Mutale catchment (Munyathi and Kabanda, 2009)

Species name	Scientific name	Area
Red-leafed rocky fig	*Ficus ingens*	Damani
Broom cluster fig	*Ficus sur*	Albasini, Damani, Mambedi, Nandoni, Vondo
Sycomore fig	*Ficus sycomorus*	Vondo, Damani, Nandoni
African wattle	*Peltophorum africanum*	Damani, Vondo
Sneezewood	*Ptaeroxylon obliquum*	Albasini, Mambedi
Weeping boer-bean	*Schotia brachypetala*	Albasini, Mambedi, Nandoni
Marula	*Schlerocyabirrea*	Albasini, Damani, Mambedi, Nandoni, Vondo
Buffalo thorn	*Ziziphus mucronata*	Albasini, Damani, Mambedi, Nandoni, Vondo
Scented thron	*Acacia nilotica*	Albasini
Sweet thorn	*Acacia karroo*	Albasini
Ankle thorn	*Acacia robusta*	Nandoni
Common hook thorn	*Acacia caffra*	Albasini, Mambedi, Nandoni
Flame thorn	*Acacia ataxacantha*	Albasini, Damani Nandoni, Vondo
Black Monkey thorn	*Acacia burkei*	Albasini, Damani, Mambedi, Nandoni, Vondo
White thorn	*Acacia polyacantha*	Mambedi
Knob thorn	*Acacia nigrescens*	Mambedi, Nandoni
Pride of de Kaap	*Bauhinia galpinii*	Albasini, Damani, Mambedi, Vondo
Red ivory	*Berchemia zayhari*	Albasini, Vondo
Forest silver oak	*Brachylaena tranvaalensis*	Albasini, Nandoni, Vondo
Large-fruited bush willow	*Combretum zeyhari*	Damani, Vondo
Sickle bush	*Dichrostachys cineria*	Albasini, Damani, Mambedi, Nandoni, Vondo
Transvaal milk plum	*Englerophytum magalismontanum*	Damani, Mambedi, Nandoni, Vondo
White stinkwood	*Celtis africana*	Albasini, Damani, Mambedi, Nandoni, Vondo
River bush willow	*Combretum erythrophyllum*	Albasini, Damani, Mambedi, Nandoni, Vondo
Leadwood	*Combretum imberbe*	Damani, Nandoni, Vondo
	Common grass species in the study area	
Blue buffalo grass	*Cenchrus ciliaris*	Albasini, Damani, Mambedi, Nandoni, Vondo
Wire grass	*Elionurus muticus*	Albasi, Mambedi
Thimble grass	*Fingerhuthia africana*	Albasini, Damani, Mambedi, Nandoni, Vondo
Red Autumn grass	*Schizachyrium sanguineum*	Albasini, Vondo
Vlei Bristle Grass	*Setaria incrassata*	Albasini, Damani, Mambedi, Nandoni, Vondo
Bur bristle grass	*Setaria verticillata*	Vondo, Nandoni
Rhodes grass	*Chloris gayana*	Albasini, Damani, Mambedi, Nandoni, Vondo
Common crowfoot	*Dactyloctenium Aegyptium*	Albasini, Damani, Mambedi, Nandoni, Vondo
Finger grass	*Digitaria eriantha*	Albasini, Damani, Nandoni, Vondo
Veld paspalum	*Paspalum scrobiculatum*	Mambedi, Nandoni, Vondo
Swamp grass	*Diplachne Fusha*	Albasini, Damani, Mambedi, Nandoni, Vondo
Gum grass	*Erugrotis Gummiflua*	Albasini, Damani, Mambedi, Nandoni, Vondo
Purple plume grass	*Bothriochloa bladhii*	Albasini, Damani, Mambedi, Nandoni, Vondo
Weeping love grass	*Eragrotis curvula*	Albasini, Damani, Mambedi, Nandoni, Vondo
Sweet buffalo grass	*Panicum schinziu*	Albasini, Damani, Nandoni, Vondo
Giant turpentine grass	*Cymbopogon validus*	Albasini, Mambedi, Vondo
Boat thatching grass	*Hyparrheria cymbaria*	Albasini, Mambedi
Yellow thatching grass	*Hyperthelia dissoluta*	Albasini, Damani, Mambedi, Nandoni, Vondo
Fine thatching grass	*Hyperrheria Filipendula*	Nandoni, Mambedi

1.5 Justification of the study

Studies on structural and distributional changes in vegetation downstream of dams due to altered microclimates, flow regimes and water quality have been conducted mainly in the first world countries like Scandinavia, Canada, United States, Britain and France, but such studies are few in developing countries (Bunn and Arthington,

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2002). Most developing countries conserve water in dams with very little interest in retaining or maintaining the ecosystem functioning of riverine ecosystems downstream of the dams. This is because these impacts are considered to be occurring at a smaller scale or are geographically confined (Bunn and Arthington, 2002). However, these impacts have been profound over greater distances away from the dams and they are generally exacerbated by natural hazards and regulated low flows during dry spells (Basson, 2004). All parts of a river ecosystem are interconnected and disturbance in one part directly or indirectly affects the whole ecosystem of a particular river basin. The presence of dams together with the alternating wet and dry climatic conditions of Limpopo Province can have serious impacts on downstream ecosystems. Therefore, any river management strategies should consider the changes that might be triggered by any developmental project along a river ecosystem. Therefore, it is necessary to develop strategies for utilization of rivers as natural resources and this research will attempt to come up with guidelines for sustainable flow characteristics, as well as guidelines for utilization of different types of rivers under various climatic regions in order to sustain various natural riparian ecosystems.

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CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The review aims to explore different literature on the impacts of dams on riverine ecosystems. There are serious impacts that have had profound changes on the downstream environments. These changes are strongly related to the alteration of ecosystems on a large scale. Most southern African reservoirs are situated in areas of high evaporation rates and unpredictable runoff. South Africa is situated in an arid to semi-arid region with few relatively humid parts whose rainfall greatly exceeds 500 mm per year (Davies and Day, 1998). This means that the impacts of dams on their downstream environments in South Africa will further be worsened by the aridity of the region. According to Dollar and Goudie (2000), South Africa's mean annual rainfall is 483 mm, compared to the higher world's average of 860mm, and only 9 percent of the 483 mm is available for stream flow due to losses by evapotranspiration. This review also includes some information on the impacts of dams on downstream ecosystems and effective catchment management. It also highlights how dam impact studies in other countries have been conducted, and how management strategies have been put in place to minimize adverse environmental impacts associated with dams. These reviewed management strategies are assessed in order to adopt effective management controls or measures for Limpopo Province.

The study of the impacts of dams can be viewed from the perspective of Environmental Sciences and Resource Management. According to Pepper (1993), modern environmentalism prefers concerns over the state of the natural, as well as the man-made environment and agrees that our relationship with nature has to be improved. The management of river basins and river restorations and maintenance of biodiversity along rivers is part of environmental sciences (Cunninham and Saigo, 1992). Pepper (1993) has argued that it is not population growth that has to be blamed for the world's environmental predicament, but the nature of technology in

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preserving natural resources, like water retention in dams and their function. It is from the logical positivism point of view, through the use of field observation and the study of the nature of laws that govern ecosystem functions, that one can arrive at an explanation why changes in ecosystems composition and function of downstream environments of the dams occur. Griggs (2000) uses the logical positivism approach to argue that if there is proof that dams and curtailment of water downstream cause changes in ecosystem composition and functioning, then a universal law governing the use or modification of river systems can be established. Such laws or principles can be adopted from the research findings on river functioning and human impacts.

2.2 Dams

Dams can be defined as structures or barriers built to obstruct the flow of water in rivers. They were first constructed more than 5000 years ago and the regulation of rivers for water security has been at the heart of the advancement of human civilizations (Petts and Gurnell, 2005). Their main function is to store water and to increase hydraulic head or difference in height between levees in the lake created upstream and downstream river; but their existence has impacted on their downstream ecosystems. According to the World Commission on Dams (WCD) (2000), dams have been built for various purposes which include the following:

(i) generating electricity
(ii) supplying water for agriculture, industries and household needs.
(iii) controlling the impacts of flood waters and;
(iv) enhancing river navigation.

Dams are operated in a manner that simultaneously augment downstream water quality and provide recreational activities such as fishing and boating. WCD (2000) also reported that large dams have profound and irreversible environmental impacts including extinctions of species and loss of forest, wetlands and farmlands.

2.3 Impacts of dams

Despite their positive uses, dams have been associated with negative impacts on both upstream and downstream of rivers (WCD, 2000). According to Mallik and

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Richardson (2009), dams across rivers create barriers of natural water flow and interfere with the ecological processes of riparian zones that can influence vegetation composition, richness and diversity. Dams can change the local humidity of surrounding areas, the water quality and impair the normal functioning of the river ecosystems. According to Wohl *et al.* (2007), landscape modification and subsequent changes in hydrology, channel morphology and physiochemical properties result in the decrease in biological diversity in the riparian and aquatic ecosystems. The same idea is purported by Zeng *et al.* (2001) when they state that dam construction and river dredging will alter the hydrological or hydrodynamic regime of the river system. Lajoie *et al.* (2007) have argued that river flows can be defined by five main characteristics which are magnitude, period of occurrence, duration, variability and frequency. They argue that these factors allow detection and quantification of the man-made impacts, particularly by dams, on natural stream flow regimes. Magilligan and Nislow (2005) stated that dams have major impacts on river hydrology, primarily through changes in the timing, magnitude and frequency of low and high flows ultimately producing a hydrologic regime differing significantly from the pre-impoundment natural flow regimes.

Lerer and Scudder (1999) have stated that large dams have been criticized because of their negative environmental and social impacts. The IUCN, World Bank (1997) and Joyce (1997) have similarly observed that large dams have serious downstream health impacts. They state that the amount of downstream water flow and periodic controlled releases are important ecological and health issues. Grigg (1996) has stated that downstream of reservoirs, water quality changes may occur due to choices of the quantity or quality of water releases. The releases are associated with seepage caused by reservoir impoundment and this can change the local patterns of ground water flows. The ecosystems can also be changed because of the schedule of water release. The water quality is also altered. Newson (1997) also stated that the impact of a dam upon the physical, chemical and biological environment downstream varies mainly with the way in which a dam is opened with regard to timing and magnitude of water releases.

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According to Smith-Adao and Scheepers (2007), rivers and fluvial processes are affected by catchment controls and site or channel control like damming. Rowntree (2000) has indicated that there is a strong relationship between channel morphology, riparian plant communities and channel processes. Riparian zones, according to Rowntree (2000), are more prone to destruction and replacement by alien species than terrestrial vegetation. The presence of alien plant species along major dams is a sign of anthropogenic impact through damming. The downstream impacts of dams reduce the proper functioning of riparian ecosystems. Bombino *et al.* (2006) state that lack of reliable criteria for assessing the impact of engineering works on riparian vegetation has often yielded difficulties and uncertainties in the approval process for torrent control works.

Nilsson and Svedmark (2002) summarized three basic principles that determine the important qualities of riparian vegetation. These principles include the following:

(i) The flow regimes determine the ecological processes and successional evolution of riparian plant communities. This means that reduced flows downstream of the dam will automatically alter species composition.

(ii) The riparian zone serves as a pathway for redistribution of organic and inorganic material that influences plant communities along rivers.

The riparian system is a transition zone between land and water ecosystems and is disproportionately plant-species rich, when compared to surrounding ecosystems. However, according to Nilsson and Svedmark (2002), when dams disrupt longitudinal pathways, plant dispersal is greatly reduced and plant communities become fragmented. The dispersal process becomes difficult to restore without opening or removing the dams. This option is difficult for developing countries and therefore recommendations on how to utilise rivers under various climatic regions will be developed.

Bravard *et al.* (1997) mentioned that when riparian communities are disconnected from rivers, they no longer receive and release plant propagules as during natural conditions. Riparian plants become isolated in a landscape context and overall

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biodiversity decreases. According to Bunn and Arthington (2002), flow modification of Scandavanian rivers, and many rivers in the United States, Britain, France, southern Africa, India, Canada and Australia, are responsible for increases in macrophyte abundance especially upstream of the dam. This normally leads to reduced water depth. The aquatic weeds that develop, especially floating vegetation limit light penetration, and biological productivity and nutrient cycling are reduced (Wang *et al.,* 2009). The most common macrophyte species include ponweed (*Potamogeton natans* L.), water-starwort species (*Callitriche species*), common hornwolt (*Ceratophyllum demersum* L.), western waterweed (*Elodea nuttallii*), sago pondweed (*Stucania pecttinatus*), Europoean bur-seed (*Spargunium emersum Rehm*) and branched bur-reed (*Sargunium erectum* L.)

Lin *et al.* (2002) have indicated that riparian vegetation buffer strips have proved to be efficient in pollutant absorption, riverbank stabilization and microclimate improvement. They have also stated that riparian vegetation can solve problems of non-point source pollution from agricultural slope lands. Also Andersen *et al.* (2007) have stated that riparian forests and woodlands provide important ecosystem services through their high productivity and habitat values, and the food and fibre they provide. This idea was further supported by Finch and Ruggiero (1995), Wright and Flecker (2004) and Skagen *et al.* (2005).

Andersen *et al.* (2007) have also mentioned that riparian forests, defined as populations of streamside trees, rely on the streams for establishment and persistence. However, they indicate that dam construction has the most significant impact on rivers around the world. This means that a cut in water downstream of the dam will alter species composition. Graf (2006) has stated that development of river systems through damming results in dramatic shifts in river flow regimes, sediment transport and deposition patterns, as well as floodplain landuse. Each of these changes has proven to have independent impacts on riparian vegetation. A report by WCD (2000) has estimated that 60% of the world's largest rivers are fragmented by dams and diversions leading to the loss of aquatic biodiversity, upstream and

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downstream fishing, and the services of downstream floodplains. Negative environmental impacts are not predicted and efforts to mitigate the impacts fail.

The reported impact of dams on downstream environment is supported by studies conducted by Herron *et al.* (2002). They have indicated that marshes downstream of the Burendong Dam (Australia) have shown sensitivity to changes in flow regimes. These marshes shrunk by more than 40% since the construction of the Burendong Dam. Marshes are important in trapping sediments and other pollutants in a river or an estuary (Almeida *et al.*, 2010). Marshes normally act as phyto-stabilizers by reducing metal bioavailability. Other importance of marshes are highlighted by Simas and Ferreira (2007). They state that marshes are associated with nitrogen increase in salt marsh sediments. This is accompanied by increased productivity of vascular vegetation species and increased rates of vegetation decay and higher community respiration rates.

2.3.1 Dams and water quality

The construction of dams brings about changes in the state of water quality both upstream and downstream of rivers. Such changes are prominent in the chemical and physical properties of the water. Snoussi *et al.* (2007) have stated that damming and water abstraction cause major changes in the state of water and sediment fluxes. Johnstone and Markendya (2006) have argued that environmental improvements of rivers will automatically result in specific outcomes such as reduction in phosphorus concentration or increases in biodiversity. Phosphorus assists in converting the sun's energy and other chemicals, such as nitrogen, into usable food for plants. Deficiency in phosphorus leads to stunted, sickly looking plants characterized by weak fragile stems and low quality of flowering. This is because dams are associated with nutrient sinks, which removes large quantity of nutrients from the photosynthetic zone. Eutrophicated dams cause oxygen depletion in the upper light absorbent zones and increased concentration of iron and manganese, as well as increased pH (Simas and Ferreira, 2007). According to D'Amelio (2007), low oxygen levels can cause increased phosphorus (P) release

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from sediments in standing water bodies. High concentration of ammonia (NH_3) can affect invertebrates, species composition and distribution of aquatic plants.

According Basson (2004), damming of rivers can cause serious water quality deterioration due to reduced oxygenation and dilution of pollutants by relatively stagnant reservoirs, flooding of biomass and resulting in underwater decay and reservoir stratification. Since dam water is almost stagnant higher temperatures can build up and such warm waters can have significant impacts on the downstream environment during flushing. However, some researchers like Gu and Li (2002) have argued that with discharges greater than 10 m^3s^{-1}, water temperatures decrease with increasing discharges. This means that if very little water is released from dams higher temperatures will build-up downstream in the late afternoon.

Chung *et al.* (2008) have noted that the river water quality below Doucheong Dam on the Geum River of Korea deteriorates every drought season from December to February. This has led to an increase in ammonia and nitrogen concentration to levels of 20 to 50 mgl^{-1}. These figures were found to be above the water quality standard of 0.5 mgl^{-1}. Their study further indicated that flushing of water downstream also increased water temperature from 10°C to 13 and 14°C because the reservoir water that was flushed away was withdrawn from the middle layer of the reservoir. These changes in temperature, nitrogen, potassium and increase in biological oxygen demand (BOD) impact negatively on downstream environment.

2.4 Studies on impacts of dams

2.4.1 USA

In a study conducted by Andersen *et al.* (2007) on *Dams, Floodplains, landuse and riparian forest conservation in the summer, Upper Colorado River Basin, USA*, findings have shown that dams can have significant impacts on downstream riparian ecosystems. The main goal of the study was to determine whether variations in current riparian forests and the pattern of land use on alluvial floodplains in the semi-arid region, can be largely explained by the upstream presence of large dams and

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the attenuated levels of flow regulation. To perform this type of study, a series of sub basins were randomly selected where the floodplains were occupied by forests or other natural vegetation, as well as an area that has been developed. A total reservoir capacity was determined in the contributing watershed as well as the level of flow regulation on the mainstream. A relationship between a reservoir capacity and flow regulation was assessed. This study was done in the 2.9×10^5 km^2 of the Upper Colorado River Basin.

An ArcView 3.2 was used to digitally map the mainstream river and floodplain in each sub basin from black and white Digital Orthophoto Quarter Quadrangles (DOQQ) with 1m pixel resolution. A riparian vegetation map of Fenton (2002) based on 1: 12 000 scale colour-infrared aerial photographs was used.

Andersen *et al.* (2007) also used total annual peak discharges for historic (predevelopment) and recent (post development) periods for the mainstream reach. Regression analysis was used to examine whether catchment reservoir capacity was related to change in mean annual discharge or mean annual peak discharge. Their findings indicated that estimates of historic (predevelopment) mainstream annual discharge from the sub basins ranged from 15×10^6 m^3 per year to 7285 x 10^6 m^3 per year. Historic mean annual discharge explained 54% of the variation in storage capacity. A decline in annual discharge between prehistoric and recent periods was noted in 19 of the 24 sub basins. The decline was greater than 20% in 9 sub basins and greater than 50% in four. Mean annual peak flows declined in 23 sub basins. These findings indicate the impact of damming of rivers which ultimately leads to impact on downstream environments due to reduced river flows.

2.4.2 Studies in other parts of Africa

In a study conducted on Cahora Bassa Dam on the Zambezi River by Basson (2004), it was discovered that the dam had an impact on flood attenuation, both upstream and downstream of the dam. The impacts of the dam were considered with specific reference to the role of low flows, intraannual floods and inter-annual

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floods and the sediment regime, as well as ecosystem functioning. The following flow regimes (Table 2.1), provided by King (2002), were considered during the study:

Table 2.1 Different river flows, and their importance for a healthy river (King, 2002).

Flow component	Importance
Low flows	The low flows are the daily flows that occur outside of high-flow peaks. They define the basic seasonality of the river: its dry and wet seasons, and degree of perenniality. The different magnitudes of low flows in the dry and wet seasons create more or less wetted habitat and different hydraulic and water-quality conditions, which directly influence the balance of species at any time of the year.
Small floods	Small floods are usually of large great ecological importance in semi-arid areas in the dry season. They stimulate spawning in fish, flush out poor-quality, re-set a wide spectrum of condition in the river, triggering and germination of riparian seedlings.
Large floods	Large floods trigger many of the same responses as do the small ones, but additionally provide scouring flows that influence the form of the channel. They mobilize coarse sediments, and deposit silt, nutrients, eggs and seeds on floodplains. They inundate backwaters and secondary channels, and trigger bursts of growth in many species. They recharge soil moisture levels in the banks, inundate floodplains and scour estuaries thereby maintaining links with the sea.
Flow variability	Fluctuating discharges constantly change conditions through each day and season, creating mosaics of areas inundated and exposed for different lengths of time. The resulting physical heterogeneity determines the local distribution of species: higher physical diversity enhances biodiversity.

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From the study, conducted by Basson (2004) it was discovered that low flows for release downstream in the dry season may punish aquatic plants that need to push flowers above the water surface in the dry season for pollination. It was discovered that plants may fail to pollinate and gradually the species disappear. It was further indicated that dry season low flows are periodically completely eradicated by damming or discrete abstraction. This was evident along the Luvhuvhu River, that transverses Kruger National Park (KNP), and could happen to the linear oases of trees along the river flowing from east to west across Namibia, that supports large desert mammals and local indigenous people (King, 2002).

This study made on the Zambezi showed curtailment in the lower Zambezi Valley. This impact was identified by the use of aerial surveys of June 1996. The aerial surveys indicated dramatic changes in morphology of the river floodplain system downstream of the dam. The aerial survey techniques further indicated a 40% loss of mangrove and severe coastal erosion. The delta decreased in length from 600 km to 150 km since the construction of the Cahora Bassa Dam, Mozambique. This clearly shows the severity of the existence of dams on downstream plant communities.

In a study by Snoussi *et al.* (2007) on *Downstream and Coastal impacts of Damming and Water abstraction in Africa,* anthropogenic impacts associated with dams, water abstraction and the resultant environmental pressures were reviewed in six African river catchments. Their study focused on the Moulouga basin (Morocco), the Senegal Basin, Tana River (Kenya), Rufiji River (Tanzania), Sibou river, Querrha and Inaouene (Sudan). Their study emphasized the environmental pressures of dam building in relation to other pressures such as land-use change and climate change, leading to state changes in functions and processes of ecosystems and impacts on human welfare that required policy responses to management options to modify or mitigate the originating drivers and pressures of change. Data was obtained by using records and forecasts of climate, demographic and land-use change. The impacts of changes on downstream and coastal environments and their

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communities were described in past, present and future perspectives. In their study, they were able to show that while impoundment and abstraction of freshwater in the river ecosystems for power generation and agricultural irrigation provided huge economic benefits, large dams have been poorly accounted for in economic terms. They showed that large dams alter seasonal flooding that is important in the maintenance of floodplains, fishes, pasture and riparian forests. The study found that in all six regions damming and water abstraction caused major changes in the state of water sudden fluxes. The also showed that the physical adjustment to water fluxes will continue to change downstream deltas and coastal sea environments.

2.4.3 South Africa

Another study on the impacts of the Pongolapoortdam, in KwaZulu-Natal, on the Pongola floodplain was conducted by Rossouw (1985). A report on the study indicated a gap between theory and practice. This is a common problem in South Africa, as evidenced by Papu-Zamxaka *et al.* (2010) when they mentioned that South Africa has a progressive legislation to both prevent and clean up environmental contamination, but a large gap between legislation and practice exists. The report indicated that it was agreed, during the construction of the dam (1972-1974) that floods must be released from the dam to simulate the flood regime before the dam was built. However, according to the report, the minimum operating level was never reached due to the severe drought of 1982. This means that the floods were never released from the Pongolapoortdam. It was also agreed that a baseflow of $2m^3s^{-1}$ would be maintained in the river down to the confluence with the Usuthu River at all times. It was further agreed that the total volume of water released during controlled flood would be the volume in the dam in excess of the minimum operating level at 43% full, and that the gates will be opened over a period of 48 hours and kept fully open until the minimum operating level was reached. However, the minimum operating level was never reached until the Domoina Floods in February 1984, ten years after the dam was completed. This led to the desiccation of pans downstream of the dam. Failure to implement the conditions of agreements indicates a gap between theory and practice.

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Rossouw (1985) also mentioned that prior to the Domoina Floods most pans around the dam were totally dry and concentrations of nutrients and sediment were lower or non-existent. Downstream of the dam aquatic community of the floodplain, *Potamogeton crispus* and *Cynodon dactylon*, which provide food and shelter for secondary producers, were resurrected during the Domoina Floods. Therefore the lack of water downstream of the dam, cut down biological productivity. This shows the severity of the impacts of dams on their downstream river ecosystems.

Heath and Plater (2010) conducted another similar study on the Pongolapoortdam to assess the impacts of dam impoundment. They acknowledged that during times of increased flooding, the river floodplain connects the pans to create a heterogeneous environment, but during drier times, the river system contracts, leaving a string of disconnected turbid water bodies. After the construction of the dam there was a reduction in natural flooding downstream and loss of fertile topsoil, causing siltation in lakes and eutrophication of surface water bodies and loss of aquatic biodiversity. The high siltation levels in the Pongolapoortdam are attributed to the following:

(i) Dam operations which moderate extreme flow levels and entrap a large proportion of stream sediment load upstream of the floodplain.
(ii) Decreased streamflow downstream of the dam, reducing the sediment-carrying capacity and competency; and
(iii) More regular flows which reduce average flow velocities, leading to less flushing of the system and leaching of waters rich in nutrients.

According to National Water Resource Strategy (NWRS) (2002), very few rivers in South Africa are truly natural systems, and these are mostly located in the protected areas such as national or provincial parks (National Water Resource Strategy, 2002). It was stated that even lower reaches of a river that flows through a protected area may be impacted on by upstream developments that fall outside the protected area, as in the case of rivers (Great Letaba, Luvuvhu, Massintonto, Olifants and

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Shingwedzi) flowing through the Kruger National Park (NWRS, 2002). It was further stated that 11% of South African rivers are in a natural state, 26% in a good state, 32% in a fair state, and 31% in a poor state. However, the figures might have drastically changed because of some ongoing human use of rivers and modifications. The most common threats to South African Rivers can be summarized as follows:

(i) Over-utilization of the riparian zones. This impairs the ability of these buffer zones to filter nutrients and sediment from entering the river, to provide habitat and migration options for many species, and to stabilize river banks, and in acting as a flood control mechanism.

(ii) Alien species of fauna and flora. This includes both aquatic species such as trout, and terrestrial species such as wattle trees. Since these are species that are deliberately introduced into aquatic environments, they tend to out-compete indigenous aquatic and riparian species in nutrient consumption.

(iii) Regulation flows and abstraction. Dam walls act as barriers to the natural movement of fish and other aquatic species. Regulated flows that do not mirror natural seasonal variation have an impact on the resilience of river systems. Reduced water levels result in reduced diversity and availability of aquatic habitats.

According to Davies and Day (1998), a majority of dams in South Africa do not have release valves and water cannot pass through them. The only time that rivers downstream of these dams receive water is when floods overtop them. This has also been noted by Rossouw (1985) in his study on the Pongolapoortdam. In South Africa, recent assessment of water quality shows that 44% of the main streams of South Africa's rivers are critically endangered (Amis *et al.*, 2007).

The study by van der Walt *et al.* (2002) assessed possible environmental impacts of river modification along the Mooi River catchment which has four major dams that

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include Klerkskraal, Boskop, Klipdrift and Potchefstroom. The study found that diffuse water-borne as well as particulate-bound pollution from slime dams, rock dumps, sand heaps and informal settlements contributed to the contamination of the river water. This deterioration in water quality had serious consequences on ecosystems downstream of the dams, by altering the rate of nutrient intake, inhibiting the rapid decomposition of dead organic matter and leading to eutrophication. Eutrophicated water bodies are characterized by low oxygen content and retarded decomposition and slow nutrient cycling (Simas amd Ferreira, 2007).

2.5 Remote Sensing and Environmental Management

Remote sensing is defined as the science of acquiring information about the Earth's surface without actually being in contact with it (Lillesand *et al.,* 2004). Remote sensing techniques have generally been used to help solve environmental problems. According to Hudak and Wessman (1998), remote sensing has emerged as the most powerful data source for characterizing land use cover across landscapes. There are two main classes of remote sensors which are **active** and **passive sensors**. **Active remote sensors** transmit some form of energy and detect its reflection from the sensing target. An example of an active sensor is a radar. **Passive remote sensors** collect reflected energy from natural sources such as the sun. An example is a camera and satellite image sensors. According to Govender *et al.* (2007), remote sensing involving multispectral imagery has been used as data source for water and land observational remote sensing from airborne and satellite systems since the early 1960s. They further state that over the past two decades, advances in sensor technology have made it possible for the collection of several hundred spectral bands.

Aerial photography is one of the oldest and convenient forms of remote sensing and serves as the earliest synoptic depiction of vegetation cover (Browning *et al.*, 2009). Aerial photographs are normally acquired in an overlapping pattern, in order to create a stereoscopic effect when adjacent pairs are viewed together (Liebenberg, 1993). The overlapping views of the same ground area produce a parallax effect,

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which is a basis for depth perception in human vision (Lillesand *et al.,* 2004). According to Lillesand *et al.* (2004), photography was born in 1839 and the first known aerial photograph was taken in 1858 by a Parisian photographer named Gaspard-félix Tournachon. According to Tickle *et al.* (2006), large scale photography (LSP) has long been recognised as a valuable tool for forest inventory, improving the efficiency of ground sampling through improved stratification and plot selection and bridging the gap between ground measurements and other forms of remotely sensed data using multi-phase and multi-stage techniques. The most accurate and common elements of aerial photograph interpretation according to Lillesand *et al.* (2004) are as follows:

(i) **Shape**: It refers to the general form, configuration, or outline of individual objects. For example, the object's height also defines its shape. A cricket field appears round while a soccer field looks rectangular.

(ii) **Size**: Sizes on photographs are considered in the context of the image scale. For example, a small storage shed might be misinterpreted as a barn, if size in not considered.

(iii) **Pattern**: It relates to the spatial arrangement of objects. The spatial arrangement of orchards is different from that of natural forests.

(iv) **Tone**: It refers to the relative brightness or colour of objects of an image. Deciduous trees and coniferous trees appear differently on black and white aerial photographs.

(v) **Texture**: This refers to the frequency of tonal change on an image. It is produced by an aggregation of unit features that may be too small to be discerned individually on an image. Texture is usually a product of the object's individual shape, size, pattern, shadow, and tone. It determines the overall visual smoothness or coarseness of features.

(vi) **Shadow**: They are important in two respects: (1) the shape or outline of a shadow affords an impression of the profile view of objects and (2) objects within shadows reflect little light and are difficult to discern on an image.

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(vii) **Site**: It refers to topographic or geographic location. For example, certain tree species are found at well-drained upland sites while others are found on poorly-drained lowland sites.

(viii) **Association**: It refers to the occurrence of certain features in relation to others. For example, agricultural fields are associated with rivers and reservoirs.

Fensham *et al.* (2007) have stated that issues concerning photo-quality may bias assessment through time and that the limited sample of the permanent monitoring network may inadequately change at regional scale. Temporal changes which affect the relationship between cover and basal area could impact on the detection of trends using aerial photograph techniques. However, Browning *et al.* (2009) argues that there are no published records documenting the detection limits and accuracy of vegetation cover estimates derived from early aerial photography. Fensham *et al.* (2003) had earlier on argued that aerial photographs can best derive estimates of woody cover change (like trees) as a point of sampling technique that generate an aerial measure of tree and shrub cover. Fensham and Fairfax (2002) have also argued that aerial photographs can be used to assess vegetation change. They further argue that its advantage is the length of the available record. Another advantage of aerial photography is that it offers opportunities to assess vegetation structure in three dimensions, using the stereo-view provided by overlapping aerial photographs. However, Kadmon and Harari-Kremer (1999) have stated that aerial photographs have been rarely used to generate quantitative data in the broader landscape, as has been the case with the study conducted by Pellikka *et al.* (2009).

Pellikka *et al.* (2009) used aerial photography to study spatio-temporal change in indigenous and exotic forest cover in the Taita Hills of Kenya. The main aim of the study was to quantitatively study the changes in area, location and composition of Chawia, Fururu, Macha, Mwachora, Ngangao and Yale forest fragments between 1955 and 2004. To conduct this study, black and white aerial photographs (1955-1994), airborne digital camera mosaics (2004) and field data (2007 and 2008) were used. The 1955-1994 data was acquired by the Survey of Kenya at a scale of 1: 30

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000 using a photogrammetric camera equipped with a 152.3 mm lens. The prints were then scanned using a resolution of 14 μm in order to produce a ground resolution of 46cm. The 2004 digital camera data were acquired with 60% overlap and 30% sidelap. The interpretation of the 2004 mosaic was done based on colour and texture information as well as previous knowledge of the area.

In the 1955-1994 aerial photographs, the image was classified using grey scale and texture as interpretation keys for indigenous forest, rock bushland, heathland and barren land classes. The land cover model was created in ArcGIS. The change detection was analyzed by the areal change, percentage changes and by trajectory analysis. Their findings indicated that the indigenous forest decreased by 50% (260.2 ha), but the total forest cover decreased by 2% due to establishment of exotic plantations.

Remote sensing was also used by Mendoza and Etter (2002) on *Multispectral analysis (1940-1996) of land cover changes in the southwestern Bogotá highplain (Colombia).* The study area is located in the southwest of the high plain, some 30km to the west of the capital Bogotá. To conduct this type of the study land cover patterns were drawn from selected standard black and white aerial photographs (scales 1: 20 000 – 1:35 000), of the years 1940, 1964, 1988 and 1996. The comparative analysis of land cover changes was done on a physiognomic basis, starting with the construction of a landscape ecological map (1: 25 000) based on the 1996 set of photographs. The interpreted land covers for each temporal set were transferred as vector maps to the ArcView GIS 3.1.To evaluate the overall impact of historic landscape transformation; a general potential vegetation map of the study area was constructed. From their study they were able to identify changes in natural vegetation. Dry shrublands which originally extended over 704 ha were observed to have been reduced to 15.6 ha. This finding also demonstrates the effectiveness of aerial photography in studying vegetation pattern changes.

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Another study was conducted by Schmitz *et al.* (2009) on *Using historical aerial photography and Paleohydrological techniques to assess long-term ecological response to two Montana dam removals.* The two dams are Mystic Lake and Pattengail. To conduct the study they assessed photos showing the Mystic site from 1971, 1989, 1995 and 2001, and the Pattengail site from 1942, 1979, and 1995. The 1995 digital orthophoto quadrangles (DOQ) for study sites were obtained. Hard copies of Mystic photos from 1971 and 1989, and 1942 and 1979 of Pattengail were digitized using high resolution scanner. These images were georeferenced to the 1995 photos using ArcView 9.1. Using 15 control points in each image, georeferenced images with maximum root mean square values of 3.5 and 2.6 for Mystyic Lake and Pattengail dams respectively were produced. Logistic Generalized linear Models (LGLMs) were used to analyse the land cover response for each photo year to three variables indicative of vertical, lateral and longitudinal environmental gradients.

From their findings, the dam failure of 1927 on Pattengail Creek yielded catastrophic stream flows, marked channel changes and substantial floodplain vegetation response. The vegetation response indicated the maximum probability of coniferous cover beyond 60m from the thalweg and deciduous cover within that distance. This is good to floodplain irrigation which was previously curtailed by the existence of the Pattengail dam. The same response was shown by vegetation on the Tokachi River in Japan after dam failure (Namakura *et al.*, 1997). The Mystic Lake dam was inoperable most of the time because of poor spillway design. However, after the removal of the dam vegetation, mostly coniferous, it responded well to changes in stream flow. However, removal of a dam is not an option but there should be a standing principle about regulated flows since some agreements are never met.

2.6 Management strategies

Various management strategies have been applied in different countries to manage river ecosystems as well as to minimize the direct impacts of dams on riparian

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ecosystems. In the following subsections various strategies, as advanced by different countries, are highlighted.

2.6.1 China

Generally, the management of river ecosystems or catchments requires management on a more national than local level. Zhang (1999) proposed various management strategies for effective dam functioning following a research on the social impacts of dams in China. These include the following:

1. Good location of a dam is vital to the success of better water management strategies. A good site for constructing an irrigation dam should meet the following criteria:
   (i) favourable natural geological conditions;
   (ii) prone to removal of sedimentation;
   (iii) a guarantee of mature techniques for the dam at the site; and
   (iv) minimum of rehabilitants affected by the dam.
2. Scientific project planning and programming is the key to technological, economic, environmental and social feasibility of the dam.
3. To increase the social equity between poor and rich farmers, and to help achieve gross control of water fee collection, block water charging approach has been one feasible option.
4. Effective and sustainable management system is a guarantee for the success of a dam.

For example, in China the structure of water management system during the Dujiangyan Dam Project from 1979 to 1999 can be summarized as in Table 2.2.

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Table 2.2 Structure of Water Management Agency in China (Zang, 1999)

Level	Name of institution	Function and responsibilities
1	Dujiangyan administration bureau	• Top leader • Water fee collection • Annual maintenance • Flood control • Water distribution between countries and canals • Collaboration
2	Irrigation zone administration and county administrative bureau	• Water management of the local riparian zones • Supervision of the local canal maintenance • Water distribution within irrigation zones • Water fee collection • Sedimentation removal • Flood control
3	Main canal administrative station	• Water distribution • Water fee collection • Sedimentation removal • Canal maintenance • Flood control
4	Sub-canal and small canal management committee	• NGOs • Water distribution • Water fee allocation • Sedimentation removal • Canal maintenance • Flood control
5	Water management team	• NGOs • Water distribution within production teams or villages • Water fee collection • Canal maintenance • Sedimentation removal
6	Water delivering group	• NGOs • Definition of water delivering order between farmers and households.

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From the study of Zhang (1999) in China, it was evident that any form of river management should involve different stakeholders in order to come up with the most effective strategies to minimize environmental impacts.

2.6.2 USA

In the United States of America some of the options implemented by government to restore river functioning included the removal of smaller dams. Roberts *et al.* (2007) highlighted that the removal of small dams was normally advocated without adequate attention to possible hydrological, geological and chemical consequences. However, Roberts *et al.* (2007) suggested that the best method for dealing with dam removal is to form an interdisciplinary team to partner with the state and local government and the owners of dams, to assess the concerns raised by potential removal of a particular dam. Alexander and Allan (2007) also highlighted the following working strategies that help in river restoration processes:

(i) Project planning and implementation should be cognisant of restoration needs and activities throughout the watershed to further people's understanding of cumulative and interactive effects of dispersed restoration projects.

(ii) Projects should be implemented with the formal understanding of the larger landscape-scale processes influencing the stream ecosystem.

(iii) Project designs that state success criteria based on ecological performance of the project rather than project implementation would also aid in comparing the success of similar projects.

(iv) Monitoring programs that collect pre-project and post-project data for extended periods of time.

(v) Granting agencies need to allocate money to monitoring and allow for disbursement of monitoring support during a long period of time (at least ten years). Such arrangements would facilitate the implementation of restoration projects at the watershed scale.

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These strategies seemed very effective but they will always rely on the nature of their application from one country to the other, since no policy can always bear the same consequences when applied in two different places.

2.6.3 South Africa

In the Limpopo Province of South Africa, management of rivers is the responsibility of Department of Water Affairs (DWAF, 1999). The current management strategies are administered under different sectors due to different types of water users.

Howard and Heymans (1999) identified current approaches of the South African Department of Water Affairs to the development of a catchment management strategy as follows:

(i) Situation analysis to determine the current status in the catchment.
(ii) Identify required management tools.
(iii) Set objectives regarding water quality and quantity.
(iv) Develop management strategies.
(v) Develop the necessary infrastructure.

This means that all dams that were built by the South African government underwent these management strategies.

According to DWAF (1997), during the course of Water Resources Situation Assessment study, a first order estimate of the ecological importance of all river reaches in Luvuvhu/Letaba was done based on the following:

(i) The presence of rare or endangered species.
(ii) Habitat diversity.
(iii) The importance of a river reaches in providing connectivity between different sections of the river.
(iv) The sensitivity of the reach to environmental changes.

However, there is still a continuing threat to river ecosystems which is also accelerated by alternating wet and dry spells, as well as natural hazards. During dry spells which are characterized by lower than normal rainfall, and droughts, the downstream section of the dam suffers water curtailment and vegetation density

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deterioration at an alarming rate. This means that in some places sensitivity of the reaches was not taken into consideration or was misjudged.

The development of catchment management strategies became cause for concern during the 1980s when rural water supply schemes collapsed, river ecosystems endured stress, water pollution became critical and extremely difficult to manage (Smakhtin *et al.*, 1998). There are five types of water-related institutions which play a role in the Luvuvhu/Mutale subcatchments (DWAF, 2004a):

(i) District municipality (Vhembe). The district is defined as a Water Service Authority (WSA) fro preparing Water Services Development Plans (WSDPs)
(ii) Local municipalities (Musina, Mutale, Thulamela, and Makhado) These municipalities do not have WSA status, but prepare Water Sector Plans (WSPs) which provide input to the District WSDP.
(iii) Irrigation Boards. These were established under the old Water Act of 1956 to administer the provision of bulk water to irrigators within a defined area
(iv) Water Boards (Lepelle Northern Water). It deals only with water matters, usually bulk water distribution.
(v) DWAF's Regional Office (in lieu of the Catchment Management Agency - CMA).

The following are the different types of Regional Water Supply Schemes under the Luvuvhu/ Mutale subcatchment (DWAF, 2004a):

(i) The Vondo Regional Water Scheme which draws water from the Vondo dam on the Mutshindudi River. The full irrigation allocation to the Tshivhase Tea Estate is only available when the storage in the dam is above 90% of full supply capacity. The domestic water requirements are also supplied from this scheme from Donald Fraser in the north to Vuwani in the south.
(ii) The Tshakhuma Water Supply Scheme which is supplied from the Tshakhuma Dam. Its main aim is to reduce the dependency of rural domestic demand of the area on the Vondo Scheme.

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(iii) The Damani Water Supply Scheme which was established to supply water to the 27 surrounding villages which were supplied from the Vondo Scheme.

(iv) The Mhinga/ Lambani Water Supply Scheme which draws water from a weir in the Luvuvhu River and serves 7 of the 27 surrounding villages.

(v) The Malamulele East Regional Water Scheme whose water is abstracted from the Luvuvhu River near Malamulele village. Its water is supplied to 55 villages.

(vi) The Levubu Irrigation Water Supply Scheme is supplied from the Albasini Dam and from weirs on the Luvuvhu, Latonyanda and Barotta streams via an extensive system of interlinking canals. The Albasini dam also supplies domestic water to Makhado in the Limpopo Water Management Agency (WMA)

(vii) The Mutale River Water Supply Scheme was planned to supply water to some 130 villages within the catchment area of the Mutale River.

(viii) The Masisi River Water Supply Scheme currently supplies water to 10 villages from boreholes for domestic use. The proposed water supply scheme in this area has been planned to consist of an abstraction weir on the Mutale River.

DWAF (1999) has suggested the following guideline principles for appropriate public participation in catchment management meetings:

(i) Processes must be flexible to accommodate local needs and appropriate to local circumstances, but this differs from catchment to catchment. According to Howard *et al.* (1995) this is done when identifying and prioritizing issues to be addressed.

(ii) The process must include all sectors, perspectives and interests of society. A single interest group or sector should not dominate catchment structure.

(iii) Transparency and honesty is required. Negative issues must be presented along with the positive.

(iv) Stakeholders need to know that the authorities are committed to and believe in the process. The duty of the authorities is to exercise neutrality.

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(v) Information received by stakeholders should not be prescriptive, but should form guidelines for an efficient process with room to adapt to the process if necessary to accommodate local preferences.

(vi) Public participation should from the outset, focus stakeholders' minds on a common goal, i.e. a common-goal approach enables the public to participate in managing water resources within its water management area.

Proper catchment management on rivers and dams requires the inclusion of all stakeholders to avoid many conflicting ideas during decision-making processes. According to Hiscock *et al.* (2001), integrated river basin management deals with the whole ecosystem and aims to integrate management of water resources with objectives for water quality, biology, fisheries and catchment engineering like dam building. The Limpopo Province seems to have improved on water management strategies but more conservation strategies for downstream ecosystems of the dams are now a necessity. From management strategies adopted by other countries it is clear that South Africa needs to adopt certain approaches for effective catchment management. It is now obvious that the idea of good catchment management is there but institutional failure might be the problem. Certain government departments do not enforce relevant legislations (Environment Conservation Act 73 of 1989, National Environmental Management Act 107 of 1998, National Environmental Management: Biodiversity Act 10 of 2004 and Development Facilitation Act 67 of 1995) with regard to the utilisation of rivers. The maintenance of ecological reserves is well documented in several government gazettes, but implementation seems to be lacking.

2.7 Conclusion

It is clear from the review of various studies conducted in different countries that dams have both negative and positive impacts on both downstream and upstream river ecosystems. It is clear that downstream river ecosystems are more often affected by the upstream presence of dams and there is a need to suggest strategies that would minimize the impacts of dams in order to conserve species

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diversity and ecosystem functioning. It is also clear that the impacts are also accompanied by geographical location of dams, which affect river discharges. The review has also shown that remote sensing is a powerful tool in assessing vegetation cover changes over time, and there is still a need to use large scale aerial photography in producing quantifiable data to solve current environmental problems. There is still much to be researched on the impacts of dams downstream of the dams during extreme climate events like drought and floods. The review has also shown that a constant and consistent monitoring of the downstream and upstream impacts of dams needs to be monitored from time to time.

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CHAPTER THREE: METHODOLOGY

3.1. Introduction

This chapter focuses on the methods used in collecting data from the five dams studied in the Luvuvhu/Mutale sub-catchment. Data were collected from the field, remotely sensed images obtained from Surveys and Mapping Section of the Department of Land Affairs, rainfall and discharge data obtained from South African Weather Services (SAWS) and DWA respectively. All methods of data analysis used are also discussed in this chapter.

3.2 Data collection methods

3.2.1 Primary data collection

3.2.1.1 Data on vegetation characteristics

A checksheet for vegetation data was used. This was used to record data on vegetation type, morphology and density. Data for these variables were collected both upstream and downstream of the dams. Before the actual collection of data a pilot survey was done to record the type of vegetation found along the major river courses of the Luvuvhu/Mutale catchment. This was done to study the ecological setting of the study area and to identify points where data were to be sampled. Species were identified on the basis of life forms such as trees, shrubs and herbs. All three life forms where identified in the field and measurements were done to determine pattern of vegetation change and density both downstream and upstream of the dams. Pattern of change was identified by studying vegetation composition along riparian zones both upstream and downstream of the dams to compare vegetation composition associated with water-deficient (downstream) and water-rich (upstream) environments. This was done to establish whether there is an increase in terrestrial vegetation along dry and wet riparian zones and the changes in morphological characteristics of vegetation itself (whether short, dispersed or clustered). Horizontal photographs were also used to show vegetation distribution and impacts downstream of the dams along riparian zones.

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3.2.1.2 Tree density

Tree density was considered as the concentration of *Acacia* tree species within a given area, expressed in square meters. The **nearest individual method** (Kent and Coker, 1992) as the simplest **plotless sampling** (Kent and Coker, 1992) was carried out to measure tree density. Since the study area was characterised by tall, dense and sometimes scattered trees, **plotless sampling** as a form of random sampling was used. Dense, sparse and tall tree species of the area limited the use of quadrants, and other probabilistic sampling methods. With plotless sampling, sampled points were randomly selected using the random walk procedure. These sampled points are called **random walk points**. The random walk points were chosen using random numbers selected from the random number table. The first selected random number represented the direction of the location of the random walk point. A standard prismatic compass was used to measure the direction of the randomly selected spots, ranging from 0º to 360º. The numbers that were selected from the random number table were between 000 and 360, because compass readings ranged from 0 to 360º. The second number, which was also chosen from the random number table, represented the distance that was travelled to locate a sampled point, in the direction that was previously chosen. Eight random walk points, from where tree density measurements were taken, were selected both downstream and upstream of the selected dams. A total of sixteen spots (eight on either side of the dam wall) were selected.

All the random walk points were used as starting points to measure tree density using the **nearest individual method**. For each selected spot a total of five distance measurements were taken and all measurements were averaged to firstly determine the mean distance of each tree species from the random walk point. A 30m tape was used to measure distances from selected random walk points to the nearest individual tree species. Five distance measurements between similar tree species, per random walk point, were taken and averaged to determine the mean distance of individual tree species from the random walk points. All mean distances were then

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averaged and squared to determine the **mean area** of Acacia tree species using a formula adapted from Kent and Coker (1992: p56) as follows:

$$\bar{A} = (\text{đ}N)^2$$

Where $\bar{A}$ = mean area of tree species

$\text{đ}N$ = mean distance to the nearest individual species

After the calculation of mean area, tree density was also calculated using a formula adapted from Kent and Coker (1992: p56) as follows:

$$TD = \sqrt{\frac{\bar{A}}{2}}$$

Where TD = Tree density

$\bar{A}$ = mean area of tree species

To measure distances between similar individual tree species starting points for measurements were determined by using.

3.2.1.3 Water quality data

Only two variables were considered for the measurement of water quality, and these are **pH** and **stream temperature**. The **pH** of water is a measure of its alkalinity and acidity and was based on a 0 – 14 scale, with 7 being neutral. Any value that measured below 7 was considered acidic and above 7 alkaline. Freshwater plants, according to Bornmann *et al.* (2009), have a wide range of pH tolerance and can adjust to pH values between 6 and 8. pH was considered an important riparian ecosystem parameter because it controls the rate of plant metabolism (nutrient intake, evapotranspiration, osmosis, etc). Water samples for pH measurements were collected at depths of 15cm because this is the depth at which temperature is not extreme (Bornmann *et al.*, 2009). In order to obtain standard pH readings, 10 samples were collected both downstream and were averaged. The procedure was then repeated for upstream samples. The water samples were stored in methanol-washed 500ml containers before analysis. A total of twenty samples were collected

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for each studied dam. The samples were randomly collected at 15m interval along a 200m stream reach. Samples were collected in an alternating way, where the first sample was collected along the bank and the next, in the middle of the river. This was done to measure the extent of pH variation along the banks and in the middle of a river. Samples were collected at noon when the temperature was also high. A pH meter was used to measure pH.

Temperature was also considered to be another important riparian ecosystem parameter, because it controls heat energy processes in streams. According to Johnson and Jones (2000), temperature of water is controlled by the amount of shade provided by streamside vegetation in forested environments. Therefore, temperature was measured in order to determine its influence on plant species richness, since it also controls rates of plant metabolism. Stream temperatures were recorded *in* situ in December (mid-summer) at noon using a mercury thermometer. This was done to standardize water temperature values before temperatures could build-up in the late afternoon. To the same 10 water samples collected for pH measurements, were also measured for the temperature for both the downstream and upstream samples. The values were averaged to determine the mean diurnal temperature values. Mean daily temperature is defined as the mean of the maximum and minimum temperature at the sampling point for that day. Anything above or below these values can harm the plants. Heat energy transfer processes, solar radiation flux exerts the greatest influence on maximum stream temperatures and is predominantly controlled by the amount of shade provided by streamside vegetation in forested environments (Johnson and Jones, 2000; Danehy *et al.*, 2005). Impacts can include changes in nutrient cycling, thermal characteristics, detention storage of water, sediment, and organic matter and recruitment of coarse woody debris (D' Souza *et al.*, 2011).

3.2.1.4 Remotely sensed data for treeless cover area

Vertical aerial photographs (1: 16666) and orthophoto maps (1:10 000) of Luvuvhu/ Mutale area (Table 3.1) were used to calculate the size of treeless area in all studied

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dams. Tree cover is defined as the extent of tree canopy cover in relation to the ground surface. Therefore, treeless area is an area that is devoid of trees, but still has grasses as ground cover. These scales were chosen because they are able to show many landscape features and minimise misinterpretation of features. Booth *et al.* (2007) argue that the accuracy of land or vegetation characterization from remote sensing data is a function of spatial resolution. They recommend the use of the lowest-resolution photographs (1:6000 to 1:40 000). This is why in this study of Luvuvhu/Mutale dams resolutions of 1:10 000 and 1:16 666 were used to study vegetation density changes both upstream and downstream of the dams. Orthophotos or orthophotographs (1:10 000) were also used because they were considered more accurate and could supplement measurements and object identification from vertical aerial photographs. Cameron *et al.* (2000) argue that orthophotographs are in fact rectified photographs showing objects in their true planimetric positions. They argued that orthophotographs are geometrically equivalent to conventional line maps and are accurate in measurements of area, distances, angles and position.

The size of treeless area is the total surface area devoid of trees in a given area. The size of treeless area in each photograph was calculated within an area of 4.5 km^2 both upstream and downstream of dams making a total surface area of 9 km^2 for each dam. This size of an area was chosen because it was possible to determine any tree cover variations between downstream and upstream sections of the dams. The aerial photographs and orthophotos in Table 3.1 were obtained from Surveys and Mapping (Department of Land Affairs).

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Table 3.1 Aerial photographs and orthophotos for Luvuvhu/ Mutale dam areas (Surveys and Mapping: Department of Land Affairs)

Aerial photographs for job number 908 of 1987			
Strip number	**Photo number**	**Area**	**Scale**
10	163 & 164	Damani	1: 16 666
11	364 & 365	Vondo	1: 16 666
12	274 & 275	Nandoni	1: 16 666
Aerial photographs for job number 932 of 1989			
2	2068 & 2070	Albasini	1: 16 666
Aerial photographs for job number 982 of 1995			
7	392 & 393	Damani	1: 16 666
9	108 & 109	Nandoni	1: 16 666
9	113 & 114	Vondo	1: 16 666
11	184, 185, 186, 187, 188 & 189	Mambedi & Albasini	1: 16 666
1: 10 000 orthophotos			
Title			**Area**
2330 AA 7 STERKSTROOM			Albasini
2330 AA 12 WOLVEROODE			Albasini
2330 AA 13 RIVERSANDS			Albasini
2330 AA 14 DRIEFONTEIN			Albasini
2230 DC 6 TSHIRONGA			Damani (Mvuwe)
2230 CD 10 MUHUYU			Damani (Mvuwe)
2230 DC 11 VONDWE			Damani (Mvuwe)
2230 CD 15 NGWENANI			Damani (Mvuwe)
2230 AA 14 MVUWE			Mambedi
2230 AA 15 BEAUFORT			Mambedi
2230 DC 21 MPHEGO			Nandoni
2230 DC 22 MPONDI			Nandoni
2230 DC 23 MAKUMEKE			Nandoni
2330 BA 1 DIDIDI			Nandoni
2330 AA 15 BEAUFORT			Nandoni
2230 CD 17 VHUSHAVHELO			Vondo
2230 CD 18 VONDO			Vondo
2230 CD 22 KHONGORONI			Vondo
2230 CD 23 MAPATE			Vondo

On the aerial photographs of a scale of 1: 16 666 a grid of 0.2 cm squares, with 4125 squares, was used to calculate the total surface area devoid of tree species both downstream and upstream of the dams. The size of the grid was 15 cm x 11 cm

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which is an equivalent of 2.5 km x 1.8 km on the ground, which is the total surface area of 4.5 km^2.

All squares with no tree species were added together to obtain the total surface area devoid of tree species. The total number of squares with no tree species was then converted to square kilometres to determine the size of the area on the ground that is devoid of trees. The total surface area of 4.5 km^2, based on the 0.2 cm square size was calculated as follows:

$$A = S \times S$$

$$= \frac{(0.2 \times 16\,666)}{100\,000} \times \frac{(0.2 \times 16\,666)}{100\,000}$$

$$= 0.033 \text{ km} \times 0.033 \text{ km}$$

$$= 0.001089 \text{ km}^2 \times 4125 \text{ (number of squares)}$$

$$= 4.5 \text{ km}^2$$

Where **A** = total surface area devoid of trees

S = one side of a square

From the given formula, the total number of squares that contained no tree species was multiplied by 0.001089 km^2 to determine the total surface area devoid of tree species in km^2.

For the available 1: 10 000 orthophoto maps a grid of 0.25 cm square size was used with a total squares of 7200. The size of the grid was 25 cm x 18 cm which is an equivalent of 2.5 km x 1.8 km on the ground. Each square represented a total surface area of 0.000625km^2. Therefore, the total surface area covered by the grid can be simplified as 0.000625 km^2 x 7200 to represent 4.5 km^2. The total surface area of 4.5 km^2, based on the 0.25 cm square size for the 1: 10 000 orthophotos was determined as follows:

$$A = S \times S$$

$$= \frac{(0.25 \times 10\,000)}{} \times \frac{(0.25 \times 10\,000)}{}$$

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100 000 100 000

= 0.025km x 0.025km

= 0.000625km^2 x 7200 (number of squares)

= 4.5 km^2

3.2.1.5 Tree identification in aerial photographs and orthophotos

The identification of trees on aerial photographs was based on size, shape, tone or shades of grey, pattern and texture. To reduce bias and error in object identification a stereoscopic view was generated for adjacent aerial photographs to verify the shape, sizes, texture, pattern and tone of trees as suggested by Jensen (2007). Mirror stereoscopes were used to identify and familiarise the eye with tree properties as they appear on black and white aerial photographs and orthophotos. Jensen (2007) has stated that the hyperstereoscopy condition created by the use of stereoscopes allows us to study the terrain in three dimensions. Therefore, identification of trees was done through the use of basic elements of interpretation as follows:

Pattern: The arrangement of natural forest on aerial photographs and orthophotos is characterized by haphazard arrangement, appearing as clusters or individual stands unlike cultivated lands or orchards that are characterized by smooth texture or rows to indicate that their origin is anthropogenic.

Shape: Trees appear circular and dark characterized by rough or coarse texture.

Size: Tree crown was considered as small circular features characterized by rough texture.

Tone (shades of grey): Trees appeared generally dark grey to black colour.

Texture: Trees were distinguished from grass (smooth texture). Trees were characterized by coarse (rough) texture. Green tree crowns appear rough in texture and dark grey or black in colour.

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3.2.2 Secondary data collection

3.2.2.1 Rainfall and discharge data

Rainfall data, river discharge and spillway discharge data were used to determine whether the existing tree density measurements corresponded with these recorded data. Table 3.2 shows rainfall stations which recorded the twenty-year rainfall period in the vicinity of selected studied dams.

Table 3.2 Rainfall stations of Luvuvhu/ Mutale dam areas

Station Name	Latitude	Longitude	Reference no.	Nearest dam	Rainfall period
Driefontein	23° 08'	30° 12'	0723/338A 1	Mambedi	1960-1987
Goedehoop-Bos	23° 05'	30° 06'	0723/155 x	Albasini	1960-2008
Gooldville-Hosp	22° 53'	30° 29'	0766/863 6	Damani	1960-1984
Tate-Bos	22° 53'	30° 19'	0766/563 1	Vondo	1963-2000
Thohoyandou	22° 58'	30° 30'	0766/898 7	Nandoni	1982-2008
Vonda-Bos	22° 56'	30° 20'	0766/596 9	Vondo	1963-2008

Table 3.3 shows monthly river discharge data stations in the vicinity of Luvuvhu/ Mutale dams. River discharge is defined as the volume of water passing a given point along a river in a given time (Lenon and Cleves, 1987). Monthly river discharges and reservoir spillway discharge data (1960-2008) were obtained from the Department of Water Affairs, while monthly rainfall data was obtained from South African Weather Services.

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Table 3.3 Discharge data stations for Luvuvhu/ Mutale rivers.

Place	Period	Data type
Luvuvhu river @ Goedehoop station	1952-1968	Mean evaporation/ Mean Reservoir Spillway discharge
Luvuvhu river @ Mhinga station	1987-2008	Mean surface discharge
Mutshindudi @ Tshidzini (Vredenburg) station	1995-2007	Mean surface discharge
Mutshindudi @ Vondo dam	2001-2008	Mean surface discharge/ Reservoir Spillway Discharge

3.3 Data analysis

3.3.1 Qualitative analysis of vegetation data

Remotely sensed data was analyzed qualitatively by describing the vegetation cover on aerial photographs and orthophotos. Tree cover from the remotely sensed images was described based on Dansereau's method of vegetation description of physiognomy and structure as highlighted by Kent and Coker (1992). Dansereau's (1951) method describes cover based on the following criteria:

b = barren (This is an area characterised by an open land with scattered vegetation and sometimes no trees and grass)

i = discontinuous (This is an area characterised by dense, but intermittent cover. This interruption occurs as a result of in environmental gradients (slope, altitude, topography) and disturbed or degraded surfaces.

p = tufts & groups (Bushes growing in clusters or groups, and are separated from one by other dissimilar vegetation).

c = continuous (This is an area characterised by uniform, unbroken dense vegetation cover).

3.3.2 Quantitative data analysis (rainfall, discharge and tree density)

Graphs have been used to show variation in mean monthly and annual rainfall as well as, discharge and spillway data for different years for Luvuvhu and Mutshindudi rivers. All rainfall data from the earliest to the latest recorded period were averaged and presented as annual averages. For each rainfall year (starting from January to

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December) annual averages were obtained, while monthly averages were obtained by averaging monthly rainfall for each given year. Tables have been used to show vegetation density averages both downstream and upstream of the dams. Annual rainfall graphs have been used to show variations in rainfall averages for different years. Although the earliest rainfall data for some stations is 1960 while for others it is 1982, all stations have data for not less than twenty years. However, a twenty-year rainfall period has been considered to be sufficient to study vegetation density changes.

3.3.3 Correlation analysis between rainfall and river discharges

Correlation aims at measuring the degree of relationship between two variables and expressing it through a correlation coefficient (Bless and Kathuria, 1993). According to Welman *et al.* (2005) correlation helps in assessing the extent to which one variable influences another. In this study, correlation between rainfall and river discharge was undertaken to determine if river discharges downstream of the Luvuvhu/ Mutale dams increased with increasing rainfall. Spearman's rank correlation coefficient (r_s) was used to determine the relationships between annual rainfall averages and associated river discharge downstream of Luvuvhu river at Mhinga village and Mutshindudi River at Tshidzini village. Mhinga village lies downstream of the Nandoni dam, while Tshidzini lies downstream of the Vondo dam. The hypotheses to tested were:

i. The annual average rainfall corresponds with river discharge (alternative hypothesis or H_1)
ii. There is no relationship between river discharge and average annual rainfall (null hypothesis or H_0)

Where H_o: rho = 0 and H_1rho ≠ 0 (non-directional). The rejection level () was chosen as 0.05.

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Spearman's rank correlation coefficient formula can be expressed as follows:

$$r = 1 - \frac{6 \sum d^2}{n^3 - n}$$

Where d = the difference in ranks of the values of each matched pair

n = number of pairs

$\sum$ = the sum of

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CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Introduction

This chapter presents data that was collected from Albasini, Damani, Mambedi, Nandoni and Vondo dams. Thesedata were collected to assess the impacts of the damson their downstream river ecosystems using remote sensing, rainfall, river discharge and spillway discharge data. Data presented in this chapter show the tree species richness, water quality and flow characteristics of dammed rivers.

4.2 Rainfall averagesat dam areas

4.2.1 Goedehoop station (1960-2008)

This station records rainfall data in the vicinity of Albasini dam which lies on the LuvuvhuRiver. Rainfall figures have been provided to determine periods of low rainfall (lower than average) and the associated downstream impacts. The amount of rainfall determines the amount of river discharge which is responsible for the maintenance of riparian ecosystems. Figure 4.1shows the total annual rainfall recorded at Goedehoop station.

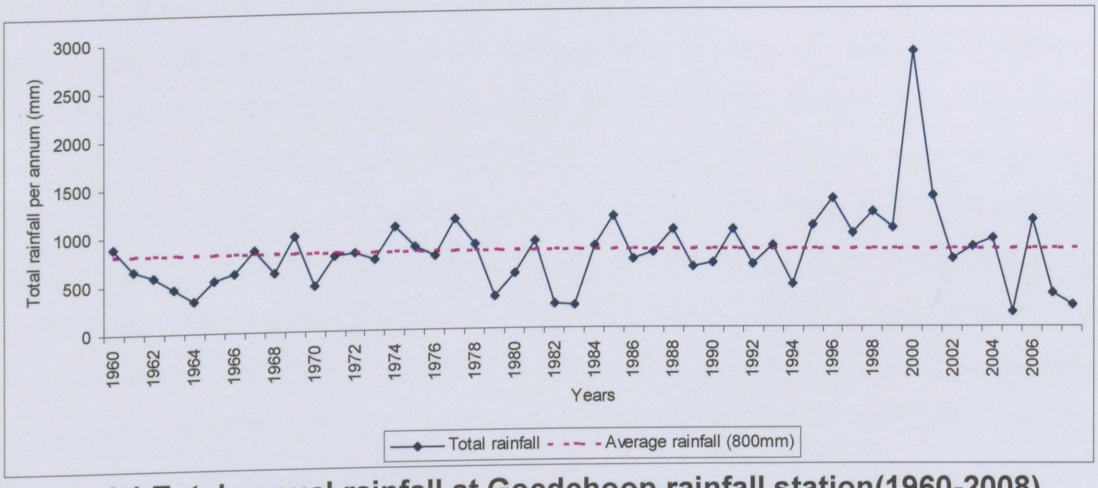

Figure 4.1 Total annual rainfall at Goedehoop rainfall station(1960-2008)

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The highest total annual rainfall recorded at Goedehoop rainfall station between 1960 and 2008 was 2841.2 mm for the year 2000 and the lowest was in 2005 (149.1 mm). The average annual rainfall for all years from 1960 to 2008 is 800 mm. The area also experiences rainfall below the average 800mm during dry seasons (1961-1966, 1982-1984 and 2007-2008). This affects downstream vegetation irrigation over a given period because the period of low rainfall will naturally interfere with ecological processes. Therefore, the reduction in natural flow along the Luvuvhu River due to damming will worsen during periods when rainfall is below the annual average of 800 mm. Once this happens riparian communities might suffer and be replaced by terrestrial species leading to changes in vegetation composition, richness and diversity. The presence of *Dodonaea Angustifolia* (sand olive) along downstream reaches of Albasini dam (Plate 4.1) is a clear indication of species composition changes. The proliferation of *Dodonaea Angustifolia* in the area is a clear indication of the replacement of riparian species by terrestrial species. *Dodonaea Angustifolia* thrives well in scrubs, on mountains and rocky soils, as well as poor soils. It is common where mean annual rainfall is 450 mm (Hong, *et al.*, 1996). This means that it can adapt to low rainfall areas. Its proliferation in the area therefore indicates that it will not be affected even during lower rainfall periods like 1961-1966, 1982-1984 and 2007-2008.

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Plate 4.1 *Dodonaeaangustifolia* species along downstream reaches of Albasini dam (December, 2008).

Figure 4.2 shows monthly rainfall averages indicating a period of high and lower rainfall in a year. From the monthly rainfall data in Figure 4.2, rainfall values show an increase from September and reach peak of 176.2 mm in February of the following year with rainfall averages greater than the average of 67.7 mm. Generally, above average rainfall is received from November to March of the following year. The below average rainfall occur during the seven months of April to October, with August recording the lowest rainfall average of 10.3mm. This implies that low flows downstream of the dam are experienced during low rainfall months, especially during lower rainfall cycles indicated in Figure 4.1 (1961-1966, 1982-1984 and 2007-2008). During these periodsrainfall is lower than the annual average of 800mm.This shows that downstream vegetation along the Luvuvhu River suffers severe drought during lower rainfall cycles and riparian vegetation is highly likely to be replaced by terrestrial vegetation because these species can tolerate arid conditions created by the upstream presence of the Albasini dam.

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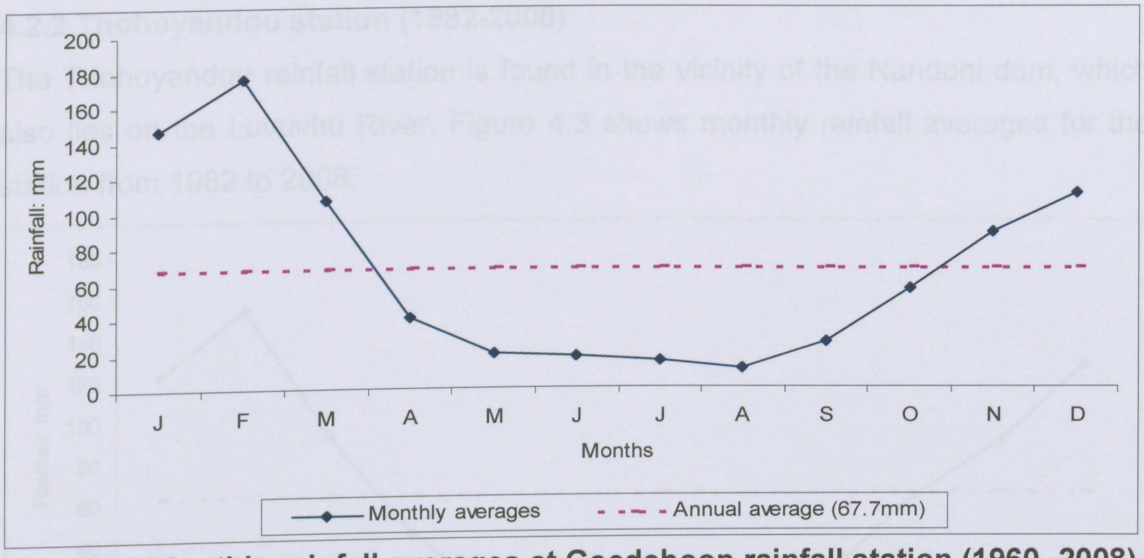

Figure 4.2 Monthly rainfall averages at Goedehoop rainfall station (1960 -2008)

Plate 4.2 shows the downstream section of Albasini dam where water is absent in December 2008. In the picture, terrestrial grass species can be seen in front of the dam wall. The riverflow has been cut off and no water is available downstream of the dam in summer because this was the period when rainfall was lower than the annual average of 800mm. This is another indication of species composition change due to the upstream presence of the Albasini dam.



Plate 4.2 Terrestrial vegetation along downstream section of the LuvuvhuRiver at Albasini dam (December, 2008)

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4.2.2 Thohoyandou station (1982-2008)

The Thohoyandou rainfall station is found in the vicinity of the Nandoni dam, which also lies on the Luvuvhu River. Figure 4.3 shows monthly rainfall averages for the station from 1982 to 2008.

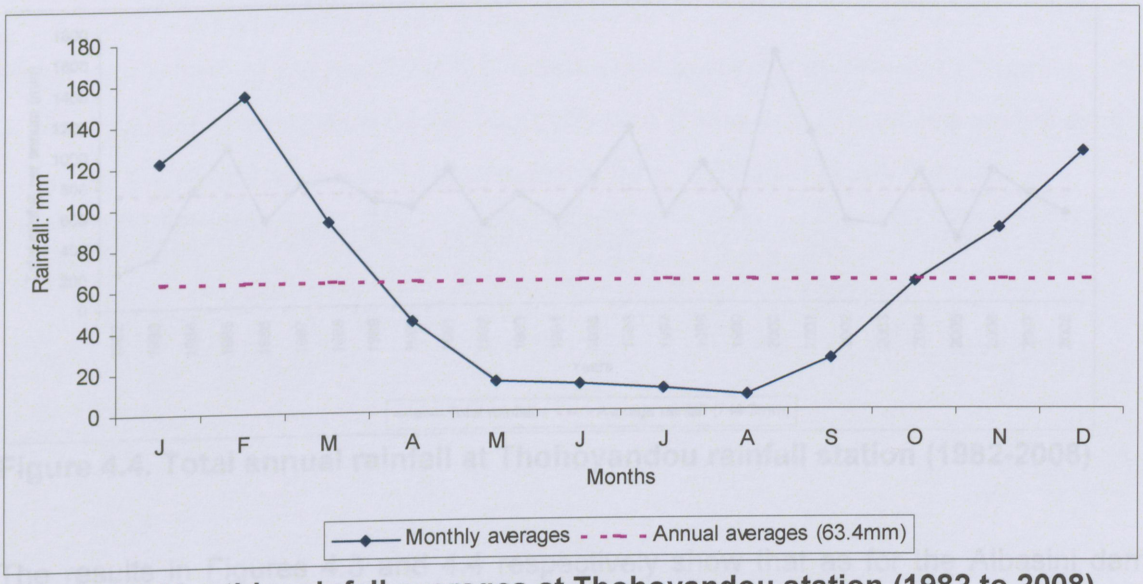

Figure 4.3. Monthly rainfall averages at Thohoyandou station (1982 to 2008)

Just as the Goedehooprainfall station at the Albasini dam, the highest average monthly rainfall of 154.2mm occurs in February. The average monthly rainfall values from April to October are lower than the monthly average of 63.4mm, whilst the average monthly values from November to the following March are above the monthly average. Just as for the Albasini dam, riparian vegetation downstream of the Nandoni dam is also highly likely to suffer from drought especially during low rainfall period as depicted in Figure 4.4 (1983-1984, 1989-1990, 2002-2003 and 2007-2008). This is bound to lead to vegetation composition changes along downstream reaches of the Nandoni dam. This will make riparian species to be replaced by terrestrial species. Figure 4.3 shows terrestrial grasses that have colonised formerly inundated area, leading to vegetation composition changes.

Figure 4.4 shows the total annual rainfall for Thohoyandou from 1982 to 2008. The area is characterized by alternating wet-dry seasons with an average annual rainfall

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of 744.3 mm. The highest total annual rainfall (1653.9mm) was recorded in the year 2000 while the lowest (229.3 mm) was recorded in 1982. The average rainfall for the years from 1982 to 2008 is 744.3 mm. The dry periods are 1983-198-4, 1989-1990, 2002-2003 and 2007-2008.

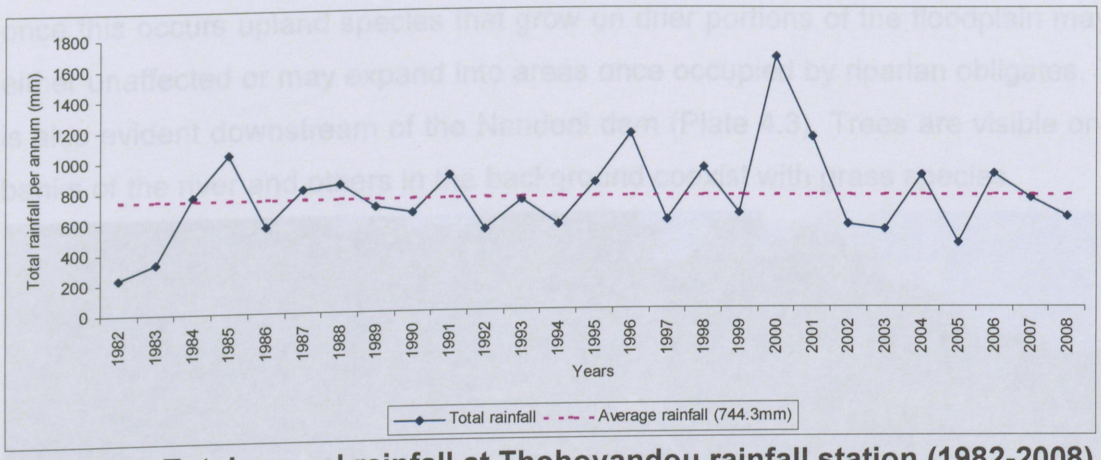

Figure 4.4. Total annual rainfall at Thohoyandou rainfall station (1982-2008)

The results in Figures 4.3 and 4.4 respectively show that as for the Albasini dam area the Nandoni dam area also suffered periods of wet-dry seasons. The low average annual and monthly river discharges (Figure 4.13 and 4.14) recorded at Mhinga village, which lies downstream of the Nandoni dam, confirm that the area downstream of the Nandoni dam suffered severe water curtailment. This suggests that riparian vegetation downstream of the Nandoni dam also suffered water shortages, especially during dry seasons. This would have ultimately led to changes in vegetation composition and the reduction in wetted perimeters, which include riparian zones. This is what happens when terrestrial vegetation encroaches into the former riparian zones. Gordon and Meentemeyer (2006) have stated that reduced wetted perimeter of a river will allowterrestrial vegetation to increase by 50% along formerly inundated areas. Plate 4.3 shows areas where terrestrial vegetation started to grow in formerly inundated areas of the Luvuvhu River downstream of the Nandoni dam.Grass species can be seen in the foreground where the area was once inundated. These recently desiccated areasare now being colonised by terrestrial grasses which tolerate arid conditions. Orr (2002) has stated that plant composition differed among recent and older sites as newer sites were dominated

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by a combination of grasses and early successional forbs. The same is true with Nandoni dam area where grasses, as shown in Plate 4.3,have colonised the newly desiccated riparian zone. With the passage of time,upland terrestrial trees will also start to proliferate in the formerly inundated areas. Stromberg (2001)also argues that once this occurs upland species that grow on drier portions of the floodplain may be either unaffected or may expand into areas once occupied by riparian obligates. This is also evident downstream of the Nandoni dam (Plate 4.3). Trees are visible on the banks of the river and others in the background coexist with grass species.

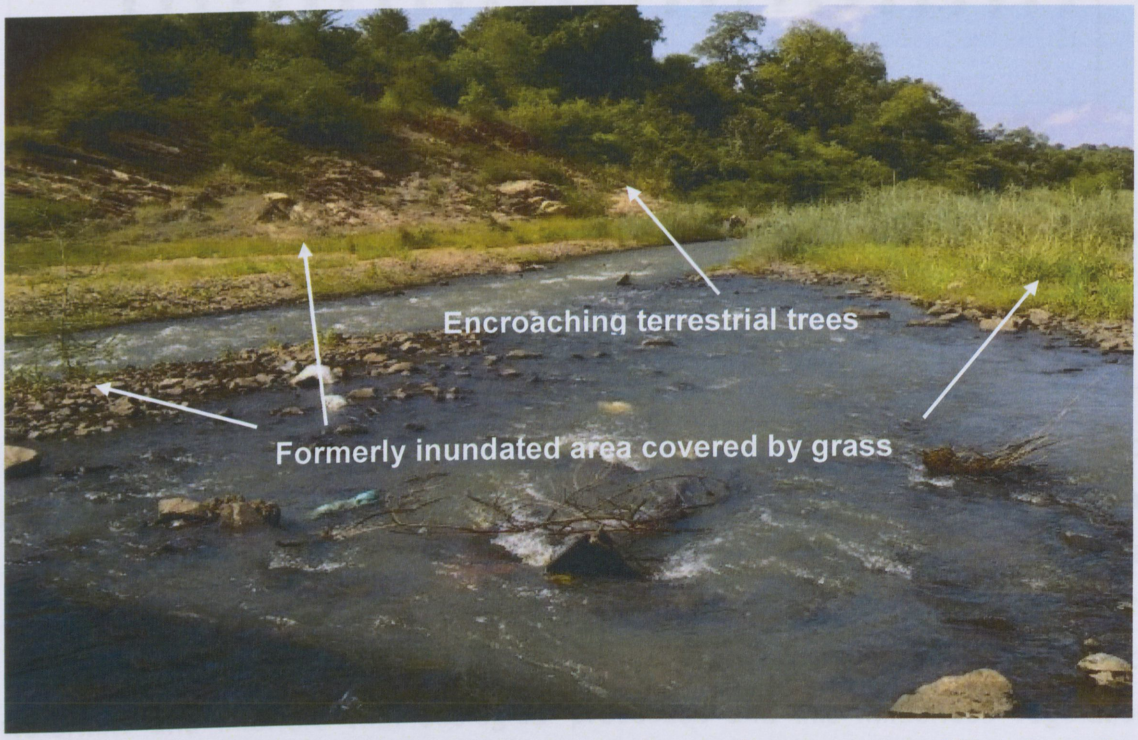

Plate 4.3 Colonisation of formerly inundated area downstream of Nandoni dam on the LuvuvhuRiver (December, 2008)

4.2.3Driefontein station (1960-1987)

Driefontein station records rainfall data for areas in the vicinity of Mambedi dam which lies on the Mambedi river. Figure 4.5 shows the total annual rainfall for the years 1960 to 1987 for the station. The highest total annual rainfall of 1559 mm was recorded in the year 1977 and the lowest in (335 mm)1982. The average total annual rainfall for the area is 834.6mm.

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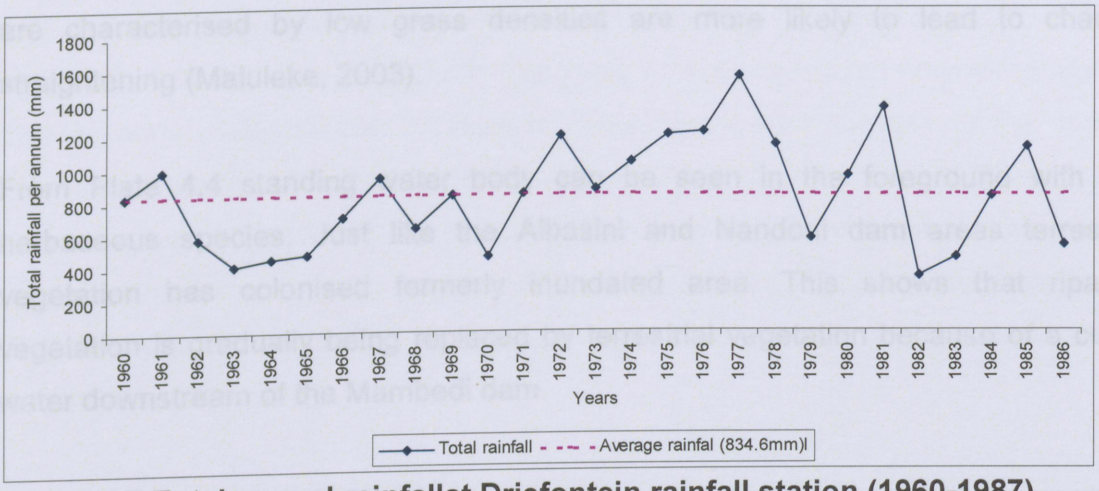

Figure 4.5 Total annual rainfallat Driefontein rainfall station (1960-1987)

The area is characterized by alternating wet-dry seasons just as in the Albasini and Nandoni dam areas. This means that the area downstream of the Mambedi dam experiences low flows during dry seasons with much lower low flows during dry cycles as occurred in 1962-1966 and 1982-1984. This is because the Mambedi dam creates a barrier of water flow and this deprives downstream riparian vegetation of much needed water for growth. Rainfall was lower than the annual average rainfall as occurred in the years 1962-1966, 1968, 1970, 1979, 1982-193 and 1996.The total annual rainfall for these years was lower than the annual average of 834.6mm. According to Malik and Richardson (2009), dams across rivers create barriers of waterflow and interfere with ecological processes and this influences vegetation richness and diversity. The same is true of the Mambedi dam area, where little water is available downstream of the dam, and terrestrial grass species have occupied formerly inundated area.Again, the presence of low grass density on the banks will make the river banks to be more unstable (Plate 4.4). Such banks will be characterised by calving due to their increased instability. Once this occurs, erosion of banks will increase and sedimentation will also increase. Simon and Collison (2002) have noted that if vegetation development progresses to trees strata, banks are expected to be more stable than if banks are dominated by grass communities. This is why Congalton *et al.* (2002) have argued that without riparian vegetation,

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erosion will increase and sedimentation will also increase in dams. Channels that are characterised by low grass densities are more likely to lead to channel straightening (Maluleke, 2003).

From Plate 4.4 standing water body can be seen in the foreground with few herbaceous species. Just like the Albasini and Nandoni dam areas terrestrial vegetation has colonised formerly inundated area. This shows that riparian vegetation is gradually being replaced by terrestrial vegetation because of a cut in water downstream of the Mambedi dam.

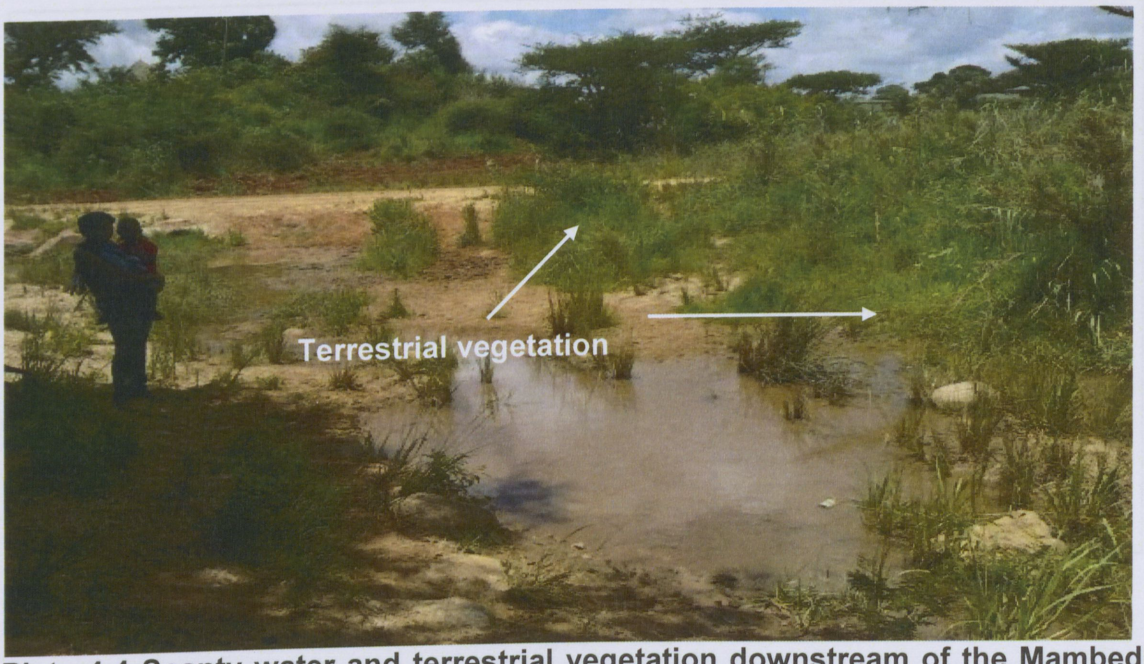

Plate 4.4 Scanty water and terrestrial vegetation downstream of the Mambedi dam (December, 2008).

Figure 4.6shows monthly rainfall averages for Driefontein station. The lowest monthly rainfall averages (lower than average of 69.2mm)are experienced during the seven months of April to October, with July recording the lowest average of 8mm. Only in five months of November to March is there rainfall above the average of 69.2mm with February recording the highestmonthly rainfall average of 160.3mm.

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Areas downstream of the Mambedi dam receive low flows or nothing during low rainfall periods, especially during low rainfall years like 1961-1966 and 1982-1984. It is obvious that during those periods there was no water released downstream of the dam to nurture downstream ecosystem. This means that the size of the riparian zone downstream of the Mambedi dam reduced.As in the Albasini and Nandoni dam areas (Figures 4.2 and 4.3), the Mambedi dam area also experiences below monthly rainfall averages during the seven months from April to October. This also means that downstream vegetation experience water shortage and will be replaced by terrestrial vegetation.

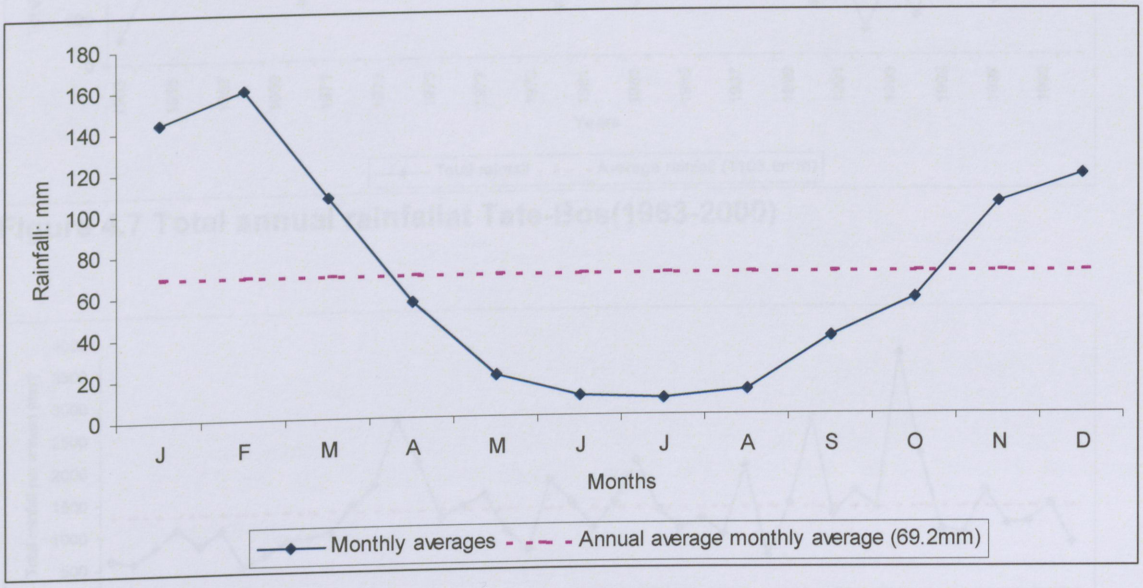

Figure 4.6 Monthly rainfall averages at Driefontein (1960-1987)

4.2.4 Vonda-Bos (1963-2008) and Tate-Bos stations (1963-2000)

These two stations have recorded rainfall data for areas in the vicinity of Vondo dam from 1963 to 2000 (Tate-Bos) and 1964 to 2008 (Vonda-Bos).Vondo dam lies on the Mutshundudi river.Figures 4.7 and 4.8 show the total annual rainfall for Tate-Bos (1963-2000) and Vonda-Bos (1964-2008) rainfall stations respectively. The highest total annual rainfall of 2757.7 mm occurred at Tate-Bos in 1977 and the lowest (261 mm) at Vonda-Bos (Figure 4.8) in 1963. The average total annual rainfall at Tate-Bos (1963-2000) was 1108.9 mm. Most of the annual rainfall values at both Tate-

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Bos (1963-2000) and Vonda-Bos (1964-2008) were below the annual averages of 1108.9 mm (Tate-Bos) and 1297.9 mm (Vonda-Bos). The highest total annual rainfall indicates that the area is expected to have high vegetation density than in all studied dam areas (Albasini, Damani, Mambedi and Nandoni). Low flows are expected to be higher than in all studied dam areas.

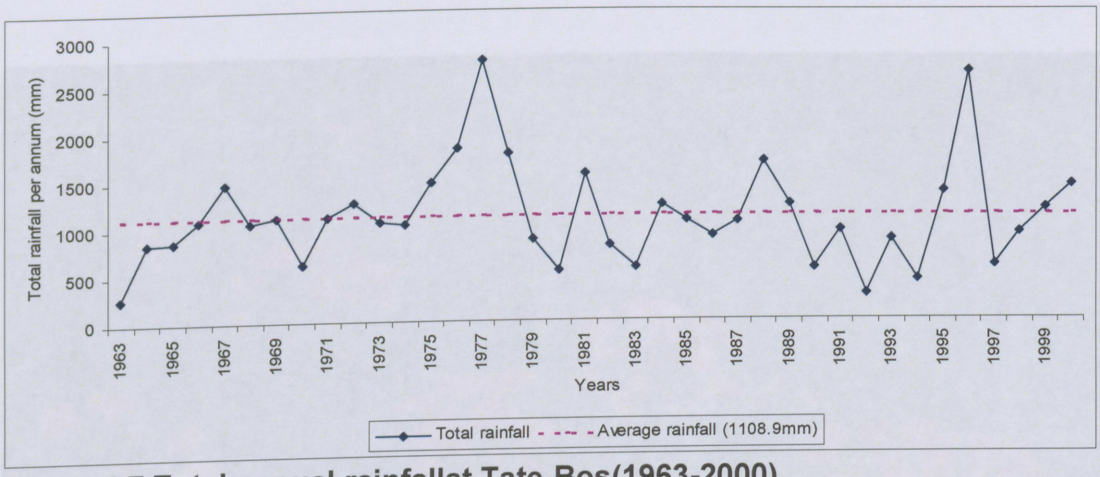

Figure 4.7 Total annual rainfallat Tate-Bos(1963-2000)

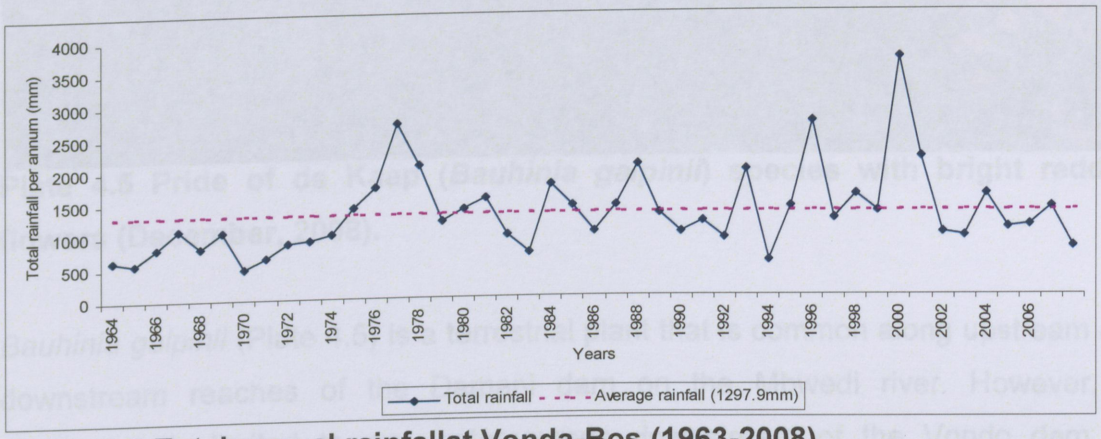

Figure 4.8 Total annual rainfallat Vonda-Bos (1963-2008)

From Figure 4.8 it can be concluded that vegetation downstream of the Vondo dam could have suffered from drought during the lower low flows as recorded in 1982-1985 period, because this was during low rainfall period that was followed by two others in 1990-1992 and 2003-2004. Total annual rainfall values for these periods were lower than annual averages of both 1108.9 mm (Figure 4.7) and 1297.9 mm (Figure 4.8) respectively. This shows that there would have been water flow

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interruptions downstream of the dam because streamflowswere generally lower during the low rainfall periods, and because the upstream presence of the dam would have worsened the situation. Riparian vegetation richness would therefore have started to reduce immediately after the construction of the dam and this is evident in the distribution of *Bauhinia galpinii* (Pride of de Kaap) (Plate 4.5).



Plate 4.5 Pride of de Kaap (*Bauhinia galpinii*) species with bright reddish flowers (December, 2008).

Bauhinia galpinii (Plate 4.5) is a terrestrial plant that is common along upstream and downstream reaches of the Damani dam on the Mbwedi river. However, its distribution is limited to wet watercourses downstream of the Vondo dam. Its presence indicates a replacement of indigenous riparian vegetation due to the presence of the dam. Riparian zones, according to Rowntree (2000), are more prone to destruction and replacement by alien species. The presence of *Bauhinia galpinii*indicates the replacement of indigenous riparian species by alien species.From Plate 4.5 it is evident that *Bauhinia galpinii* has flowered because of its location along watercourses. It has replaced riparian vegetation. This is because its seeds require continuous inundation in order to germinate quicker. This explains

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why its distribution is not continuous downstream of the Damani dam. It is more common upstream than downstream. Lytle and Merritt (2004) also noted that riparian ecosystems have declined substantially since the early 1900s, primarily as a result of construction of dams for flood control and water storage. The same change in vegetation density was noted by Herron *et al.* (2002) along the Burendong Dam (Australia) where marshes shrunk by more than 40% downstream of the dam, after the construction of the dam.

Figures 4.9 and 4.10 show the monthly rainfall averages at Tate-Bos and Vonda-Bos respectively. Mean monthly rainfall for the two stations increased from August to February of the following year and decreases from March until July when lowest rainfall occurred. The highest monthly rainfall averages for both stations which occurred in February are 278.6 mm (Tate-Bos) and 271.7 mm (Vonda-Bos). Monthly rainfall averages for the two stations fall below averages of 97.9 mm (Tate-Bos) and 108.3 mm (Vonda-Bos) from April October. Both stations recorded rainfall averages of above averages form November to March of the following year. As in the Albasini, Nandoni and Mambedi dam areas, the Vondo dam area would have had insufficient water for riparian irrigation and riparian zone would have decreased in size during the seven months of low flows from April to October.

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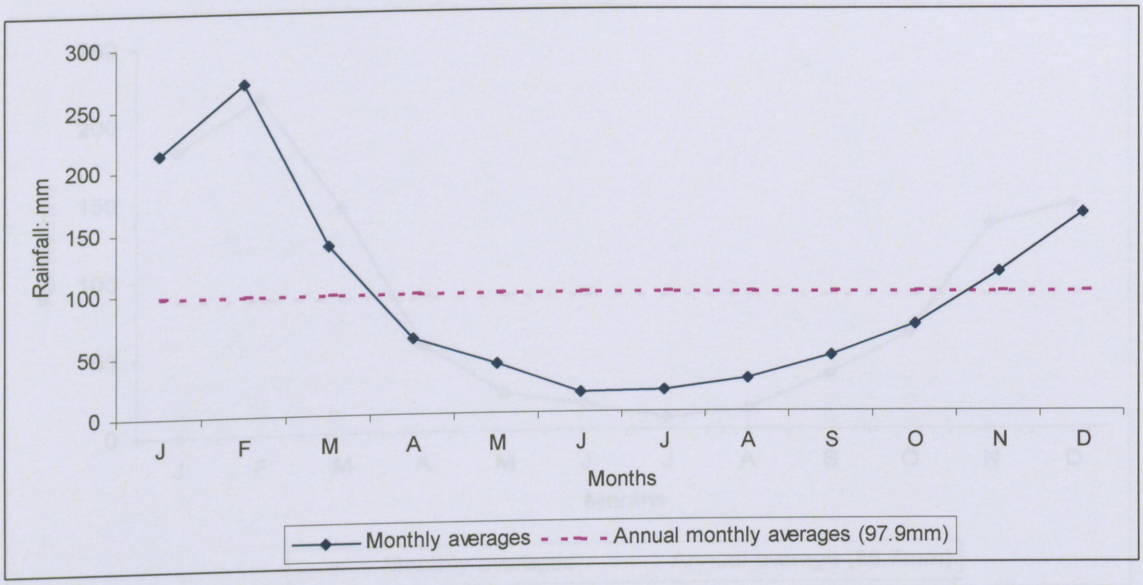

Figure 4.9 Monthly rainfall averages at Tate-Bosstation (1963-2000)

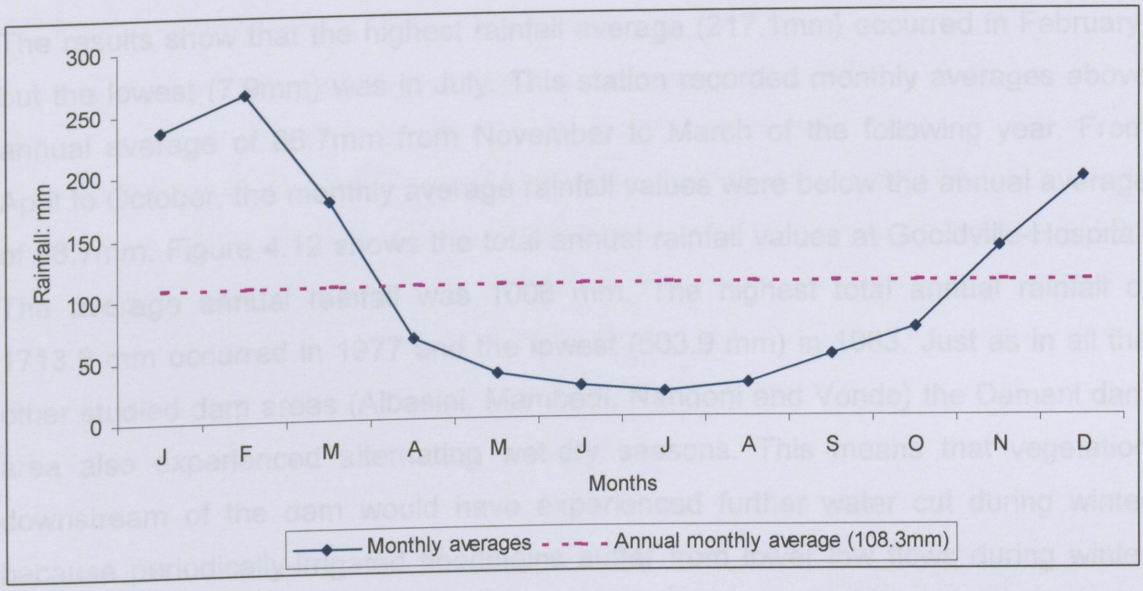

Figure 4.10 Monthly rainfall averages at Vonda-Bosstation (1963-2008)

4.2.5 Gooldville-Hospital station (1960-1984)

Thisstation records rainfall data in the vicinity of Damani dam which lies on the MbwediRiver. . The average monthly rainfall data from 1960 to 1984 is shown in Figure 4.11.

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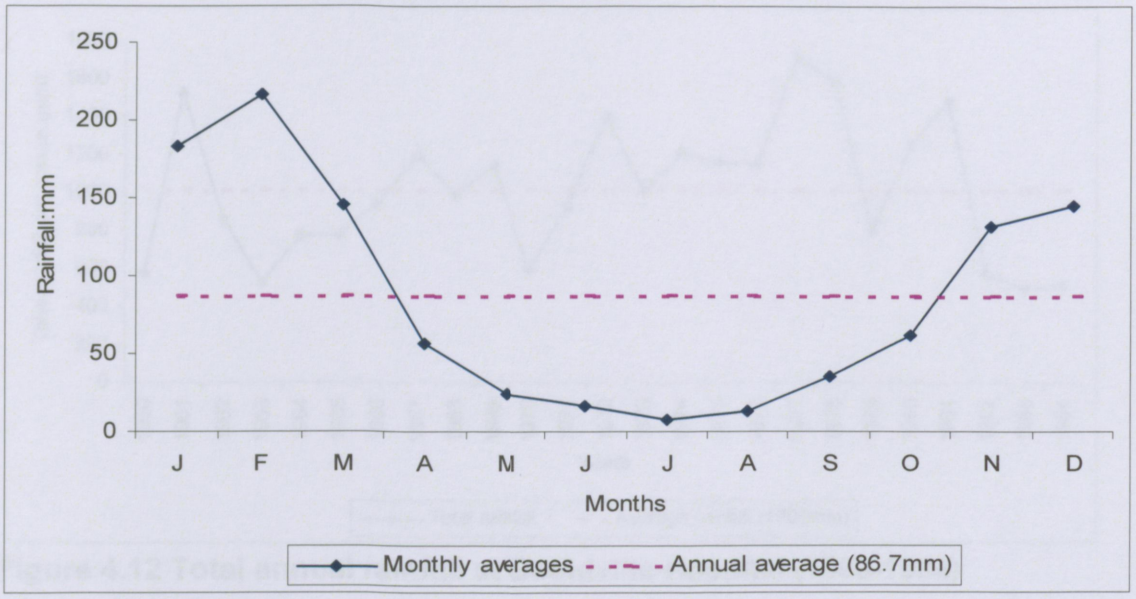

Figure 4.11 Monthly rainfall averages at Gooldville-Hospital station (1960-1984)

The results show that the highest rainfall average (217.1mm) occurred in February, but the lowest (7.9mm) was in July. This station recorded monthly averages above annual average of 86.7mm from November to March of the following year. From April to October, the monthly average rainfall values were below the annual average of 86.7mm. Figure 4.12 shows the total annual rainfall values at Gooldville-Hospital. The average annual rainfall was 1006 mm. The highest total annual rainfall of 1713.6 mm occurred in 1977 and the lowest (503.9 mm) in 1983. Just as in all the other studied dam areas (Albasini, Mambedi, Nandoni and Vondo) the Damani dam area also experienced alternating wet-dry seasons. This means that vegetation downstream of the dam would have experienced further water cut during winter because periodically-irrigated floodplains suffer from lower low flows during winter months of the dry spells (1962 -1966 and 1882-1984). This reduced density of riparian species and led to the dominance of terrestrial species along formerly inundated floodplains.

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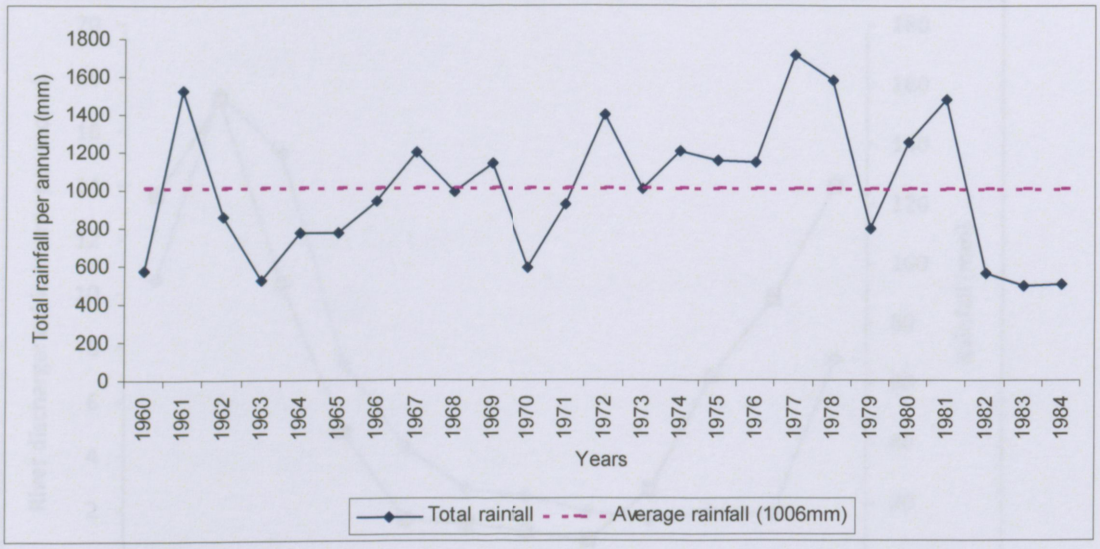

Figure 4.12 Total annual rainfall at Gooldville-Hospital (1960-1984)

4.3 Riverand reservoir spillway discharges

4.3.1 Luvuvhu Riverdischarge at Mhinga village (1988-2008)

River discharge is defined as the volume of water passing a given point on a river channel in a given time, and is expressed as cubic meters per second (m^3s^{-1}) (Lenon and Cleves, 1987). River discharge determines the amount of water that is available for floodplain and riparian zone irrigation. Mean monthly river discharge was obtained by averaging annual discharges from 1988 to 2008. The mean monthly river discharge of the Luvuvhu River at Mhinga village downstream of Nandoni damis shown in Figure 4.13.

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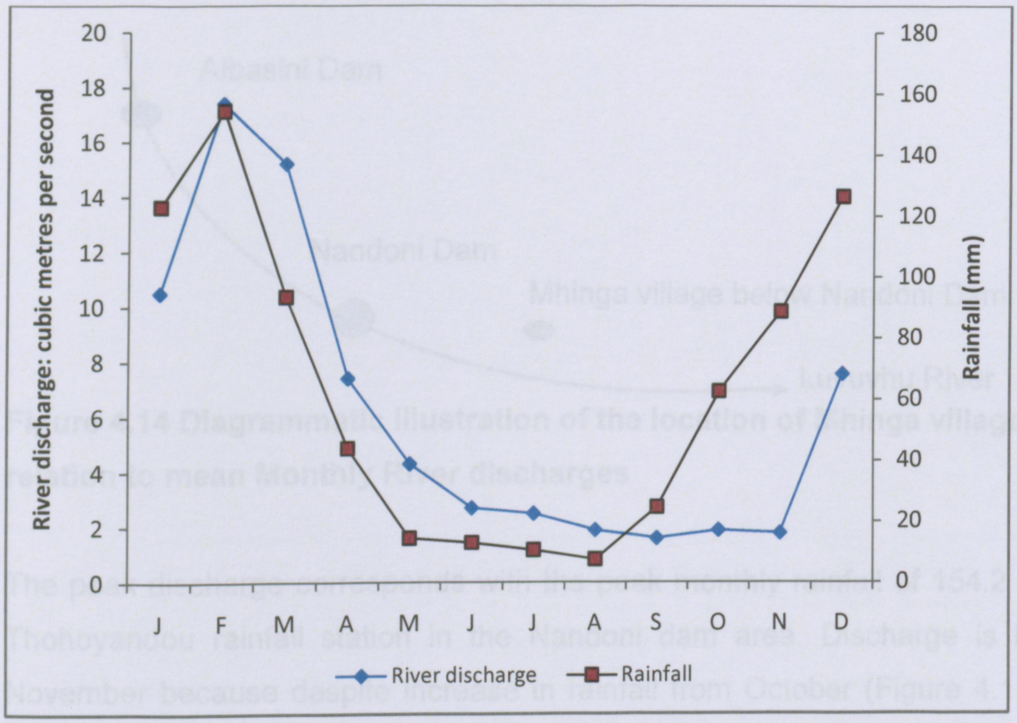

Figure 4.13 Mean monthly Luvuvhu riverdischarge(m^3s^{-1}) and for Luvuvhu at Mhinga (1988-2008) and monthly rainfall averages at Thohoyandou station (1982 to 2008)

From Figure 4.13,the highest mean monthly river discharge of the Luvuvhu river below Nandoni dam at Mhinga was in February (17.4m^3s^{-1}).This corresponds with the highest average monthly rainfall at theThohoyandou rainfall station in the Nandoni dam area, where discharge is higher from November to the next February (Figure 4.13). At Mhinga village, that is located downstream of the Albasini and Nandoni dams, there were lower than average river discharges that occurred between March (15.2 m^3s^{-1}) and November (1.8 m^3s^{-1}) (Figure 4.14). The Luvuvhu River dischargesthen increased from December (7.6 m^3s^{-1}) and a peak of 17.4 m^3s^{-1} was reached in February, down to 15.2 m^3s^{-1}in March.

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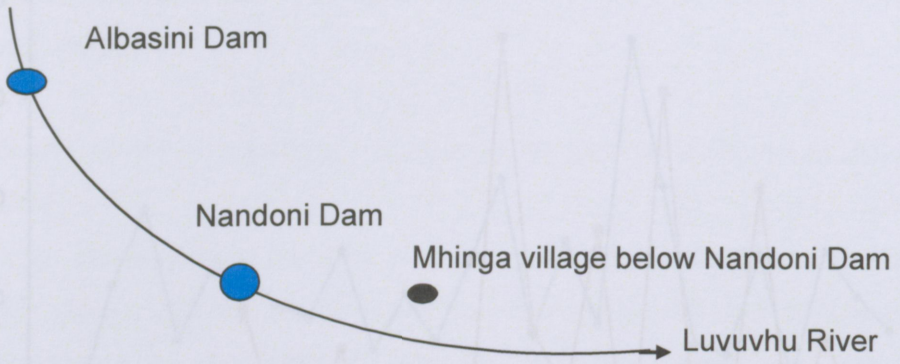

Figure 4.14 Diagrammatic illustration of the location of Mhinga village in relation to mean Monthly River discharges

The peak discharge corresponds with the peak monthly rainfall of 154.2 mm at the Thohoyandou rainfall station in the Nandoni dam area. Discharge is lower until November because despite increase in rainfall from October (Figure 4.13) there is always a lag in throughflow that determines the amount of water available for floodplain irrigation. According to Alemaw and Chaoka (2006), the fluctuation of river discharge in southern Africa is also influenced by El Nino Southern Oscillation (ENSO). This is because after rainfall, more water is lost to the ground through infiltration following a dry spell in winter months (May to July), causing low stream discharges. This means that during dry seasons, especially during May to November of 2007 and 2008 (Figure 4.14), river discharge will be greatly reduced and riparian irrigation will be interrupted. This will impact negatively on riparian species and they will always fail to sprout in numbers. According to Nilsson and Svedmark (2002), when dams disrupt longitudinal pathways, plant dispersal is greatly reduced and plant communities become fragmented. This explains why formerly inundated floodplains in Plate 4.3 are being colonised by terrestrial grasses and trees.

Figure 4.15 shows the average annual river discharge for Luvuvhu River at Mhinga village. The average annual river discharge is 70 m^3s^{-1} (Figure 4.15). The highest average annual discharge (230.1 m^3s^{-1}) for Mhinga was recorded in 1996 and the lowest (7.82 m^3s^{-1}) in 2000.

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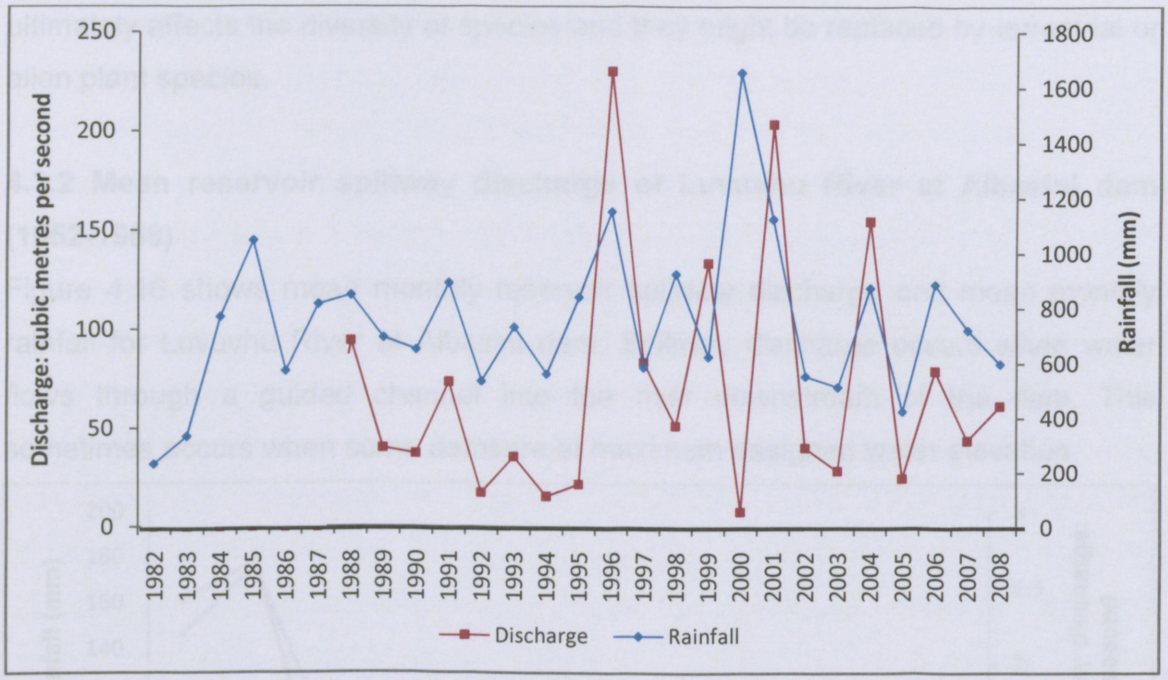

Figure 4.15 Average annual riverdischarges(m^3s^{-1}) of Luvuvhu River at Mhinga (1988-2008)

However, most recordings are below the annual average of 70.4m^3s^{-1}. The average annual river discharges for Luvuvhu at Mhinga are more often lower than the average of 70 m^3s^{-1}. These low river discharges impact negatively on floodplain irrigation. The discharges shown in Figure 4.15 correspond well with rainfall recorded at Thohoyandou rainfall station.When rainfall averages were lower than averageso did the total annual discharges (Figure 4.15). This poses a threat in water supply downstream of the Nandoni dam because of decreased stream flow that was caused by the existence of the dam and low rainfall in winter and dry seasons. The low discharges also suggest that the upstream presence of the Nandoni dam reduced river discharges, and this would have been severe in winter months of dry seasons as recorded in Figure 4.15(1989-1990, 2003-2004 and 2007-2008). This means that the downstream sections of the Nandoni dam, on the Luvuvhu river,were low flow zones because of the upstream presence of the dam. The same can be said about all other studied dams. Once flows are lower, floodplain irrigation is curtailed and riparian species fail to sprout due to insufficient irrigation. This

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ultimately affects the diversity of species and they might be replaced by terrestrial or alien plant species.

4.3.2 Mean reservoir spillway discharge of Luvuvhu River at Albasini dam (1952-1968)

Figure 4.16 shows mean monthly reservoir spillway discharge and mean monthly rainfall for Luvuvhu River at Albasini dam. Spillway discharge occurs when water flows through a guided channel into the river downstream of the dam. This sometimes occurs when some damsare at maximum designed water elevation.

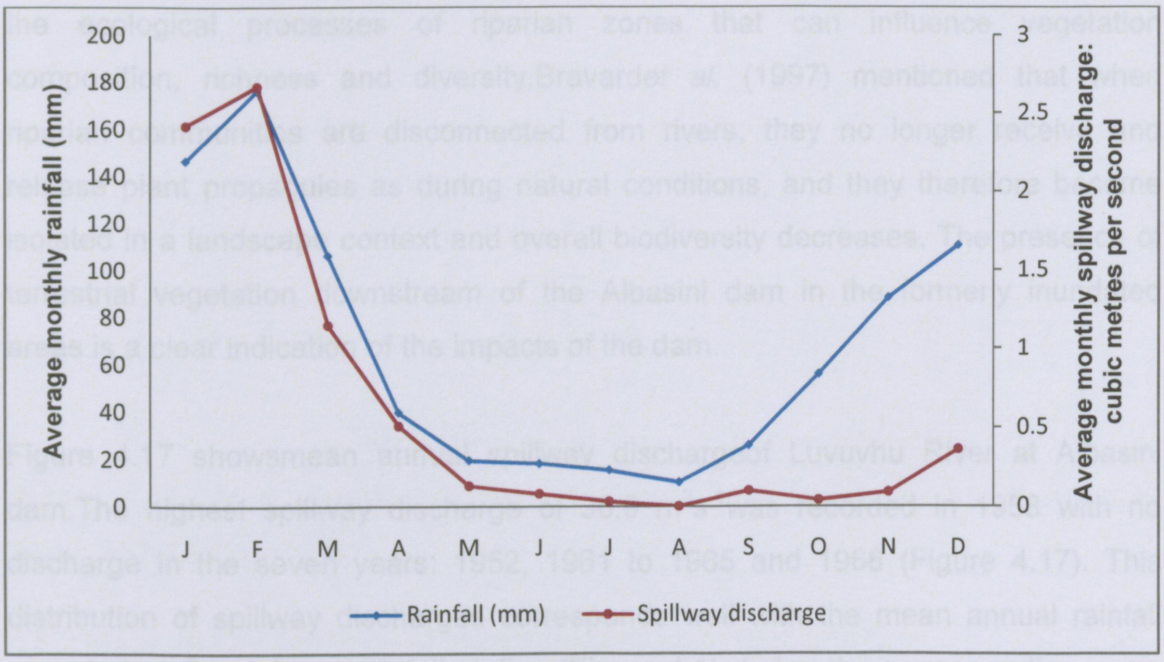

Figure 4.16 Mean monthly reservoir spillway discharge (m^3s^{-1})and mean monthly rainfall ofLuvuvhu at Albasini dam (1952-1968)

Spillway discharge is low from May to November, but starts to show an increase from December until the next February. The mean monthly spillway discharge pattern corresponds with the rainfall amounts for the LuvuvhuRiverrecorded at Goedehooprainfall station. From Figure 4.16very lowor no water is released during dry months,as it is the case with low rainfall averages recorded at Goedehoop stationduring the same period. The lower rainfall months explain why river dischargesare also lower. The highest mean spillway discharge was recorded in February ($2.67m^3s^{-1}$) and the lowest in August ($0.007m^3s^{-1}$). These discharges also

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corresponds with rainfall averages recorded at Goedehoop rainfall station where the highest monthly rainfall average (176.2mm) was recorded in February and the lowest (10.3mm) in August. The low discharges would mean that floodplain irrigation is curtailed and this might lead to a reduction in riparian species richness. The results indicate that the Luvuvhu River downstream of the Albasini dam does not flow perennially, due to the upstream presence of the dam. This shows that lower low flows are experienced in winter and no flows are experienced in winter of the low rainfall seasons. This has been similarly observed by Richardson (2009) when he stated that dams across rivers create barriers of natural water flow and interfere with the ecological processes of riparian zones that can influence vegetation composition, richness and diversity.Bravard*et al.* (1997) mentioned that when riparian communities are disconnected from rivers, they no longer receive and release plant propagules as during natural conditions, and they therefore become isolated in a landscape context and overall biodiversity decreases. The presence of terrestrial vegetation downstream of the Albasini dam in the formerly inundated areas is a clear indication of the impacts of the dam.

Figure 4.17 showsmean annual spillway dischargeof Luvuvhu River at Albasini dam.The highest spillway discharge of 36.9 $m^3s^{-1}$was recorded in 1958 with no discharge in the seven years: 1952, 1961 to 1965 and 1968 (Figure 4.17). This distribution of spillway discharges corresponds well with the mean annual rainfall recorded at Goedehoop rainfall station (Figure 4.1) during the corresponding years (1960 to 1965). During these years the mean annual rainfall was below the average (800mm) for all years (1960 to 1966).Consequently, during this period,the downstream reach of Luvuvhu river at Albasini suffered drought.The existence of the dam, together with these low annual and monthly rainfall averages would have reduced floodplain irrigated areasand the riparian species composition would have been reduced as a result. Therefore, it would be expected that more terrestrial species would colonise the area downstream of the dam.Stromberg (2001) has stated that riparian species diversity would be lower along streams that do not flow perennially. It can be concluded that the LuvuvhuRiver downstream of the Albasini

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dam does not flow perennially, and this leads to riparian species decline. The low flows recorded in August show that flow is interrupted during lower or no rainfall months. This shows that even though the drought period is natural the existence of the dam worsens drought conditions downstream of the dam and this leads to lower low flows or no flows. The lower low flows or no flows limit the size of irrigated floodplain, hence reduced wetted area for riparian species. This leads to the colonisation of the dry area by alien or terrestrial species.

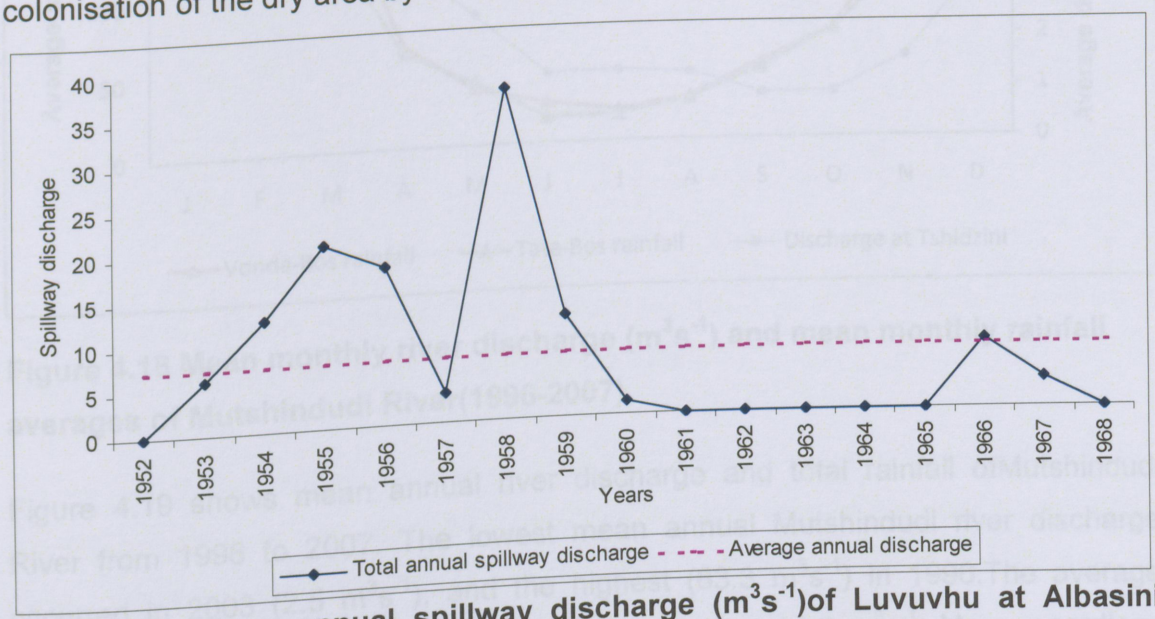

Figure 4.17 Mean annual spillway discharge (m^3s^{-1})of Luvuvhu at Albasini dam(1952-1968)

4.3.3 Mean river discharge of Mutshindudi River (1996-2007)

Figure 4.18 shows the mean monthly river discharges for Mutshindudi River at Tshidzini village. The Vondo dam that is used for agricultural irrigation by theThathe-Vondo Tea Estate is located on the Mutshindudi river. The highest mean monthly river discharge of $8.3m^3s^{-1}$occurred in January followed by a gradual decline in February ($7.8m^3s^{-1}$) and March ($7.2m^3s^{-1}$). The sharp decline in discharge from March coincided with the drop in the rainfall averages recorded by Vonda-Bos and Tate-Bos stations. This is a period when riparian irrigation suffers water shortage. This would have therefore decreased species composition on the downstream reaches of the Vondo dam.

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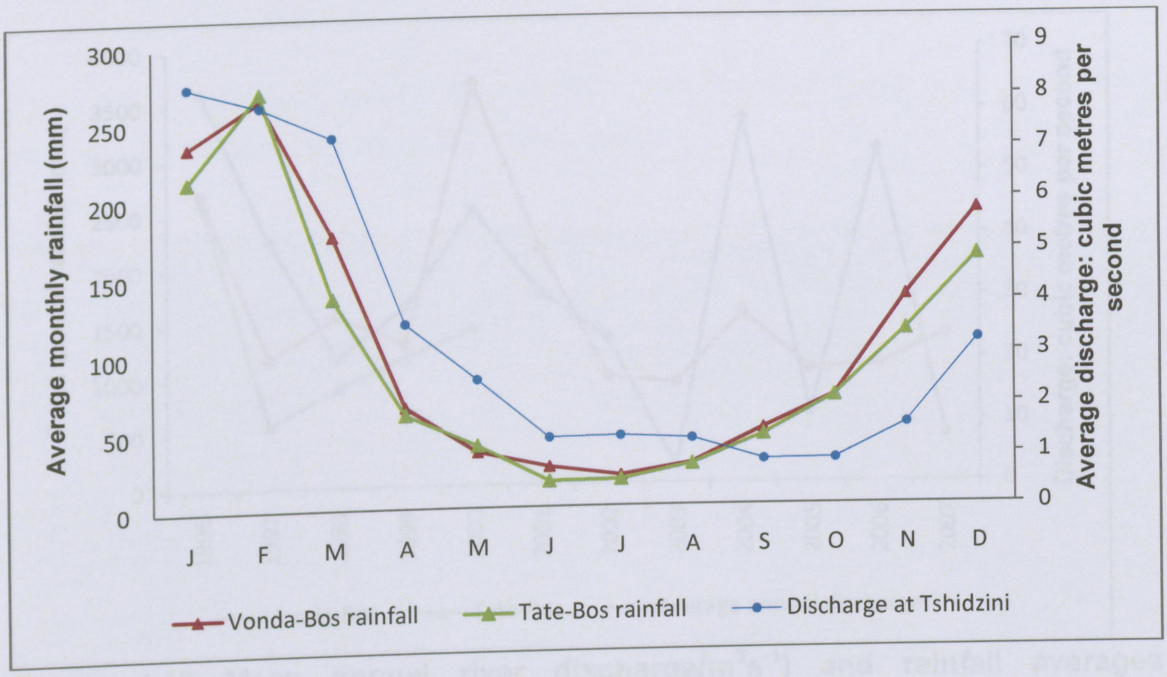

Figure 4.18 Mean monthly river discharge (m^3s^{-1}) and mean monthly rainfall averages of Mutshindudi River(1996-2007)

Figure 4.19 shows mean annual river discharge and total rainfall ofMutshindudi River from 1996 to 2007. The lowest mean annual Mutshindudi river discharge occurred in 2003 (2.5 m^3s^{-1}), and the highest (63.3 m^3s^{-1}) in 1996.The average annual river discharge recorded at Tshidzini village is 31.9 m^3s^{-1}. More recordings fall below an average of 31.9 m^3s^{-1}which means that river discharge data corresponds with rainfall data recorded at Tate-Bos and Vonda-Bos rainfall stations respectively.Just as in the Albasini, Damani, Mambedi and Nandoni dam areas, the upstream presence of Vondo dam reduced water available for downstream Mutshindudi river discharge which is important in the irrigation of riparian plant communities. This would have allowed grass to grow in formerly inundated areas.

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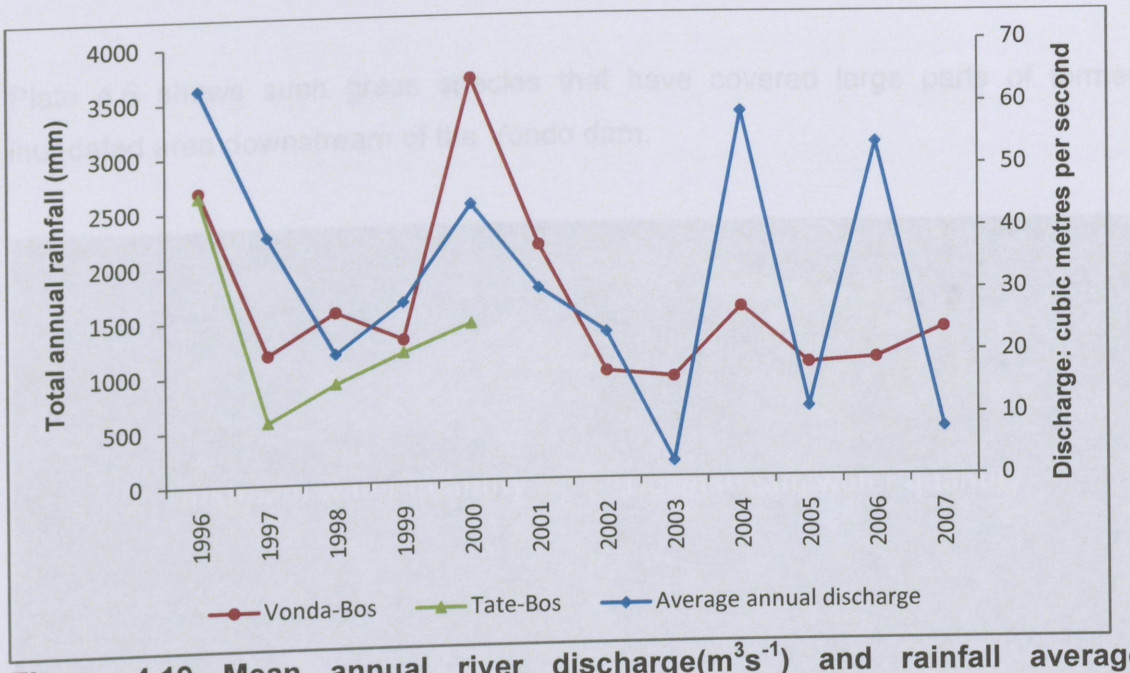

Figure 4.19 Mean annual river discharge(m^3s^{-1}) and rainfall averages ofMutshindudiriver at Tshidzini village (1996-2007)

During low annual rainfall years as occurred in Tate-Bos and Vonda-Bos(2002-2008) discharge averages were also low. Therefore, the existence of the Vondo dam would have further worsened the situation by completely cutting off water downstream on the Mutshinddudiriver. This is because dams naturally reduce downstream river discharges and during low rainfall periods, downstream discharges may be completely curtailed. Andersen *et al.* (2007) have similarly observed that river discharges declined in all 24 subbasins studied along the Upper Colorado River Basin (Basin) due to the presence of the dam. It was also similarly observed by Tealdi*et al.* (2011) where discharge below the Alamo Dam (Canada) on the Arkansar River was reduced by 50% after the construction of the dam. During low rainfall periods, the mean monthly river discharges at are extremely low and this means that there might be no water that is released from the dam to sustain the downstream ecological reserve. It can therefore, be concluded that all studied dams reduce river discharges by a considerable amount. These low flows impact negatively on the diversity of riparian vegetation which might be replaced by terrestrial or alien plant species.

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Plate 4.6 shows such grass species that have covered large parts of formerly inundated area downstream of the Vondo dam.

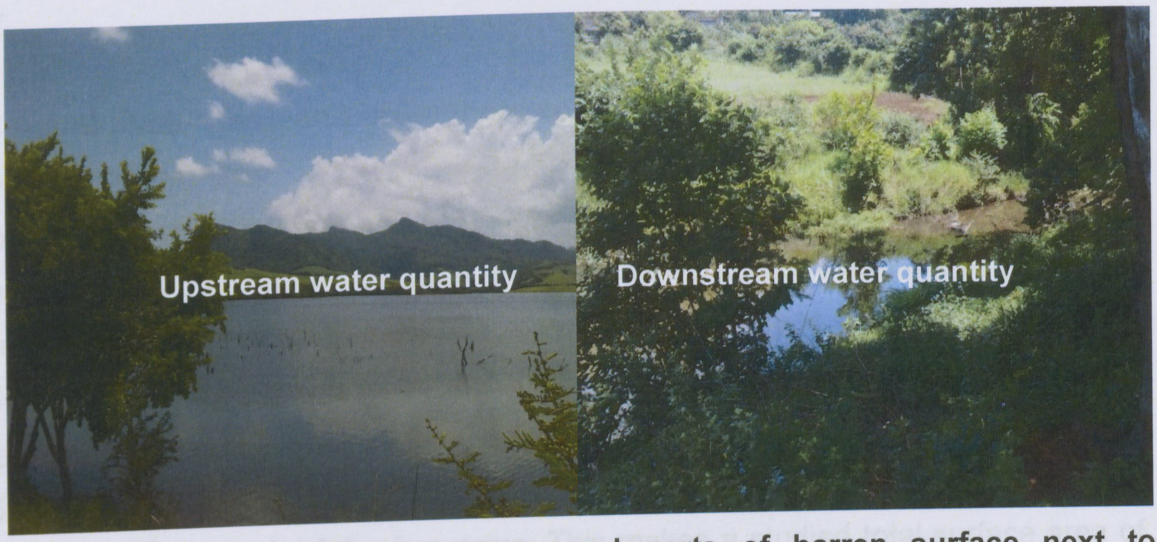

Plate 4.6 Less water downstream and parts of barren surface next to settlement that are slightly visible in the background (December, 2008).

The degraded riparian area was quickly invaded by grass communities and few mango, sycomore fig (*Ficussycomorus*) and Forest Silver Oak (*Brachylaenatranvaalensis*) trees because of the area's high annual average rainfall compared to all other studied dam areas. The area has more trees in newly exposed riparian sites than in all other studied dams. The area receives annual average rainfall of 1108.9 mm (Tate-Bos) and 1294.9 mm (Vonda-Bos) respectively (Figures 4.9 and 4.10). The presence of these treesalong river watercourses indicates that the Mutshindudi river's banks is being stabilised by terrestrial vegetation. Trees that are seen in the background show that banks are to some extent stabilised. The presence of trees is usually associated with bank stability. Simon and Collison (2002) have noted that if vegetation development proceeds to the growth of trees banks are expected to be stable,more so than if banks were dominated by grass communities as in the downstream reaches of Mambedi and Nandoni dam areas (Plates 4.3 and 4.4). Scanty water body is also visible downstream of the Vondo

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dam. Plate 4.6 shows the impact of the upstream presence of the dam because the photo was taken in December 2008. This was the period when low annual rainfall was recorded at Vonda-Bos (Figure 4.8) and Tate-Bos rainfall stations (Figure 4.7). This means that the problem of scanty water downstream of the Vondo dam would have worsened in the winter months (May, June and July), when rainfall is generally low.

4.4 Aerial photograph and orthophoto analysis of tree cover data

4.4.1 Tree cover data

From the aerial photograph data,vegetation cover data has been presented in tabular and graphical form, showing areas upstream and downstream in the vicinity of dams that are devoid of trees. To determine these areas, squares of 0.2cm for 1:16 666aerial photograph scale and 0.25cm for 1:10 000 orthophoto scale were used to calculate the total surface area devoid of tree species within an area of 4.5km^2 downstream and upstream of the studied dams. This gave a total surface area of 9 km^2 for each of the five dams. This makes a studied total surface area of 45km^2. The total surface area devoid of trees from the aerial photograph of 1: 16 666 was calculated as follows (see below Table 4.1):

$$\text{Area} = S \times S$$

$$= \frac{(0.2 \times 16\,666)}{100\,000} \times \frac{(0.2 \times 16\,666)}{100\,000}$$

$$= 0.033\text{km} \times 0.033\text{km}$$

$$= 0.001089\text{km}^2 \times \text{number of squares devoid of trees}$$

$$= \text{total area devoid of trees in km}^2$$

Where **S** = one side of a square

The total surface area devoid of trees from the 1:10 000 orthophotos was similarly calculated as follows:

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Area = S x S

$$= \frac{(0.25 \times 10\,000)}{100\,000} \times \frac{(0.25 \times 10\,000)}{100\,000}$$

= 0.025 km x 0.025 km

= 0.000625 km^2 x number of squares devoid of vegetation in an orthophoto

= total area devoid of trees in km^2

Table 4.1summarizes the calculated surface areas devoid of trees for different aerial photographs with the scale of 1:16666. The total surface areas devoid of trees for both upstream and downstream sections of the dams have been shown separately.

Table 4.1 Surface areas devoid of treesupstream and downstream of studied dams (from aerial photo and orthophoto calculation)

Dam	Number of squares upstream	Number of squares downstream	Total area in km^2upstream	Total area in km^2downstream	Total area in km^2	Photo year
Albasini	756	944	0.82	1.02	1.84	1989
	749	986	0.82	1.07	1.89	1995
Damani	287	295	0.31	0.32	0.63	1987
	391	420	0.42	0.46	0.88	1995
Mambedi	1934	2280	2.10	2.48	4.58	1995
	2663	2393	2.90	2.60	5.50	2001
Nandoni	1023	1078	1.11	1.17	2.28	1987
	1066	1121	1.16	1.22	2.38	1995
Vondo	1755	1869	1.91	2.03	3.94	1987
	2120	2345	2.30	2.55	4.85	1995

Table 4.2 shows the size of area devoid of trees both upstream and downstream of the studied dams. Table 4.3 shows the total surface area devoid of trees for all studied periods on aerial photographs and orthophotos.

Table 4.2 Surface areas devoid of trees upstream and downstream of the studied dams (from aerial photo calculation)

Dam	Number of squares	Number of squares downstream	Total area in km^2 upstream	Total area in km^2 downstream	Total area in km^2	Ortho photo year

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	upstream					
Albasini	1357	1812	0.84	1.13	1.97	1997
Damani	658	873	0.42	0.55	0.96	2004
Mambedi	3397	4201	2.12	2.50	4.62	1997
Nandoni	1923	2301	1.20	1.44	2.64	2004
Vondo	3867	4125	2.42	2.58	5.00	2004

Table 4.3 Total surface area devoid of tree species of the selected Luvuvhu/ Mutale dams

Area	Period studied	Size of area degraded in km^2 (upstream)	Size of area degraded in km^2 (downstream)	Total surface area in km^2
Albasini	1989-1995 (**6 years**)	0	0.05	0.05
	1995-1997 (**2 years**)	0.02	0.06	0.08
Total area	**1989-1997 (8 years)**	**0.02**	**0.11**	**0.13**
Damani	1987-1995 (**8 years**)	0.10	0.14	0.24
	1995-2004 (**9 years**)	0	0.09	0.09
Total area	**1987-2004 (17 years)**	**0.10**	**0.23**	**0.33**
Mambedi	1995-1997 (**2 years**)	0.02	0.02	0.04
	1997-2001 (**4 years**)	0.78	0.10	0.88
Total area	**1995-2001 (6 years)**	**0.80**	**0.12**	**0.92**
Nandoni	1987-1995 (**8years**)	0.05	0.05	0.10
	1995-2004 (**9 years**)	0.04	0.22	0.26
Total area	**1987-2004 (17 years)**	**0.09**	**0.27**	**0.36**
Vondo	1987-1995 (**8 years**)	0.39	0.52	0.91
	1995-2004 (**9 years**)	0.12	0.03	0.15
Total area	**1987-2004 (17 years)**	**0.51**	**0.55**	**1.06**

Table 4.1 shows that for the **Albasini dam area** on the Luvuvhu River, the surface area devoid of trees immediately upstream of the dam remained relatively the same at 0.82 km^2 between 1989 and 1995 (Tables 4.1 and 4.3) During this period, thetotal annual rainfall at Goedehoop station was lower than the average of 800mm (Figure

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4.1). This means that during this period biological productivity would have been extremely slow and riparian biomass production reduced. The area downstream of the dam devoid of treesduring the same period increased from 1.02km^2 to 1.07km^2. This is an increasein treeless area by 0.05km^2 in a period of six years (Tables4.1 and 4.3). This density increase in the treeless area is as to be expected because of the shortage in water that would have occurred due to the upstream presence of the dam. The total surface area devoid of trees for the whole study area (9km^2) in 1989 was1.84km^2 and 1.89km^2 in 1995. However, the size of treeless area upstream of the dam from 1995 to 1997 (latest studied period) increased from 0.82km^2 to 0.84km^2. This is growth of treeless area by 0.02km^2. The size of the treeless area downstream of the dam from 1995 to 1997 increased from 1.07km^2 to 1.13km^2 (Tables 4.1 and 4.2). This is a growth by 0.06km^2 (Tables 4.2 and 4.3). This is expected because the 1997 photographs were taken after the low rainfall period recorded at Goedehoop (Figure 4.1). Rainfall was relatively lower between 1989 and 1994. Therefore, the impact of shortage of water downstream of the dam was well mirrored in the 1997 photographs. The total surface area devoid of trees for the study area from 1995 to 1997 was 0.08km^2. Therefore, the total surface area devoid of trees for the dam study area between 1989 and 1997 grew from 1.84 km^2 to 1.97km^2(Tables 4.1 and 4.2)in a period of eight years. This is an increase by 0.13km^2 in eight years (Table 4.3). From Table 4.3 the total surface area devoid of trees downstream of the dam between 1989 and 1997 was bigger (0.11km2) than upstream (0.02km2). The increase in treeless area downstream of the dam can be explained with specific reference to alternation wet-dry season of the dam area (Figure 4.1). Shortage of water downstream of the dam during low rainfall period (1961-1966, 1982-1984 and 2007-2008) gradually leads to a decline in riparian species richness and lower species diversity of colonising vegetation. Gordon and Meentemeyer (2006) stated that reduced wetted perimeter of a river allows vegetation to increase by 50% along formerly inundated area. However, the colonising species are become terrestrial like *Acacia Karroo* along downstream reaches of Luvuvhu River at the Albasini dam.

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For the **Damani** dam on the Mwedi River, the total surface area devoid of trees upstream of the dam changed between 1987 and 1995 from 0.32 km^2 to 0.42 km^2 (Tables 4.1 and 4.3). This is an increase in area by 0.10 km^2 (Table 4.3). The increased in treeless area occurred after a dry period of 1982 to 1984 recorded at Gooldville rainfall station (Figure 4 12). The area downstream of the dam devoid of trees between the same period increased from 0.32 km^2 to 0.46 km^2. This is an increase in area by 0.14 km^2 in a period of eight years. The total surface area devoid of trees for the whole dam study area (9 km^2) in 1987 was 0.64 km^2 and 0.88 km^2 in 1995 (Tables 4.1 and 4.3). This is a total surface area devoid of trees of 0.24 km^2 in a period of eight years (Table 4.3). However, the treeless area upstream of the dam from 1995 to 2004 (latest studied period) remained constant at 0.42 km^2 (Tables 4.2 and 4.3), whilst the treeless area downstream of the dam grew from 0.46 km^2 to 0.55 km^2 from 1995 to 2004. This is an increase in area by 0.09 km^2 (Table 4.3). Therefore, the total surface area devoid of trees grew from 0.64 km^2 to 0.97 km^2 between 1987 and 2004 within a studied dam area of 9 km^2. The total surface area devoid of trees between 1987 and 2004 grew by 0.33km^2 within a dam area of 9km^2. Despite the higher average rainfall than the Albasini area, the size of the treeless area both upstream and downstream is bigger than that of the Albasini dam area. This means that the scale and magnitude of impact by upstream presence of the dam is bigger than at the Albasini dam area. This shows that downstream riparian vegetation does not receive sufficient water to support biomass production through photosynthesis. Just like with the Albasini dam area, the Damani dam area has also shown an increase in treeless area, with downstream reaches having bigger treeless areas.

For the **Mambedi** dam on the Mambedi River, the total surface area devoid of trees upstream of the dam changed between 1995and 1997 from 2.10km^2 to 2.12km^2(Tables 4.1 and 4.2). This is an increase in area by 0.02km^2 (Table 4.3). The areadevoid of treesimmediately downstream of the dam during the same period increased from 2.48km^2 to 2.50km^2. This is also an increase in an area by 0.02km^2 (Table 4.3). The total surface area devoid of trees for the whole dam study area in

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1995 was 4.58km^2 and 4.62km^2 in 1997 (Tables 4.1 and 4.2). This is a total surface area of 0.04km^2 (Table 4.3) However, the size of the treeless area upstream of the dam in the 2001 aerial photograph was 2.90km^2 (Table 4.2).This is an increase in area from 2.12km^2 (1997) to 2.90km^2 (2001). This is an increase in area by 0.78km^2 in a period of 4 years. The size of the treeless area immediately downstream of the dam increased from 2.50km^2 (1997) to 2.60km^2. This is an increase in area devoid of trees by 0.10km^2 in a four-year period. This means that the total surface area for the whole dam within the studied area increased from 4.62km^2 (1997) to 5.50km^2(2001) in a period of 4 years. This is a total surface area devoid of trees of 0.88km^2 (Table 4.3) in a four-year period (1997 to 2001).However, the total surface area devoid of vegetation for the whole dam study area (9km^2) devoid of trees grew from 4.58km^2 (1995) to 5.50km^2 (2001) (six-year period). This is an area of 0.92km^2 (Table 4.3).Since the area is also characterised by alternating wet-dry seasons (Figure 4.5) downstream riparian communities suffer water shortage during low rainfall months (April to October)(Figure 4. 6). This also explains why there is an increase in treeless area, both upstream and downstream of the dam. The size of treeless area upstream of the dam is further worsened by the fact that after the collapse of the dam wall in the year 2000, a large formerly inundated area was left dry, but was later replaced by terrestrial grass species and very few tree species. This is why the size of the treeless area in the 2001photograph is bigger than the treeless area shown in the 1995 and 1997 aerial photographs respectively. Plate 4.7 shows the area that was exposed after the failure of the Mambedi dam.

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Plate 4.7The defunct Mambedi dam after the 2000 floods (December, 2008)

From Plate 4.7 it can be seen in the background, where less water accumulates, that the area is characterized by fine thatching grass (*Hyparrhenia filipendula*) with few unevenly scattered *Acacia ataxacantha* trees. However, the density of trees both upstream and downstream of the dam does not correspond with average annual rainfall of 834.6 mm (Figure 4.5). Vegetation is still in its primary stage of succession and the stagnant water body that can be seen in the background has shown deterioration in water quality.

For the **Nandoni** dam on the Luvuvhu river, thetotal surface area devoid of trees upstream of the dam changed between 1987 and 1995 from 1.11km^2 to 1.16km^2 (Table 4.1) This is anincrease in area of 0.05km^2(Table 4.3). The area downstream of the dam devoid of vegetation during the same period increased from 1.17km^2 to 1.22km^2. This is also an increase in area by 0.05km^2. The total surface area devoid of trees for the whole dam study area (9km^2) in 1987 was 2.28km^2 and 2.38km^2 in 1995. This is a change in treeless area by 0.10km^2;this change occurring equally upstream and downstream of the dam.The increase in treeless area both upstream

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and downstream of the dam might have occurred during the dry seasons recorded in Figure 4.4 (1989-1990 and 1992-1994). This explains why an increase in treeless area was noted in the 1995 aerial photograph. This means that treeless area increased during these dry periods, but it became severe downstream of the dam. This is because there is generally less water available for riparian irrigation and the situation worsens during low rainfall periods. However in the 2004 orthophoto the total surface area devoid of trees upstream of the dam was 1.20 km^2. This is an increase in area by only 0.04 km^2 from 1995 to 2004. Downstream of the dam the treeless area grew from 1.22km^2 (1995) to 1.44 km^2 (2004). This is an increase of0.22km^2 in a period of nine years. However, the total surface area devoid of trees for the dam study area (9km^2) grew from 2.28 km^2 to 2.64 km^2 in a seventeen-year period. This is an increase of0.36 km^2. The cause of an increase in treeless area between 1995 and 2004 is due to the dry period that occurred in1997, 1999 and 2002-2003 (Figure 4.4). The larger treeless area downstream of the dam between 1995 and 2004 is also a function of the upstream presence of the dam.

For the **Vondo** dam on the Mutshindudi river, the total surface area devoid of trees upstream of the dam changed between 1987 and 1995 from 1.91km^2 to 2.30 km^2 (Table 4.1). This is an increase in area of 0.39km^2 in a period of eight years (Table 4.3). The area immediately downstream of the dam devoid of trees between the same period increased from 2.03km^2 to 2.55 km^2; a higher increase in area of 0.52km^2. The total surface area devoid of trees for the Vondo dam in 1987 was 3.94$km^2$and 4.85km^2 in 1995 (Table 4.1). This means that from 1987 to 1995 the total surface area devoid of tree species grew by 0.91km^2 within an area of 9km^2. Just like with other studied dams (Albasini, Damani, Mambedi and Nandoni) there has been an increase in the size of the treeless area. This is because the area also experiences wet-dry periods. Therefore, dry seasons recorded at Tate-Bos (1990-1995) (Figure 4.9) and Vonda-Bos (1989-1992, 1994) (Figure 4.10) have accelerated the degradation of downstream reaches of the dams. It can therefore be concluded that there was no water available for downstream vegetation during these dry periods. This accelerated the disappearance of trees along downstream reaches of all studied dams, including Vondo dam. The area upstream of the dam increased

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from 2.30 km^2 (1995) to 2.42 km^2 in 2004 (Table 4.2). This is an increase of 0.12 km^2. However, the area downstream of the dam only increased from 2.55km^2 to 2.58 km^2. This is increase of 0.03km^2. This means that the total surface area between 1995 and 2004 increased from 4.85 km^2 to 5.00 km^2 (Table 4.1 and 4.2). This is a total surface area of 0.15 km^2 (Table 4.3). Therefore, the total surface area devoid of trees in a seventeen year period (1987-2004) increased from 3.94 km^2 to 5.00 km^2. This is the total surface area of 1.06km^2 (Table 4.3).The constant increase in treeless area shows that the growing conditions have been altered by reduced river discharge (Figures 4.18 and 4.19), and alternating wet-dry periods (Figures 4.7, 4.8, 4.9 and 4.10). This means that the growing conditions that existed before or during the construction of the Vondo dam, differed from those existed after the construction. Therefore, colonisation and primary plant succession takes place under different conditions that existed before the construction of the dam. Doyle *et al.* (2005) also argued that succession of plant communities in the formerly inundated area will occur under very different conditions than those existed at the time of dam construction. This is why the succession conditions downstream of the Vondo dam area favoured the proliferation of terrestrial species like *Acacia ataxacantha*. This has also been experienced in all other studied dams (Albasini, Damani, Mambedi and Nandoni).

From Table 4.3 it has been observed that Damani, Nandoni and Vondo dams have the same studied period (17 years), but their scale of degradation is different. Vondo showed bigger treeless area (1.06 km^2), followed by young Nandoni dam (0.36 km^2), then Damani area (0.33 km^2). However, the studied period for the Albasini dam area is 8 years and its treeless area is 0.13 km^2. The studied period for Mambedi area is 6 years but its treeless area is 0.92km^2, which is bigger than that of Albasini dam area, which has less studied period (0.13km^2). Of all studied dam areas the Vondo dam area has the highest annual rainfall average of 1297.9mm and 1108,9 mm (Figures 4.7 and 4.8) respectively, and yet its treeless area is the highest at 1.06km^2. Albasini dam area has an annual average rainfall of 800 mm, but its treeless area is 0.13km^2 (Figure 4.1). Damani dam area has an annual rainfall average of 1006mm

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(Figure 4.12) and its treeless area is 0.33 km^2. Mambedi dam area has an average annual rainfall of 834.6 mm (Figure 4.3) and a treeless area of 0.92 km^2. Nandoni dam area has an annual rainfall average of 744.3mm and a treeless area of 0.36 km^2. It can therefore be concluded that the nature regeneration of vegetation along downstream reaches of the dams does not depend on rainfall only, but also on the fragility of the area, the magnitude of disturbance, and the resilience of the area. It will take time for the Mambedi dam area to be covered completely with trees in the formerly inundated areas of the upstream section due to the size of degraded area (Table 4.3). The Vondo area which is situated in the high rainfall area has shown a huge increase in treeless area, both upstream and downstream. The soils of the Vondo dam areas are nutrient-poor. This is because this type of soil is developed under wet conditions (mesic) (Meadows, 2000). This explains why the upstream presence of the Vondo dam, along the Mutshindudi River, led to the development of a bigger treeless area. The riparian vegetation that was acclimatised to more humid conditions was sensitive to arid conditions created by the upstream presence of the dam. This explains why the size of the degraded area is bigger (1.06 km^2) than in all studied dams.

Figure 4.20 shows the total surface area (km^2) of studied dams devoid of trees calculated from aerial photographs and orthophotos of different years, as depicted in Table 4.3.

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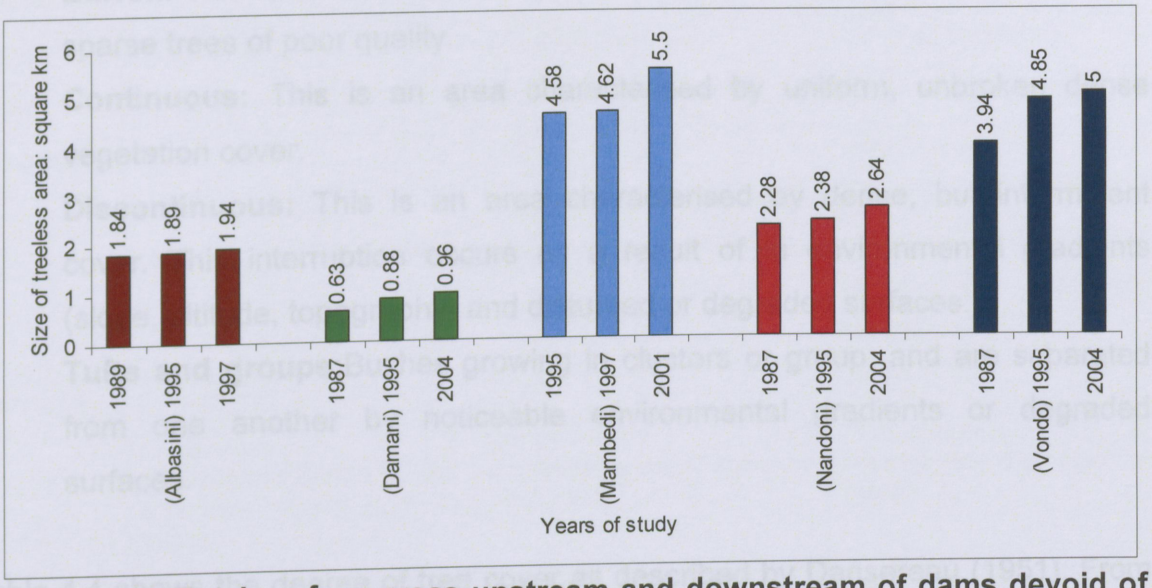

Figure 4.20 Total surface areas upstream and downstream of dams devoid of trees

The first set of graphs with years starting from 1989 to 1997 represent data for Albasini dam. The second set of graphs represents Damani area from 1987 to 2004. The third set of graphs represents Mambedi area. The fourth set of graphs from 1987 to 2004 represents Nandoni area. The last set of graphs for the years 1987, 1995 and 2004 represents Vondo. Damani area has small treeless area while Mambedi has the biggest of all dams.

4.4.2 Vegetation cover data from aerial photographs and orthophotos

The degree of tree cover for all studied dams has been expressed based on Dansereau's (1951) method of vegetation description as highlighted by Kent and Coker (1992). The degree of cover is expressed in descriptive form based on the following scale:

b = barren

i = discontinuous

p = tufts & groups

c = continuous

These descriptive words are defined below as follows:

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Barren: This is an area characterised open land with no trees and grass, or sparse trees of poor quality.

Continuous: This is an area characterised by uniform, unbroken dense vegetation cover.

Discontinuous: This is an area characterised by dense, but intermittent cover. This interruption occurs as a result of in environmental gradients (slope, altitude, topography) and disturbed or degraded surfaces.

Tufts and groups: Bushes growing in clusters or group, and are separated from one another by noticeable environmental gradients or degraded surfaces.

Table 4.4 shows the degree of tree cover as described by Dansereau (1951). From Table 4.4 it is evident that all studied dam areas showed a progressive increase in treeless area downstream than upstream of the dams from the earliest studied photograph to the latest. All latest photographs showed that all studied dam areas have increased in treeless area compared to the earliest studied photographs (Table 4.4).The decline in tree cover, especially downstream is strongly related to reduced river and river discharges (Figures 4. 15, 4.17 and 4. 19). This impact of reduced water downstream of the studied dams becomes severe during dry periods as shown in Figures 4.1, 4.4, 4.5, 4.9, 4.10 and 4.12. During these low rainfall periods tree cover might have gradually declined until it was noticeable in latest studied periods. This is because trees are sensitive to drought conditions than grass. This explains why trees are dominant in humid environments than in arid regions of the Karroo and the dry Savannas. Andersen *et al.* (2007) also noted that dams can reduce surface discharge by up to 20 or 50%. Therefore, the prolonged cycle of limited rainfall from early autumn to late spring, together with curtailment of water downstream of the dam and the repeated wet-dry cycles reduce tree cover.

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Table 4.4 Degree of vegetation cover for the five selected Luvuvhu/Mutale dams

Study area	1st photograph	2nd photograph	3rd photograph
Albasini	**1989**	**1995**	**1997**
	Discontinuous(i) both upstream and downstream	Discontinuous (i) both upstream and downstream	Discontinuous (i) both upstream and downstream (signs of patchiness evident)
Damani	**1987**	**1995**	**2004**
	Continuous (i) downstream(Before the existence of the dam in 1991) Continuous (c) upstream(Before the existence of the dam in 1991)	Discontinuous (i) downstream with signs of patchiness. Continuous (c) upstream. Dam present.	Discontinuous (i) downstream and close to barren Continuous (c) upstream
Mambedi	**1995**	**1997**	**2001**
	Discontinuous (i) downstream with signs of patchiness (barren) Discontinuous(i) upstream	Discontinuous (i) downstream with signs of patchiness (barren) Discontinuous (i) upstream	Discontinuous (i) downstream with signs of patchiness (barren) (after wall failure) Discontinuous (i) downstream with signs of patchiness (barren) (after wall failure)
Nandoni	**1987**	**1995**	**2004**
	Continuous (c) over the entire area before dam was constructed	Continuous (c) over the entire area but shows signs of discontinuity because of the existence of the small Mutoti dam and human settlements.	Discontinuous (i) over the entire area because of the existence of the small agriculturallands and human settlements.
Vondo	**1987**	**1995**	**2004**
	Tufts and groups(p) downstream and upstream of the dam because of tea plantation fields	Tufts and groups (p) downstream and upstream of the dam because of tea plantation fields	Tufts and groups (p) downstream and upstream of the dam because of tea plantation fields

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Tree density is a function of rainfall or abundant moisture. This explains why humid environmentslike the Vondo dam areas are characterised a continuous tree cover. Therefore, a cut in water downstream of the Luvuvhu/ Mutale dams, due to the upstream presence of the dams has led to a decline in tree density (Table 4.4). This explains why an increase in treeless areaalso occursalong downstream reaches of areas with high annual rainfall averages of more than 1000mm (Vondo and Mambedi dam areas) (Figures 4.9, 4.10 and 4.12). Jones *et al.* (2008) have also noted that tree stands decreased along the Colorado and Gila River systems of USA due to the existence of dams.

4.5 Field data from the Luvuvhu/ Mutale dams

4.5.1 Tree density

Data for determining tree density was also collected from the five dams studied. Tree density was determined using the following formulae (Kent and Coker, 1992: p56):

$$\bar{A} = (\eth N)^2$$

$$TD = \frac{\sqrt{\bar{A}}}{2}$$

Where $\bar{A}$ = mean area of tree species

$\eth N$ = mean distance to the nearest individual species

TD = Tree density

The mean distance for tree species from the Luvuvhu/Mutale dams was measured. Table 4.5and Figure 4.21show tree densitiesupstream and downstream of the dams studied.

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Table 4.5 Tree density upstream and downstream of the dams studied (December, 2009)

Dam	Mean distance (*m*) to nearest*n* individual species upstream	Mean distance (*m*) to nearest *n*individual species downstream	Tree density upstream in m^2	Tree density downstream in m^2	Tree species name
Albasini	8.29	8.32	5.86	5.88	Sweet thorn (*Acacia karroo)*
Damani	5.98	9.65	4.22	6.82	Flame thorn (*Acacia ataxacantha)*
Mambedi	10.04	12.06	7.09	8.52	Flame thorn (*Acacia ataxacantha)*
Nandoni	6.5	9.3	4.59	6.57	Flame thorn (*Acacia ataxacantha)*
Vondo	7.7	14.3	5.44	10.11	Flame thorn (*Acacia ataxacantha)*

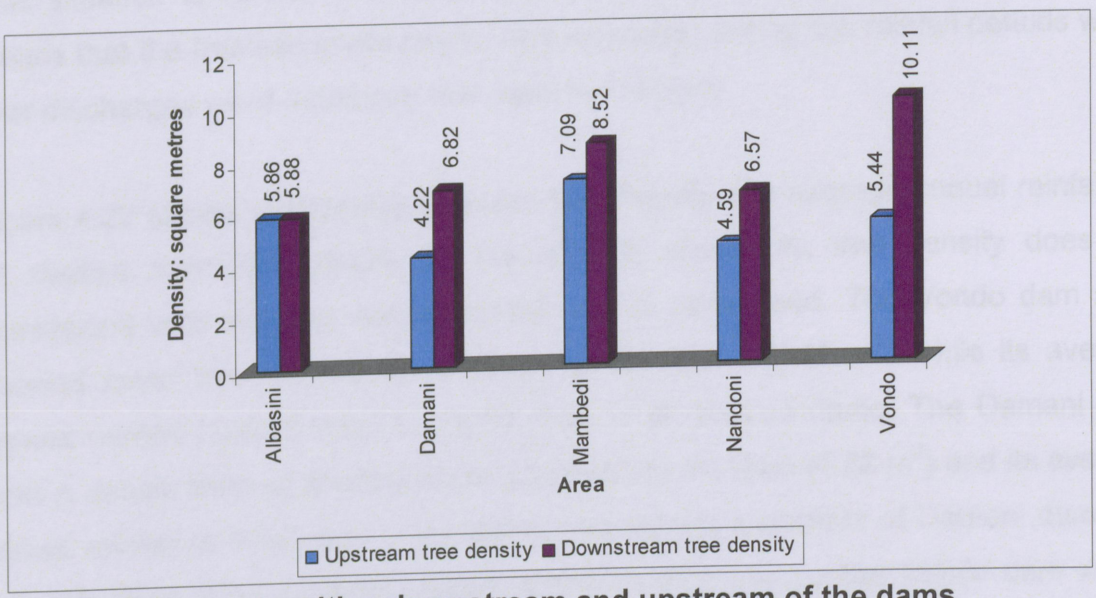

Figure 4.21 Tree densities downstream and upstream of the dams

Figure 4.21and Table 4.5 show the upstream and downstream tree densities that were measured in the field. The graphical presentation of tree densitiesin Figure 4.21 shows that the Vondo dam area, which has the highest average annual rainfall

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(Figures 4.7 and 4.8), is less dense (1001m^2) while Albasini dam area with an average annual rainfall of 800mm (Figure 4.1) is more dense. However, the Vondo dam area is characterised commercial agriculture and human settlement along the Mutshindudi river. Therefore, the extent of the impact of the dam downstream is complicated by the existence of settlements and intense commercial farming (tea plantations). Therefore, the less tree density downstream of the Vondo dam corresponds with the size of the treeless area (1.06 km^2) calculated from remotely sensed images. Results in Table 4.5 and Figure 4.21also show that upstream tree density is highest at Damani dam (4.22 m^2) on the Luvuvhu river and lowest at Mambedi dam (7.09 m^2) on the Mambedi river. Tree density results for the downstream stretches of the dams indicate that the highest tree densities are downstream of the Albasini dam (5.88 m^2) and lowest on the Vondo dam (10.11 m^2). This is because it is has a low tree density than along all dams and its treeless area is also high. Tree density upstream of Nandoni dam is higher (4.59 m^2) downstream of the dam (6.57 m^2). Therefore, the growth in treeless area downstream of all studied dams occurs as a result of low flowswhich are available for riparian irrigation. This situation is further worsened by the upstream presence of the dams. This means that the treeless areas might have increased during low rainfall periods when river discharges were extremely low (April to October).

Figure 4.22 shows relationship between tree density and average annual rainfall for all studied dams.The results in Figure 4.22 show that tree density does not correspond with average annual rainfall of the dam areas. The Vondo dam area showed lower tree density downstream of the dam (10.11 m^2) while its average annual rainfall (1297.9 mm) is higher than in all studied dams. The Damani dam area is denser than all studied areas upstream of the dam (4.22 m^2) and its average annual rainfall is 1006 mm. The higher tree density upstream of Damani dam is a true reflection of its average annual rainfall of 1006 mm, unlike Vondo dam with a lower tree density but higher rainfall averages of 1297.9 mm and 1108.9 mm recorded at Tate-Bos and Vonda-Bos respectively (Figure 4.7 and 4.8). Tree density at Albasini dam area both downstream (5.88 m^2) and upstream (5.86 m^2) is almost

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the same whilst its average annual rainfall is 800 mm. However, tree density along the Mambedi dam area is lower than that of Albasini dam area even though it has a slightly higher average annual rainfall (834.6 mm). Tree densities upstream and downstream of Damani dam are lower than those of Nandoni dam, though its average annual rainfall (1006 mm) is higher than that of Nandoni dam (744.3 mm). Tree densities upstream of all studied dams are higher than along downstream reaches (Figures 4.21 and 4.22).

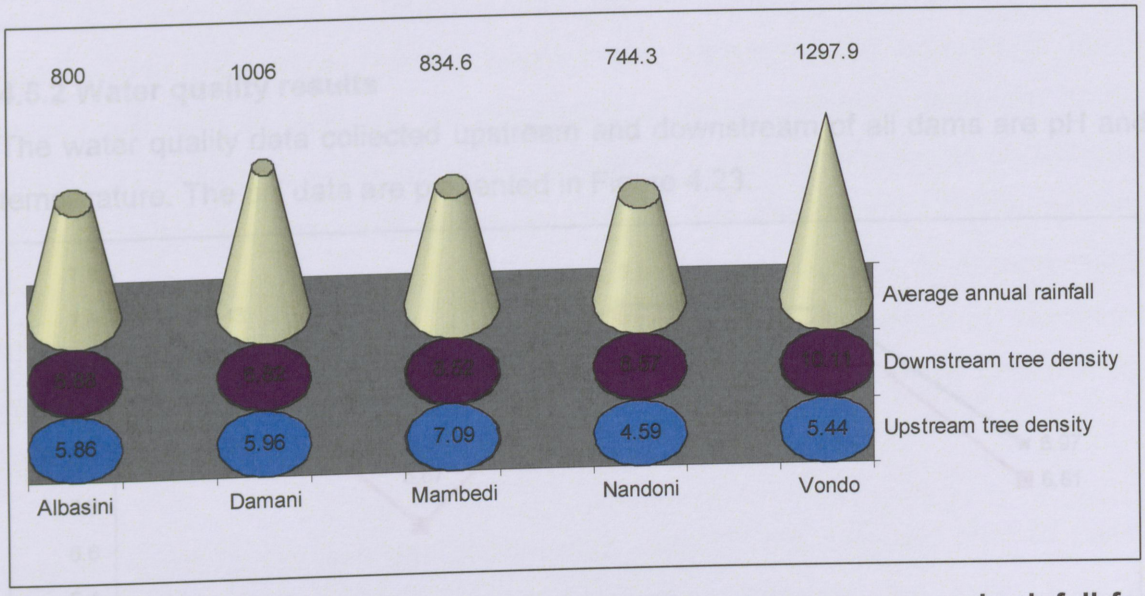

Figure 4.22 Relationship between tree density and average annual rainfall for Luvuvhu/ Mutale dams

Therefore, the magnitude of degradation is a function of resilience and fragility of the area which is controlled by soil type, size of the dam, age of dam, size of degraded area during the construction of the dam, species diversity, succession stages and climatic variability, energy pools and routes and soil instability (Tivy, 1993). Albasini dam area has a slight difference in tree density both downstream (5.88 m^2) and upstream (5.86 m^2). This is a function of the age of the dam. Vegetation, predominantly terrestrial, had sufficient time to regenerate after the construction of the dam in 1952. However, Vondo dam area has less tree density because it is located in a more humid area characterised by high rainfall and sensitive soils. Soils

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of the area are therefore dystrophic (nutrient-poor). This explains why the area became sensitive to water shortage downstream of the dam. Vegetation that thrived well under humid conditions suffered when river discharge was reduced downstream of the Vondo dam on the Mutshindudi river. This is because conditions became dry for riparian communities to survive and therefore their diversity became lower. Graf (2006) similarly argued that regulated reaches are less likely to support extensive ecosystem components requiring a dry period of summer, and the species diversity will be lower.

4.5.2 Water quality results

The water quality data collected upstream and downstream of all dams are pH and temperature. The pH data are presented in Figure 4.23.

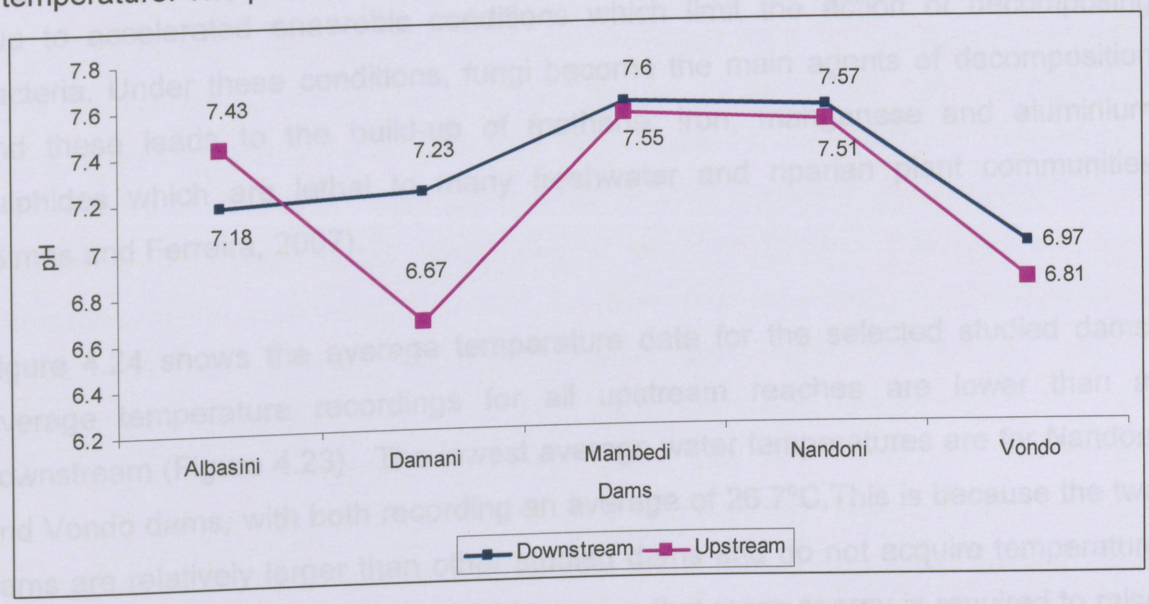

Figure 4.23 Average pH values up and downstream of the dams

From Figure 4.23 water downstream of Vondo dam is slightly acidic both downstream (average pH = 6.97) and upstream (average pH = 6.81) of the dam than at all other areas. At Mambedi dam the average water pH is alkalinic recording average values of 7.6 (downstream) and 7.55 (upstream) respectively. The same can be said about Nandoni dam. The Albasini and Damani dams have pH values that are remarkably different from the other dams (Mambedi, Nandoni and Vondo)

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with pH values that are more or less similar both upstream and downstream of the dams. Upstream of Damani dam is slightly acidic. The pH values downstream and upstream of the studied dams range from 6.67 to 7.6. These pH values still fall within the required limit for freshwater plants and riparian ecosystems. Freshwater plants, according to Bornman*et al.* (2009), have a wide range of pH tolerance and can adjust to a pH values between 6 and 8. However, since pH is strongly related to temperature, the pH values have also been recorded under different temperature conditions because of the sizes of water bodies of different studied dams. However, the upstream sections of the dams are also eutrophic. These means that toxic metals like zinc, cadmium and mercury will be released downstream in large quantities when reservoir flushing takes place. However, the amount of toxins released will also depend on the magnitude of water releases (Newson, 1999). Eutrophication in dams leads to low oxygen content and an increase in phosphorus due to accelerated anaerobic conditions which limit the action of decomposing bacteria. Under these conditions, fungi become the main agents of decomposition and these leads to the build-up of methane, iron, manganese and aluminium sulphides which are lethal to many freshwater and riparian plant communities (Simas and Ferreira, 2007).

Figure 4.24 shows the average temperature data for the selected studied dams. Average temperature recordings for all upstream reaches are lower than at downstream (Figure 4.23). The lowest average water temperatures are for Nandoni and Vondo dams, with both recording an average of 26.7ºC.This is because the two dams are relatively larger than other studied dams and do not acquire temperature faster. Tyson and Preston-Whyte (2000) argue that more energy is required to raise the temperature of large water body since water is a poor conductor of heat. The highest downstream average water temperatures recorded were for Damani (28.8ºC) and Albasini (28.7ºC). Nandoni recorded a lower temperature of 26.7ºC but the pH of water is alkalinic (7.57). However, average water temperature for water for Vondo area is lower (26.7ºC) while the pH is also lower (6.97).

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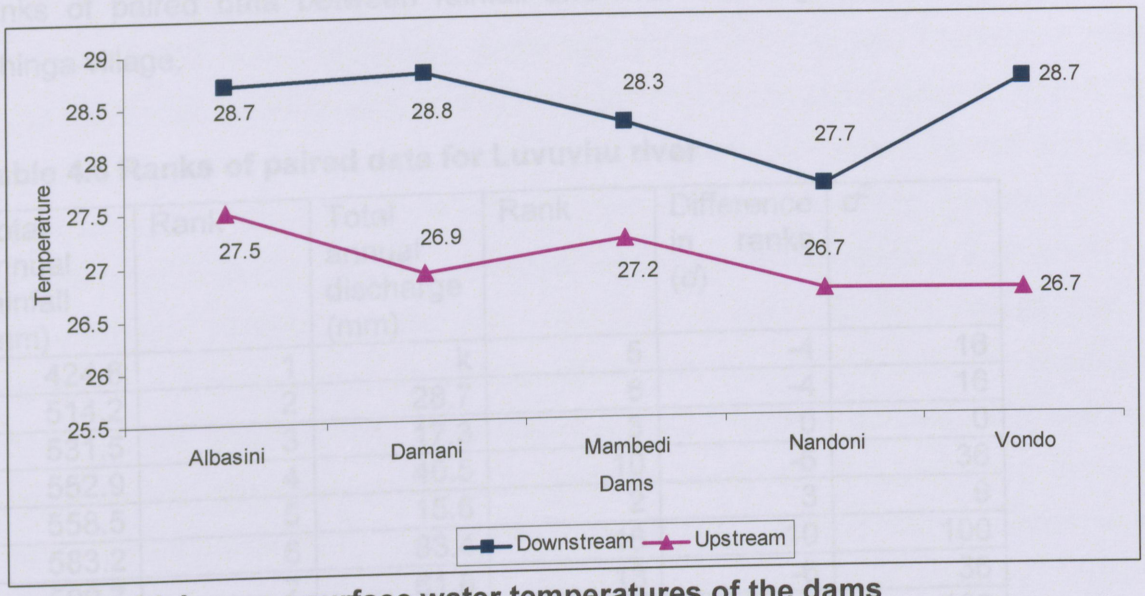

Figure 4.24 Average surface water temperatures of the dams

From Figure 4.23 it is clear that downstream average water temperatures in all dams are higher than upstream. Downstream reaches of all studied dams have higher average temperatures because of their bigger treeless areas and low tree density. Open grounds tend to absorb more and this raises the surface temperature of water downstream of the studied dams. Eva *et al.* (2006) have observed that vast bareness of the area along dammed rivers will increase the ground temperature which will also increase adjacent shallow river water temperature. Higher downstream temperatures will affect benthic environments downstream of the dam and reduce species diversity. This also means that the reduction in tree density reduces protection of river water from intense heating from the sun. Therefore, it can be argued that riparian trees provide shade for maintenance of optimum river temperature for effective plant biomass production.

4.6 Correlation analysis of rainfall and river discharge of Luvuvhu and Mutshindudi rivers.

4.6.1 Luvuvhu river at Mhinga village (1988-2008)

Rainfall and river discharge data were correlated using the **Spearman's rank correlationcoefficient,**to determine the nature and magnitude of the relationship between annualriver discharge (downstream) and total annual rainfall. Rainfall and

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stream discharge data for corresponding 21 years were correlated. Table 4.6 shows ranks of paired data between rainfall and river discharge for Luvuvhu River at Mhinga village.

Table 4.6 Ranks of paired data for Luvuvhu river

Total annual rainfall (mm)	Rank	Total annual discharge (mm)	Rank	Difference in ranks (d)	d^2
424.8	1	k	5	-4	16
514.2	2	28.7	6	-4	16
531.5	3	17.3	3	0	0
552.9	4	40.5	10	-6	36
558.5	5	15.6	2	3	9
583.2	6	83.4	16	-10	100
599.7	7	61.8	13	-6	36
622.8	8	133.6	18	-10	100
645.9	9	36.9	8	1	1
690.7	10	39.9	9	1	1
722.9	11	44.2	11	0	0
728.8	12	35.7	7	5	25
837	13	21.8	4	9	81
842.7	14	94.05	17	-3	9
874.7	15	154.9	19	-4	16
887	16	79.4	15	1	1
887.7	17	73.3	14	3	9
921.9	18	51.4	12	6	36
1122.1	19	203.7	20	-1	1
1147.6	20	230.1	21	-1	1
1653.9	21	7.86	1	20	400
					$\sum d^2 = 894$

The Spearman's rank correlation coefficient was calculatedusing the relationship.

$$r = 1 - \frac{6 \sum d^2}{n^3 - n}$$

$$= 1 - \frac{6 \times 640}{21^3 - 21}$$

= 0.6 (Low positive correlation)

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From the Table of Critical values for Spearman's rank correlation coefficient,the significance of the correlation was determined at 0.05.The critical value determined table was 0.437 (non-directional). Since the critical value is less than the *r* value (0.6)it can therefore be concluded that *r* is significant at the significance level of 0.05. However, there was a low positive correlation between total annual rainfall and total river discharge of the Luvuvhu River at Mhinga village. However, if there was no dam, correlation would have been stronger so that as rainfall increases so would be river discharge. Therefore, the null hypothesis is rejected. This means that a reduction in river discharge at Mhinga village can be explained by the upstream presence of the Nandoni dam. Andersen *et al.* (2007) have also noted that dams can reduce surface discharge by up to 20 or 50%. Therefore, the prolonged cycle of limited rainfall, from early autumn to late spring, together with reduced river discharges downstream of the dam and the repeated wet-dry cycles, reducedspecies diversity of all studied dams.

4.6.2 Mutshindudi river (1997-2008)

Table 4.7 below shows correlation between total annual rainfall and total river discharge (downstream) of Mutshindudi riverat Tshidzini from 1997 to 2008.

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Table 4.7 Ranks of paired data for Mutshindudi at Tshidzini

Total annual rainfall (mm)	Rank	Total annual surface discharge (mm)	rank	Different in ranks (*d*)	d^2
913.4	1	2.5	1	0	0
970.9	2	23.3	5	3	9
1034.9	3	11.1	3	0	0
1075.6	4	53.5	10	6	36
1181.6	5	39.6	8	3	9
1298.3	6	28.7	6	0	0
1351.6	7	7.6	2	5	25
1547.5	8	58.4	11	3	9
1558.9	9	20.7	4	5	25
2137.7	10	30.51	7	3	9
2684.7	11	63.2	12	1	1
3675.8	12	44.2	9	3	9
					$\sum d^2 = 132$

The Spearman's rank correlation coefficient was calculated using the relationship:

$$r = 1 - \frac{6 \sum d^2}{n^3 - n}$$

$$= 1 - \frac{6 \times 132}{12^3 - 12}$$

$$= 0.54 \text{ (Low positive correlation)}$$

From the Table of Spearman's rank correlation coefficient (see page 96) the significance of the correlation was determined at 0.05. The critical value determined from table was 0.588 (non-directional). Since the critical value is more than the *r* value (0.54) $H_0$is accepted and it can be concluded that *r* is not significant at the significance level of 0.05. This means that there is no significant correlation between rainfall and river discharge for Mutshindudi River at Tshidzini village. This means that it is the upstream presence of the Vondo dam that related to the reduced river discharge downstream, making conditions to be of low flows even during rainy seasons (December to February) (Figure 4.9 and 4.10). The low flows created

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downstream of the Vondo dam due to the upstream presence of the dam would have reduced the size of the irrigated riparian zone and impacted negatively on riparian vegetation. The size of the irrigated riparian zone would have decreased and terrestrial vegetation would have colonised the area.

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CHAPTER FIVE: CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter presents a summary of the findings from the study area and also suggests a number of recommendations that can be implemented to minimise the impact of dams on downstream reaches for any area characterised by damming of the river, especially in developing countries were people still rely on natural resources like rivers and vegetation to meet their daily needs.

5.2 Summary of the results

5.2.1 The nature of vegetation changes along downstream river courses

All studied dams showed a change in the type of vegetation along downstream reaches. Obligate riparian species have been replaced by obligate terrestrial species. The newer Nandoni dam has also shown signs of riparian species replacement by terrestrial species along formerly inundated areas. The downstream reaches for Albasini, Damani, Mambedi, Nandoni, and Vondo dam areas are characterised by grass communities in the formerly inundated areas. The Albasini and Vondo dam areas are characterised by terrestrial tree species along their respective downstream reaches of Luvuvhu and Mutshindudi river banks. This may imply that the river banks in these two areas are more stable than those of the other studied dams. Therefore, it can be concluded that the reduction in the irrigated zones along the downstream reaches of the studied dams has resulted in the colonisation of the area by terrestrial vegetation due low flows. Gordon and Meentemeyer (2006) have stated that the reduction in the wetted perimeter of a river allows vegetation to increase by 50% along formerly inundated areas. This colonising vegetation normally becomes terrestrial. However, the diversity of the colonising species becomes lower due to arid conditions created by the upstream presence of selected Luvuvhu/Mutale dams. This occurs because dams naturally

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create barriers across rivers and interfere with floodplain irrigation, thereby reducing species richness.

5.2.2 Upstream and downstream vegetation species richness from remotely sensed images

Data from the aerial photographs and orthophotos for different years show a progressive increase in treeless area downstream of all studied dams. Upstream sections of the studied dam areas have a relatively smaller treeless areas compared to their downstream reaches. The downstream treeless area (0.51 m^2) of Vondo dam is almost the same with the size of its upstream treeless area (0.55 m^2). These are higher than treeless areas for all studied dams except for the upstream area of the Mambedi dam (0.80 m^2). This is so even though the Vondo dam area's annual rainfall averages recorded at Tate-Bos (1108.9 mm) and Vonda-Bos (1297.9 mm) respectively, are higher than rainfall averages for all other studied dams. The bigger treeless areas downstream of all studied dams show the impact of the upstream presence of the dams. The Mambedi dam area has a bigger treeless area upstream of the dam because the area was increased by the failure of the dam in the year 2000. After the failure of the dam wall water that was trapped behind the dam wall escaped and left a large barren area behind. From the calculations of treeless areas, it is evident from the results that upstream sections of all the studied dams, with the exception of the Mambedi dam, have higher species composition. This is because these areas are continuously irrigated than downstream sections which become irrigated when dams overflow their tops. This explains why downstream reaches have lower species richness and bigger treeless areas. However, the predominant vegetation along the downstream riparian zones is obligate terrestrial species, but of lower density. All the studied dams showed discontinuity in tree cover from the earliest to the latest studied aerial and orthophotos. This is the result of the upstream presence of dams which lead to lower low flows during dry seasons.

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5.2.3 Nature of water quality upstream and downstream of Luvuvhu/Mutale dams

The pH and temperature averages for all studied dams fall within the required range of inland water streams. pH averages for all dams fall within a range of 6 and 8. Bornman *et al.* (2009) have argued that freshwater plants have wide range of pH tolerance and can adjust to a pH values between 6 and 8. However, there is a remarkable difference between upstream and downstream average temperatures. The downstream reaches of all studied dams have higher temperatures. This is because of scanty water that is found downstream of all studied dams. This is also because of presence of bare areas that were formerly inundated. These areas increase ground temperature which increases temperature of adjacent shallow and slow-moving downstream water. This means that biological productivity differs between upstream and downstream reaches of the studied dams. Certain decomposing bacteria become inactive when temperature increases and this will ultimately lead to the gradual accumulation of dead organic matter (DOM) downstream of the studied dams. This is because water downstream tends to be slow moving or stagnant.

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5.2.4 Flow regimes of Luvuvhu/Mutale dams with respect to rainfall variability

All downstream reaches of the studied Luvuvhu/Mutale dams are characterised by low flows. The surface discharges recorded at Mhinga village along the Luvuvhu River and Tshidzini village along the Mutshindudi river and low spillway discharges show that the upstream presence of the dam reduces water that is available for riparian irrigation. From the study of all five dams rainfall is lower between April and October. This means that the downstream reaches of dammed rivers lower low flows when rainfall is below annual averages. This explains why there is a progressive increase in treeless areas. The high rainfall averages recorded at Tate-Bos and Vonda-Bos, do not correspond with the amount of water that is available as streamflow downstream of the Vondo dam. This is a clear indication of the impact of the upstream presence of the dam on downstream river ecosystems. This also

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explains why there is low positive correlation between annual rainfall and downstream river discharges.

From the above summary of the findings of all five dams studied, it can be concluded as follows:

(i) Any modification of river flow through damming alters flow characteristics and impacts negatively on nutrient cycling of lotic environments. This is accompanied by low downstream species diversity. All dams are characterised by low surface or runoff downstream.

(ii) Changes in river flow due to damming has led to the replacement of riparian vegetation with terrestrial vegetation or alien plant species in other dams. All downstream sections of the studied dams are characterised by terrestrial vegetation in formerly inundated riparian zones.

(iii) Lack of consistent regulated flooding is an indication that there is an ineffective or no legislation that governs the utilization of rivers under various climatic regions. This implies that environmental standards were compromised during the construction of dams.

(iv) Total annual rainfall does not guarantee the regeneration of disturbed areas since regeneration depends on many combined factors such as size of dams, size of degraded area during dam construction, natural species diversity, successional stages, climatic variability, energy pools and routes and soil instability. The resilience and fragility of disturbed areas depend on the combination of some of these factors.

(v) All dams are characterised by alternating wet-dry cycles. This means that during dry periods, especially in winter downstream reaches of the dam have little or no water. This is evident from low stream discharges in summer in all dams. All dams receive little or no water downstream in winter, suggesting that degradation is continuous, and vegetation will continuously be replaced by terrestrial or obligate terrestrial species.

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5.3 Recommendations

From the results obtained from the field and remotely sensed images some recommendations are necessary to minimize environmental impacts of dams in developing countries or give alternatives for further research:

(i) The current Rivers Health Programme (RHP) initiated and implemented by Department of Water Affairs (DWA) should be implemented effectively to monitor impacts initiated by the upstream existence of dams.

(ii) The current classification system of rivers as proposed by DWA should be implemented effectively to retain rivers in their undisturbed or minimal state of disturbance.

(iii) All existing legislations pertaining to river utilization and dams should be reviewed from time to time based on ongoing research findings about dams and rivers.

(iv) The status of ecological reserves of rivers in semi-arid or low rainfall areas should be assessed every second year, based on research findings.

(v) Water purification from time to time is necessary in both high and low rainfall areas since during the release of water upstream of the dam, entrapped chemical elements cause irreparable damage downstream of the dam.

(vi) Not only should DWA regulation or control be emphasized at dammed areas, rather all surface waters should equally be protected by such legislations.

(vii) The proposed licensing systems of dams by WCD (2004) should be fully reviewed.

From the findings conducted from the five dams there is therefore a need for further research in the following areas:

(i) The assessment of the effectiveness of current environmental legislations in relation to river regulations or modifications.

(ii) The impact of check dams on the sustainability of ecological reserves and species richness in developing countries.

(iii) The rate at which eutrophication of dams take place.

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Appendix 1 River discharge data

		LUVUVHU MEAN RIVER DISCHARGE AT MHINGA IN CUBIC M/SEC												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual discharge	Mean monthly discharge
87											0.055	13.29	**13.345**	**6.6725**
88	4.706	17.44	29.23	7.42	3.72	2.662	2.926	1.772	1.896	8.596	6.243	7.439	**94.05**	**7.8375**
89	2.741	11.78	7.551	3.042	1.669	0.399	1.08	1.035	0.454	1.495	1.555	7.175	**39.976**	**3.3313**
90	11.76	7.521	5.016	4.801	2.023	1.481	1.098	0.933	0.535	0.512	0.169	1.128	**36.977**	**3.0814**
91	20.69	11.08	18.53	9.25	4.509	3.175	2.189	1.514	1.283	0.547	0.206	0.285	**73.258**	**6.1048**
92	0.033	0.084	0.28	0.006	0	0.025	0	0.109	0	0	0.663	16.08	**17.28**	**1.44**
93	7.352	11.02	8.155	1.559	0.802	0.454	0.592	1.355	1.036	0.106	0.047	3.269	**35.747**	**2.9789**
94	4.234	5.489	2.125	1.044	0.621	0.423	0.3	0.271	0.119	0.145	0.668	0.165	**15.604**	**1.3003**
95	3.577	1.679	5.03	3.264	2.916	1.443	0.86	0.472	0.238	0.099	0.98	1.279	**21.837**	**1.8198**
96	23.83	116	23.25	12.56	16.6	7.264	8.071	6.912	3.988	3.028	3.005	5.6	**230.11**	**19.176**
97	10.45	17.61	17.07	12.2	6.433	4.25	3.069	2.35	3.244	2.287	1.987	2.492	**83.442**	**6.9535**
98	7.506	8.434	3.024	3.526	1.308	0.992	1.006	1.122	0.721	3.545	4.582	15.59	**51.356**	**4.2797**
99	24.01	46.47	22.3	12.04	8.638	6.561	5.595	3.369	2.434	2.228			**133.65**	**13.365**
0												7.863	**7.863**	**7.863**
1	4.655	42.92	54.26	30.05	14.62	9.41	7.977	5.237	3.904	3.256	5.116	22.28	**203.69**	**16.974**
2	5.279	4.75	4.549	4.491	3.513	3.211	3.14	2.397	2.042	1.558	1.581	4.023	**40.534**	**3.3778**
3	4.46	2.223	9.353	1.675	1.262	1.634	1.535	0.763	0.658	2.204	1.637	1.327	**28.731**	**2.3943**
4	9.354	12.34	66.71	27.26	10.9	5.964	5.046	4.675	4.034	3.437	2.674	2.575	**154.97**	**12.914**
5	1.706	1.499	1.172	0.796	0.424	0.433	0.626	0.635	0.551	0.783	0.449	15.89	**24.964**	**2.0803**
6	24.89	20.25	14.99	6.398	3.865	2.053	1.497	1.834	0.627	0.44	1.281	1.274	**79.399**	**6.6166**
7	4.194	1.34	2.309	3.078	1.06	0.975	1.095	0.766	2.194	2.267	2.021	22.93	**44.229**	**3.6858**
8	34.73	8.163	8.515	3.664	2.088	1.773	1.536	1.375					**61.844**	**7.7305**
9	**10.508**	**17.405**	**15.171**	**7.4062**	**4.3486**	**2.7291**	**2.4619**	**1.9448**	**1.5767**	**1.9228**	**1.8378**	**7.5977**		

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		MUTSHINDUDI @VONDO W.COMPONENT VONDO DAM												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual discharge	Mean monthly discharge
1											0.068	0.064	**0.132**	**0.066**
2	0.062	0.059	0.056	0.055	0.054	0.053	0.039	0.041	0.039	0.044	0.042	0.047	**0.591**	**0.0493**
3	0.052	0.05	0.054	0.042	0.034	0.029	0.027	0.028	0.029	0.027	0.027	0.029	**0.428**	**0.0357**
4	0.04	0.05	5.327	2.253	1.477	1.478	1.11	1.769	1.623	1.103	0.756	0.673	**17.659**	**1.4716**
5	0.598	0.27	0.197	0.036	0.027	0.023	0.02	0.03	0.039	0.039	0.034	0.038	**1.351**	**0.1126**
6	0.047	1.032	3.31	1.23	0.603	0.154	0.051	0.058	0.062	0.065	0.069	0.068	**6.749**	**0.5624**
7	0.077	0.069	0.067	0.066	0.061	0.06	0.061	0.054	0.056	0.055	0.06	0.936	**1.622**	**0.1352**
8	3.601	0.482	0.299	0.087									**4.469**	**1.1173**
	0.146	**0.255**	**1.5018**	**0.6137**	**0.376**	**0.2995**	**0.218**	**0.33**	**0.308**	**0.2222**	**0.1647**	**0.2985**		
		MUTSHINDUDI @ TSHIDZINI MEAN DISCHARGE												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total annual discharge**	**Mean monthly discharge**
95											0.402	0.463	**0.865**	**0.4325**
96	6.506	28.32	8.02	4.461	6.465	2.351	2.646	2.21	1.264	1.053			**63.296**	**6.3296**
97	9.308	8.178	7.785	4.937	2.253	1.413	1.193	0.948	1.132	0.833	0.809	0.825	**39.614**	**3.3012**
98	2.648	2.944	1.227	1.011	0.547	0.442	0.425		0.397	1.999	2.104	6.977	**20.721**	**1.8837**
99	13.6			4.124	3.202	1.439	1.689	1.181	0.997	0.952	0.738	0.795	**28.717**	**2.8717**
0	37.35										3.176	3.718	**44.244**	**14.748**
1	1.704	9.633					2.503	1.761	0.926	0.498	4.054	9.431	**30.51**	**3.8138**
2	8.687	3.414	1.769	1.491	1.211	0.998	0.363	0.96	0.88	0.963	1.87	0.699	**23.305**	**1.9421**
3	0.277									0.858	0.701	0.625	**2.461**	**0.6153**
4	3.19	3.755	27.14	9.434	4.736	2.611	2.026	1.645	1.255	0.902	0.933	0.824	**58.451**	**4.8709**
5	0.631	0.342	0.261	0.37	0.203	0.266	0.329	0.374	0.289	0.276	0.454	7.352	**11.147**	**0.9289**
6	12.73	12.92	10.54	5.621	3.296	2.121	1.745	1.136	0.801	0.639	0.922	1.073	**53.544**	**4.462**
7	2.436	1.167	1.097	1.045	0.592	0.568	0.746						**7.651**	**1.093**
8	**8.2556**	**7.8526**	**7.2299**	**3.6104**	**2.5006**	**1.3566**	**1.3665**	**1.2769**	**0.8823**	**0.8973**	**1.5761**	**3.2319**		

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	LUVUVHU @ GOEDEHOOP MEAN RESERVOIR SPILLWAY DISCHARGE IN CUMECS													
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total annual discharge	Mean monthly discharge
52										0	0	0	**0**	**0**
53	0	0.699	1.076	2.013	0.259	0.034	0.098	0.01	0.078	0	0.587	1.324	**6.178**	**0.5148**
54	9.722	1.629	1.14	0.089	0	0	0	0	0	0	0	0	**12.58**	**1.0483**
55	1.508	11.78	2.908	1.335	0.917	0.578	0.083	0	0	0.068	0.446	0.963	**20.586**	**1.7155**
56	1.008	6.611	5.799	2.641	0.775	0.259	0.147	0	0.183	0.057	0.053	0.269	**17.802**	**1.4835**
57	0.455	0.268	1.52	0.282	0.003	0	0	0	0	0	0	0.896	**3.424**	**0.2853**
58	18.9	8.157	3.828	1.265	0.206	0.409	0.12	0.103	1.261	0.625	0.39	1.698	**36.962**	**3.0802**
59	6.53	2.945	1.258	0.155	0	0	0	0	0	0	0	0.564	**11.452**	**0.9543**
60	0.189	1.299	0.055	0	0	0	0	0	0	0	0	0	**1.543**	**0.1286**
61	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
62	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
63	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
64	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
65	0	0	0	0	0	0	0	0	0	0	0	0	**0**	**0**
66	0	7.142	0.577	0	0	0	0	0	0	0	0	0	**7.719**	**0.6433**
67	0.441	2.339	0.196	0.382	0	0	0	0	0	0	0	0	**3.358**	**0.2798**
68	0	0	0	0	0	0							**0**	**0**
	2.4221	**2.6793**	**1.1473**	**0.5101**	**0.135**	**0.08**	**0.0299**	**0.0075**	**0.1015**	**0.0469**	**0.0923**	**0.3571**		

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Appendix 2 Rainfall data

Rainfall (mm) Data at station [0723126 X] - BEJA Measured at 08:00														
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	**Monthly average**	**Annual total**
1960	38.2	122.7	40	84.3	8.5	39	3.5	4	9	24.5	137.7	238.5	**62.49167**	**749.9**
1961	60.5	335.5	71.7	51.7	3.5	24.7	9.9	14	0	11.5	42.7	54	**56.64167**	**679.7**
1962	138	58	54	96	10.5	0	0	0	8.4	3.8	166.2	137.5	**56.03333**	**672.4**
1963	49.8	51.8	65.5	82.3	131	50	4.7	0.4	7.2	33.1	11	91.9	**48.225**	**578.7**
1964	91.1	76.5	5.4	2.6	0	0		6.5	2.1	50.5		82.1	**31.68**	**316.8**
1965	93	30	20.5	28.3	2.7	1.5	0	0	12.5	11	64.8	73.5	**28.15**	**337.8**
1966	109.5	339.7	15	13	7	4.5	0	2.2	20.5	42.5	48.6	75	**56.45833**	**677.5**
1967	326.5	232.5	32.5	118.2	0.7	6.6	10	2	0	58.6	135	39.5	**80.175**	**962.1**
1968	18	66.5	11.8	48.9	46.5	11	0	0	0	26	153	121.5	**41.93333**	**503.2**
1969	47.5	37.5	278	46.3	0	0	0	0	16	55	13	107.5	**50.06667**	**600.8**
	0													**607.89**
	88.3727	**135.07**	**59.44**	**57.16**	**21.04**	**13.73**	**3.12222**	**2.91**	**7.57**	**31.65**	**85.7778**	**102.1**		

Rainfall (mm) Data for station [0723155 X] - GOEDEHOOP Measured at 08:00														
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
1960	43.5	202.4	76.5	76.5	7	56	10	1.5	9.3	24.1	134	242.3	**73.59167**	**883.1**
1961	108	307	81		0	28.5	18	13.2	5.3	11.9	37.7	45.8	**59.67273**	**656.4**
1962	147.5	76	57.8	116	6.7	0	0	0	1.6	2.7	91.3	88	**48.96667**	**587.6**
1963	52.5	56.2	35.5	32.3	124.5	44	0	0	1.8	15.7	17.5	77.1	**38.09167**	**457.1**
1964	61.5	38.5	20.3	7.5	0.6	0	0	3.5	1.8	41.3	83.6	73.9	**27.70833**	**332.5**
1965	110	37.5	22	30.5	0	16	0	16.6	42.5	29.8	133.1	102.3	**45.025**	**540.3**

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1966	178		58.2	33.7	9	16	0.5	3.3	37	85.2	69.3	122.5	**55.67273**	**612.4**
1967	264.3	209.5	64		0	23.5	11	7.4	4	80.5	153.9	30.5	**77.14545**	**848.6**
1968	19.2	102	25.6	49.5	68	17.5	15.2	10	8	30.5	149.9	114	**50.78333**	**609.4**
1969	74	102.5	293.5	66.5	17.6	16	0	3.3	35	165.5	40	174.5	**82.36667**	**988.4**
1970	9	66.7	26	16	31	25.5	8.3	0	8	76.5	97.5	112.7	**39.76667**	**477.2**
1971	208	48.5	98.5	83.5	30	17.5	0	0	27	65.5	162	43.5	**65.33333**	**784**
1972	228.5	114.5	221	38.4	43	0	2	17.5	9.5	75.5	30	28	**67.325**	**807.9**
1973	73.8	69.5	51	73	8.5	6.5	30	6.5	112.5	83	51	175	**61.69167**	**740.3**
1974	215	347.5	107	55.5	26.5	0	7	8	47.5	15	179.5	63	**89.29167**	**1071.5**
1975	163	266	60	95	35	16	0	10	9	21.5	51	135	**71.79167**	**861.5**
1976	190	149	132	42	88	13	0	2	11.2	28.7	55.2	59	**64.175**	**770.1**
1977	268.5	302.4	224.7	5.2	5.2	0.2	0.1	25.4	58.7	23	44.5	185.5	**95.28333**	**1143.4**
1978	253	198.5	150.9	10	0	0	11.5	10.8	16.5	16.4	109.3	105	**73.49167**	**881.9**
1979	48.1	24.5	62	2.4	13	13	12.9	37	2	34.5	42.2	40.7	**27.69167**	**332.3**
1980	76	99.1	125.3	17	4	0	5.9	24.9	21.5	14.6	93	91	**47.69167**	**572.3**
1981	392.5	150	144.5	3	13	0	1.5	18	39.5	37	94.1	16.6	**75.80833**	**909.7**
1982	84	84	0.2	30.2	0	0	0	0	1.1	33.5	2.5	12	**20.625**	**247.5**
1983	104.5	0	47.8	0	0	33	7	25.3	0	0		21.7	**21.75455**	**239.3**
1984	0	0.5	131.5	1.5	0	0	204	1	10.2	217	266.5	20.5	**71.05833**	**852.7**
1985	199	250	64.5	0	113	25	11	1	129	37.5	24.3	303	**96.44167**	**1157.3**
1986	29	143	23.5	158.5	3	10.5	0	12	21	70	101	131.7	**58.6**	**703.2**
1987	46.5	64	29.5	19	12	28.7	0	24	62	27.1	86.8	379	**64.88333**	**778.6**
1988	74	319.1	128	44.4	0	50.5	0	26	48.7	212	70	47.5	**85.01667**	**1020.2**
1989	15.5	184.8	52.4	28.3	9.1	31.6	0	0	0	89.1	67	143.4	**51.76667**	**621.2**
1990	152.8	39.2	116.8	48.6	10.2	0		21.6	4	70.4	67.5	133.4	**60.40909**	**664.5**
1991	330.5	154.2	273.9	6.5	30.5	5.8	2	1	18.6	8.7	89	92.5	**84.43333**	**1013.2**
1992	179	65	64.5	9.9	0	56.2	6	13.5	12.6	19.8	48.5	174	**54.08333**	**649**

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1993	89.3	586	80.1	16.5	4.5	8.5	37.1	12.8	0.3	16	0	0	**70.925**	**851.1**
1994	0	81.5	49.3	42	0	0	0	0.7	12	58.5	82.5	121.5	**37.33333**	**448**
1995	59	322	98	139	53	0	5.5	28.5	4.5	51.5	129.5	169	**88.29167**	**1059.5**
1996	545	432.5			62.5	8.2	113	30.5	2.2	8	108.5	20.4	**133.08**	**1330.8**
1997	291.1	97	188.7	32.9	10	0	24.5	0	105.5	97	75	54	**81.30833**	**975.7**
1998	323.5	46.6	69.5	8.7	0	0	51	21	63.5	135	136	340.8	**99.63333**	**1195.6**
1999	202	230.5	109.5	53	12	15	58.2	13	24	67	165	85	**86.18333**	**1034.2**
2000	411.5	1388	366	55	24	77.5	17.9	2.5	99	182.3	120.5	97	**236.7667**	**2841.2**
2001	28	451.3	177.3	93.5	35	3	31.5	7	8	41	293	187	**112.9667**	**1355.6**
2002	192.8	18	27	34	0	136	4	20.5	2.3	101.7	49	126.5	**59.31667**	**711.8**
2003	86.5	70.5	88	0	10.5	61.5	0	1	43	144.5	92	234.5	**69.33333**	**832**
2004	163.5	127.5	453.4	51.4	0	3	0	0	0	0	0	118.5	**76.44167**	**917.3**
2005	0	28	0	0	0	0	0	0	0	2.5	15.3	103.3	**12.425**	**149.1**
2006	280.7	254	201	72.1	37	11	5	0.2	0	17	166.9	71.5	**93.03333**	**1116.4**
2007	108	54.1	65.1	33.1	0	0	11	13	60.5	0	0	0	**28.73333**	**344.8**
2008	0	0	60	0	0						62.6	103	**32.22857**	**225.6**
	146.516	**176.231**	**106.308**	**39.8174**	**19.5286**	**18.2125**	**15.3745**	**10.3125**	**25.8583**	**55.9479**	**88.3021**	**110.543**		**800.0673**

Rainfall (mm) Data for station [0723338A1] - DRIEFONTEIN Measured at 08:00

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
1960	28	151.5	28	118.5	6.5	35.5	0	5		16.5	113	332.5	**75.90909**	**835**
1961	118	451	115.5	85.5	0	31.5	6.5	12	10	38	41.5	84.5	**82.83333**	**994**
1962	74.5	63	101	86.5	4	0	0	0	8.5	0	107	134	**48.20833**	**578.5**
1963	58	65.5	62	52	24	47.5	3	0	0	18.5	7.5	72.5	**34.20833**	**410.5**
1964	66.5	66.5	10	11	0	0	0	2	0	78.5	116.5	97	**37.33333**	**448**

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1965	94	67.5	26.5	54.5	0	11.5	0	13	30.5	19	110.5	51.5	**39.875**	**478.5**
1966	105.5	280.5	23.5	31.5	9	10	0	7.5	54.5	57	32	90.5	**58.45833**	**701.5**
1967	235.5	236	45.5	119	0	8	5	0	0	67.5	163.5	64	**78.66667**	**944**
1968	15	73	28	56		19.5	6.5	6	0	34	195.5	201	**57.68182**	**634.5**
1969	77	22.5	312	52	5	3.5	0	42	41.5	113.5	52	115	**69.66667**	**836**
1970	9	94	7.5	18	21.5	17	4	0	3	54	58	171.5	**38.125**	**457.5**
1971	247.5	66.5	58.5	88	78.5	5.5	0	0	28	66	146.5	55	**70**	**840**
1972	307	336	220.5	30.5	46	0	0	10	1	72	64.5	104.5	**99.33333**	**1192**
1973	66	70	115	48.5	6.5	5	17	0	175.5	116.5	41	208.5	**72.45833**	**869.5**
1974	140	362.5	74.5	68.5	12	0	7.5	6.5	65	27	178	95.5	**86.41667**	**1037**
1975	210.5	355	112.5	96.5	18.5	19	0	4	0	24	52.5	310.5	**100.25**	**1203**
1976	378	173	178.5	86	79.5	3	0	2	8	25.5	186	97.5	**101.4167**	**1217**
1977	251	377.5	373.5	17	0	0	0	29.5	124	68.5	77.5	240.5	**129.9167**	**1559**
1978	351.6	339.7	151.9	20.1	17	0	24.8	0	17	24.5	121	77.5	**95.425**	**1145.1**
1979	82.5	41.5	113.5	4.5	11	6.5	0.8	40	2.5	89	78.5	97	**47.275**	**567.3**
1980	172	163	101	28	0	0	4	38	39	48	260	100	**79.41667**	**953**
1981	479	207	231.5	18	57	5	0	44	57	65	155.8	51	**114.1917**	**1370.3**
1982	55	48	34	74	12	0	11		3	62	12	24	**30.45455**	**335**
1983	94	11	103	5	4	7	10	31	7	45	89	48	**37.83333**	**454**
1984	53	41	138	41	4	15	114	9	44	147	182	34	**68.5**	**822**
1985	195	132	116	10	80	14	3	1	239	79	31	228	**94**	**1128**
1986	24	32	16	193	20	2	0	19	22	66	89	65	**45.66667**	**524**
1987	59											0	**29.5**	**59**
	144.504	**160.248**	**107.311**	**56.0407**	**19.8462**	**9.85185**	**8.04074**	**12.3654**	**37.6923**	**56.3519**	**102.27**	**116.089**		
Rainfall (mm) Data for station [0723664 6] - THOHOYANDOU WO Measured at 08:00														
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
1982								2.2	1.2	83.6	43.8	98.5	**45.86**	**229.3**

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1983	25.5	59.3	53.5	4.5	7.9	14.2	8.6	19.7	0	53.9	52.3	31.3	**27.55833**	**330.7**
1984	53.3	52.4	89.1	15.4	0.5	20.8	67.5	5	23.7	106.3	296.5	35.9	**63.86667**	**766.4**
1985	135.1	198.8	66.9	13	68.8	31	4.2	1.2	162.5	67.6	7.3	284	**86.7**	**1040.4**
1986	40.8	45.1	10.6	249.2	4.7	0	0	5	22.7	51.7	54.6	84.4	**47.4**	**568.8**
1987	46.7	64.1	128.7	11.5	12	8.4	0	48.5	90.4	85.2	59.8	255	**67.525**	**810.3**
1988	37.4	186.4	124.8	40.4	10.8	32.6	0	6.8	44.9	243.8	67	47.8	**70.225**	**842.7**
1989	12	225.7	5.7	13.2	9.1	27	7.2	3.8	2.3	117.7	71.9	194.5	**57.50833**	**690.1**
1990	239.2	32	119.4	31	8.8		24.4	6.3	1.5	25.6	29.1	128.6	**58.71818**	**645.9**
1991	420	139.8	204	2	20.8	7.6	0	0.1	2.3	3.5	33.4	54.2	**73.975**	**887.7**
1992	76.2	22.4	58.7	0.1	0	45.9	0	0	1.5	23	81.3	222.4	**44.29167**	**531.5**
1993	74.5	139.6	91.5	37.1	8.5	0.7	26.4	4.6	2.3	33.8	212.3	97.5	**60.73333**	**728.8**
1994	191.2	74	12.7	20.1	2.8	1.5	0	13.8	11.6	39.2	56	135.6	**46.54167**	**558.5**
1995	197.5	204	114.1	88.6	11.3	0.1	0	5.1	8.5	16.3	128.9	62.6	**69.75**	**837**
1996	255.5	420.7	40.3	32.7	122.8	7.1	0	22.5	14	49.2	61.9	120.9	**95.63333**	**1147.6**
1997	165.3	43.5	70	23	15.5	0	3	0	75.8	37.9	101	48.2	**48.6**	**583.2**
1998	204.3	11.8	8.6	65	0	0	22.7	2.9	28.8	160.9	137.1	279.8	**76.825**	**921.9**
1999	183.5	169.7	93.1	31	12.7	5.6	38.3	5	7.1	76.8	0	0	**51.9**	**622.8**
2000	0	1016.2	269.4	72.7	22.3	20.3	8.6	0.5	36.3	43.7	111.9	52	**137.825**	**1653.9**
2001	18.3	337.9	86.5	113.5	15.4	2.9	6.4	0.7	15.2	16.5	262.1	246.7	**93.50833**	**1122.1**
2002	86	5.3	14.5	79.5	0	24.4	0	12.9	14.7	111.7	37.6	166.3	**46.075**	**552.9**
2003	79	54.6	72.3	2.6	0.1	37.2	0.7	0	14.3	118.6	58.6	76.2	**42.85**	**514.2**
2004	132.5	103	361.2	80.6	0	1.1	1.2	13	6.8	25.6	30.5	119.2	**72.89167**	**874.7**
2005	37.3	9.6	38.7	52.1	1.9	2.4	3.7	7.6	0	11.7	84.6	175.2	**35.4**	**424.8**
2006	283.9	223.1	125.3	11.6	18.9	9	0.2	0.5	1	1	139.9	72.6	**73.91667**	**887**
2007	58.6	71.6	94.2	7.7	0.2	1.4	27.1	7.3	71.6	73.8	84.5	224.9	**60.24167**	**722.9**

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2008	136.1	98.9	80.6	40.1	0.2	21.9	23.8	4.6	0.1	5.4	89	99	**49.975**	**599.7**
	122.681	**154.212**	**93.6308**	**43.7769**	**14.4615**	**12.924**	**10.5385**	**7.39259**	**24.4852**	**62.3704**	**88.6259**	**126.419**		
Rainfall (mm) Data for station [0766563 1] - THATHE - BOS Measured at 08:00														
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
1963										73.5	62	125.5	**87**	**261**
1964	156	160	57	37	10.5	1	6.5	25	7.5	60	119	214.5	**71.16667**	**854**
1965	114	113.5	81.5	110.5	4	16.5	0	37.5	60.5	22.5	165	142.5	**72.33333**	**868**
1966	174.2	395.5	100	54.5	3.5	27	0	14.5	72.5	67.5	53.5	122	**90.39167**	**1084.7**
1967	341.5	366.1	175.5	160.8	32.5	31.5	19.5	14	12	76.7	174.5	70.5	**122.925**	**1475.1**
1968	93.5	238	74	58.7	89.5	10	19.1	16.2	10.5	33	249	162	**87.79167**	**1053.5**
1969	121.5	85.5	296	81.7	46.5	12	3.5	23.5	42.5	153	106.5	140.5	**92.725**	**1112.7**
1970		87	66.5	25	42.5	29.5	10.5	5.5	6	64.5	88	190	**55.90909**	**615**
1971	378.9	115.5	108	74	28	14.5	1.5	1.5	31.5	96.3	142.8	113	**92.125**	**1105.5**
1972	299	273	392.5	20	51.2	2	6	4.5	5	51.5	99	67	**105.8917**	**1270.7**
1973	80	119	77	82.2	13	28	26	0	253.5	71	46.5	259.5	**87.975**	**1055.7**
1974	253.5	276	92.5	32	65	0	18	8	37	36	215.5	0	**86.125**	**1033.5**
1975		511	220	98	31	44	0	21	15	38	90	410.4	**134.4**	**1478.4**
1976	528	335	191	138	148.4	19	0	10.5	23.5	79.6	137	218	**152.3333**	**1828**
1977	356.5	1015.2	531	40	26	0	0	54.5	91	73	51	519.5	**229.8083**	**2757.7**
1978	447	515		58.9	14	0	38.5		10.1	71.6	185	433.1	**177.32**	**1773.2**
1979	195		13.5	10	11.5	5.9	16.5	31.5	19.8	17.4	299	242.1	**78.38182**	**862.2**
1980	18	82.8	91.5	32	10.5	0	12	52	28	35	102	67	**44.23333**	**530.8**

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1981	126.5	571.5	235	35	168.5	0	0	142.5	84.4	114	21.5	54	**129.4083**	**1552.9**
1982	136.7	240	60.1	69	38	0	4.5	0	11.5	64.5	18.7	146.4	**65.78333**	**789.4**
1983	136.6	88	29.5	16.5	0	0	18.5	68	6.5	60.6	68.1	57.6	**45.825**	**549.9**
1984	68.2	112	275	92.5	11	22.1	74.1	17.9	20.5	186	249.8	92.7	**101.8167**	**1221.8**
1985	207.3	172.9	136	13.1	72.1	9.1	6.1	8.4	180	66.6	31	147.8	**87.53333**	**1050.4**
1986	178.9	54.5	35.5	219.3	16.2	0	9.6	11	74.6	75.1	99.3	118.3	**74.35833**	**892.3**
1987	60.7	53.8	44.2	40.5	36.7	47.2	0	31.9	127.5	52.9	138.5	407	**86.74167**	**1040.9**
1988	134	448.9	379.4	53.5	19.5	100.8	0	30	52.4	279.5	107.6	75.5	**140.0917**	**1681.1**
1989	130	411	60.5	36.5	12	23.5	13.1	12.9	12	101.1	207.5	203.5	**101.9667**	**1223.6**
1990	202	20	51	40.5	0	0	0	3.5	22	14	58.5	134	**45.45833**	**545.5**
1991	314.5	262	253	0	28	13	0	0	36.9	23.2	7	0	**78.13333**	**937.6**
1992	50	0	11		0		0	0	25	22.5	154.5	0	**26.3**	**263**
1993	0	59	51.2	23	0	77.5	71.1	34.6	27.7	85	176.6	247	**71.05833**	**852.7**
1994	149.5	125	17.4	43.4	0	4.8	0	22.8	0	56.4	73.7	42.6	**44.63333**	**535.6**
1995	272.4	74.1	111.5	11.8=	128.3	0	0	103.9	15.4	40.4	212.7	405.5	**124.0182**	**1364.2**
1996	1021.4	659.4	95.6	143.7	223.8	40.9	106.5	74.5	22.2	76.4	46.1	131.1	**220.1333**	**2641.6**
1997	139	58.2	0	13.3	27.1	0	42.7	0	118.3	42.5	133.5	0	**47.88333**	**574.6**
1998	410.5	21.9	85.6	20.9	0	0	36	46.7	40	123.5	18.3	107.1	**75.875**	**910.5**
1999	177.1	333	249	106.2	50.9	0	74.1	10.2	39	15	0	128	**98.54167**	**1182.5**
2000	0	1144.1	184	55.1	35	16.1	0						**204.9**	**1434.3**
	213.483	**266.594**	**137**	**61.0086**	**40.3973**	**16.5528**	**17.1324**	**26.8143**	**45.6056**	**70.7919**	**113.735**	**162.032**		

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Rainfall (mm) Data for station [0766596 9] - VONDA - BOS Measured at 08:00														
Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
1963											20.8	73	**46.9**	**93.8**
1964	167.7	98.7	21.7	29.2	5.9	0	6.7	12.4	11.7	47.6	73.5	157.6	**52.725**	**632.7**
1965	97.2	101.5	37.4	51	1.8	7.4	0	16.8	19.8	16.7	134	91.8	**47.95**	**575.4**
1966	126.2	305.2	81.4	22.8	4	12	0	11.3	34	47.5	38.5	136	**68.24167**	**818.9**
1967	321.5	287.6	95.3	141	1.7	18.8	13	4.5	5	41.7	111.3	56	**91.45**	**1097.4**
1968	49	176	63.3	51.7	62.5	14.6	11.2	13.3	8.3	16.3	178	168	**67.68333**	**812.2**
1969	87.1	113	266.3	136.2	50.7	8.1	2.5	6.5	37	94.7	175.5	71	**97.39333**	**1048.6**
1970	28	75.5	11	14.7	22.1	33.2	7.3	2.5	3.4	43.5	59.7	172.5	**39.45**	**473.4**
1971	212	60.5	43	101	23	5.5	1	0	21.5	53.9	42.5	75	**53.24167**	**638.9**
1972	268.8	182	241.5	10	25	1.5	2	3	3.2	41.8	61	22.5	**71.85833**	**862.3**
1973	44.3	36	191.9	49.5	18.9	7.5	26.9	3.5	134.2	79.7	21.5	295.9	**75.81667**	**909.8**
1974	177.7	226	63.5	49.8	72.8	0	5	2	18.8	6	220.7	153	**82.94167**	**995.3**
1975		535.3	179.5	104.7	35.5	32.1	2.5	23.6	12.1	38	32	415.2	**128.2273**	**1410.5**
1976	406.7	347	229.8	137	184	19	1	8.1	27.1	60.3	130.7	175.3	**143.8333**	**1726**
1977	395.8	674	634.7	38.7	4	0	0	80.3	67.1	78	127.2	603.4	**225.2667**	**2703.2**
1978	631	534.9	293.2	81.5	14	1.5	38.5	7.4	7.3	71.6	297.5	70.2	**170.7167**	**2048.6**
1979	246.1	124.1	87.5	0	42.4	6.3	15.5	32	23	96.5	278.5	232.2	**98.675**	**1184.1**
1980	238.2	338.9	215	52.5	4.5	0	5	51	66.2	68.5	262.5	74.1	**114.7**	**1376.4**
1981	388	391.5	115.5	53	107.5	0	0	129	83.4	107.7	204	63.5	**136.925**	**1643.1**
1982	234	188.1	36.4	108.4	85.5	0	6	0	19.5	79.8	39.9	162.2	**79.98333**	**959.8**
1983	111.3	74.3	91.1	0	26.2	46.5	24.1	72.6	5.8	84.1	94.1	57.5	**57.3**	**687.6**

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1984	132.1	144.2	268.1	72.3	16	29	142	24.5	40	292.4	462.6	110.9	**144.5083**	**1734.1**
1985	271.7	245.1	214.4	10.6	74.2	28	11.9	6.6	166.3	94.2	43	245.3	**117.6083**	**1411.3**
1986	168.7	123.1	44	232.9	31	3.1	4	7.5	43.3	69.4	133.1	130.8	**82.575**	**990.9**
1987	56	88.8	132.9	124.4	34.3	60.5	0	85.3	127.3	95.7	123.8	485.5	**117.875**	**1414.5**
1988	103.5	574	398	53.5	56.5	146	0	30.5	369.5	0	175.5	124	**169.25**	**2031**
1989	100.3	419.6	15.5	55	27	33.8	13.5	12.2	17.7	138.4	145.4	302.9	**106.775**	**1281.3**
1990	256	37.5	90.2	166.3	39.3	2.5	0	28.5	19.4	29	93.8	219.1	**81.8**	**981.6**
1991	420.3	208.5	350.7	15.5	42.7	18.7	0	0	67.5	12.1	18.5	0	**96.20833**	**1154.5**
1992	86.6	0	64.5	2.5	0	138.4	2.5	30	53	28	231.3	254.1	**74.24167**	**890.9**
1993	106	622.8	143.7	21	0	55.5	61.3	30	12	83.5	251.9	552	**161.6417**	**1939.7**
1994	307.9	0	16.3	46.4	0	4.4	0	16.1	0	45.7	62.6	42	**45.11667**	**541.4**
1995	358.3	72	157.4	20.2	114	0	0	99.5	7.6	32.5	210.8	294.2	**113.875**	**1366.5**
1996	859.5	782.5	106.2	142.6	152.6	44.1	138	83.1	18.3	83.3	105.8	168.7	**223.725**	**2684.7**
1997	359.2	65	184.9	3.5	21.7	0	48.7	0	162.8	121.7	147.2	66.9	**98.46667**	**1181.6**
1998	395.7	60.4	114.5	25.7	2.4	0	61.3	36.4	85.4	213.3	143.3	420.5	**129.9083**	**1558.9**
1999	300.2	303.5	244.3	76.1	52.5	42.5	67.9	11.5	35.9	38.7	0	125.2	**108.1917**	**1298.3**
2000	609.6	1742.9	490.6	120	35.1	81.6	16	0	149.5	91.5	191.5	147.5	**306.3167**	**3675.8**
2001	45.5	781.5	386.1	140.9	70.6	4.5	46.9	4.1	42.4	39	330.8	245.4	**178.1417**	**2137.7**
2002	263.9	32.9	79	31.6	0	119.3	9.5	17.8	27.1	82.6	105.5	201.7	**80.90833**	**970.9**
2003	14	211.8	196.9	0	14	59.5	0	5.5	41.4	143.5	71.8	155	**76.11667**	**913.4**
2004	186	173	627.7	192.1	0	13.5	33.9	36.7	18	45.4	39.2	182	**128.9583**	**1547.5**
2005	111.	99.6	133.5	57	12	9.5	18.8	111.1	0	51.5	96.8	334	**86.24167**	**1034.9**

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	1													
2006	248.5	183.6	139.9	41.4	22	18	0.2	0	0	13	246.5	162.5	**89.63333**	**1075.6**
2007	136	60.8	228.1	46	0	18	28	52.6	110.6	148.5	99	424	**112.6333**	**1351.6**
2008	245	50.5	135	24.5	7.8	18	9.3	13	3	18	110	97.5	**60.96667**	**731.6**
	235.732	**265.638**	**176.92**	**65.66**	**35.9489**	**25.8311**	**19.5978**	**27.1622**	**49.4756**	**70.7733**	**135.72**	**191.687**		

Rainfall (mm) Data for station [0766863 6] - GOOLDVILLE - HOSP Measured at 08:00

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC		
1960	18.4	314.2	45.7	133.1	9.2	34.9	13.3	6.9					**71.9625**	**575.7**
1961	123.6	515.5	170.4	54.7	7.8	57.4	11.3	25.4	27.4	36.5	247.5	244.9	**126.8667**	**1522.4**
1962	170.2	132	116.9	111.1	3.7	0.4	4.5	0	8.9	11.6	164	137	**71.69167**	**860.3**
1963	44.3	75.3	43.2	71	51.3	68.1	1.2	0.4	3.8	35.9	18.7	108.1	**43.44167**	**521.3**
1964	118.4	174.5	69.5	10.6	6.7	0	2.9			73.2	127	191	**77.38**	**773.8**
1965	130.5	101.6	77.5	54.4	0	11.8	0.1	18.2	52.9	11.8	197.3	120.8	**64.74167**	**776.9**
1966	143.2	296.6	62.2	31.1	27.2	18.8	1.2	15.9	56.9	57.9	28.1	205.6	**78.725**	**944.7**
1967	295.8	425	80.4	98.3	0.9	31.3	9.4	4.4	2.3	76.2	143.8	35.6	**100.2833**	**1203.4**
1968	45	214.9	25.2	55.6	82.3	15.1	12.8	7	7.1	21.7	227.8	280.7	**82.93333**	**995.2**
1969	152.1	66.1	275.5	55.5	17.1	9.2	0.9	20	86	160.5	169.1	127.3	**94.94167**	**1139.3**
1970	17.5	101	38.6	9.1	20.6	30.3	5.1	2.3	10.5	43.8	128.2	181	**49**	**588**
1971	287.2	55.5	105.9	99.9	23	19.5	1.3	0	43.2	82	131.3	73.3	**76.84167**	**922.1**
1972	519.5	232.7	336.5	14.9	27.7	1.3	0.7	8.9	6.8	132.9	72.6	43.1	**116.4667**	**1397.6**
1973	124.	48.3	187.2	71.1	5	10.2	14.1	2	158.6	91.2	12.1	280.5	**83.75**	**1005**

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	7													
1974	192.4	301.5	128.5	74.6	36.8	0	12.2	10.3	64.7	18.4	235.7	133.6	**100.725**	**1208.7**
1975	238	471.3	75.3	70.2	29	13.7	0	6.7	7.1	23.4	41.6	182.7	**96.58333**	**1159**
1976	260.4	245.2	162.5	91.3	105.6	6.9	0	0	16.5	43.5	150.1	70	**96**	**1152**
1977	129.5	491.5	486	12.5	0	0	0	11.5	95.9	55.2	92.5	339	**142.8**	**1713.6**
1978	393.5	477	190.6	61.5	5	3.9	13.7	0	26.5	60.5	189.2	165.3	**132.225**	**1586.7**
1979	112.1	53.3	127.3	15.5	30.2	9.9	12.5	52.5	15.2	95	151.5	127	**66.83333**	**802**
1980	162.7	285	273.6	65.7	1.5	1.1	5.6	28.2	32.9	71.7	190.7	139.9	**104.8833**	**1258.6**
1981	631.3	129.8	235.2	29.8	58.4	1.2	2.4	43.4	56.2	73.4	189.8	33.3	**123.6833**	**1484.2**
1982	64.4	101.5	28.3	81.6	57.5		2.6	1.3	4.4	92.3	39.9	92.7	**51.5**	**566.5**
1983	46	27	138.3	8.8	3.8	23.8	27.8	35.8	0.5	63	87.5	41.6	**41.99167**	**503.9**
1984	156.5	90	169.8	30.8	2	20.6	42.2						**73.12857**	**511.9**
	183.088	**217.052**	**146.004**	**56.508**	**24.492**	**16.225**	**7.912**	**13.0913**	**35.65**	**62.2435**	**132**	**145.826**		

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Appendix 3 Tree Density measurement

Albasini dam

Upstream			Downstream	
1	7.8		1	13
2	5.5		2	13.6
3	4.8		3	16.3
4	11.4		4	12
5	13.7		5	15.6
	8.64			**14.1**
6	12.7		6	13.5
7	15		7	17.4
8	9.7		8	14
9	5.3		9	12.5
10	4.8		10	10.3
	9.5			**13.54**
11	15.8		11	9.5
12	10.3		12	11.5
13	11.9		13	10.7
14	12.7		14	15.3
15	8.5		15	11.6
	11.84			**11.72**
16	10.8		16	12.5
17	3.2		17	9.6
18	6.1		18	16
19	9		19	11.7
20	12.7		20	15
	8.36			**12.96**
21	8.5		21	12.5
22	10.7		22	13
23	13		23	14.6
24	5.7		24	7.8
25	6.6		25	11.6
	8.9			**11.9**
26	15.7		26	14.5
27	17.9		27	13.4
28	19.7		28	14
29	14.6		29	9.4
30	9.5		30	6.9
	15.48			**11.64**
31	14.7		31	9.3
32	6.1		32	16
33	3.9		33	10
34	2.8		34	12
35	10.4		35	6.9
	7.58			**10.84**
36	8.4		36	11.7

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37	6.5		37	11
38	6.8		38	13
39	13.9		39	6.5
40	14.6		40	4.7
AV	**10.04255**		**AV**	**12.06596**
	10.04			**9.38**

Damani dam

Upstream			Downstream	
1	3.94		1	12.6
2	3		2	15.3
3	3.37		3	9.21
4	5.15		4	29.3
5	5.63		5	11.5
	4.218			**15.582**
6	3.2		6	6.4
7	1.4		7	3.87
8	9.3		8	1.87
9	0.78		9	23.8
10	1.6		10	11.3
	3.256			**9.448**
11	2.43		11	2.76
12	2.7		12	1.87
13	12.5		13	4.87
14	6.21		14	6.36
15	6		15	9.23
	5.968			**5.018**
16	7.2		16	19.5
17	4.2		17	11.5
18	13.4		18	13.54
19	4.6		19	24.6
20	5.8		20	1.4
	7.04			**14.108**
21	5.12		21	3.65
22	5.87		22	21.5
23	8.3		23	10.7
24	7.3		24	4.5
25	12.4		25	10.3
	7.798			**10.13**
26	15.73		26	4.5
27	6.3		27	6.86
28	4.5		28	2.54
29	3.54		29	4.76
30	3.7		30	3.22
	6.754			**4.376**
31	4.21		31	1.43
32	6.12		32	1.98

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33	3.9		33	9.67
34	4.1		34	24.5
35	3.12		35	17.4
	4.29			**9.796**
36	8.23		36	14.65
37	6.6		37	10.21
38	10.1		38	3.1
39	4.6		39	2.03
40	15.7		40	13
AV	**5.982426**		**AV**	**9.654**
	9.046			**8.598**

Mambedi dam

Upstream			**Downstream**	
1	9.75		1	15.61
2	3.67		2	16.56
3	6		3	13.8
4	9.2		4	13.5
5	6.36		5	15.61
	6.996			**15.016**
6	4.3		6	7.9
7	9.23		7	6.9
8	9.34		8	17.8
9	7.8		9	10.1
10	12.6		10	7.61
	8.654			**10.062**
11	6.8		11	12.72
12	7.3		12	16.2
13	6		13	14.5
14	5.2		14	14.1
15	7.3		15	12.8
	6.52			**14.064**
16	8		16	5.3
17	4.4		17	18.3
18	5.7		18	22.8
19	8.02		19	20.1
20	8.7		20	17.3
	6.964			**16.76**
21	11.6		21	15.5
22	6		22	14.7
23	8.4		23	18.3
24	9.3		24	15.3
25	8		25	13
	8.66			**15.36**
26	6.32		26	11.5
27	4.4		27	8.5
28	3.6		28	9.3

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29	4.8		29	13.6
30	5.7		30	15.5
	4.964			**11.68**
31	6.4		31	4.6
32	9.3		32	17.9
33	4.3		33	13.6
34	12.4		34	14.4
35	14.2		35	16.8
	9.32			**13.46**
36	10.4		36	14.4
37	11.34		37	11.8
38	9.4		38	28.4
39	10.3		39	21.5
40	8.1		40	18.9
AV	**7.702298**		**AV**	**14.32791**
	9.908			**19**

Nandoni dam

Upstream

1	11.4		1	12.2
2	14.8		2	14.5
3	14		3	14.7
4	11		4	10
5	12.7		5	9.6
	12.78			**12.2**
6	14.5		6	13
7	13.6		7	15
8	12.5		8	13.8
9	9.3		9	7.8
10	7.8		10	15
	11.54			**12.92**
11	11.6		11	12.3
12	6.3		12	9
13	13		13	8.6
14	10.1		14	6
15	8.9		15	5.4
	9.98			**8.26**
16	7		16	9.3
17	6.7		17	7.7
18	5.4		18	11.4
19	6.1		19	5.4
20	6.5		20	7.2
	6.34			**8.2**
21	10		21	5.7
22	7.1		22	8.8
23	5.3		23	8.2
24	11.5		24	5.6

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25	7.3		25	6.6
	8.24			**6.98**
26	8		26	10.4
27	12.4		27	11.5
28	4		28	6.6
29	5.9		29	5
30	3		30	4.3
	6.66			**7.56**
31	13.5		31	5.7
32	4		32	4.5
33	5.2		33	4.2
34	5.1		34	8.6
35	3.5		35	4.8
	6.26			**5.56**
36	4.7		36	3.6
37	4		37	5
38	3.1		38	4.1
39	4		39	3.8
40	3.3		40	4.7
AV	**8.295745**		**AV**	**8.325106**
	3.82			**4.24**

Vondo dam

Upstream			Downstream	
1	6.7		1	19.6
2	9.4		2	11.9
3	7		3	13.9
4	14.1		4	16.7
5	7.3		5	14.1
	8.9			**15.24**
6	13.5		6	10
7	6		7	11.9
8	8.1		8	7
9	3.4		9	7.6
10	8.3		10	9.9
	7.86			**9.28**
11	9.4		11	6
12	4.7		12	7.7
13	10.6		13	18.5
14	13.6		14	13.7
15	11.4		15	10
	9.94			**11.18**
16	9		16	15.3
17	7.7		17	14.2
18	13.2		18	16.9
19	11.4		19	10.2
20	5.1		20	11.4

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	9.28			**13.6**
21	2.3		21	8.6
22	4.9		22	13.7
23	3.1		23	6.7
24	4		24	8.5
25	6.2		25	6
	4.1			**8.7**
26	2.9		26	3.9
27	7.1		27	5
28	5.1		28	2.5
29	3.9		29	7
30	4.4		30	6.6
	4.68			**5**
31	5.3		31	10.3
32	2.6		32	8
33	3.8		33	4.2
34	2.4		34	5.7
35	2.9		35	3.9
	3.4			**6.42**
36	4.7		36	5.9
37	6.7		37	7
38	2.1		38	5.6
39	3.3		39	2.7
40	2.8		40	3
AV	**6.565106**		**AV**	**9.377021**
	3.92			**4.84**

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Appendix 4 Total Annual rainfall in mm

	Total Annual Rainfall in mm				
Dam	Albasini		Damani	Mambedi	
Rainfall station	*Beja*	*Goedehoop*	*Gooldville-Hospital*	*Driefontein*	*Gevonden*
1960	749.9	883.1	575.7	835	803.7
1961	679.7	656.4	1522.4	994	908.3
1962	672.4	587.6	860.3	578.5	654.3
1963	578.7	457.1	521.3	410.5	521.8
1964	316.8	332.5	773.8	448	518.7
1965	337.8	540.3	776.9	478.5	454.4
1966	677.5	612.4	944.7	701.5	546.8
1967	962.1	848.6	1203.4	944	906.8
1968	503.2	609.4	995.2	634.5	644.2
1969	600.8	988.4	1139.3	836	757.6
1970	*	477.2	588	457.5	584.7
1971	*	784	922.1	840	882.8
1972	*	807.9	1397.6	1192	296.9
1973	*	740.3	1005	869.5	*
1974	*	1071.5	1208.7	1037	*
1975	*	861.5	1159	1203	*
1976	*	770.1	1152	1217	*
1977	*	1143.4	1713.6	1559	*
1978	*	881.9	1586.7	1145.1	*
1979	*	332.3	802	567.3	*
1980	*	572.3	1258.6	953	*
1981	*	909.7	1484.2	1370.3	*
1982	*	247.5	566.5	335	*
1983	*	239.3	503.9	454	*
1984	*	852.7	511.9	822	*
1985	*	1157.3	*	1128	*
1986	*	703.2	*	524	*
1987	*	778.6	*	59	*
1988	*	1020.2	*	*	*
1989	*	621.2	*	*	*
1990	*	664.5	*	*	*
1991	*	1013.2	*	*	*
1992	*	649	*	*	*
1993	*	851.1	*	*	*

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1994	*	448	*	*	*
1995	*	1059.5	*	*	*
1996	*	1330.8	*	*	*
1997	*	975.7	*	*	*
1998	*	1195.6	*	*	*
1999	*	1034.2	*	*	*
2000	*	2841.2	*	*	*
2001	*	1355.6	*	*	*
2002	*	711.8	*	*	*
2003	*	832	*	*	*
2004	*	917.3	*	*	*
2005	*	149.1	*	*	*
2006	*	1116.4	*	*	*
2007	*	344.8	*	*	*
2008	*	225.6	*	*	*

	Total rainfall in mm				
Dam	Nandoni	Vondo			
Rainfall station	*Thohoyandou*	*Thathe-Bos*	*Vondo-Bos*		
1960	*	*	*		
1961	*	*	*		
1962	*	*	*		
1963	*	261	93.8		
1964	*	854	632.7		
1965	*	868	575.4		
1966	*	1084.7	818.9		
1967	*	1475.1	1097.4		
1968	*	1053.5	812.2		
1969	*	1112.7	1048.6		
1970	*	615	473.4		
1971	*	1105.5	638.9		
1972	*	1270.7	862.3		
1973	*	1055.7	909.8		
1974	*	1033.5	995.3		
1975	*	1478.4	1410.5		
1976	*	1828	1726		
1977	*	2757.7	2703.2		

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1978	*	1773.2	2048.6		
1979	*	862.2	1184.1		
1980	*	530.8	1376.4		
1981	*	1552.9	1643.1		
1982	229.3	789.4	959.8		
1983	330.7	549.9	687.6		
1984	766.4	1221.8	1734.1		
1985	1040.4	1050.4	1411.3		
1986	568.8	892.3	990.9		
1987	810.3	1040.9	1414.5		
1988	842.7	1681.1	2031		
1989	690.1	1223.6	1281.3		
1990	645.9	545.5	981.6		
1991	887.7	937.6	1154.5		
1992	531.5	263	890.9		
1993	728.8	852.7	1939.7		
1994	558.5	535.6	541.4		
1995	837	1364.2	1366.5		
1996	1147.6	2641.6	2684.7		
1997	583.2	574.6	1181.6		
1998	921.9	910.5	1558.9		
1999	622.8	1182.5	1298.3		
2000	1653.9	1434.3	3675.8		
2001	1122.1	*	2137.7		
2002	552.9	*	970.9		
2003	514.2	*	913.4		
2004	874.7	*	1547.5		
2005	424.8	*	1034.9		
2006	887	*	1075.6		
2007	722.9	*	1351.6		
2008	599.7	*	731.6		

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Appendix 5 Aerial photographs

Mbwedi river before the Damani dam (1987)



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Vondo upstream (1987)



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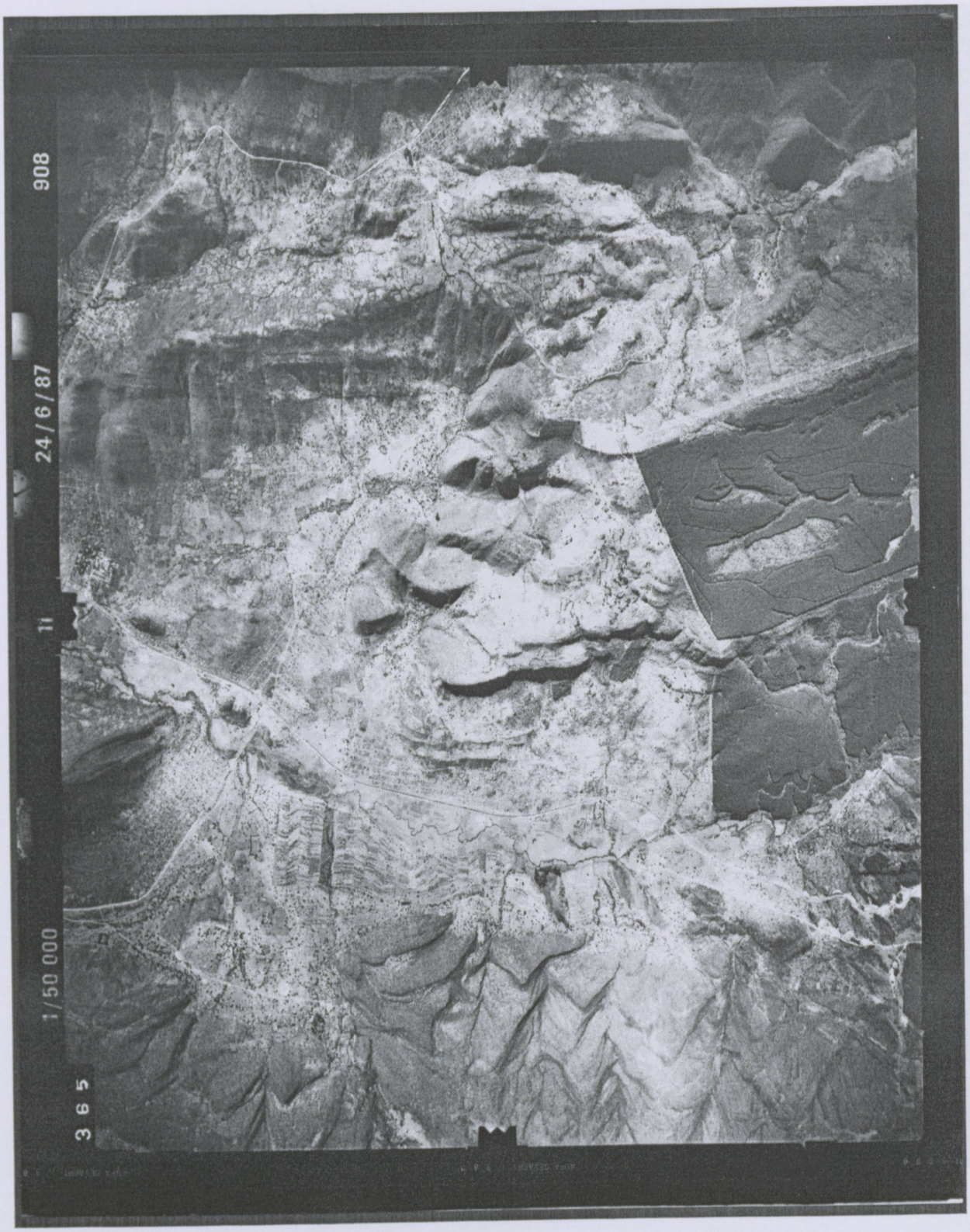
Vondo dam (1987)



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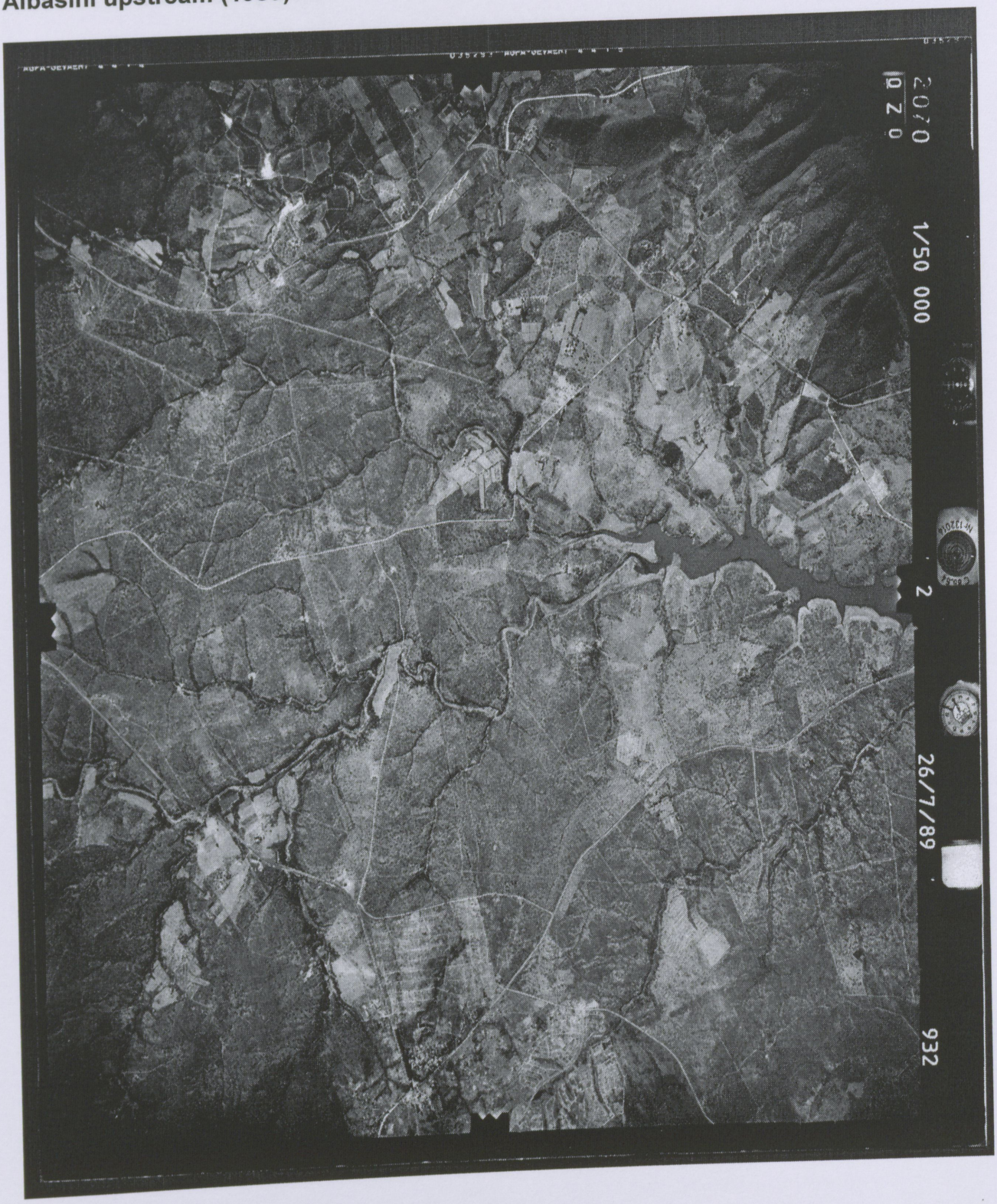
Albasini upstream (1989)



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Albasini downstream (1989)



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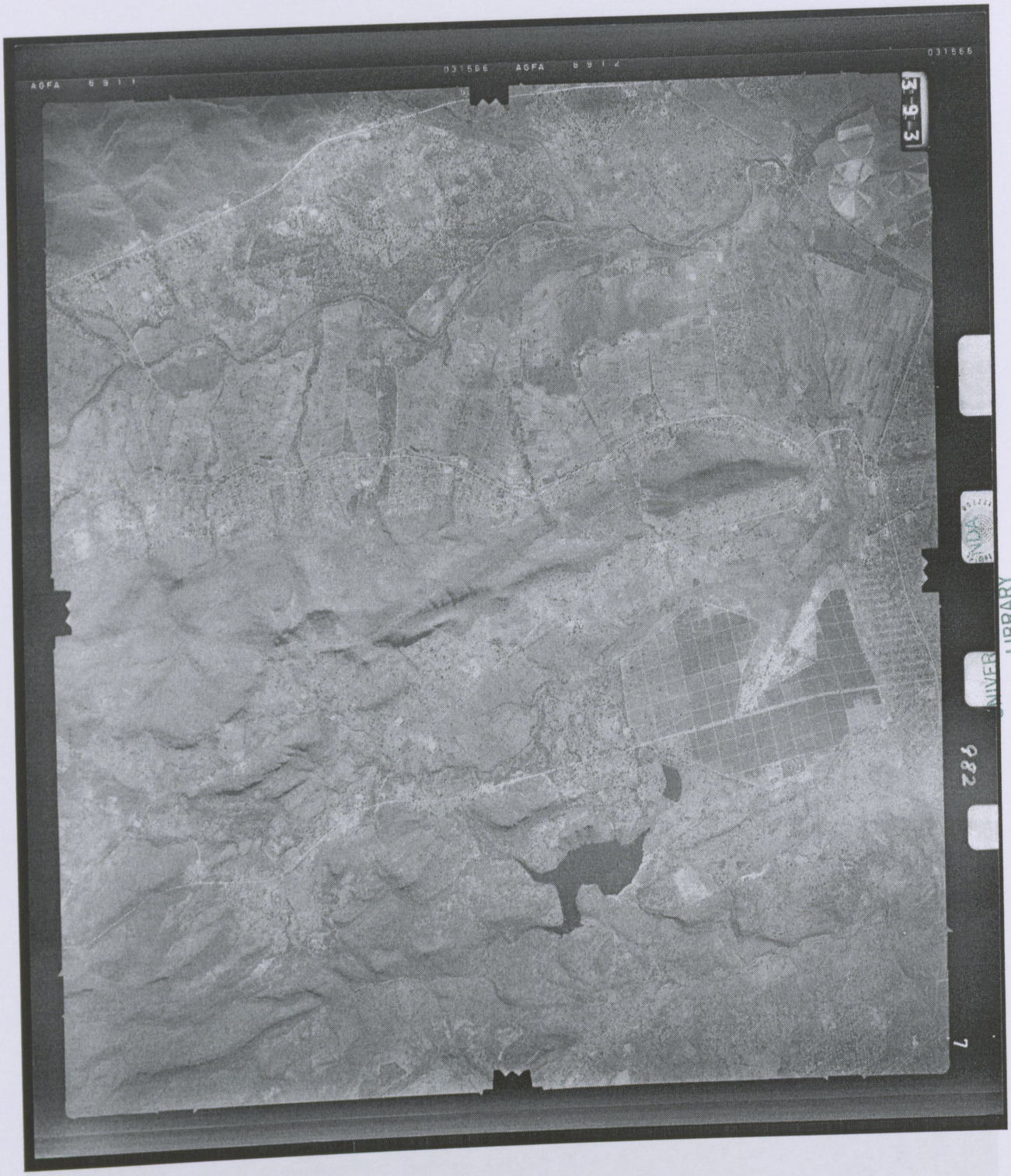
Damani dam (Upstream and downstream – 1995)



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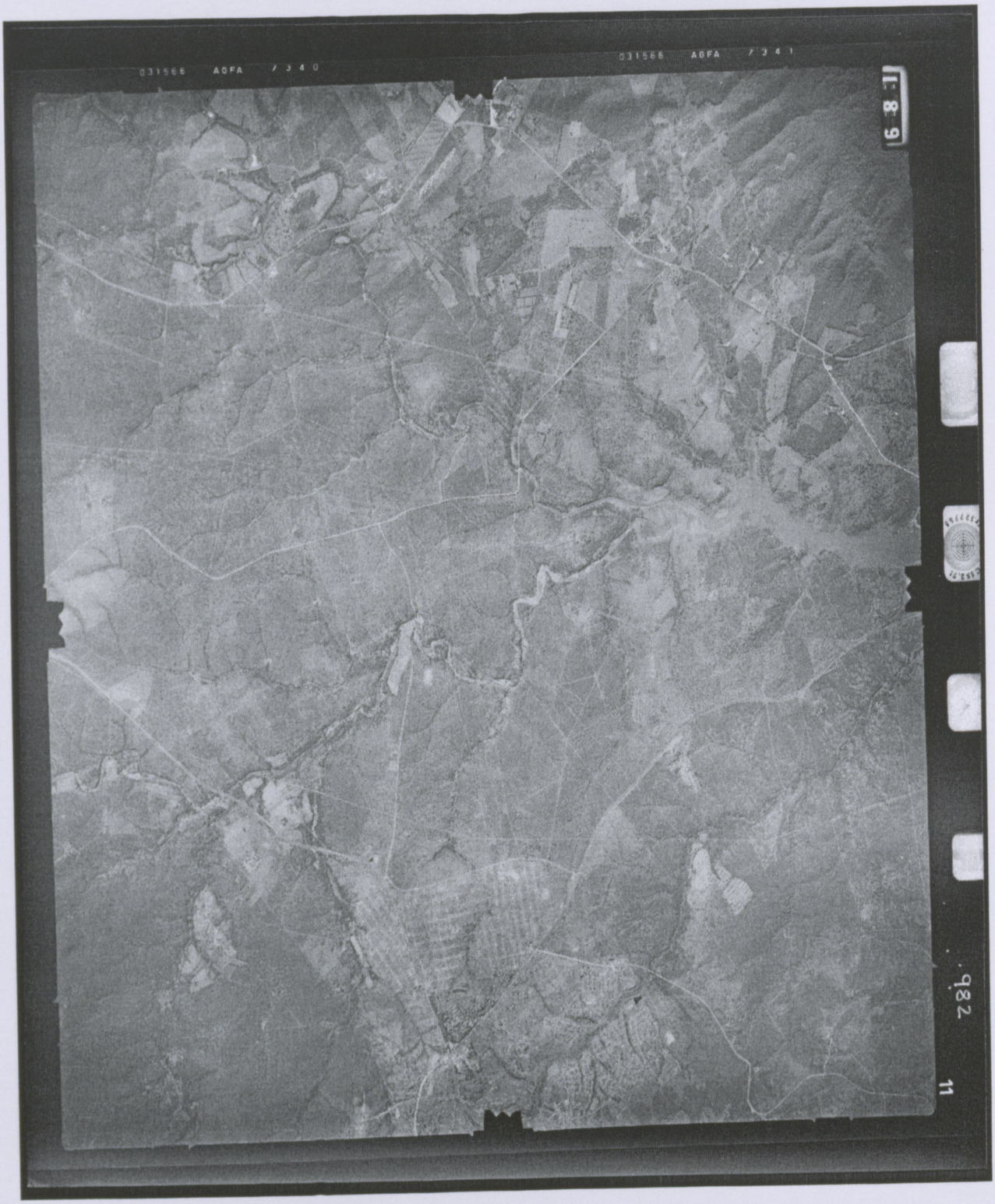
Albasini upstream (1995)



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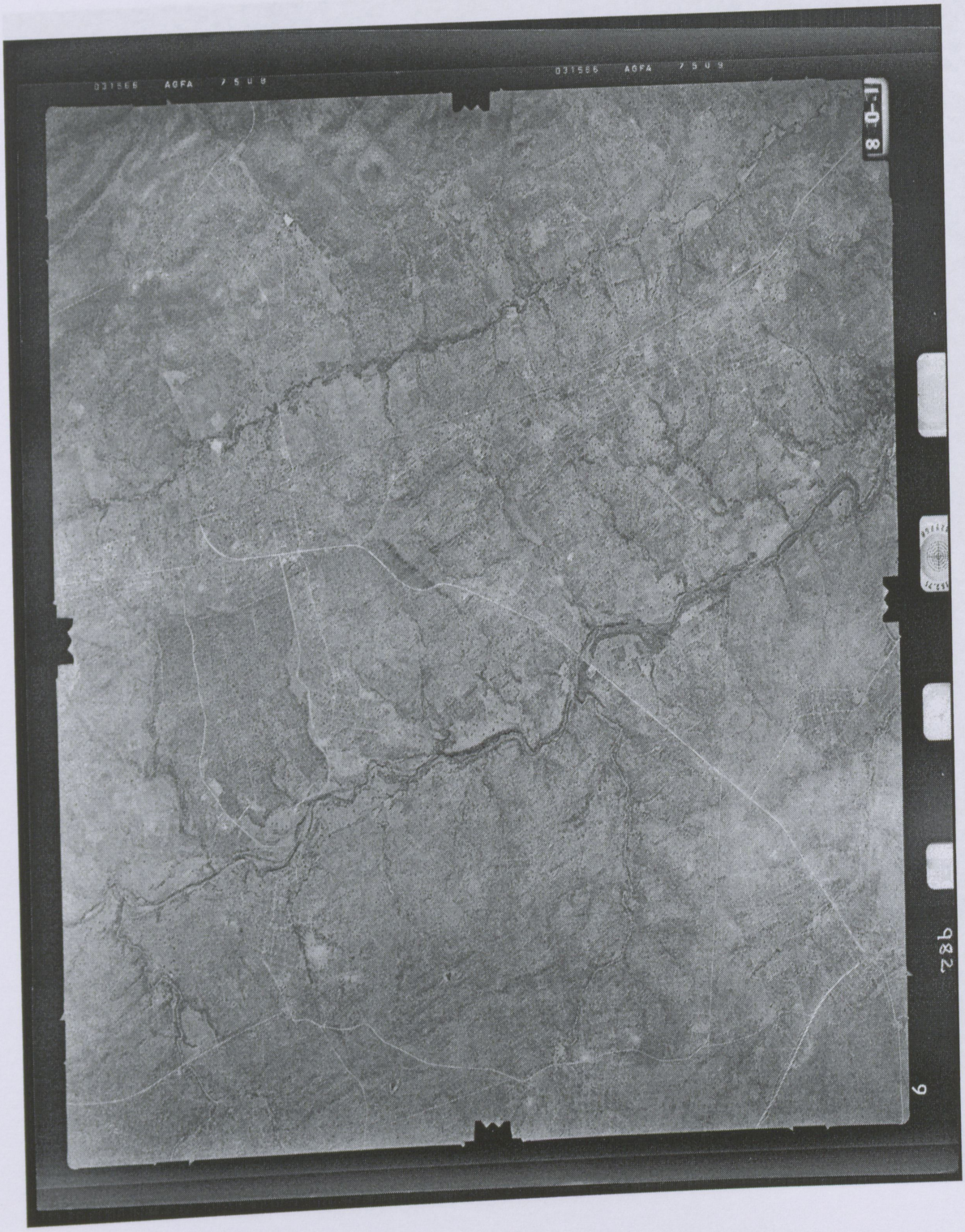
Luvuvhu river before Nandoni dam (1995)



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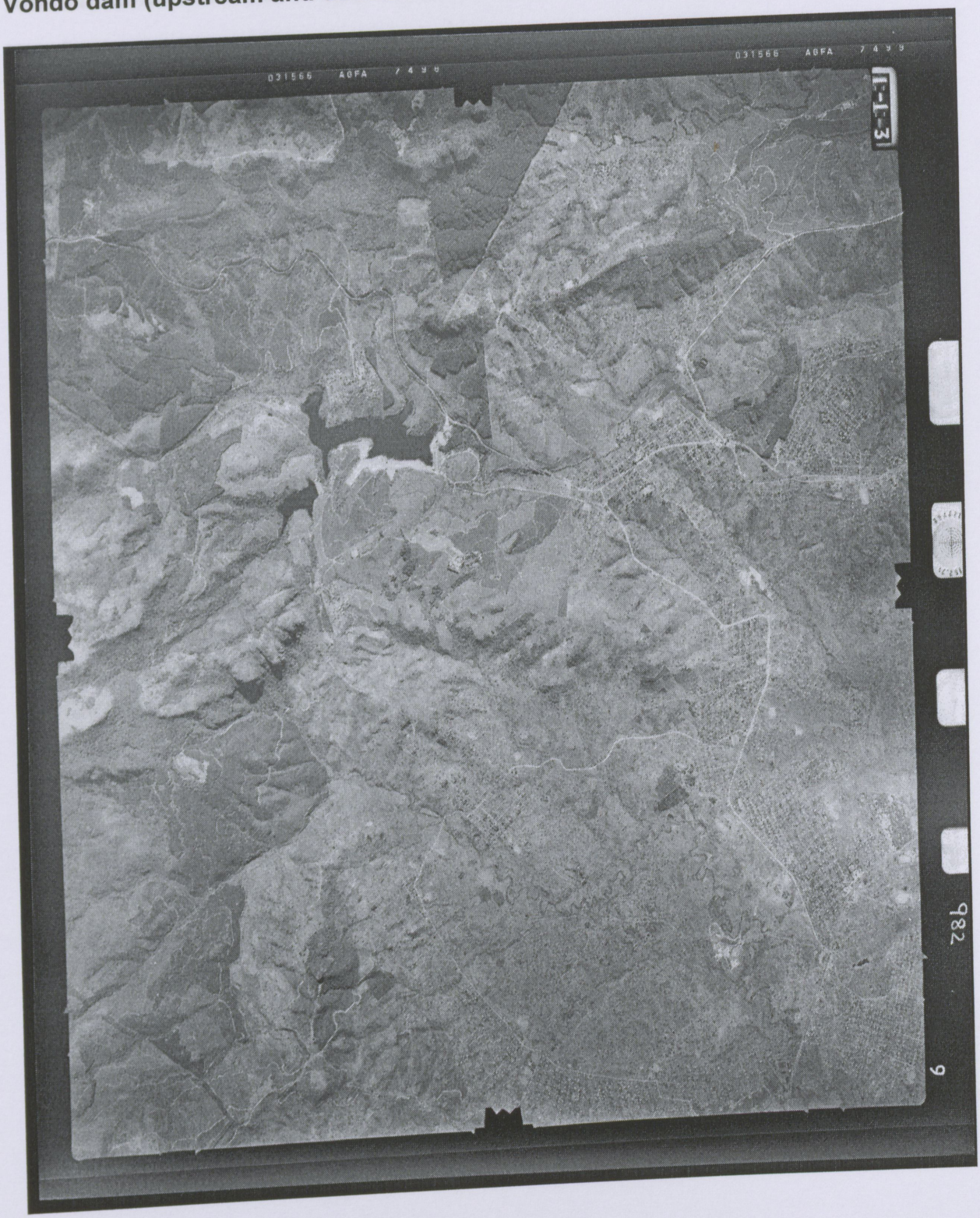
Vondo dam (upstream and downstream – 1995)



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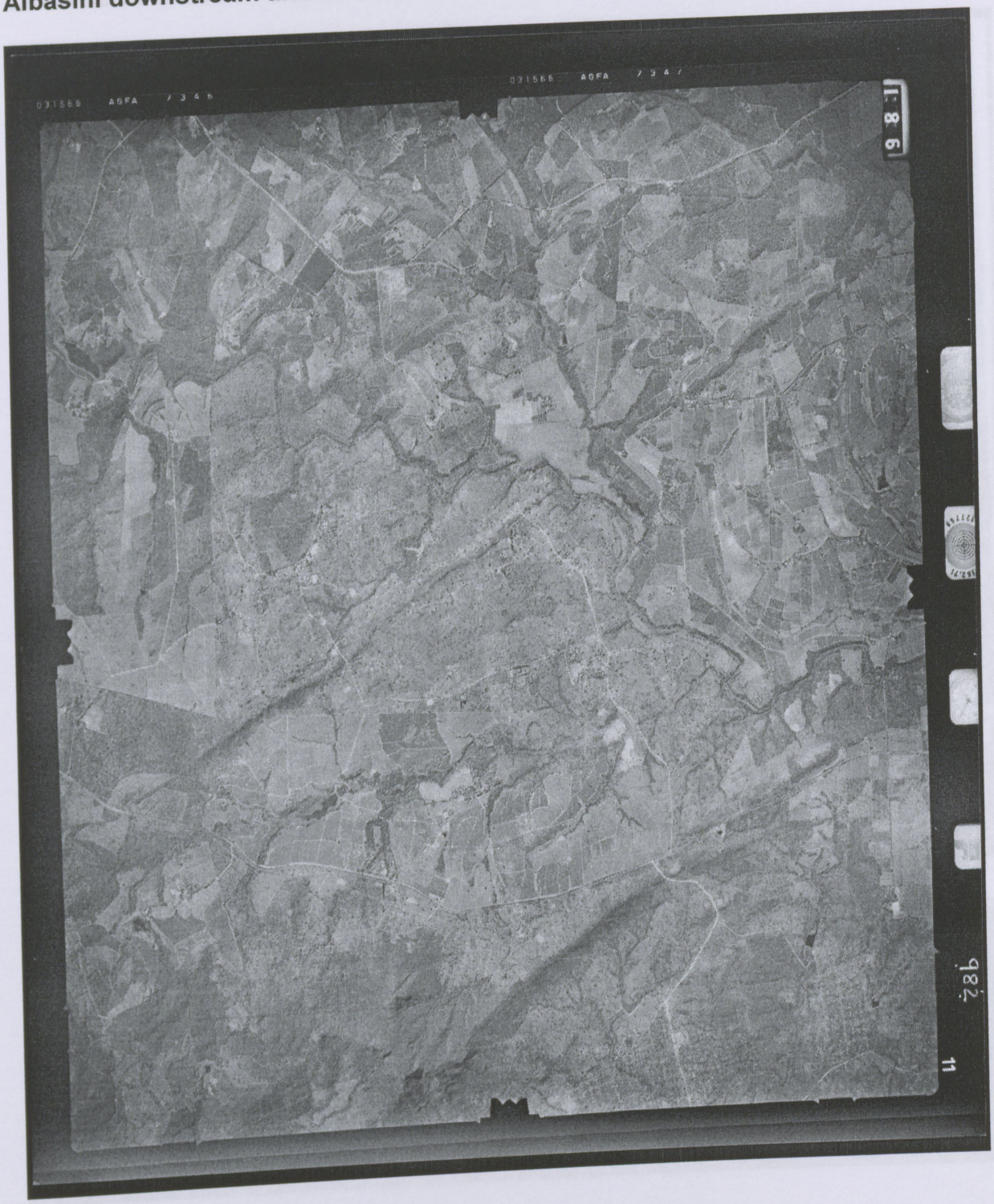
Albasini downstream and Mambedi upstream (1995)



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Luvuvhu river before Nandoni dam (1987)



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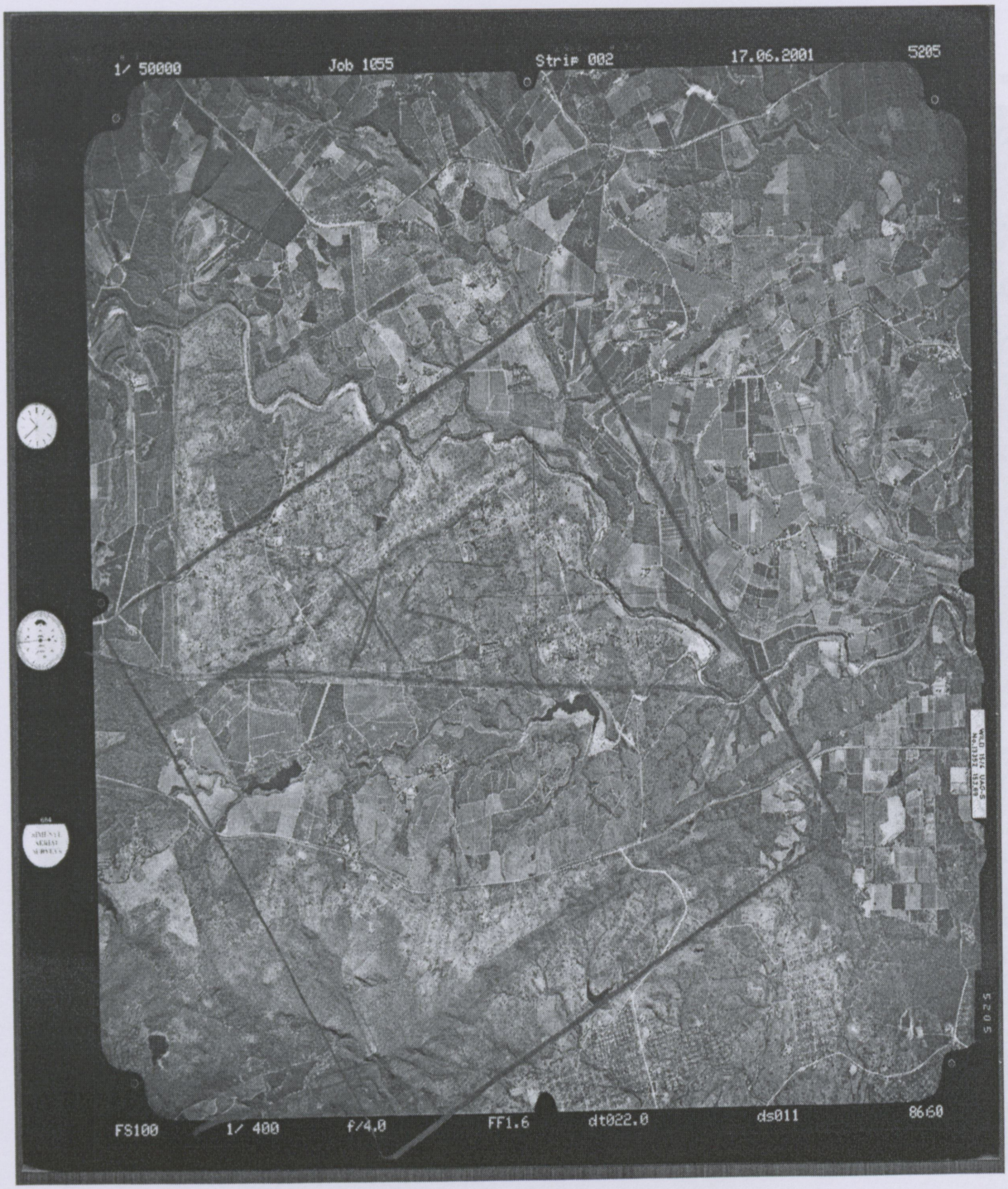

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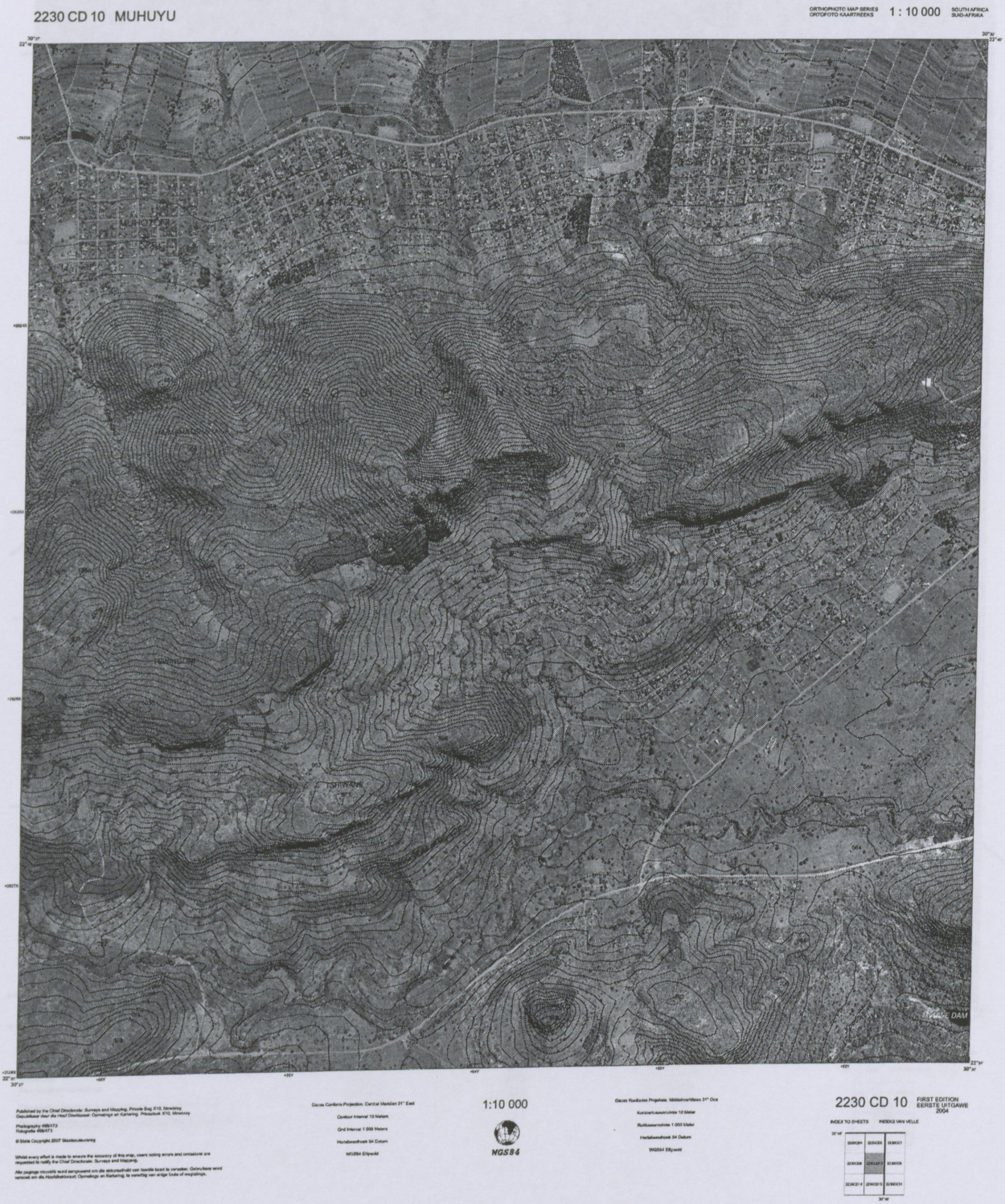
Damani upstream (2004)



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Gepubliseer deur die Hoof Direktoraat: Oprmetings en Kartering, Privaatsak X10, Mowbray

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Hartebeesthoek 94 Datum
WGS84 Ellipsoid

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Cassa Konforme Projeksie. Middelmeridiaan 31° Oos
Kontoerinterval 10 Meter
Rutkruisinterval 1 000 Meter
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Horizontal Datum 94
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Gauss Konforme Projektie, Middelmeridiaan 31° Oos
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Roosterekwisisieruimte 1 000 Meter
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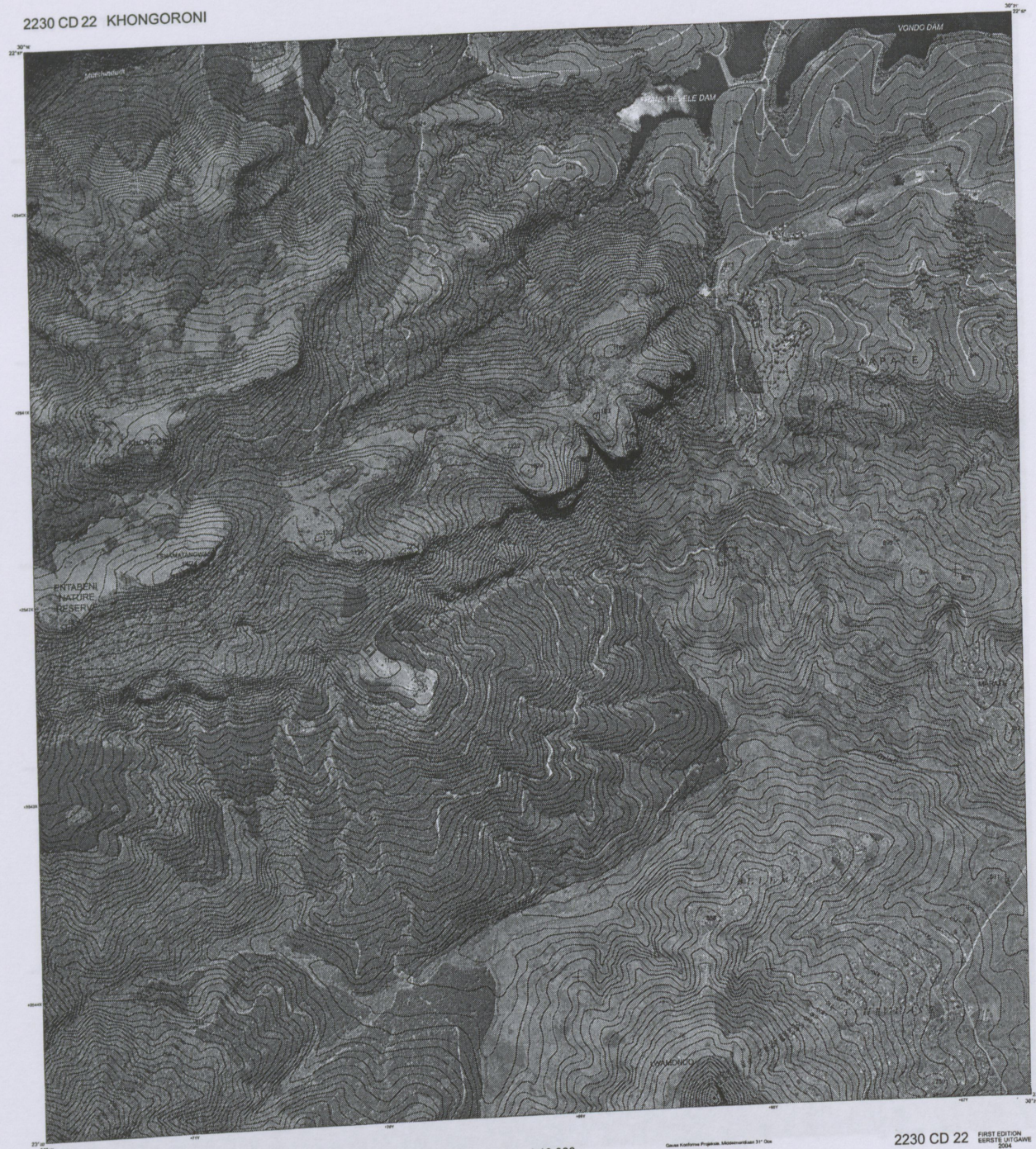

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Grid Interval 1 000 Meters
Horizontaldatum 94 Datum
WGS84 Ellipsoid

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WGS84

Cassini Konforme Projeksie. Middelmeridiaan 31° Oos
Kontoerafstand 10 Meter
Rutlyndistansie 1 000 Meter
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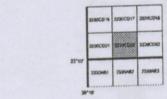

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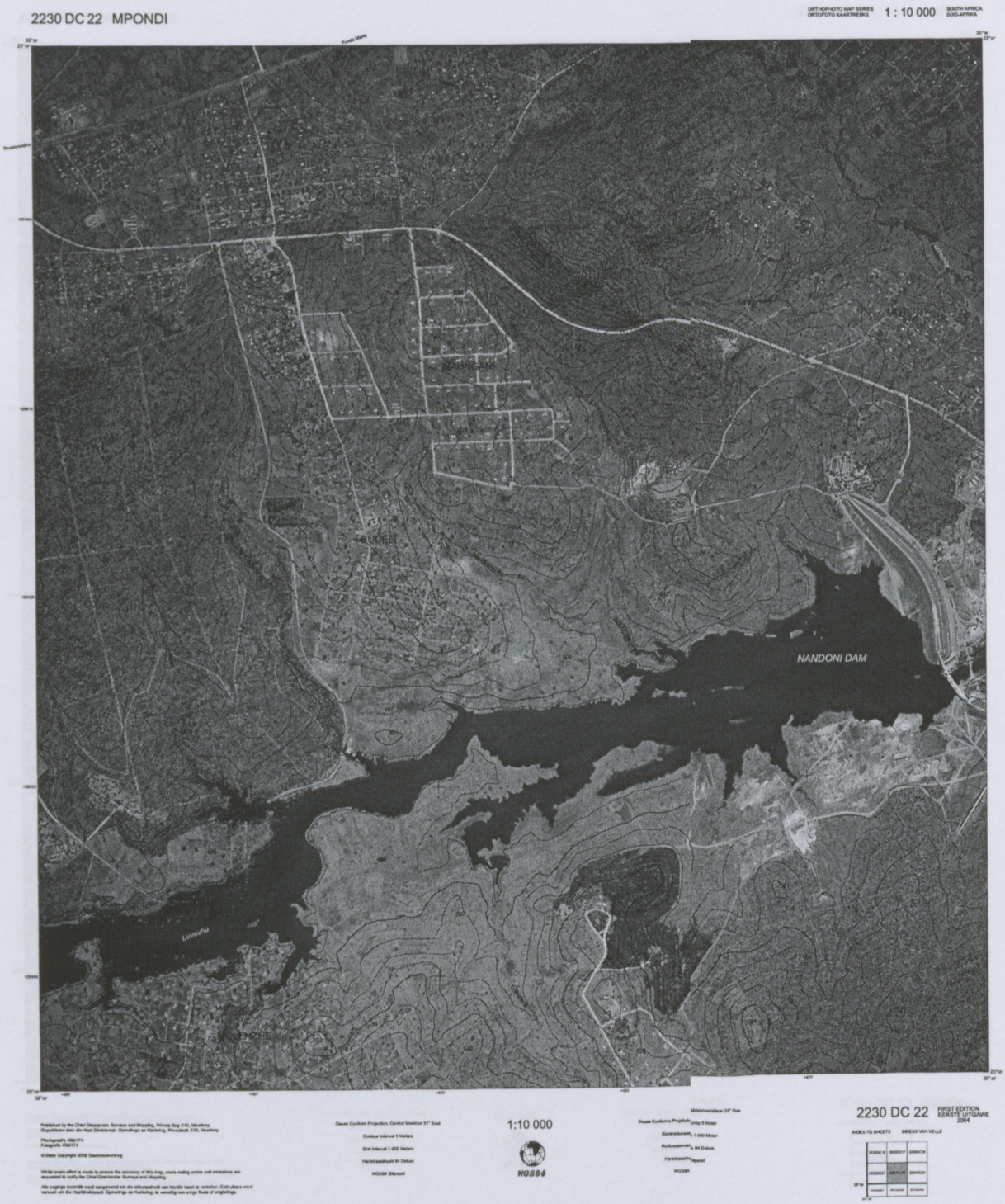

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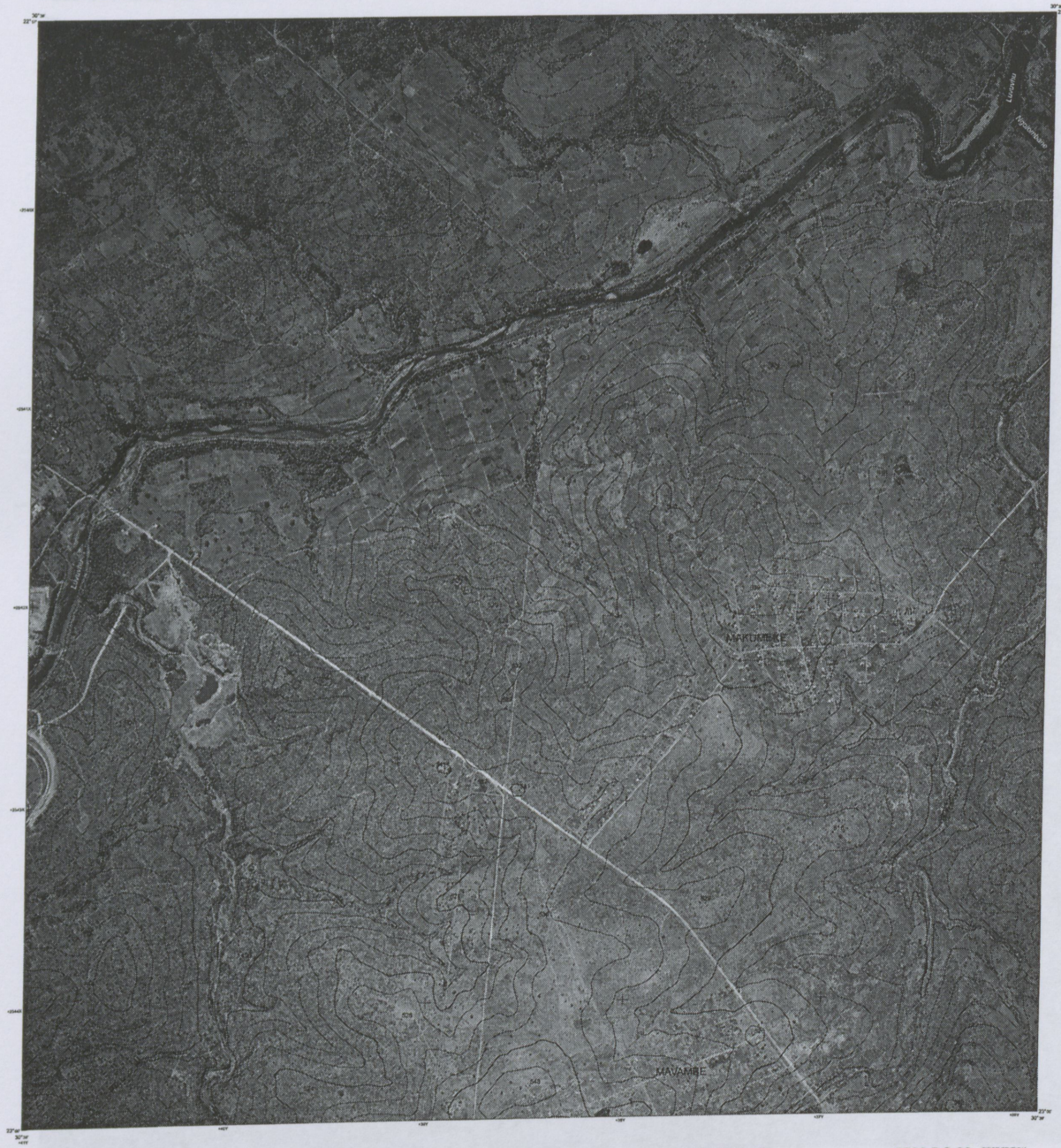

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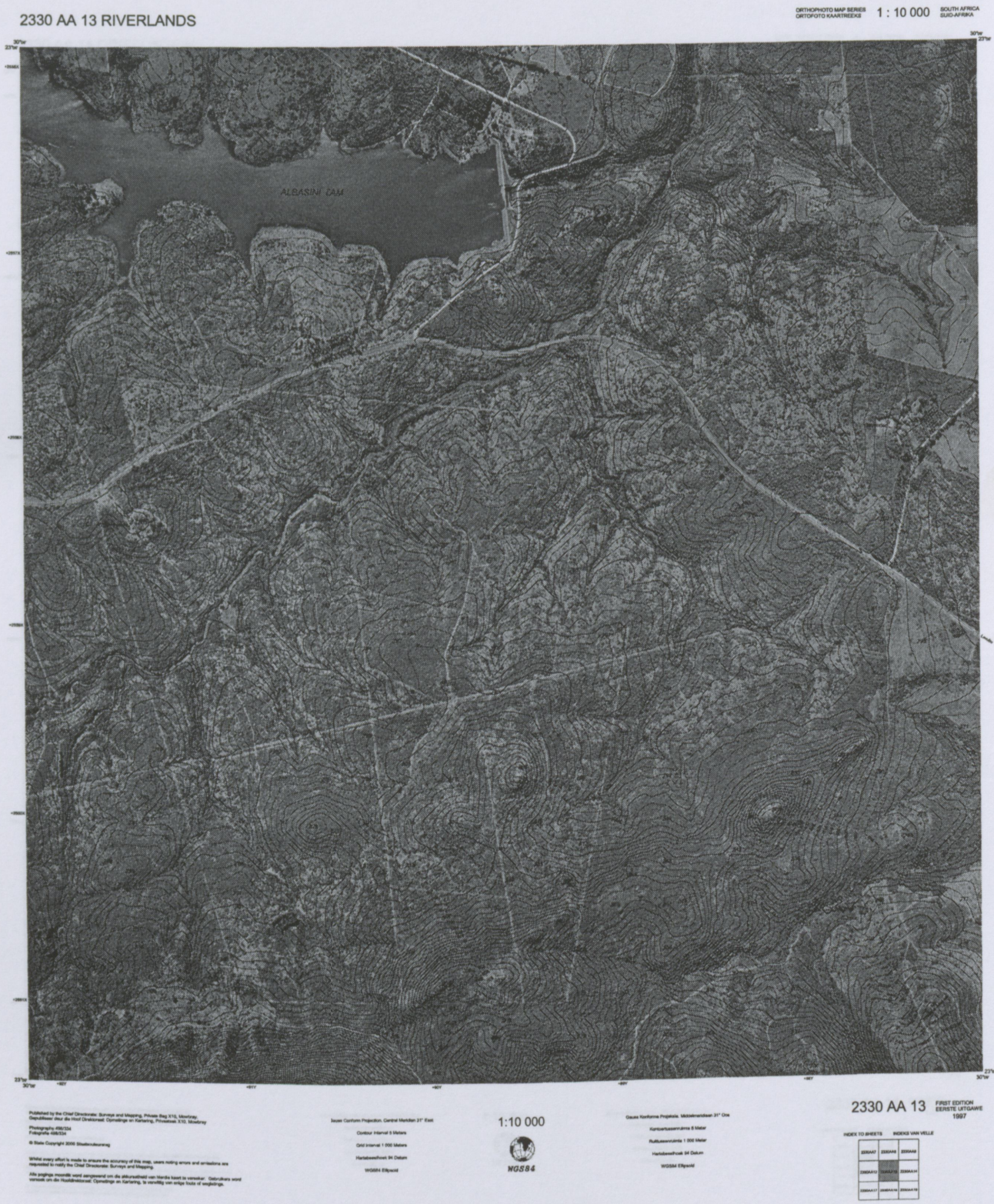

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WGS84 Ellipsoid

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WGS84

Geuse Konforme Projekte. Middelmeridiaan 31° Oos
Kontoerbeeseinsinnie 5 Meter
Rutbeeseinsinnie 1 000 Meter
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WGS84

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Rutkoasnderte 1 000 Meter
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Appendix 7

TABLE X Critical Values for Spearmen Rank-Order Correlation Coefficient

	Significance level for a directional test at			
	.05	.025	.005	.001
	Significance level for a non-directional test at			
N	.10	.05	.01	.002
5	.900	1.000		
6	.829	.886	1.000	
7	.715	.786	.929	1.000
8	.620	.715	.881	.953
9	.600	.700	.834	.917
10	.564	.649	.794	.879
11	.537	.619	.764	.855
12	.504	.588	.735	.826
13	.484	.561	.704	.797
14	.464	.539	.680	.772
15	.447	.522	.658	.750
16	.430	.503	.636	.730
17	.415	.488	.618	.711
18	.402	.474	.600	.693
19	.392	.460	.585	.676
20	.381	.447	.570	.661
21	.371	.437	.556	.647
22	.361	.426	.544	.633
23	.353	.417	.532	.620
24	.345	.407	.521	.608
25	.337	.399	.511	.597
26	.331	.391	.501	.587
27	.325	.383	.493	.577
28	.319	.376	.484	.567
29	.312	.369	.475	.558
30	.307	.363	.467	.549

Find the row corresponding to *N*, the number of pairs of scores, find the column corresponding to the chosen level of significance, taking into account the type of H_1 (directional or non-directional). The critical value is at the intersection of that row and that column. **If r_r is greater or equal to this value, then H_0 is rejected.**

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