UNIVERSITY OF ZIMBABWE

Faculty of Engineering
Department of Civil Engineering
Masters in Integrated Water Resources Management

Evaluating the effect of different water demand scenarios on downstream water availability in Thuli river basin, Zimbabwe.

By
Sangwani Mugwazu Khosa

A thesis submitted in partial fulfillment of the requirements for the degree of Masters in Integrated Water Resources Management (IWRM)

June 2007

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Supervisors

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ABSTRACT

Thuli river basin is situated in a semi-arid area, where surface water resource availability is a constraint due to low rainfall received in the area. The river basin is more developed in its upper than lower reaches. There is intensified use of blue water in the upper catchment and demand from powerful sectors such as urban is increasing. This study is being carried out to evaluate the effects of upstream water demand scenarios on downstream users in the Thuli river basin in order to improve on the management of the water resources.

To understand and manage such imbalances between upstream and downstream water users, this research applied a spreadsheet computer model as a tool to simulate the effects of different water demand scenarios on downstream water availability in Thuli river basin. Focus group discussions were done with major water demand nodes to establish the monthly demands. Historical hydrological and meteorological data were corrected and used as input to the model. Meetings were conducted with officials from different sectors involved in water utilization and development.

In this research, the impacts of different water demand scenarios on the downstream water availability were evaluated. The water demand scenarios used were categorized in four sections, based on government recommendations and plans on water resources development, technology improvement, drought risk mitigation and factors affecting water demand in urban areas. The results of the simulations of water demand scenarios were analyzed and knowledge was generated to contribute to the management of the water resource in Thuli river basin.

DECLARATION

I declare to the Registrar of examinations at the University of Zimbabwe that this dissertation is my own, unaided work. It is submitted for the Masters degree in Integrated Water Resources Management (IWRM), Department of Civil Engineering in the University of Zimbabwe, Harare. To the best of my knowledge, it has not been submitted before, for any degree or examination in any University.

Name……………………………………………………………………………………….

Signed…………………………..…day of…………………………………………2007

DEDICATION

To my late father, Gilbert,

I wish you had seen this work.

And my dear Anita,

for your support, prayers and fortitude.

And to all the relatives to whom I am indebted

for the prayers.

Let this work be the pacesetter for the great achievements to unfurl in future

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LIST OF ABBREVIATION AND ACRONYMS

AREX	Agricultural Extension Services
CV	Coefficient of variation
GWP	Global Water Partnership
IWRM	Integrated Water Resources Management
MAR	Mean Annual Runoff
MEWRD	Ministry of Energy and Water Resources Development
USGS	United States Geological Survey
WAFLEX	Water Flow Model in Excel
WRMS	Water Resources Management Strategy
ZINWA	Zimbabwe National Water Authority

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1. Introduction

1.1. General Background

The Water Sector in Zimbabwe has witnessed major reforms. Management of the water resources is being implemented based on the two new acts, the Zimbabwe National Water Authority Act (1996) and the Water Act (1998). These two acts have given powers to stakeholders to run and manage water resources through the catchment councils. In trying to streamline the activities so that they are in line with these two acts, water resources management decisions are required to be made. The decisions made have to encompass all the stakeholders and have to be supported by analytical tools for example water allocation models. In recent years, considerable effort has gone into developing decision support models (Hughes and Hannart, 2003). The models contribute to a better understanding of the real-world processes and provide quantitative information to support decision-making activities. One of the situations in which these models can be applied is in assessing the effect of the water demand scenarios on water availability to downstream users in the river basin so that better decisions are arrived at when allocating the water to different uses.

Effective decision making in water resources management can only be achieved by comprehending how the entire river basin system responds to different water demand scenarios and hydrological impacts of the planned developments. This research focuses on contributing to the planning and development of the catchment by proposing an appropriate water allocation mechanism to increase the overall management of the Thuli river basin in trying to improve the livelihoods of the people through the use of a simple spreadsheet model which simulate different water demand scenarios.

The research was carried out in Thuli river basin of the Mzingwane catchment which is situated in the south west semi arid areas of Zimbabwe. There are several water users spread throughout the river basin categorized into agriculture, domestic, urban and mines. Satisfying the demand for these various users requires a management strategy for optimal utilization of the water resources (Nyagwambo, 1998). Employing integrated water resources management (IWRM) in managing the water resources of the river basin is therefore vital.

1.2 Problem Statement

It has been observed that the Thuli river basin is more developed in its upper than lower reaches (Love *et al*., 2006). There is intensified use of blue water in the upper catchment and that demand from powerful sectors such as urban is increasing (Love *et al*., 2005).

The interventions to improve rural livelihood and food security, that involves the water uses, are being implemented in the basin. Furthermore, two irrigation schemes and two dams have been proposed to be constructed at the downstream of the basin. Requirements based on policies like satisfying the ecological water needs and inter basin water transfer have to be implemented as well. These interventions might create water demand scenarios that are likely to increase the water demand. Nevertheless, Thuli river basin is situated in a semi-arid area, where surface water resource availability is a constraint (Love *et al.,* 2005).

For the interventions to be sustainable, proper understanding of the effects of water demand scenarios, brought about by such interventions, on downstream water availability is essential in the effective management of the water resource.

1.3 Research questions

The main research question of the study was: what are the effects of water demand scenarios on water availability to downstream users and what water allocation mechanism can be suitable for the river basin?

The specific research questions of the study were formulated as follows:

- What is the total surface water demand for the catchment?
- Is there enough surface water in the catchment to satisfy the demands?
- What are surface water allocation mechanisms in the catchment?
- What will be the effect on water availability to downstream users if:
  - the planned water supply scheme to Bulawayo is put in place?
  - irrigation system management and operation is changed to achieve higher water use efficiency?
  - the cropping patterns in irrigation schemes are altered?
  - the proposed irrigation schemes and dams are implemented
  - the urban water demand increases?
  - the water is reserved for the environment and future use?

1.4 Research Objectives

The main objective was to evaluate the effect of water demand scenarios on water availability to downstream users in Thuli river basin

1.5 Specific objectives

- To establish surface water users and quantify the water demand
- To assess spatial and temporal surface water availability in the river basin
- To investigate the current water allocation system in the catchment
- To apply a model for the simulation of different water demand scenarios
- To determine and analyse the effects of different demand scenarios on water availability to downstream users.

1.6 Structure of the Study Report

Chapter One outlines the scope of the research, highlighting the research problem, research questions and the objectives of the study. Chapter Two is the review of literature relevant to this research. Chapter Three describes the methodologies followed in collecting and analysing data. A brief description of the study area, giving details on physical location, climatic characteristics and water use are briefly discussed in Chapter Four while Chapter Five presents the results and discussions. Chapter Six gives the conclusions of the study and the recommendations.

2 LITERATURE REVIEW

2.1 Introduction

The World Summit on Sustainable Water Development held in Johannesburg, South Africa in 2002 called for development of Integrated Water Resources Management (IWRM) and water efficiency plans for all countries by 2005 (UNDP, 2004). IWRM as defined by GWP (2000) "is a process, which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." One of the management principles in the context of IWRM requires identifying what is there and what needs to be achieved which implies carrying out an assessment of what is available- who needs what and when?

In the Zimbabwe National Water Resources Management Strategy, equitable access to water is one of the most immediate issues to be addressed. This requires a water allocation system that promotes equal access to water for all through equitable allocation among the different water users. The 1998 Zimbabwe Water Act replaced the water right system with the water permit system where permits are issued for defined periods (Section (34)). Issuing of the water permit is now on the basis of the of criteria defined by the catchment's outline plan, which considers among other requirements, the economic use of water and the availability of water in the catchment (WRMS, 1998).

The literature review will focus briefly on the water demand and supply, the Zimbabwe Water Act (1998) and how related studies applied a Water Allocation and Flow model in Excel (WAFLEX) and other surface water models to support water management decisions using different scenarios.

2.2 Water demand

The United States Geological Survey (USGS) defines water demand as amount of water need for all users. While Savenije and van der Zaag (2003) go a step further by incorporating the spatial component. They define water demand as the amount of water required at a certain point. However, it should be known that there are certain diffuse water demands which do not have specific demand nodes. Examples include livestock consumption and rural domestic water use. Wallingford (2003) in a simplified way considered water demand as being equal to water consumption, although conceptually the two terms do not have the same meaning. This is because in some cases, especially in rural parts of southern Africa, the theoretical water demand considerably exceeds the actual water use. To better understand the global trends of demand, several studies have been done. Studies conducted on global water demand (Seckler et al., 1998) projected that one third of the population of developing world will face severe water shortage.

The water shortage problem projected can be curbed down in several ways. Keller (1998) pointed out the importance of increasing storage, in semi-closed basins, through a combination of groundwater and large and small surface water facilities as being critical in meeting the water demands of the twenty-first century.

Zimbabwe's annual potential water yield at 10 percent risk (resources in a dry year of a 10^{th} year frequency) from all river basins, as reported by FAO (2005), is estimated to be 11260 Mm^3 / year. This assessment excludes external surface water resources from such bordering international rivers like the Zambezi and Limpopo. However, over the years, growing urbanization, changes in agricultural practices and industrial and mining activities have increased the demand for fresh water (WRMS, 1998).

2.3 Water demand scenarios

Water demand scenarios in this context are defined as a set of different future water use patterns for all water users and followed by the analysis of their impact on water availability on downstream water users.

In Modeling Water Resource Management several scenarios are created depending on the future impacts that are required to be assessed. In this context the scenarios were created based on the government plans and policy on water development, drought risk mitigation and technological improvements in water utilization because these might affect the water availability to downstream users.

In Lake Naivasha several scenarios were created based on a variety of economic, demographic, hydrological, and technological trends (Alfarra, 2004). The scenarios were modeled with Water Evaluation, Analysis and Planning (WEAP) model. Then one or more policy scenarios were developed with alternative assumptions about future developments. The scenarios addressed a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if reservoir-operating rules are altered? What if water conservation is introduced? What if new sources of water pollution are added? What if a water-recycling program is implemented? What if a more efficient irrigation technique is implemented? What if climate change alters the hydrology? These scenarios were viewed simultaneously in the results for easy comparison of their effects on the water system.

In related studies, Kite et al., (2001) used unstructured discussions with managers, water users, policy makers and fellow researchers to develop a wide range of demand scenarios, for modeling. In contrast, (Seckler et al., 1998) just assumed two scenarios in modeling world water supply and demand. Both scenarios assumed that the per capita irrigated areas would be the same in 2025 as in 1990. The difference between the scenarios was due to different assumptions about the effectiveness of the utilization of water in irrigating crops.

Smits et al., (2004) developed water demand scenarios based on the papers which earlier described Sand River Catchment in South Africa, as well as on discussions with stakeholders about possible future developments of water resources, infrastructure and demand. The starting point for all scenarios was an assumption that the water resources of the catchment should, in line with legislation, be safeguarded first for domestic and environmental requirements. Working from this assumption both existing and potential future use was examined, as were changes in land management.

2.4 The Water Resources Management Strategy and the Water Act of Zimbabwe

The water sector of Zimbabwe went through major reforms to ensure that the water resources are managed and utilized in a sustainable manner. The Government of Zimbabwe put in place a legal framework for a new approach in water resources management in the country because of the introduction of Water Act (Chapter 20:24) and the Zimbabwe National Water Authority Act (Chapter 20:25). The policy framework recognizes the role and importance of water in a multi-sectoral dimension and provides for a legal framework within which the water resources can be shared and utilized (WRMS, 1998). While WRMS, (1998) indicates that all Zimbabweans should have equal access to water as the basic right and stakeholders should be involved in decision making in the development and management of the resource. The implementation of the water resources management strategy has to overcome several challenges namely; equitable access to water for all, growing competing demands on water resources, fragmentation of water resources management, degraded environments and pollution of water resources and treatment of water as an economic good.

For the challenges to be overcome, the new Water Act of 1998 was introduced. Under this Act, all water in Zimbabwe belongs to the state (Section (4)). No person is entitled to ownership of any water and that no water can be stored, abstracted, apportioned, controlled, diverted, used or in any way dealt with except in accordance with the Act (Section (3) and Section (4) (1) Water Act 1998). Beyond basic consumption (Primary use), the users are required to obtain permits (Section (4) (2)). The Minister, after consultation with the National Water Authority may by statutory instrument, declare any catchment area a river system (Section (11) (1)) and that such a river system will be under the control of a catchment council (Section (11) (2)). To ensure optimum development and utilization of its water resources, the catchment council and the National Water Authority are mandated to prepare an outline water development plan (Section (12) Water Act 1998) through consultation with all stakeholders.

The outline plan contains the major uses within the catchment (Section (13) (a) (i)) Water Act 1998) and it indicates the extent to which actual volumes or the relative proportions of potential yield or total annual runoff of any catchment area should be allocated to different sectors of the economy (Section (13) (a) (ii)). It further indicates priority in water utilization and allocation of water following the guidelines provided by the

Minister (Section (13) (2)). The catchment outline plan shall be reviewed after every ten years (Section (19) (1)).

The catchment council observes certain principles in considering applications for permits for use of water. In a situation where more than one water users apply for the same water use, the catchment council strives to achieve equitable distribution of the available water resources, the needs of each applicant and the likely social-economical benefits of the proposed use (Section (23) (1) (a) (i) (ii) (iii) Water Act 1998). In terms of water allocation, the Minister, after consultation with the National Water Authority and the catchment council, may prescribe matters to be considered when prioritising the allocation of water to different users, the manner of allocating water between users with competing needs for water and the methods of allocating water (Section (23) (2) (a) (b) (c) Water Act 1998).

In times of water shortages in the river system when the volume does not satisfy all the permits granted, the catchment council is mandated to revise, reallocate or reapportion the permits upon such conditions and in such a manner as will ensure the equitable distribution and use of the available water (Section (54) Water Act 1998).

2.5 Surface Water Modeling

Surface water is that part of the water found in open water bodies for example, in rivers and reservoirs. Modelling is the simplification of an intricate system where variables within the system are directed. A surface water model is a hydrological model with emphasis on surface water. Clarke (1972) referred a model to a simplified representation of a complex system. Makurira and Mul (2004) further elaborated that a model is a package that facilitates the simulation of a system out of a conceptual framework of the system.

By manipulating a set of variable parameters, it becomes possible to predict the performance of the system under a set of operating rules. Models are developed and used in order to facilitate decision making. A model is viewed as an interface between data and decision making, that is, a model generates information from data and improves knowledge which is required by decision making (Schulze, 1998). Models also identify and evaluate alternatives and help to predict and better understand trade-off among goals, objectives and interests (Makurira and Mul, 2004). Models can be applied to vast problems in water resources like simulation of natural discharge, operational forecasting, and prediction of effects of future physical changes in a catchment.

Different models are used for different purposes depending on the purpose of the model and data availability (Schulze, 2003). To derive best results from the model, the input data has to be of good quality. Schulze (2003) emphasised the need to spend 80% of model input time on quality controlling the input in order to attain good results from the model there are uncertainties in the data sets used in modeling, associated with these are data quality associated resulting from the inherent inaccuracies in rainfall and runoff measurements, the incidence of missing data, inadequate instrument design and maintenance whereby control runoff gauging stations are overtopped during flooding at certain threshold stage. However, selection of the model, as explained by Savenije (1997), is the function of availability, accessibility and simplicity of the data management facilities of the model.

One such a model which is simple and has good data management facilities is the Water Flow Model in Excel (WAFLEX). It is a spreadsheet model that provides transparency and flexibility. The Waflex model has been developed to tackle problems such as the allocation of scarce resources like water. Its network functions are based on the equation of continuity and the fact that water flows from upstream to downstream.

Several studies have applied WAFLEX model as a decision support tool. In Southern Africa, for example, Nkomo (2003) used the WAFLEX model as a decision support tool to investigate the water availability for the Komati catchment in Swaziland and South Africa and it was found that releasing water from the dams in the upper Komati went some way in alleviating water shortages, especially in the Lower Komati in South Africa. In Zimbabwe, the model was applied in Odzi river of Save catchment by Symphorian (2003) to incorporate a component of Environmental Water Requirement (EWR) in reservoir simulation. It was found that the present water use levels for EWR in the river would be met and that future increase in abstractions will result in significant water releases for the environment. It was concluded that WAFLEX model can provide practical guidelines to catchment managers and dam operators to implement EWR.

However, the model can easily be abused since it cab be easily be modified and manipulated to suit ones' needs, usually over simplify issues and usually can not be used for conclusive decision making. It also oversimplifies the situation for example; water losses like evaporation, seepage and transmission are not accounted for.

The model can still be used for decision support tool particularly for strategic decisions. It can be used to give initial guidance to planning and development of water resources in a basin. The model gives quick or rapid assessment conditions of implications of measures for river basin management and development.

3 RESEARCH METHODS AND MATERIALS

3.1 Introduction.

To obtain the data required for this research several methods were used. Initially, a desk study was done where the map for the study area was studied in order to observe the physical characteristics of the river basin and different demand nodes were located. Visits were paid to different institutions and recorded data were collected from these institutions. The data collected using this method was; permitted water abstractions, runoff, existing dams, dam development proposals, rainfall and evaporation. Other methods employed, were interviews, focus group discussion, site visits to some of the water demand nodes in the catchment whose data was not available and one on one meeting with ZINWA officials (Bulawayo and Harare), officials from the mines and also AREX staff.

3.2 Data Collection

3.2.1 Runoff data

Historical monthly runoff data was collected for the thirteen selected gauging stations found in the Thuli river basin from ZINWA. The runoff data for the thirteen gauging stations were selected to be considered as inputs for the model (Appendix B). The gauging stations had the runoff records varying from 23 to 53 years. Some of these runoff stations selected had the flow characteristics that had been significantly affected by upstream impoundments or flow abstractions (Love, 2006) hence required naturalisation. The monthly data selected as input for the model was from the data records of 1983 to 2005 because this was the period with few data gaps and less in-homogeneities in the recorded time series runoff data.

The runoff data were naturalized using the naturalization equation 3.1 which was used in modeling water availability in Texas by Wurbs (2004).

$$QN = QG + \sum D - \sum RF + \sum E + \sum \Delta s \qquad \textbf{Equation 3.1}$$

Where;
Q_N is the naturalized runoff
Q_G is the gauged runoff
$\sum D$ is water diversion from river system upstream of gauge
$\sum RF$ is return flows from river system upstream of gauge
$\sum E$ is the net evaporation from reservoirs allocated upstream of gauge
$\sum \Delta s$ is the change in storage of upstream reservoirs.

The equation was applicable to the study area because it was used in the region with variation in climate and geography across the Texas State from arid west to humid east. The area where the equation was applied had a mean annual precipitation varying from 200mm/a to 1400mm/a. This therefore means that the equation is applicable to wide range of the environment. The equation did not take into account the seepage and transmission losses. The results of the natural flows are presented in Appendix D.

Some data quality checks were done on the naturalised run off data. Figure 3.2.1 shows the rainfall data from Gwanda station and the naturalised flows from gauging station B55 which is close to Gwanda rainfall station from the period 1983 to 2003.

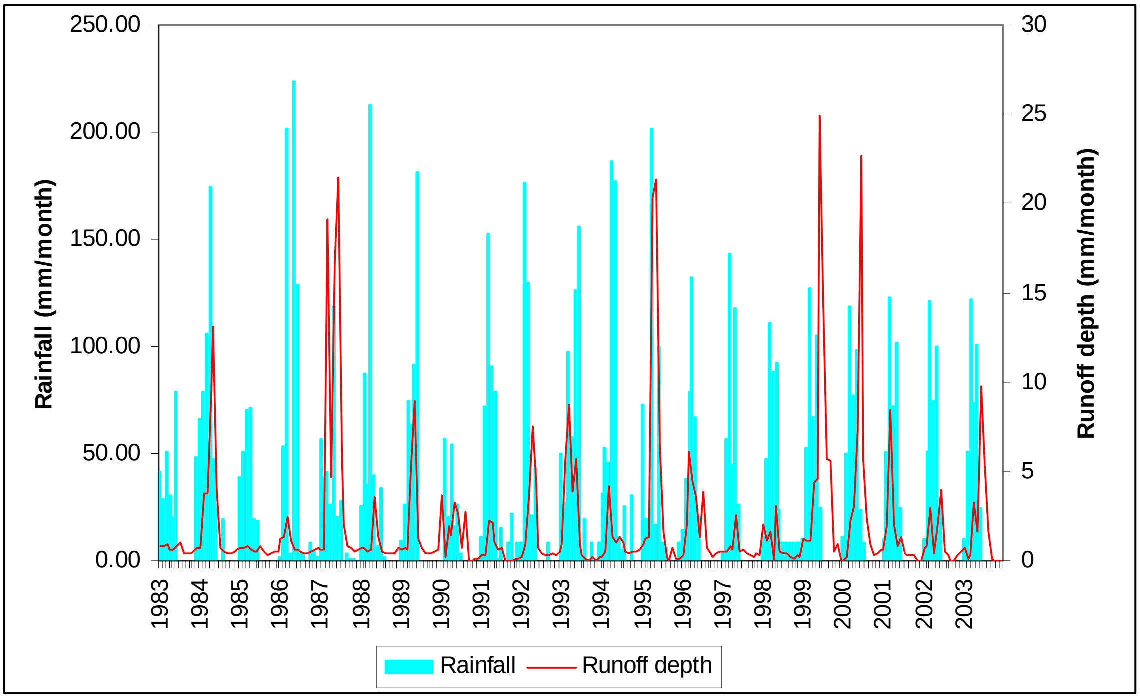

Figure 3.2.1: Rainfall and naturalised runoff

Most of the years as shown had rainfall runoff of relationship synchronizing. However, the rainfall runoff relationship in the years 1983, 1988, 1991 and 1997 looked suspicious. This led to conducting a simple linear regression between B55 and B29 which are close to each other to replace the suspicious values. The rainfall and runoff per hydrological year and runoff coefficient were also plotted see APPENDIX F (a). The results showed that most of the 75% of the years had the runoff coefficient lying between the normal range of 0.01 to 0.06 (Woltering, 2005).

3.2.2 Rainfall

The daily rainfall data was collected from the meteorological office in Harare. The data was then processed into monthly time step. The rainfall stations in the catchment where the rainfall data was collected were Thuli, Matopos, Mbalabala and Gwanda and the data collected was from 1987 to 2000. The rainfall data gaps were filled through simple linear regression see (Appendix F). The rainfall data was inputted in the model to establish the inflow in the reservoirs.

3.2.3 Evaporation

The daily pan evaporation data were collected for Thuli, Matopos and West Nicholson weather stations and ranged from 13 to 15 years. The data was then converted into monthly time step by multiplying the pan evaporation by a factor 0.67 as recommended by World Meteorological Organisation (WMO) and inputted in the model to determine the evaporation losses from the reservoirs in the catchment. Linear regression was done to feel the missing gaps (Appendix I). Evaporation losses from dams were simulated using storage-area graphs as the model was running. The model, however, did not take into account the transmission and seapage losses in the river channel**.**

3.2.4 Water permits data

The data on water permits abstractions for the Shashe sub catchment was collected from ZINWA. The water permits for the Thuli catchment were isolated from the water permits for the sub catchment. From the isolated list of water permits, the purposes of the permits were identified. Using the water permit data, the purpose for the government permit was probed further to isolate the specific uses of water as it appeared general (see Appendix E).

Interviews and four focus group discussions were done at Thuli-Makwe irrigation scheme, Chelesa, Mankokoni and Rustlers irrigation schemes to obtain the data on the cropping pattern being followed in irrigation schemes and the area assigned to different types of crops in grown in the irrigation schemes. This data was used to calculate the crop water requirements which were summed up to come up with the estimates of irrigation water demand.

3.2.5 Water demand data

Water demand for most of the users was taken from the water permit. An assumption was made that the volume specified on the water permits were equal to the water demand. In cases of non permitted water user, interviews were done and the data collected from such interviews was used to calculate the water demand. The active and non active permits were identified. All the non active permits were not considered as demand nodes.

3.2.6 Domestic water demand

To calculate domestic water demand for the non-permitted users, the information obtained from literature (DFID, 2003) was used to estimate the demand (See Appendix K)

3.2.7 Agriculture water demand

The water permits did not indicate the types of crops grown under irrigation and acreage.

For this reason water for irrigation purposes was calculated using FAO cropwat software which uses Penman-Monteith method. The meteorological data from West Nicholson weather station was used. The crop evapo transpiration was calculated using the formula:

$$ET_{crop} = K_c * ET_o \quad \textbf{Equation 3.2}$$

Where:

K_c is the crop coefficient

ET_o is the potential evapotranspiration in mm/day.

The K_c values were obtained by constructing the K_c curves taking into consideration the date of planting, the crop growth stages and their duration, crop growth duration and the cropping pattern. Figure 3.2.2, below is the example of the K_c curve.

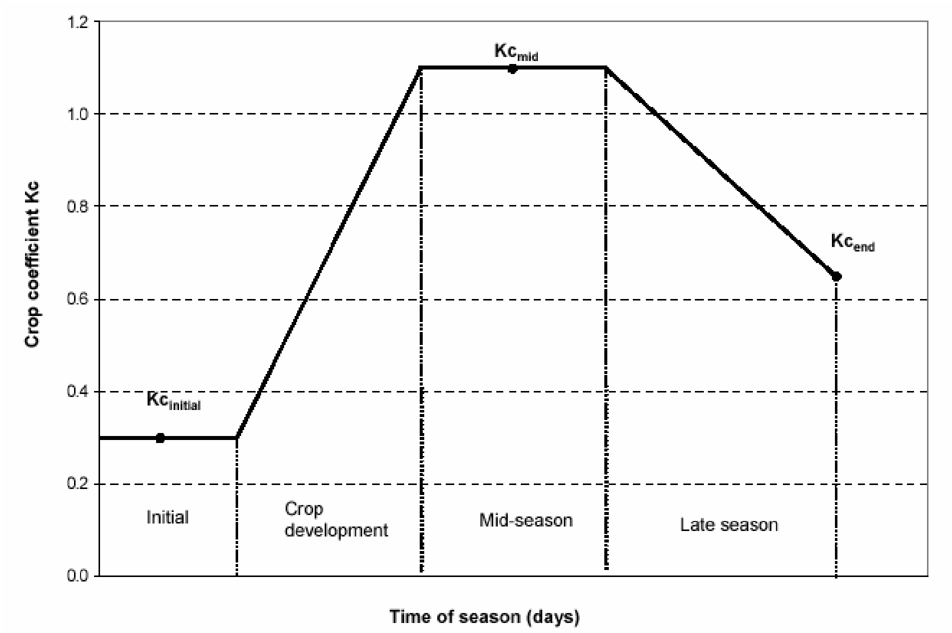

Figure 3.2.2: Example of Kc curve (Wallingford, 2003)

The results of crop water requirements are presented in Appendix G and H.

3.3 WAFLEX model configuration

This section highlights how the water flow model was configured in excel. This was aimed at applying a model for simulating the immediate and consequent downstream basin's response to the different water demand scenarios.

The Thuli river system is conceptually represented in Figure 3.3.1. The main stem is the Thuli river and the shaded text boxes represents its tributaries. The water users are shown alongside the tributaries.

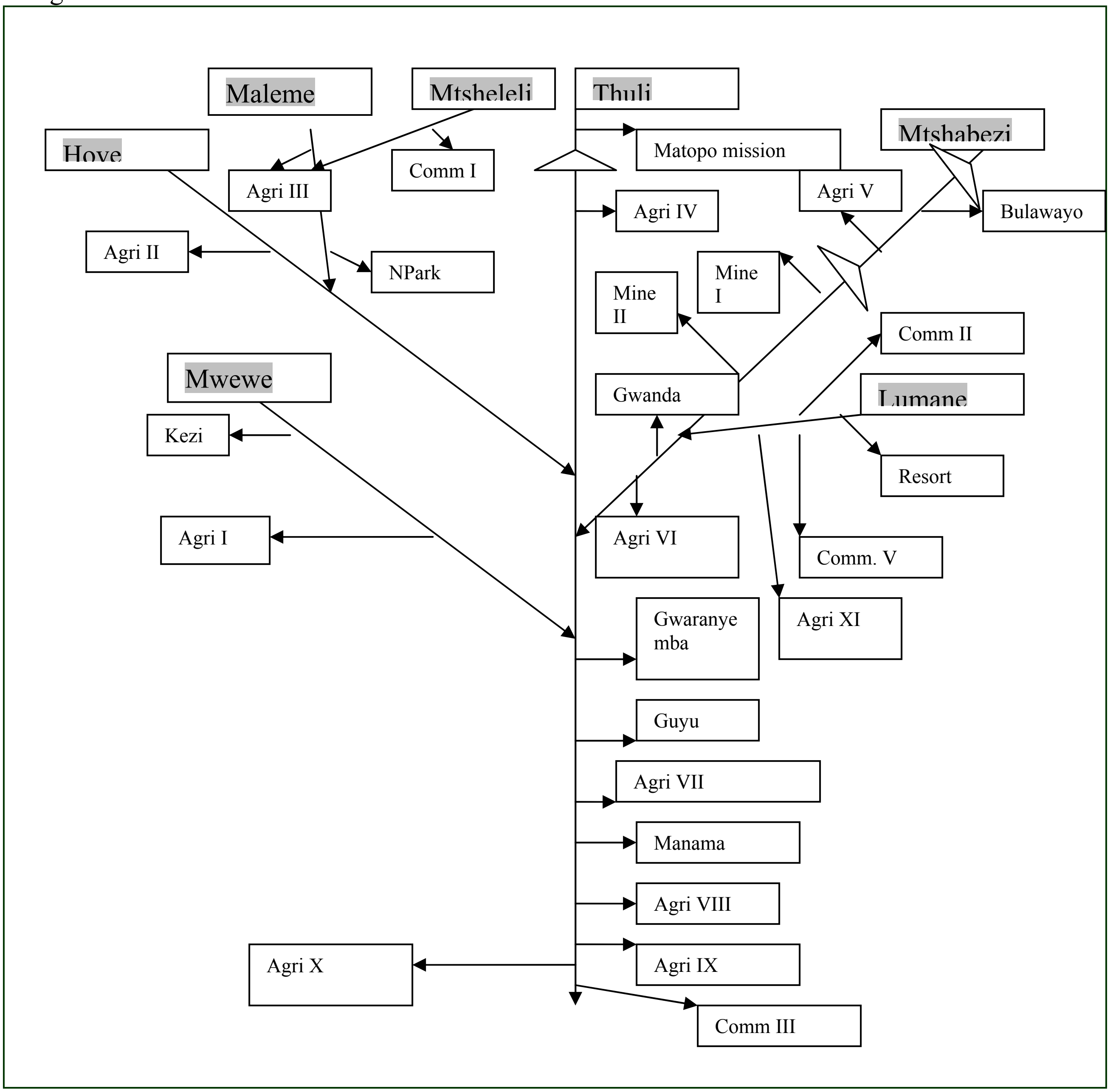

Figure 3.3.1Conceptualization of the Thuli river system

The model is based on a network of spreadsheet cells which are interlinked. The inputs into the model in this study include inflows (runoff) water demands along them. Below is an example of a simple network. It consists of a river, tributaries and a water user.

	B	C	D	E	F	
37				**1185**	downstream	
38				**1185**	**150**	*Tributary*
39				**1035**		
40	*Tributary*			**1035**		
41	**350**	**350**	**350**	**1035**		
42				**685**		
43		*User*	**-215**	**685**		
44		**City**		**900**		
45				**900**		
46				**900**	upstream	

Water balance is calculated for each spreadsheet cell. Each cell sums the flow that comes from upstream. For each time step (month), the flow is calculated in each cell adding up the flows of upstream and adjacent cells. Flow availability on each node is calculated by adding the inflows from upstream to downstream as (inflow subtracted by demand).

3.4.1 Definition of System Variables

The system variables in WAFLEX model include the water demands, inflows and outflows. This section describes how the water demands were incorporated in the WAFLEX model. Some basic assumptions were made for simplicity when representing the users/water demands along the river in the WAFLEX model. The users with the same purpose closer to each other along the same river stretch were lumped together.

The following steps were followed when developing the model:

- Step 1: Excel sheets were created for the various components. The river schematization was done in the supply sheet. In this sheet, the flows were also calculated in the downstream direction. In demand sheet, schematization of the river was also done and the demands in the river network calculated by adding them in the upstream direction. Abstraction points were represented in the network as nodes. A reservoir sheet was included.
- Step 2: Cells were interlinked to form the river system including all outflows and inflows into the river. Various colors were used to represent the users along the river.
- Step 3: In the series sheet, the inputs (observed run off) and all the demands (calculated somewhere else) were copied in columns. V-LOOKUP FUNCTIONS were also defined, which look up for each time step calculation**.**

- Step 4: The supply sheet and the series sheet were linked using the = (INDIRECT FUNCTION). On each node, a logical operation was put to allow abstraction.

- Step 5: Macros were written in the macro sheet using visual basic program in Ms Excel. An example of macros used is shown below.

```
 Sub Computation()
'This procedure starts a loop to compute all time
                              steps

 For Count = 1 To Range("end").Value
   Range("Counter").Value =
                 Count
  Calculatetimestep
       Next Count

      End Sub
 '---------------------------
    Sub Calculatetimestep()
  'Computation of one timestep. Each time step the results in the range $output are
                                                      copied
'to the right location in the output table.

Application.Calculate
     Range("Output").Copy
   Range("Output").Offset(Range("Counter").Value + 4, 0).PasteSpecial
                                       (xlPasteValues)

      End Sub
```

- The model was then run and the downstream flow was noted for each run. The scenarios run included:
    - improvement on irrigation system efficiency : how changing the surface irrigation system to sprinkler or drip system will affect water availability to downstream users
    - inter basin water transfers to Bulawayo from Mtshabezi dam: what will be the effect of changing the percentage allocation of water for inter basin transfer on water availability
    - construction of proposed Thuli Moswa and Elliot dams in the lower reaches of the river basin: if construction of the dams is to proceed how will this affect water availability to downstream users in the catchment
    - the cropping patterns: effects of changing the cropping pattern in the irrigation schemes on water availability to downstream users
    - implementation of planned irrigation schemes and how they will affect the water availability.

3.4.2 Water Balance

Water balance calculations were used to monitor the errors in the model and to ensure that all water within the system was accounted for. The following water balance equation was used:

Water inflow – water outflow-change in storage = 0
Inflows- abstractions-downstream- unaccounted losses = 0.

3.4.3 Sensitivity Analysis

The models' sensitivity was checked by making all the demand nodes constant while changing the water demand on one node. A slight change in water demand, like increasing or decreasing the demand of nodes with low water demand did not reflect much increase or decrease on downstream flow.

4 The Study Area

4.1 General Background to Zimbabwe

4.1.1 Physical Characteristics

Zimbabwe lies in the Southern part of the continent of Africa between latitudes 15°30' and 22°31' south and between longitudes 25° and 33°10' east. The country is landlocked, with 20% of its territory being more than 1200m above sea level. The country is bordered by the Zambezi river to the north and Limpopo river to the south. Zimbabwe is divided into three physiographic regions: the highveld (sometimes called the central watershed) runs from south west to north east across the country at an altitude between 1200 and 2000 m above sea level, the middleveld with an altitude between 600 and 1200 m lies on each side of the highveld, and the lowveld lying mostly in the southern part of the country and also in the northern part along the Zambezi, at altitudes below 600 meters.

4.1.2 Climate

The mean annual temperatures range approximately, from 18°C in the highveld to 23°C in the lowveld. Three distinctive seasons are experienced:

- Hot dry season (Mid-September to Mid November)
- Warm to wet season (Mid-November to March)
- Cool to warm dry season (April to Mid-September)

Annual rainfall generally declines from eastern mountains, where it is on average over 1000mm/a, towards the West and South of the country, with annual averages between 800 and 1000mm/a in the center and north, 600-800mm/a northern two thirds of the country and in the rest of the country rainfall is less than 600mm/a. The coefficient of variation of annual rainfall lies between 20 and 40 percent, with the highest values prevailing in the low rainfall areas (Musariri, 1998)

4.1.3 Surface water resources

Zimbabwe is divided into seven catchment areas each defined by a major river system and associated tributaries (WRMS, 1998). The percentage of rainfall that becomes runoff in the river systems ranges between 10% and 14%. The total runoff corresponds to 52 mm/a of depth. Spatial variations in runoff are extensive, such that run off ranges from 15.7mm/a in the lowveld to 157.8 mm/a in the highveld (MEWRD, 1986).

Thuli River Basin

Thuli River is in Mzingwane Catchment in Zimbabwe and is a tributary of the Shashe River, which is a tributary of the Limpopo. It flows from Matopo Hills World Heritage Site at an approximate altitude of 1450 m above mean sea level through resource poor communal lands and discharges in the semi-arid area south of Zimbabwe, on the edge of the Shashe-Thuli Trans frontier Conservation Area. The river is perennial in its upper reaches and ephemeral in its lower reaches. The major water users of the Thuli Basin are

City of Bulawayo, Gwanda Town, Blanket and Vubachikwe mines and the Thuli-Makwe Irrigation Scheme (Love *et al.,* 2005).

The river flows to the southeastern direction into the river Limpopo as shown in figure 4-1 below, carrying with them sediments. In certain parts of river courses, flow occurs only during the wet months (October to March), while during the dry months (April to September) the riverbed is a sandy alluvial bed of considerable thickness and provides enormous storage of water. These alluvial formations serve as sources of water for rural communities. While the temporal distribution of rainfall follows the general pattern of the Southern African region with wet months between November and March, the spatial distribution of rainfall is quite variable over the entire catchment. The annual rainfall ranges from 250mm/annum in the south to 550mm/annum in the north of the catchment, with average of about 350mm/annum over the entire catchment. One feature of the aridity of the catchment is the annual evapo-transpiration rates being higher than those of precipitation, so that there are long-term net fluxes of moisture from the catchment. Figure 4.1.1 shows the location of Thuli river basin in the Mzingwane Catchment.

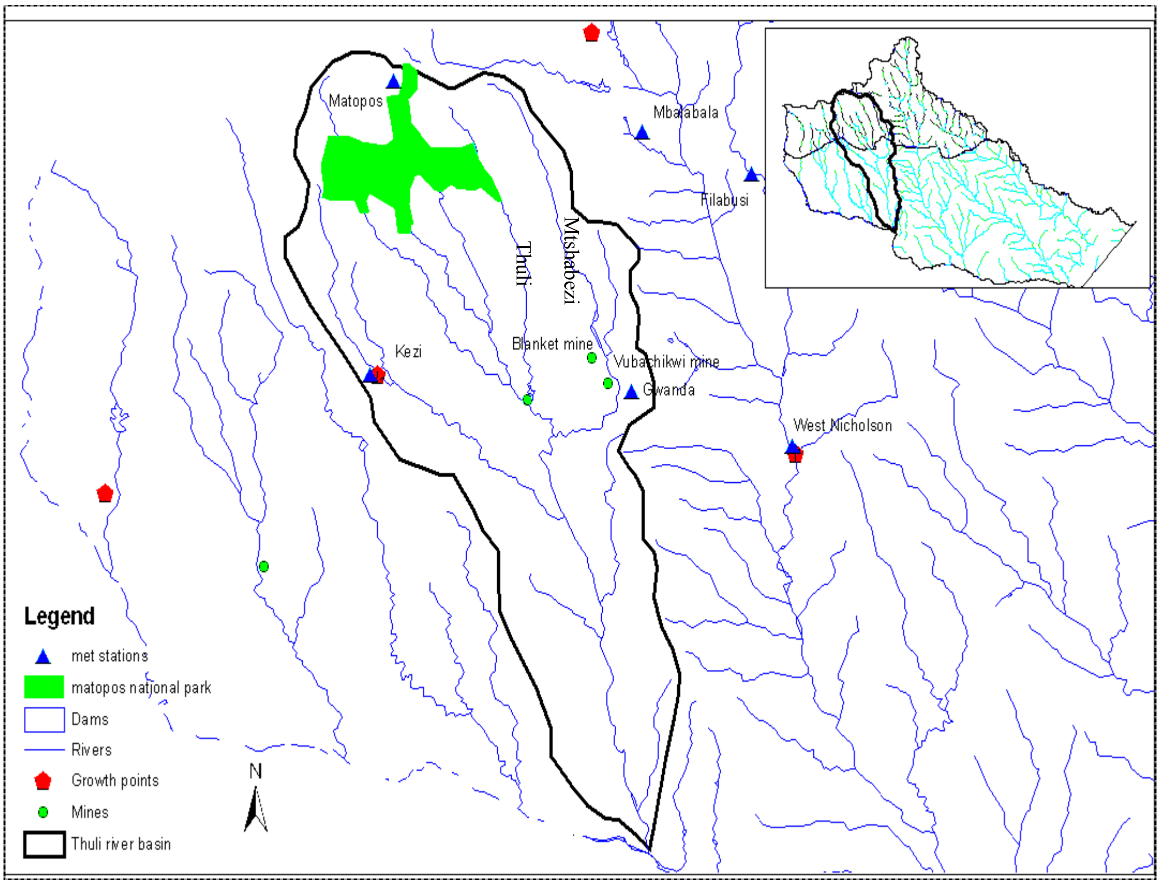

Figure 4.1.1: Thuli river basin location in Mzingwane catchment

4.2.1 Catchment Characteristics

Thuli River is under Shashe –Thuli Sub-catchment (Water Management Area).The catchment area is 7910 Km^2 in extend. Most of the sub-catchment is underlain by the Zimbabwe Craton: Gwanda Greenstone Belt, Lower Gwanda Greenstone Belt, Mphoengs Greenstone Belt and granitic terrain. The south is underlain by Limpopo Belt gneisses and the far south (Thuli Village area) by Karoo basalts. Greenstones formation has most of gold mines and has an expected average yield of 100-250 m^3/day.Granite and gneisses have an expected yield range of 50-100 m^3/day (Ashton *et al*., 2001).

Soils in the sub-catchment can be divided into four groups:
- Moderately shallow, coarse-grained kaolinitic sands, derived from the granites;
- Very shallow to moderately shallow sandy loams, formed from gneisses;
- Very shallow to moderately shallow clays, formed from the Greenstone Belts; and
- Very shallow sands, derived from the basalts.

From Kezi northwards, the sub-catchment is in Natural Region IV, with low (under 650 mm/a) and unreliable rainfall, and poor soils. South of Kezi is in Region V, with poor soils, rainfall below 600 mm/annum and in other places its below 450 mm/annum. North of Kezi, land use is commercial farming, private and resettlement land, mainly livestock rearing with some drought resistant crops. The south is Communal Lands, and agriculture limited mainly to livestock, especially goats. The main settlements are Plum tree town, Kezi and Maphisa Villages (Ashton *et al*., 2001).

4.2.2 Management

Under ZINWA, the sub-catchment is managed by the Shashe-Thuli Sub-catchment Council, which has the chairman at the top. The sub-catchment falls within the local government districts of Mangwe, Matopo and Gwanda. The sub catchment council is formed by Minister responsible for water using the statutory instrument (water act and policy) (Water act 1998, section (24)). The Minister is also responsible for the fixing of the membership of the sub catchment council and directs the manner in which the membership is elected. Membership is open to all stakeholders involved in water issues within the area of establishment. The sub catchment operates as corporate body capable of suing and being sued in its own name. Its powers are to regulate and supervise the exercise of rights to water within the area for which it was established. It also performs the functions as may be conferred or imposed upon it in terms of the water act 1998. The sub catchment can also levy rates upon persons who hold permits within the area in which the sub catchment was established and charge fees on any services rendered by it.

4.2.3 Water resource developments in Thuli catchment

(a) Existing developments

Thuli river is only developed to 0.31 MAR of which Mtshabezi dam makes up to 0.18 MAR (Yield 30600Ml). Gwanda municipality also takes water from Blank dams from Mtshabezi river. There are large irrigation schemes at Thuli-Makwe, Shashe and Ngwezi managed by a farmer committee, with support from AREX. The list of the existing dams is given in Table 4.1

Table 4.1: Existing dams in Thuli river basin

Dam	River System	Dam Capacity (ML)
Thuli Makwe	Thuli	8300
Mtshabezi	Mtshabezi	52200
Lower Mujeni (Blanket)	Mtshabezi	10500

(b) Proposed dam developments

The pre-feasibility study done on the major dam developments in the catchment proposed the developing of two storage facilities as shown in Table 4.2

Table 4.2: Proposed dams in Thuli river basin

Dam	River system	Proposed capacity (ML)
Thuli Moswa	Thuli	419000
Thuli Elliot	Thuli	33000

The figure 4.1.2 is the map of Thuli river basin showing the location of existing and potential dam sites. It also shows the location of the gauging stations and the rivers which make up the basin.

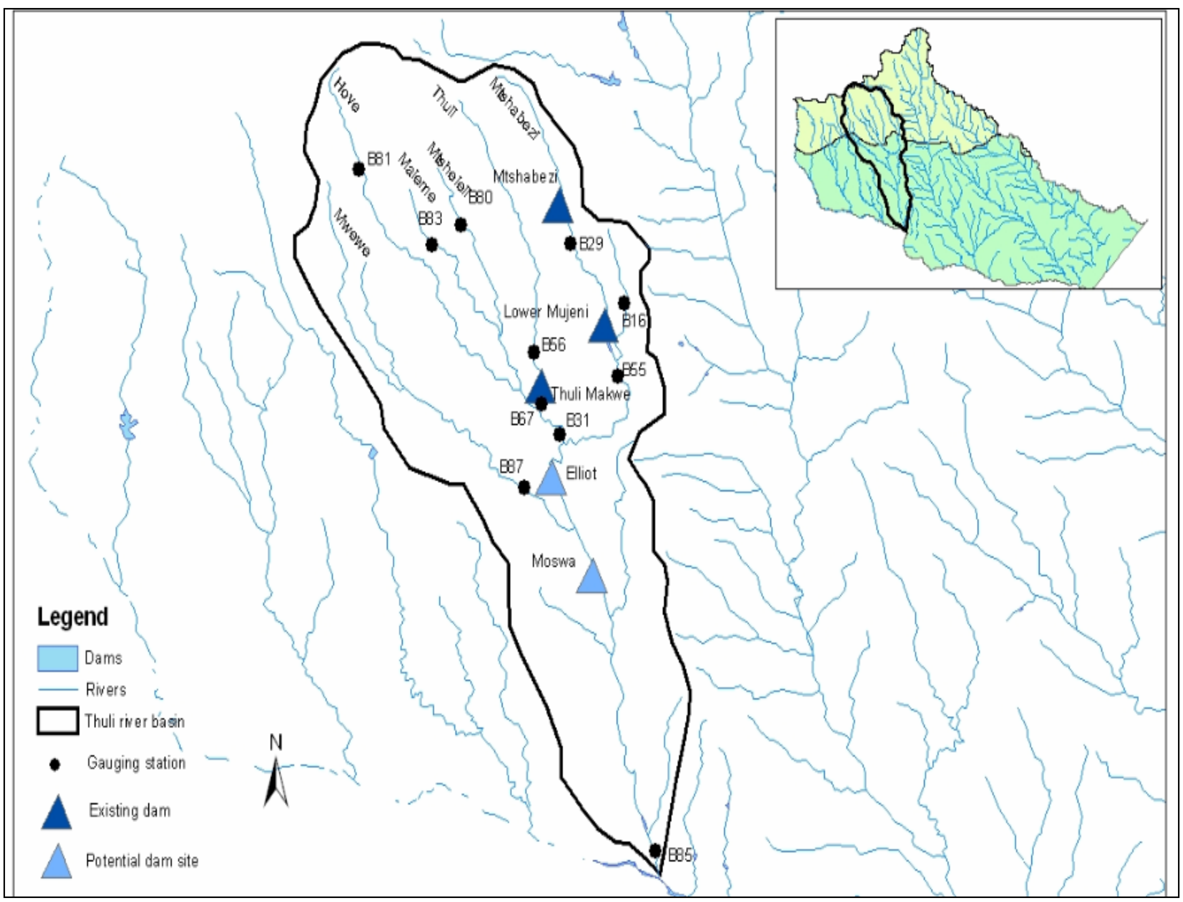

Figure 4.1.2 Thuli River Basin showing existing and proposed dams, rivers and gauging stations.

5 RESULTS AND DISCUSSION

5.1 Water Resources Availability in Thuli River Basin

The spatial water availability was assessed by looking at the 6 hydrological sub-zones. Time series run off records varying from 23 to 57 years, obtained from ZINWA research and data division, were used to calculate the mean annual runoff (see Appendix B). The runoff gauging stations used were B85, B87, B31, B67, and B55 as shown in Map 4.2 for the hydrological sub zones BT1, BT2/BT3, BT4, BT5, and BM respectively. The hydrological sub zones are shown in Map 5.1 below.

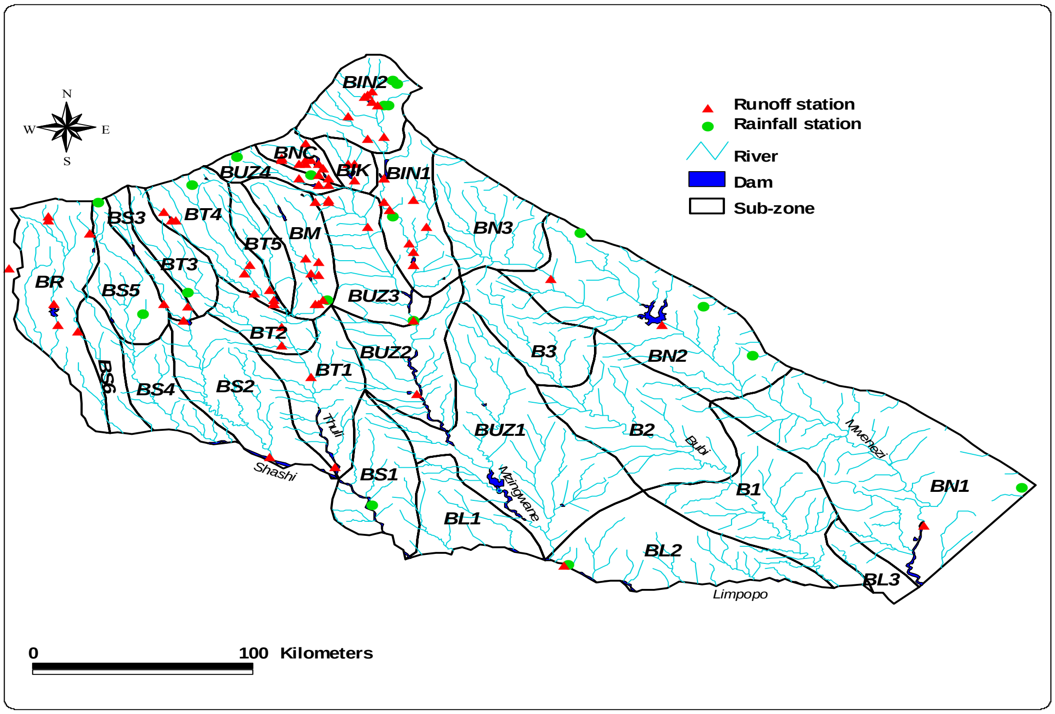

Figure 5.1.1: Showing the hydrological sub zones. (Source: ASWR for Mzingwane catchment, 2005)

Table 5.1 below shows the Mean annual runoff (MAR), coefficient of variation (CV) and the water demand in the different hydrological sub-zones in the river basin.

Table 5.1: Estimated mean annual runoff and coefficient of variation in hydrological sub zones

Hydrological Sub zone	Mean annual runoff (Mm^3/a)	Coefficient of variation	Water demand in hydrological zone (Mm^3/a)	Unit Runoff (mm)
BT1	161.4	1.29	5.3	210
BT2/BT3	22.8	1.96	0.3	16
BT4	151.8	1.19	11.9	37
BT5	31.4	1.65	2.7	41
BM	34.1	1.29	7.6	35
Total			**27.8**	

The runoff data analysis showed that that hydrological sub zones BT1 and BT4 had high MAR and high water demand while sub zone BT2/BT3 had the least MAR and water demand but had the highest CV. The hydrological sub zones BT4 and BM are allocated in the upper part of the river basin where the rivers are perennial and the water demand is also high in these zones because most of the water uses are in the upper part of the river basin. The unit runoff was high in BT1 and BT5. This means that more runoff is generated in these hydrological sub zones. The water demands were based on the assumption that all water uses were consumptive there were no return flows to the system, the users were abstracting the water quantity specified on the water permit and there were no un-permitted uses.

In addition to MAR available in hydrological sub zones BT5 and BM, there are also water storage reservoirs. Table 5.2 indicates the name and size of the reservoirs and the yield.

Table 5.2: Reservoirs and their capacities in the hydrological sub zones (Source: ZINWA)

Hydrological Sub zone	Name of Dam	Full supply capacity (10^3m^3)	Yield at 10 % (10^3m^3)
BT5	Thuli-Makwe	6.11	1.62
BM	Mtshabezi	52	11.35
BM	Lower Mujeni	10.54	7.04

Although the analysis of spatial water availability showed that the demands in the hydrological zones are satisfied, water shortages are experienced in the hydrological zones. The temporal water availability analysis from long term average runoff records of 4 stations showed that there is variation in water availability in the river basin. Figure 5.1.2 below illustrates the trend of the temporal water availability for the 1958 to 2005 runoff records.

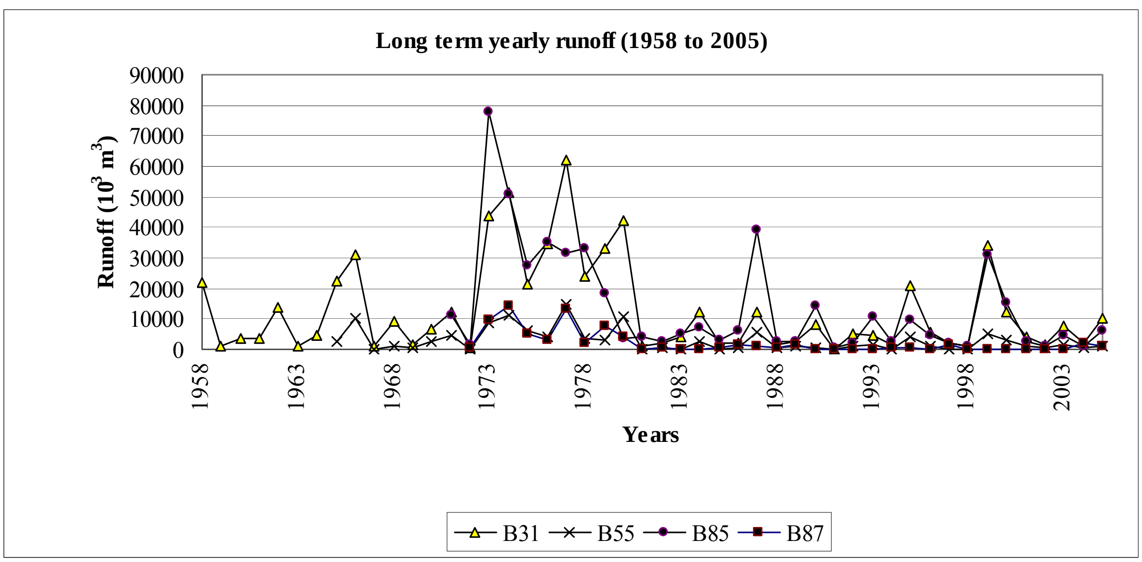

Figure 5.1.2: Temporal water availability in the river basin

As shown in the figure above, the runoff in the river basin varied significantly from one year to the other. The results show that there was a lot of runoff generated in the 1970s and late 1990s. This may be attributed to the variation of rainfall distribution in the river basin, the size of the catchment and different land uses in the river basin.

To assess how the runoff is generated in different catchment areas within the basin, figure 5.1.3 below shows how runoff varies within the river basin.

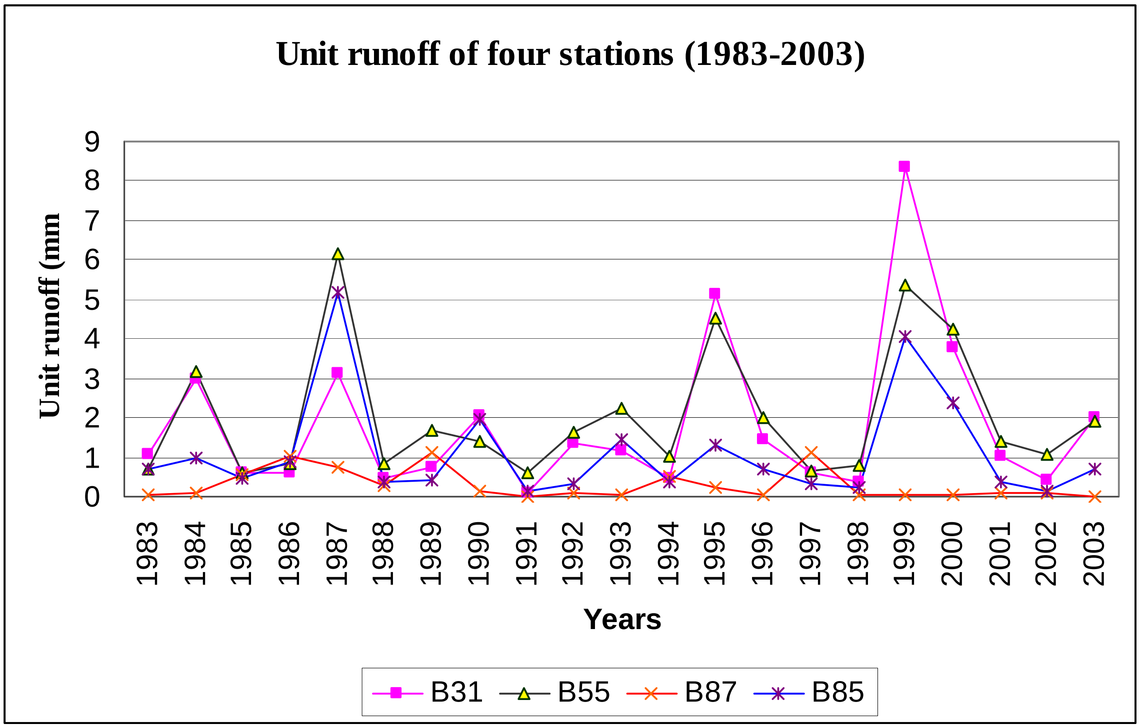

Figure 5.1.3: Spatial water availability

The knowledge of variability in spatial and temporal water availability in the river basin is very important in the management and development of the water resources. Decisions to increase the water availability through construction of dams and how to distribute or allocate the water resource in the river basin are based on such knowledge.

5.2 Water Uses in the catchment

Surface water demand for the river basin was estimated to be 28 Mm^3/year (Appendix A). This was distributed as in Figure 5.2.1.

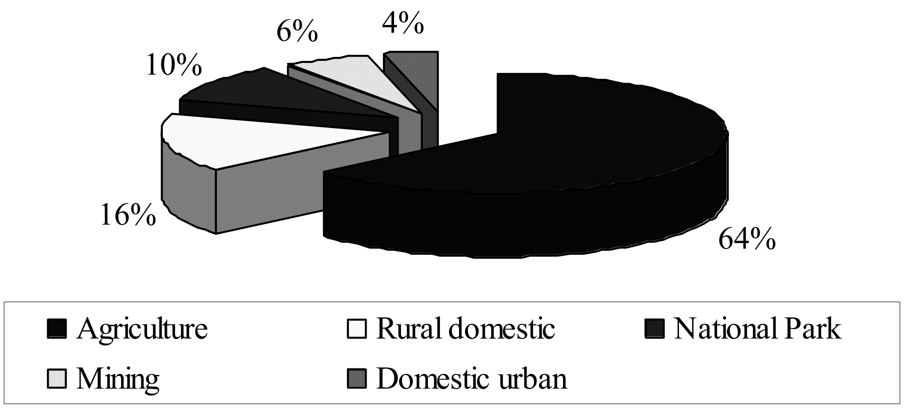

Figure 5.2.1: Water uses by sector.

The major surface water uses in the river basin are agriculture, domestic rural, National Park, mining and urban. Agriculture sector is the largest water consumer in the river basin. This is attributed to the existence of large commercial farms, government irrigation schemes, communal and resettlement area small holder schemes in the river basin. The situation showed that one sector dominates the rest by using more than half of the total water demand in the river basin.

The surface water uses are located in different hydrological sub zones. The study found out that there are more water uses in hydrological sub zone BT4 and BM. The figure 5.2.2 below illustrates how the uses are distributed in the sub zones of the river basin.

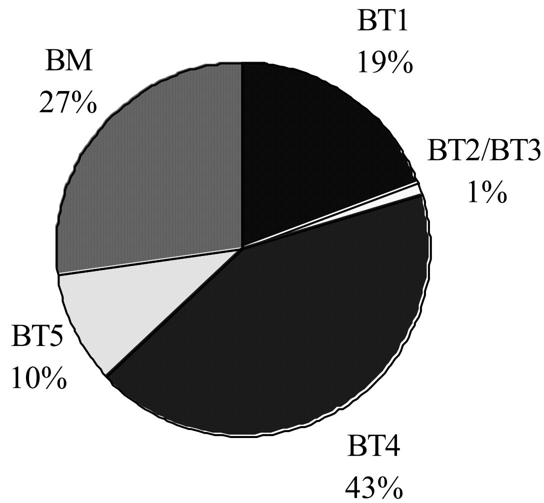

Figure 5.2.2: Location of uses in hydrological sub zones

There are future water resources development plans in the river basin. The inter basin water transfer to Bulawayo City, Mtshabezi irrigation scheme and the Great Thuli Irrigation scheme.

5.3 Water Allocation

In the current water allocation mechanism in the river basin, the users are permitted depending on the water availability. However priority is given to urban and rural domestic water demand.

The study also revealed that the water from ZINWA owned reservoirs is allocated to users through water contract agreements at 100% assurance level of supply. From Thuli-Makwe dam 80% of the dam is used for irrigation and 20% is for mines. As for Mtshabezi, the priority for water allocation is to offset the deficit in water demand for Bulawayo and to meet future water demand and for Lower Mujeni the priority is to supply water to Gwanda.

The new water act of 1998 provides framework for the allocation of water which emphasizes on equal access to water for all through equitable allocation among different water users. ZINWA has standard guidelines for water allocation for the river basin. The highest priority is primary water followed by the environment then Urban, industry and mining comes third followed by agriculture and reserve for future use. However, the current water allocation being practiced is somewhat arbitrary. There is water in the river basin reserved for the environment as the legitimate water user though not properly determined. To sustain the natural ecological processes and biodiversity, the allocation mechanism should therefore ensure the environmental water requirement is properly determined (WRMS, 1999).

5.4 The Waflex Model for the Thuli river basin.

As mentioned before, the Waflex model is based on a spreadsheet application. The model used in this research has a monthly timestep and contains worksheets. Of importance are the following:
Userinput: In this sheet various changes can be made to the model input according to the scenario.

Network: The actual river system is presented showing all the abstraction nodes, inflow nodes and dams in the model.

Demands: This sheet contains all the demand data for the catchment, namely environmental flow requirements, water transfers irrigation and urban and rural water requirements.

Supply: The sheet contains the flow availability (= inflow-demands)

Naturalised runoff: Naturalised runoff data and rainfall/evaporation calculations are contained in this sheet.

Outsheets: This is where the results are located after each run of the model.

Dams
There are five large dams that have been modelled in the catchment. These are Thuli-Makwe, Mtshabezi, Lower Mujeni, Proposed Thuli-Elliot and proposed Thuli-Moswa dams.

Evaporation losses from each dam are calculated using storage – area curves. The evaporation losses for a particular timestep are calculated using dam storage for the previous timestep. Each of the dams in the catchment has a formula which determines the amount of water stored in it per timestep. As an example, the algorithm below illustrates the formula governing Thuli Makwe Dam storage.

```
Sub Res_A()
Range("infl1_a").Value = Range("inflow_a").Value
Range("Req1_a").Value = -Range("Req_a").Value
Stor1_old_a = Range("Stor1_a").Value
Range("Stor1_a").Value = (Range("Stor1_a").Value + Range("inflow_a").Value - Range("req1_a").Value)
Range("rel1_a").Value = Range("req1_a").Value
Stor1_a = Range("stor1_a").Value

If Stor1_a > Range("FRC_a").Value Then
    Range("Rel1_a").Value = Range("Rel1_a").Value + Stor1_a - Range("frc_a").Value
    Range("Stor1_a").Value = Range("FRC_a").Value
End If

If Stor1_a < Range("URC_a").Value Then
    Range("Stor1_a").Value = Stor1_a + Range("Rat_a").Value * 1 / 100 * Range("Req1_a").Value
```

```
    Range("Rel1_a").Value = (1 - Range("Rat_a").Value / 100) * Range("Req1_a").Value
End If

If Range("Stor1_a").Value < Range("DSC_a").Value Then
    Range("Stor1_a").Value = Range("DSC_a").Value
    Range("Rel1_a").Value = Stor1_old_a + Range("infl1_a").Value - Range("DSC_a").Value
End If

Range("Stor_a").Value = Range("Stor1_a").Value
Range("rel_a").Value = Range("Rel1_a").Value

End Sub
Sub Res_B()
Range("infl1_B").Value = Range("inflow_B").Value
Range("Req1_B").Value = -Range("Req_B").Value
Stor1_old_b = Range("Stor1_B").Value
Range("Stor1_B").Value = (Range("Stor1_B").Value + Range("inflow_B").Value -
Range("req1_B").Value)
Range("rel1_B").Value = Range("req1_B").Value
Stor1_b = Range("stor1_B").Value

If Stor1_b >= Range("FRC_b").Value Then
    Range("Rel1_b").Value = Range("Rel1_b").Value + Stor1_b - Range("frc_b").Value
    Range("Stor1_b").Value = Range("FRC_b").Value
End If

If Stor1_b < Range("URC1_b").Value Then
    Range("Stor1_b").Value = (Stor1_b + Range("Rat1_b").Value * 1 / 100 * Range("Req1_b").Value)
    Range("Rel1_b").Value = (1 - Range("Rat1_b").Value / 100) * Range("Req1_b").Value
End If

If Stor1_b < Range("URC2_b").Value Then
    Range("Stor1_b").Value = (Stor1_b + Range("Rat2_b").Value * 1 / 100 * Range("Req1_b").Value)
    Range("Rel1_b").Value = (1 - Range("Rat2_b").Value / 100) * Range("Req1_b").Value
End If
```

Depending on the scenario, the dams may be required to release water for downstream users. In this case what is required and what it actually releases is computed at the beginning of each timestep.

The algorithm below illustrates the formulae which were inputted in the demand and supply worksheets

```
Algorithm for supply sheet without the environment:
=MAX (upstream cell + demand cell,0)

Algorithm for supply sheet with the environment
=MAX (Upstream cell +demand cell,0.05*(inflow in the rivers of the river basin))

Algorithm for demand sheet on the demand nodes
=MIN (upstream cell + demand cell,0)
```

5.4.1 Model Evaluation

The model was initially run using the current water demand and historical runoff. Water demand for the environment and planned developments were not considered. To evaluate the model, the simulation of the observed runoff was analysed. Figure 5.4.1 below shows how the runoff calculated by the model simulated the observed one.

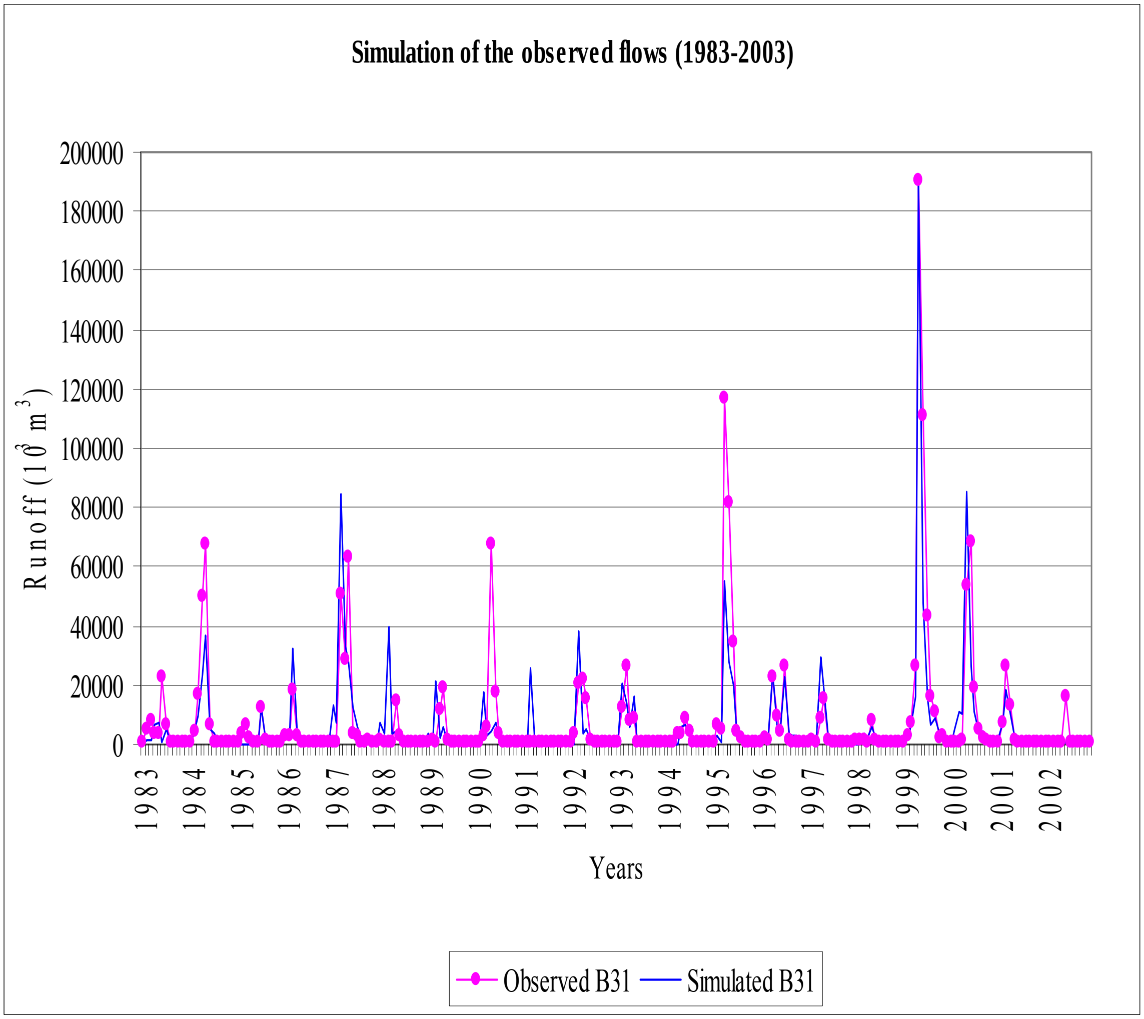

Figure 5.4.1 Simulation of the observed flows (1983-2003)

The model simulated well the observed flows in most of the years. This is statistically supported by the coefficient determination (r^2) of 0.7 from the regression analysis results as shown in figure 5.4.2 below.

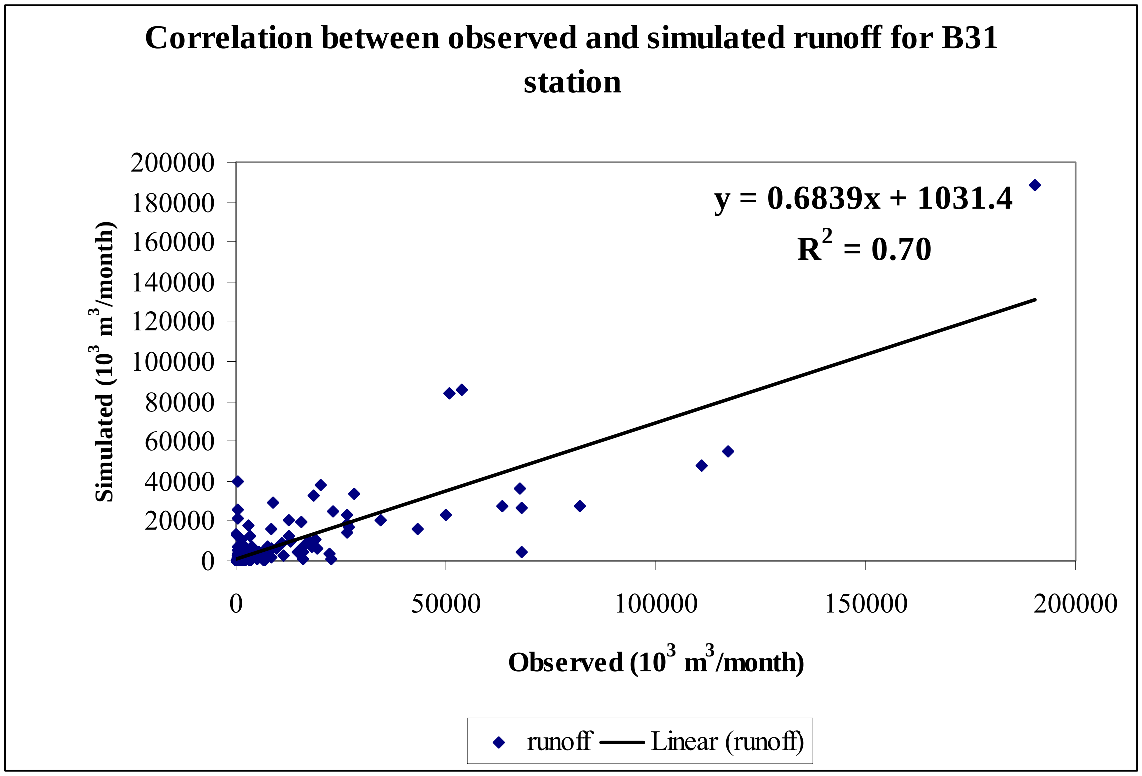

Figure 5.4.2 Regression analysis of observed and simulated run off of gauging station B31

The simulation was reasonable at low flows. But the model failed to simulate peak flows this may be attributed to errors in recording the flows. However, the regression results showed that there was a closer relationship between the observed and simulated runoff, ($r^2 = 0.7$, $p<0.05$). This testifies the reliability of outputs produced by the model.

To establish the accuracy of the simulated flows, the MAR and CV of the observed and simulated flows were compared. Table 5.3 below shows the MAR and the CV for the observed flows and the flows generated by the model.

Table 5.3: Comparison of MARs and CVs for observed and generated flows

	Observed flows	**Generated flows**
Number of years	20	20
Mean (10^3 m^3/yr)	7275	5915
Standard deviation	20002	16439
CV	2.7	2.8

The values expressed in the table showed that Waflex model is able to generate flows which approximate the observed. The mean flow generated however 17% lower than the observed mean while the CV of the flows generated by the Waflex model is almost equal to the observed flows.

5.4.2 Water demand scenario formulation

The water demand scenarios evaluated in the study were grouped in four categories based on:

(i) Government plans on water resources development

Several water resource development plans have been recommended for the river basin as stipulated in the draft catchment plan and National Water Resources Management Strategy. The water demand scenarios identified under this category include:

- Implementation of environmental water requirements in water allocation
- Construction of planned Elliot and Thuli-Moswa dams
- Construction of planned irrigation schemes (Mtshabezi and Great Thuli) in order to improve the livelihood of the people and enhance food security.
- Interbasin water transfer from Mtshabezi reservoir to City of Bulawayo

(ii) Technological improvement

The fact that the river basin is situated in semi arid area requires efficient utilization of water. Surface irrigation systems have lower efficiency in terms of water utilization when compared with high efficient irrigation systems like drip system (Maisiri et al., 2005). The water demand scenario identified in this category is converting the surface irrigation to drip irrigation system.

(iii) Drought risk reduction

Semi arid areas are prone to drought. The river basin under study is not exceptional. To reduce the risks in crop failure associated with drought, crops like sorghum and millet are recommended by AREX. The water demand scenario identified in this category is changing the cropping pattern in the existing irrigation schemes.

(iv) Factors affecting urban water demand

The category looked at the increase in demand in urban area due to the expansion in demand for water.

5.5 Water demand scenarios simulation results from the model

Initially the model is run with the water requirements and demands of the year 2006. The model is then run with future planned developments being put in place.

Run 1: current water demand scenario

The model was run with all existing water demand nodes being active. Future water demand, environmental water requirements and proposed dam developments were not considered in the run. The results are presented in Figure 5.4.3below.

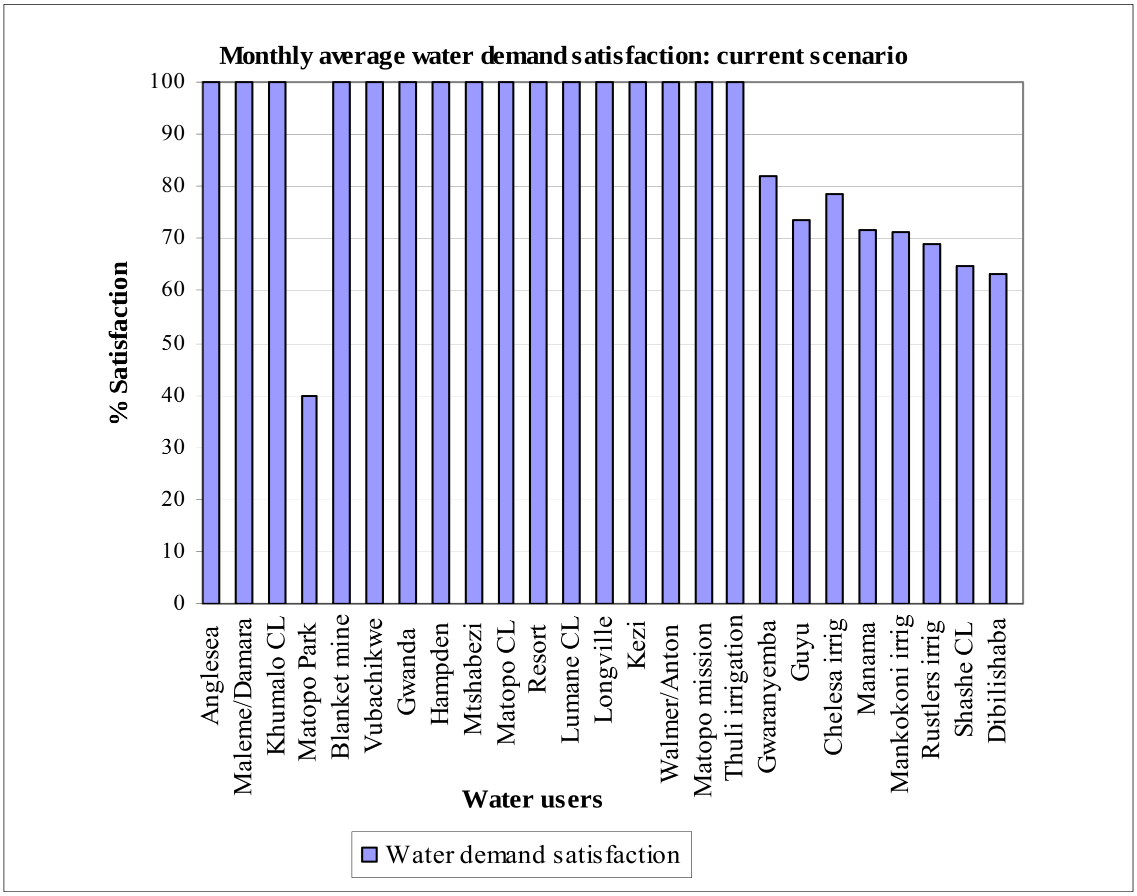

Figure 5.4.3: Water demand satisfaction for current scenario simulation

Out of the 25 water demand nodes, 16 users had their water demand satisfied by 100%. 8 had the water demand satisfaction level below 100%. Of the 8 users, Matopo National Park had the highest shortage with only 40 % of its water demand being satisfied and the rest had more than 50% of the water demand satisfied.

The table 5.4 below shows the percentage water demand satisfaction levels of different demand nodes in different sub zones.

Table 5.4: Percentage water demand satisfaction levels and comments for different demand nodes

Water Demand Node	Sub Zone	%water demand satisfaction	Comments
Anglesea	BT4	100	Demand 100% satisfied
Maleme	BT4	100	Demand 100% satisfied
Khumalo communal land	BT4	100	Demand 100% satisfied
National Park	BT4	40	Attributed to overestimation of water permit volume than the actual amount of water supplied to the node
Kezi	BT2/BT3	100	Demand 100% satisfied
Walmer	BT2/BT3	100	Demand 100% satisfied
Thuli-Makwe irrigation	BT5	100	Demand 100% satisfied
Matopo mission	BT5	100	Demand 100% satisfied
Blanket mine	BM	100	Demand 100% satisfied
Vubachikwe mine	BM	100	Demand 100% satisfied
Gwanda	BM	100	Demand 100% satisfied
Longville	BM	100	Demand 100% satisfied
Lumane communal land	BM	100	Demand 100% satisfied
Lumane resort	BM	100	Demand 100% satisfied
Mtshabezi mission	BM	100	Demand 100% satisfied
Hampden	BM	100	Demand 100% satisfied
Rustlers irrigation	BT1	100	Demand 100% satisfied, though downstream due to fact that point of abstraction has alluvial aquifers which store water and enable reliable supply
Gwaranyemba	BT1	82	18 % deficit in water demand satisfaction
Guyu	BT1	74	26 % deficit in water demand satisfaction
Chelesa	BT1	79	21 % deficit in water demand satisfaction
Manama	BT1	72	28 % deficit in water demand satisfaction
Mankokoni	BT1	71	29 % deficit in water demand satisfaction
Communal land III (Shashe)	BT1	65	35 % deficit in water demand satisfaction
Communal land IV (Dibilishaba)	BT1	63	37 % deficit in water demand satisfaction

The high levels of satisfaction in the upper part of the river basin and the low levels of satisfaction in the lower part of the river basin can be backed up by the fact that the rivers in the upper Thuli basin are perennial while in the lower part the river is ephemeral. The other factor is that the upper part has large reservoirs which even out water shortages by supplying the water stored during the time of high inflows.

Run 2: implementing environmental water requirements

The environmental water demand scenario's impact on downstream water availability was assessed. All the proposed developments were not considered. Consideration was given to the objective of the draft catchment outline plan of prioritising the environmental requirements in water allocation. 5% of the runoff in the river basin was proposed to be allocated to the environment. The results are presented in Figures 5.4.4 and 5.4.5 below.

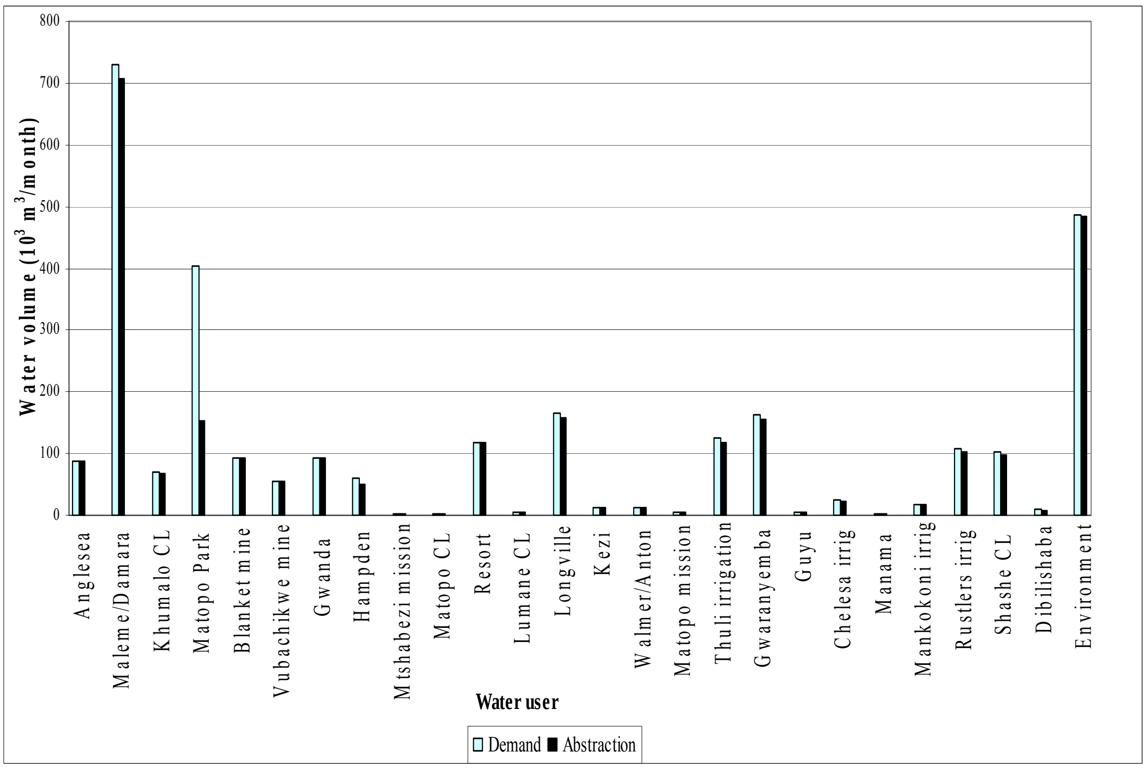

Figure 5.4.4: Water demand and abstraction after implementation of the environmental flows

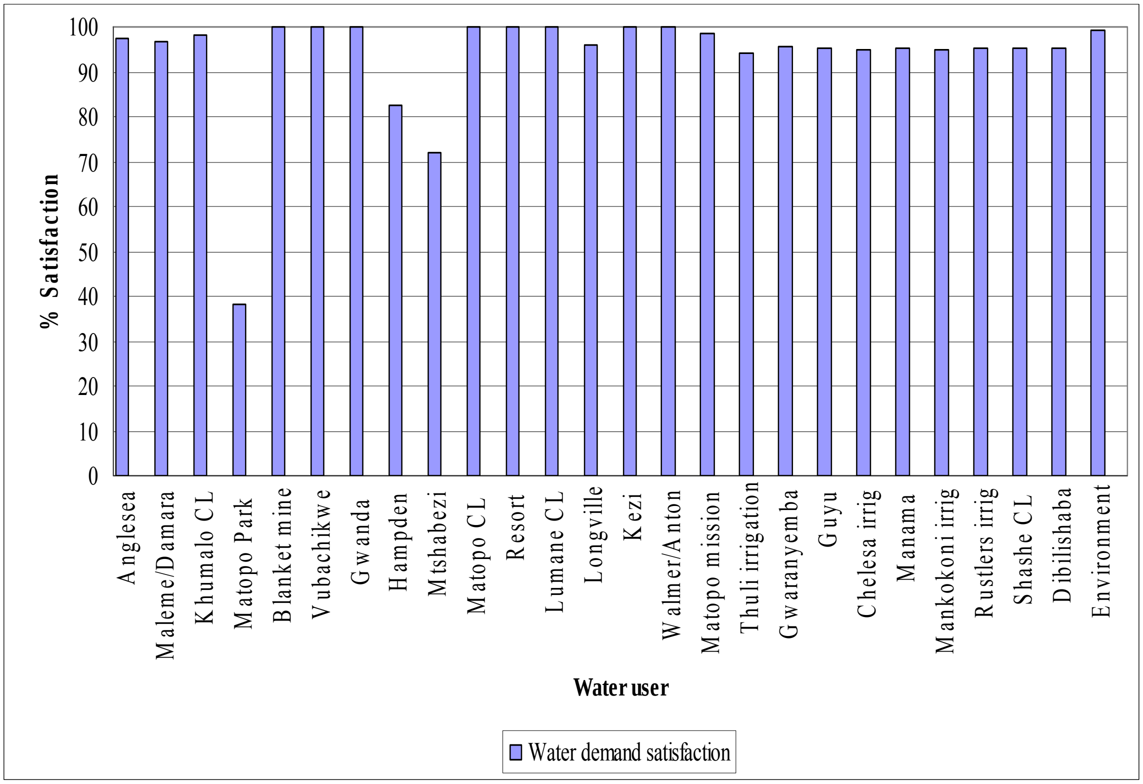

Figure 5.4.5: Water demand satisfaction after implementing environmental flows

For hydrological sub zone BM, the results showed that allocating 5% of runoff of the river basin to the environment could not affect the 100% demand satisfaction of Blanket mine, Gwanda town, Lumane Communal Land, Lumane Resort and Matopo Communal Land which was achieved in the **Run 1**. However allocating 5% of runoff to the environment reduced the water demand satisfaction of Vubachikwe mine, Longville farm, Mtshabezi mission and Hampden farm to 96%, 96%, 72% and 83% respectively.

In sub zones BT2/BT3, Kezi growth point water demand was 100% satisfied while Walmer farm water demand satisfaction was reduced to 93% after allocating 5% of the runoff to the environment.

As for sub zone BT5, Matopo mission and Thuli Makwe irrigation water demand satisfaction decreased. In **Run 1**, both users had 100% demand satisfaction while in **Run 2**, water demand satisfaction for Matopo mission was reduced to 99% and For Thuli Makwe Irrigation scheme demand satisfaction decreased to 94%.

In sub zone BT4, Anglesea water demand satisfaction remained 100% as in **Run 1**. Maleme/Damara and Khumalo communal land water demand satisfaction decreased to 97% and 98%, respectively. The National Park demand satisfaction dropped to 38%.

For the water users in BT1, the lower Thuli river basin, the **Run 2** results showed that water demand satisfaction of most demand nodes when compared to **Run 1** result increased except for Rustlers irrigation scheme. The level of water demand satisfaction for the downstream increased because the environment is a non-consumptive water user, reserving water for environment will mean an increase in the downstream flow. The reduction in the level of water demand satisfaction for the users downstream of Mtshabezi dam is due to the fact that the water stored in Mtshabezi dam is not released but spills when the reservoir is full. This means the proposed 5% water allocation to the environment is not achievable hence the failure to reach high levels of demand satisfaction.

Run 3: Improving irrigation system efficiency

The impact of improving the irrigation system was assessed by converting the existing government irrigation schemes' system to drip irrigation system which is 90% efficient. In this Run**,** 5% of the catchment runoff was allocated to the environment. All the proposed development plans were not considered. The irrigation schemes considered were Thuli, Chelesa, Mankokoni and Rustlers. This water demand scenario affected only the water users downstream of these irrigation schemes. Figures 5.4.6 shows demand satisfaction before improving the irrigation system efficiency and Figure 5.4.7 below shows demand satisfaction after improving the system efficiency.

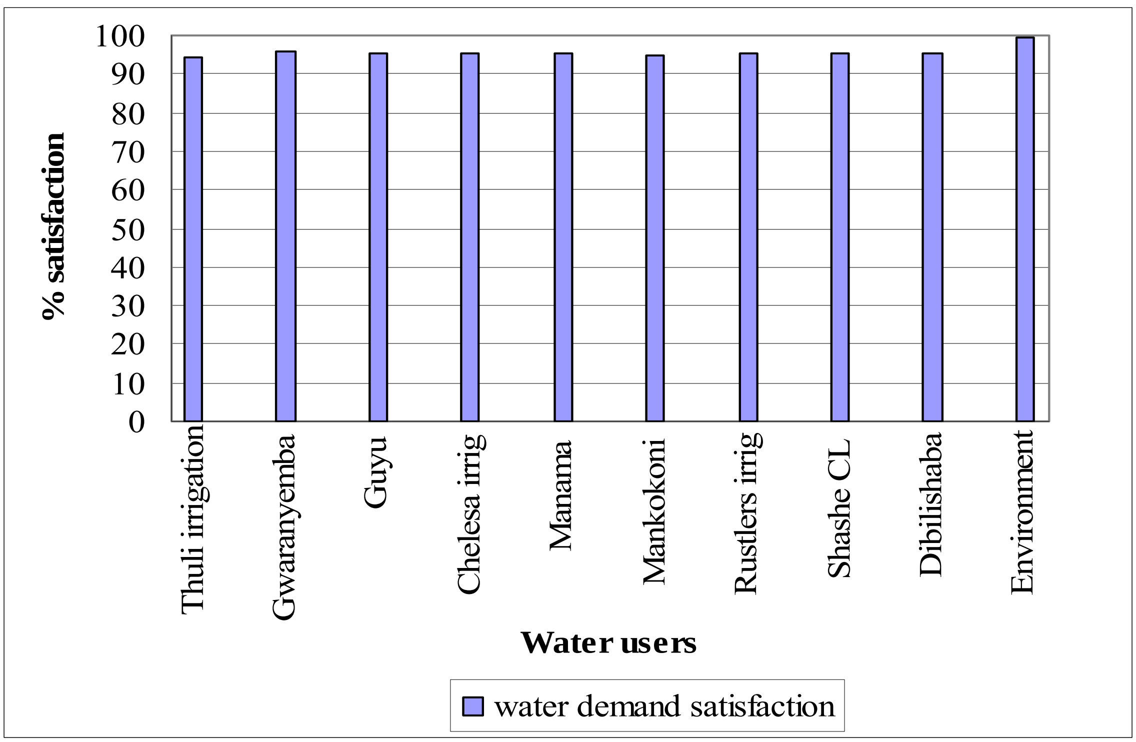

Figure 5.4.6: Water demand satisfaction before improving irrigation efficiency

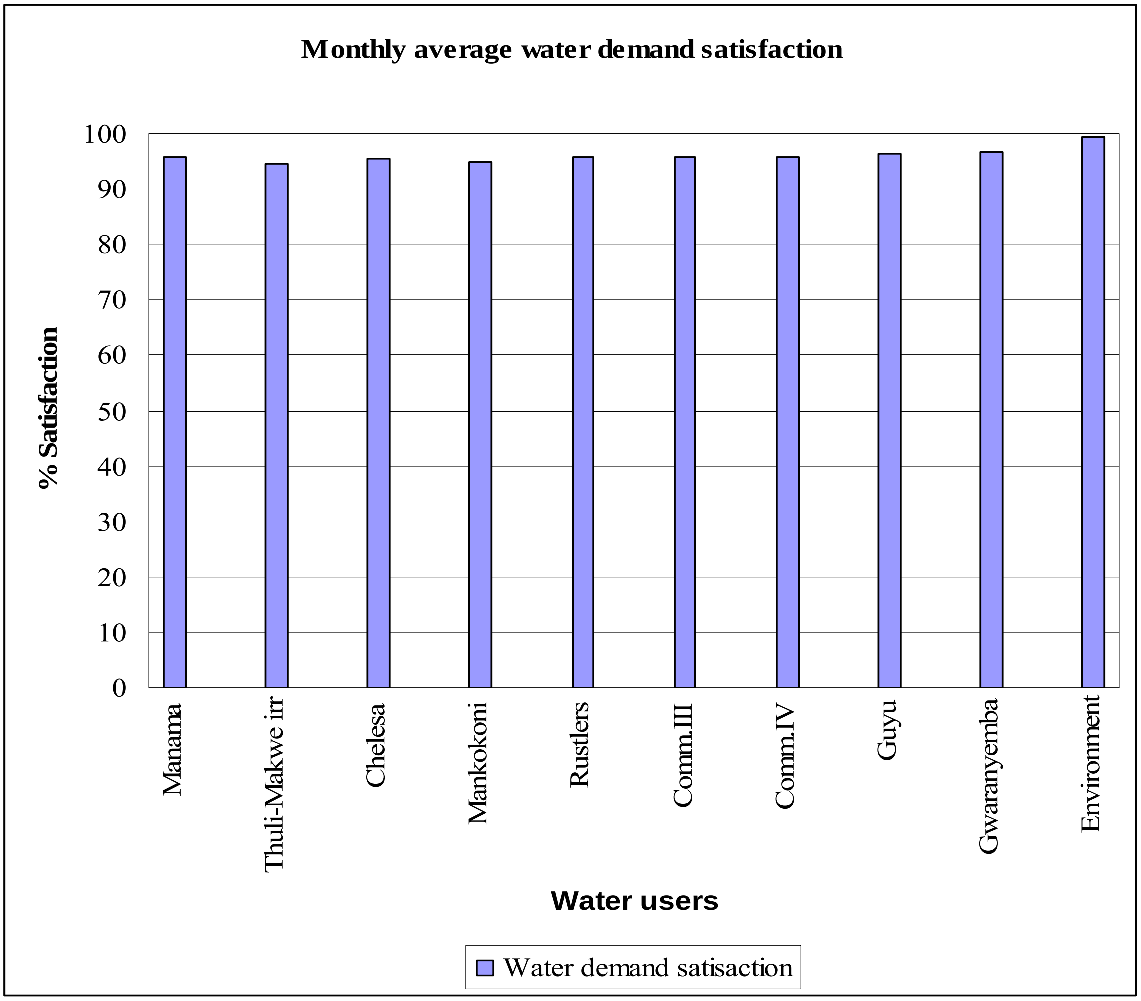

Figure 5.4.7: Water demand satisfaction after improving irrigation efficiency

The results showed that increasing the irrigation system efficiency to 90% did not change the water demand satisfaction for Guyu, Mankokoni and Rustlers attained before improvement in the system efficiency**.** However, the 95% water demand satisfaction of Gwaranyemba, Manama, Shashe and Dibilishaba Communal land attained before improvement in irrigation efficiency**,** increased to 96%.

Though a significant amount of water can be saved by this technology improvement, critical analysis in terms of cost benefits has to come into play. The technology requires expensive equipment which calls for high retains from the irrigated crops. The other disadvantages associated with the system, for example causing soil salinity, have to be looked at critically.

Run 4: Changing the cropping pattern

The impact of changing the current cropping pattern by incorporating the recommended drought resistant crops in the river basin to swap with maize crop was assessed. The crops which were recommended to swap with maize were sorghum and millet. The cropping intensity was also reduced. The changing of the cropping pattern was targeting the government irrigation schemes. The proposed developmental plans were not considered but the environmental water requirement was considered. Figure 5.4.8 and 5.4.9 shows the results from **Run 4.**

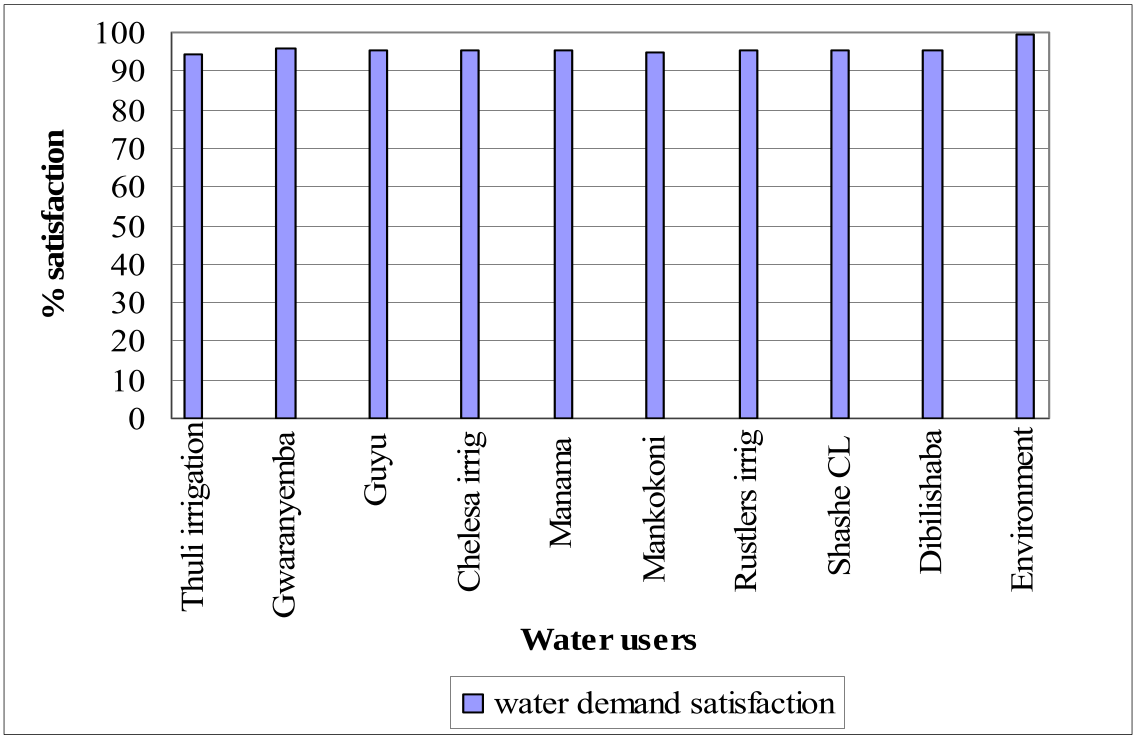

Figure 5.4.8: Water demand satisfaction for the current cropping pattern

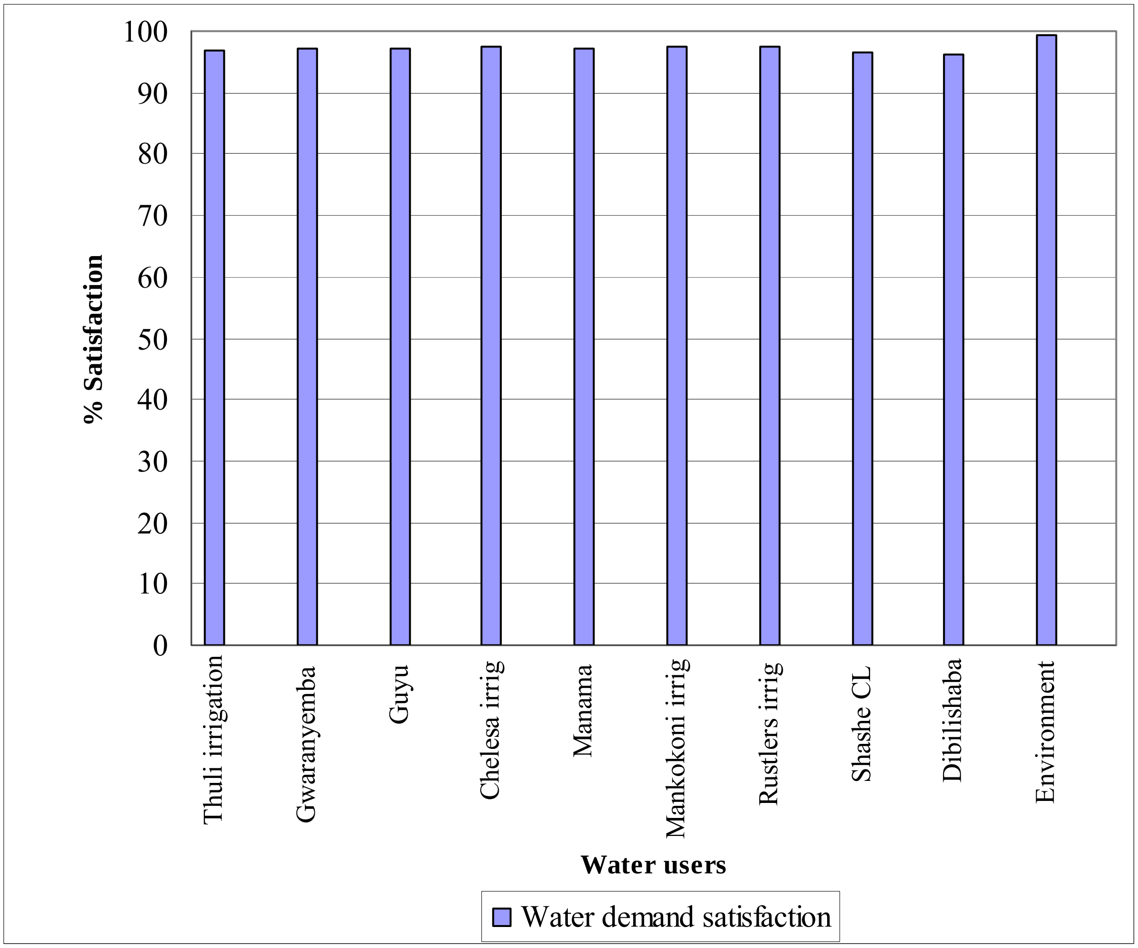

Figure 5.4.9: Water demand% satisfaction after changing the cropping pattern

Run 4 only affected the downstream users in Hydrological sub zone BT1. The water demand satisfaction increased by 1% in Guyu growth centre, Chelesa irrigation scheme, Mankokoni irrigation scheme, Rustlers irrigation scheme, Manama growth centre, Shashe and Dibilishaba communal lands.

The cropping pattern assumed was suggested by the farmers. This might cause a conflict because all the cropping patterns in the government irrigation schemes are predetermined by the government. The cropping pattern saved water and the crops opted for were drought tolerant and are very relevant to semi arid areas because they enhance food security.

Run 5: Implementing Mtshabezi irrigation scheme

The water demand scenario was run by allocating 5% of runoff to the environmental water requirement and allocating water to Mtshabezi irrigation scheme as demanded. The results are shown in Figures 5.4.10 and 5.4.11.

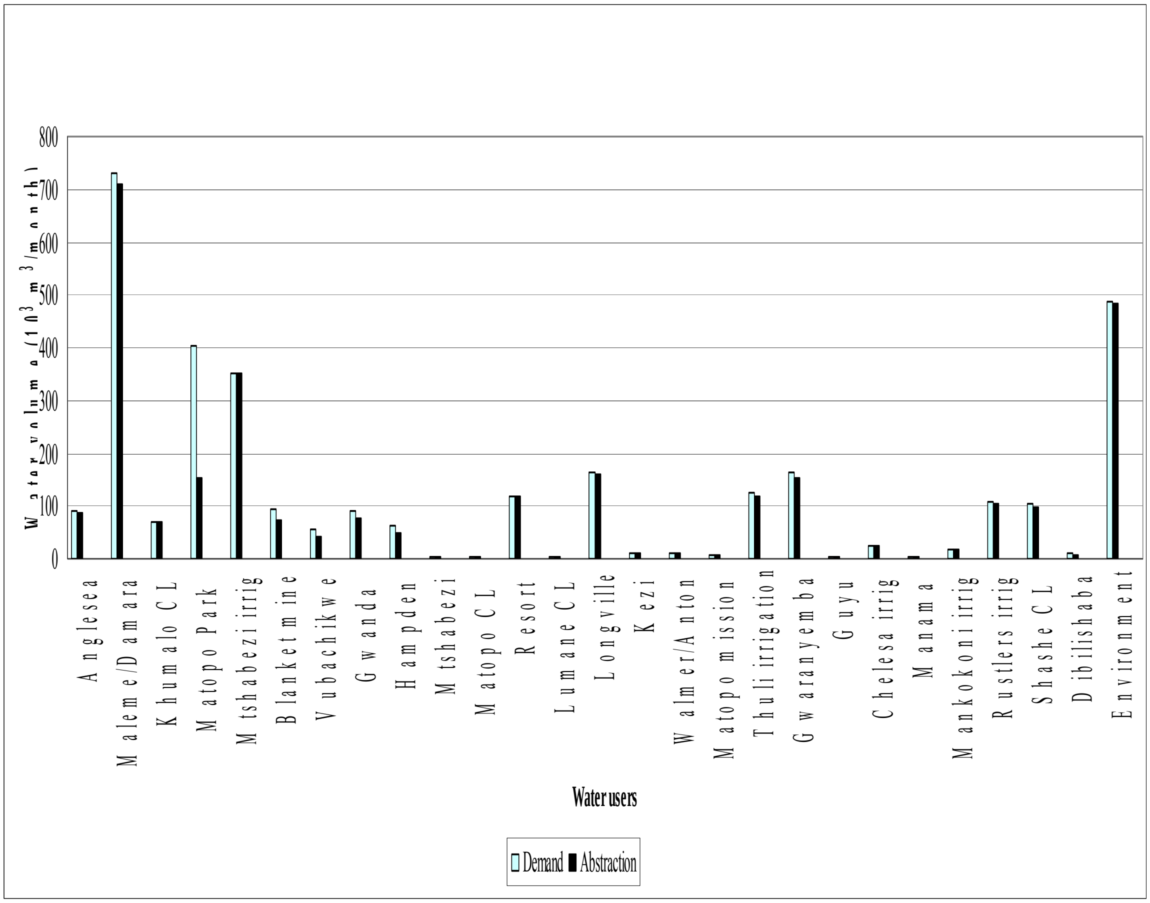

Figure 5.4.10: Water demand and abstractions after implementing Mtshabezi irrigation scheme

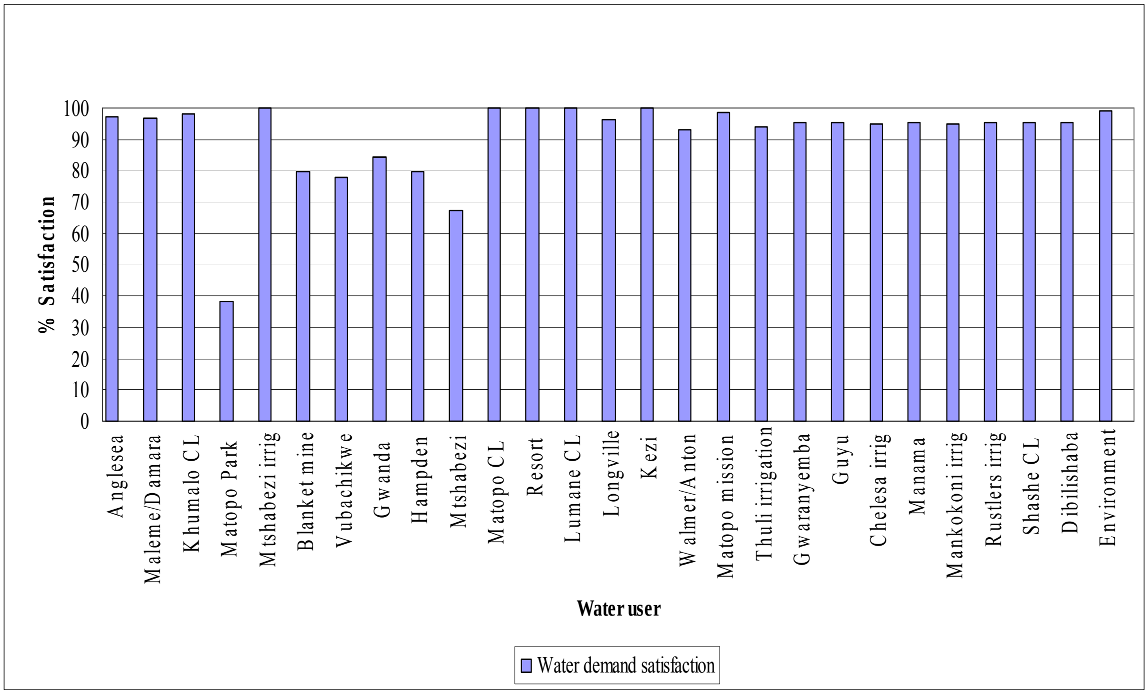

Figure 5.4.11: Water demand %satisfaction for different users after implementation of Mtshabezi scheme

The impacts of development of Mtshabezi irrigation scheme were evident to hydrological sub zone BM water users specifically to those abstracting water from Mtshabezi river. The results showed that demand satisfaction for blanket mine reduced from 100% attained in **Run 2** to 80% and for Vubachikwe mine it decreased to 78% from 96%. Gwanda town water demand satisfaction decreased from 100% in **Run 2** to 84%. Mtshabezi mission water demand satisfaction reduced from100% to 68%.

Run 6: Implementing the Great Thuli Irrigation Scheme

The run considered the implementation of the planned 3000 hectares irrigation scheme in the lower part of the river basin. The scenario was run with 5% of the runoff of the river basin allocated to the environment and the water demand of the proposed irrigation scheme.

The results of the run are shown in Figure 5.4.12 and 5.4.13:

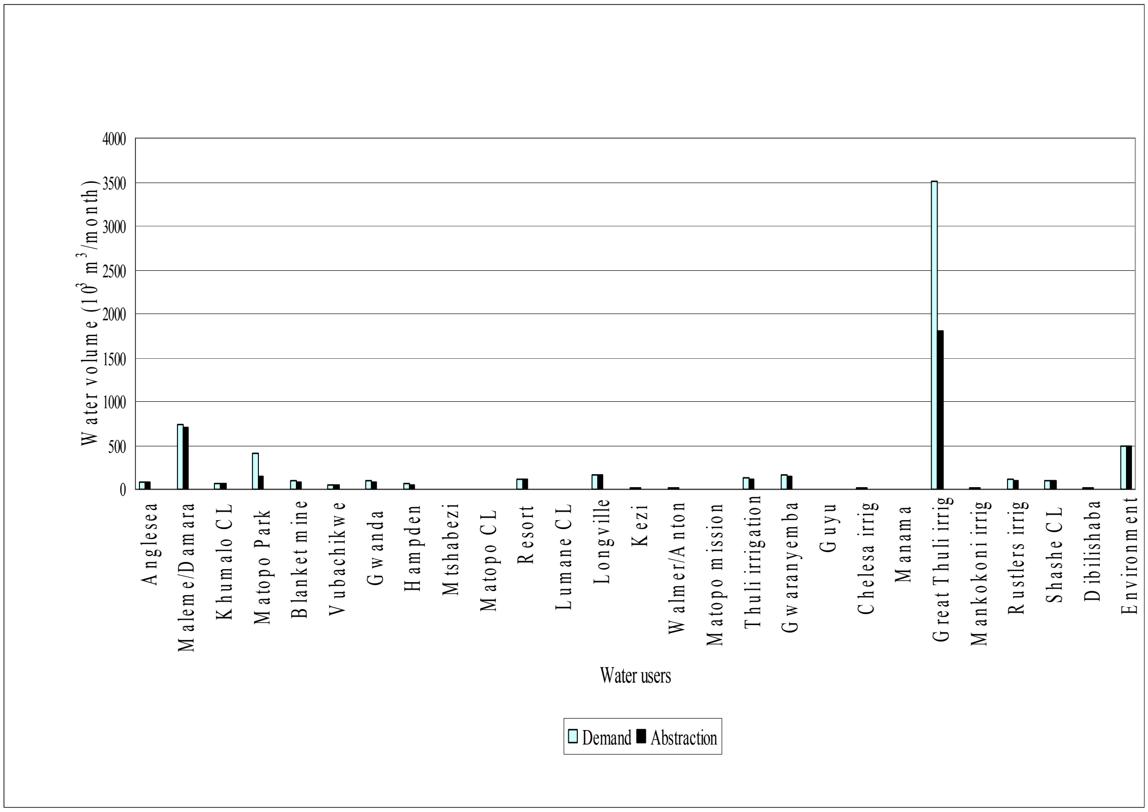

Figure 5.4.12: Water demand and abstractions after implementing Great Thuli irrigation scheme

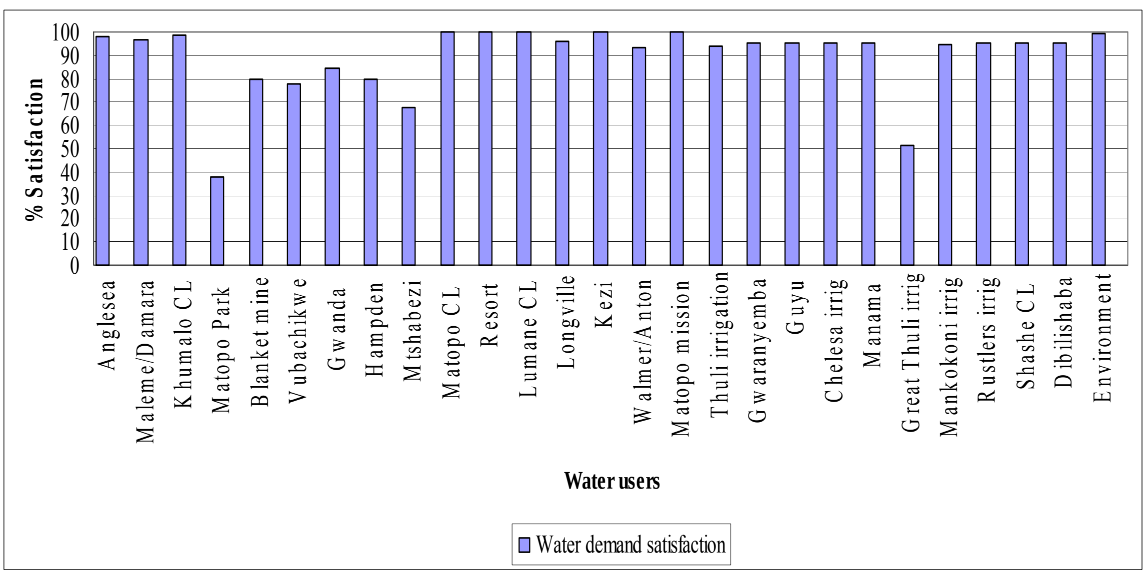

Figure 5.4.13: Water demand % satisfaction after implementing Great Thuli irrigation scheme

The run did not have effects on the demand satisfaction of the water users in hydrological sub zone BM. But the demand satisfactions of for water users in hydrological sub zone BT5 were affected significantly. Thuli-Makwe irrigation scheme water demand satisfaction decreased to 62%. The proposed Great Thuli irrigation scheme, as shown by the results, if implemented would have the water demand not met by 38%. The results further showed the reduction in water demand satisfaction for all water users in the down stream of the river basin (sub zone BT1), including the environmental water requirement demand satisfaction. The outcome is not strange. Such development with a huge water demand should always be accompanied by ample water supply.

Run7: Inter Basin Water Transfer (IBWT) scenario

The scenario considered the environmental water requirements, implementation of Mtshabezi irrigation scheme and implementation of the inter basin water transfer from Mtshabezi dam to the City of Bulawayo. Figures 5.4.14 and 5.4.15, below, show the results of the run.

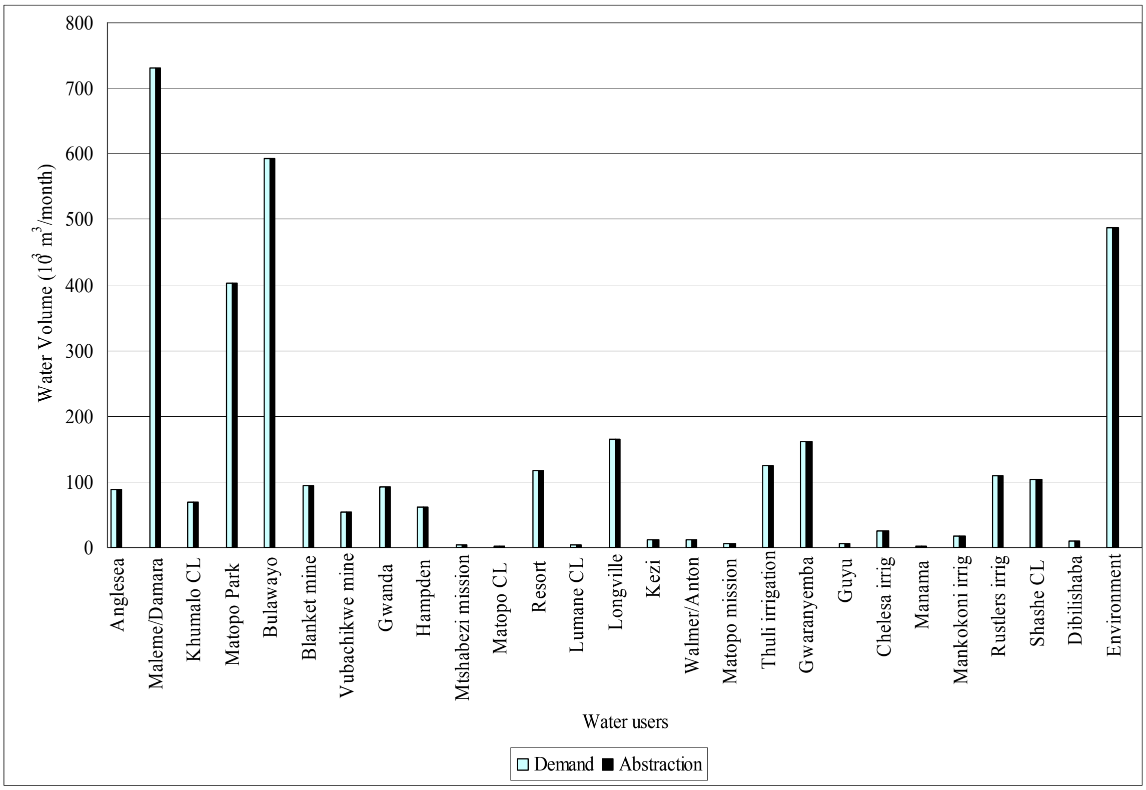

Figure 5.4.14: Water demand and abstraction after implementation of Interbasin water transfer

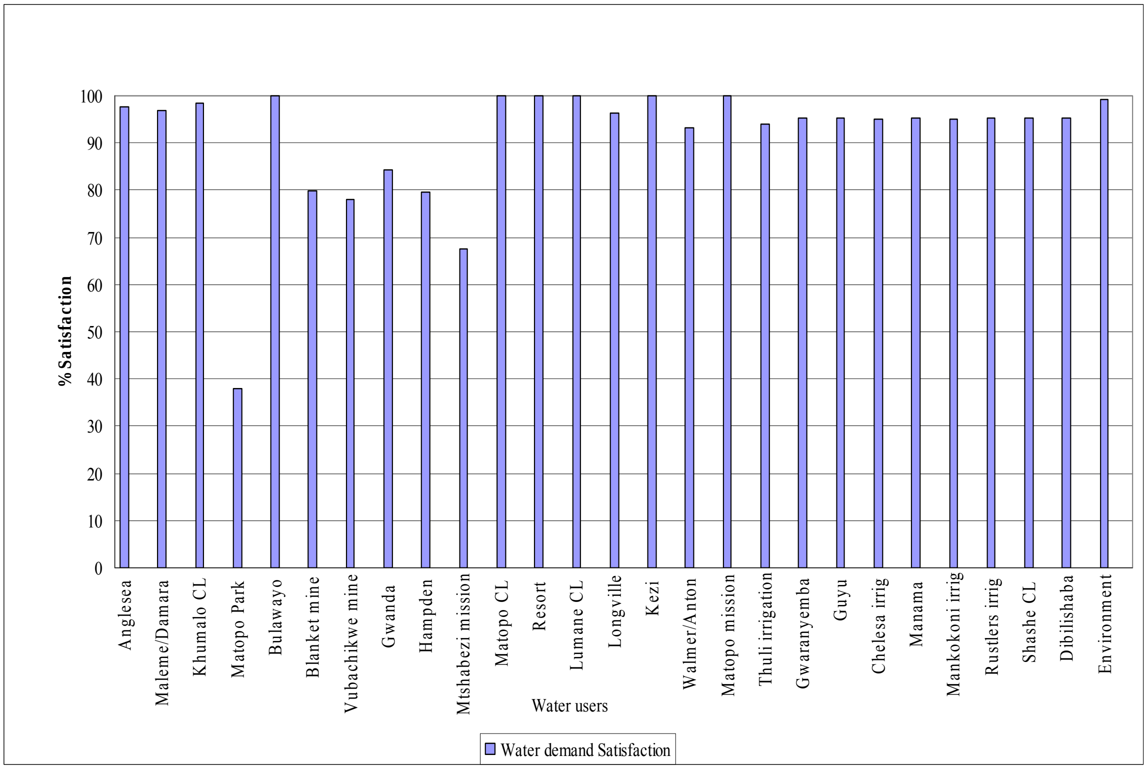

Figure 5.4.15: Water demand % satisfaction after implementing Interbasin water transfer

The results revealed that IBWT to Bulawayo City will affect the water demand satisfaction of the water users in sub zone BM. Mtshabezi irrigation scheme water demand satisfaction would be reduced to 59%, Blanket and Vubachikwe mine had both their water demand satisfaction reduced to 51%. Gwanda town's water demand could not be met by 26%. Mtshabezi mission demand satisfaction decreased to 59% and Hampden farm failed to be met by 32%. However, the environmental water demand had 99% level of satisfaction.

Run 8: Implementation of the proposed dams

The scenario assumed the implementation of Thuli-Elliot and Thuli-Moswa dams. The environmental water requirement of 5% of runoff was incorporated. The results are shown in the Figures 5.4.16 and 5.4.17 below.

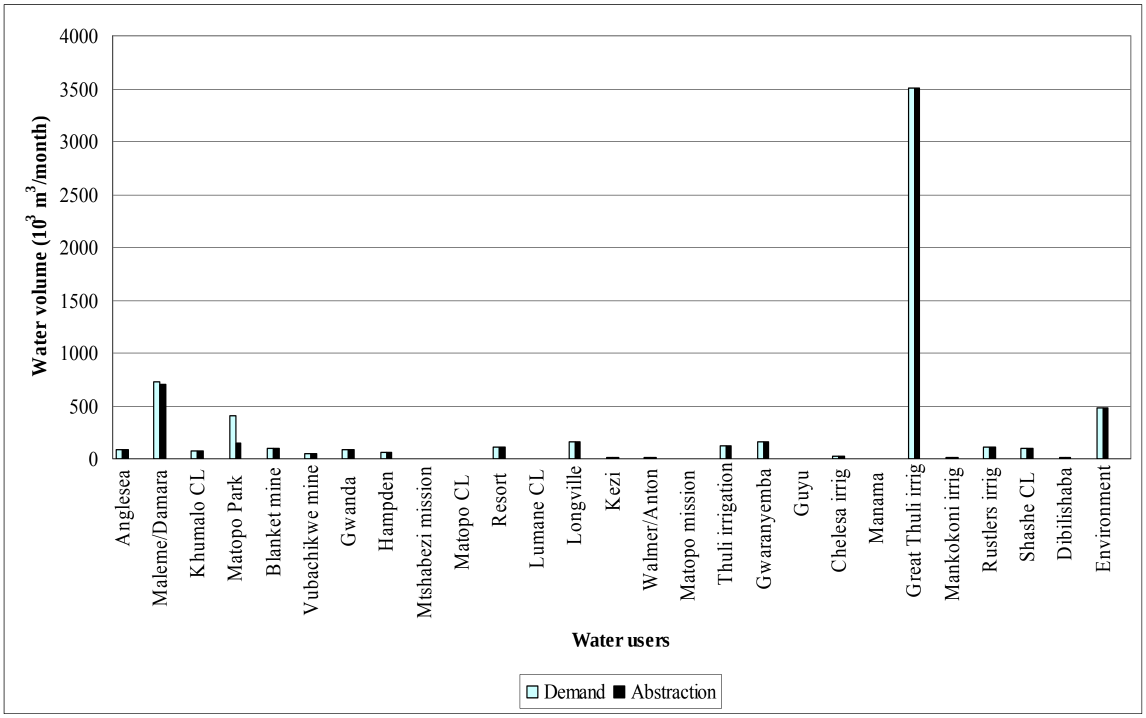

Figure 5.4.16: Water demand and abstraction after construction of proposed dams

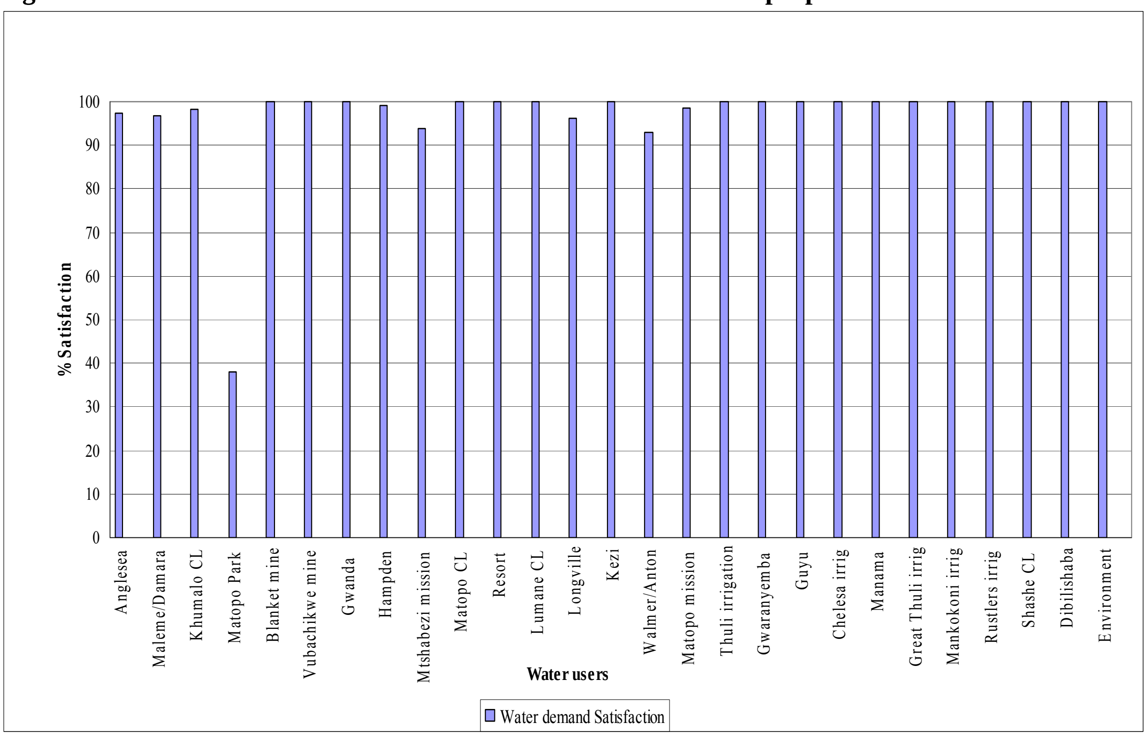

Figure 5.4.17: Water demand % satisfaction for users after construction of proposed dams

The results showed that implementation of the two proposed dams would increase the water demand satisfaction of most of the users. The results also showed that the development would satisfy the water demand for all water users in BT1 sub zone by 100%.

Run 9: Increase in urban water demand

The scenario considered the projection of expansion in water demand in Gwanda and the incorporation of the environmental water requirements. The results are presented in figures 5.4.18 and 5.4.19 below.

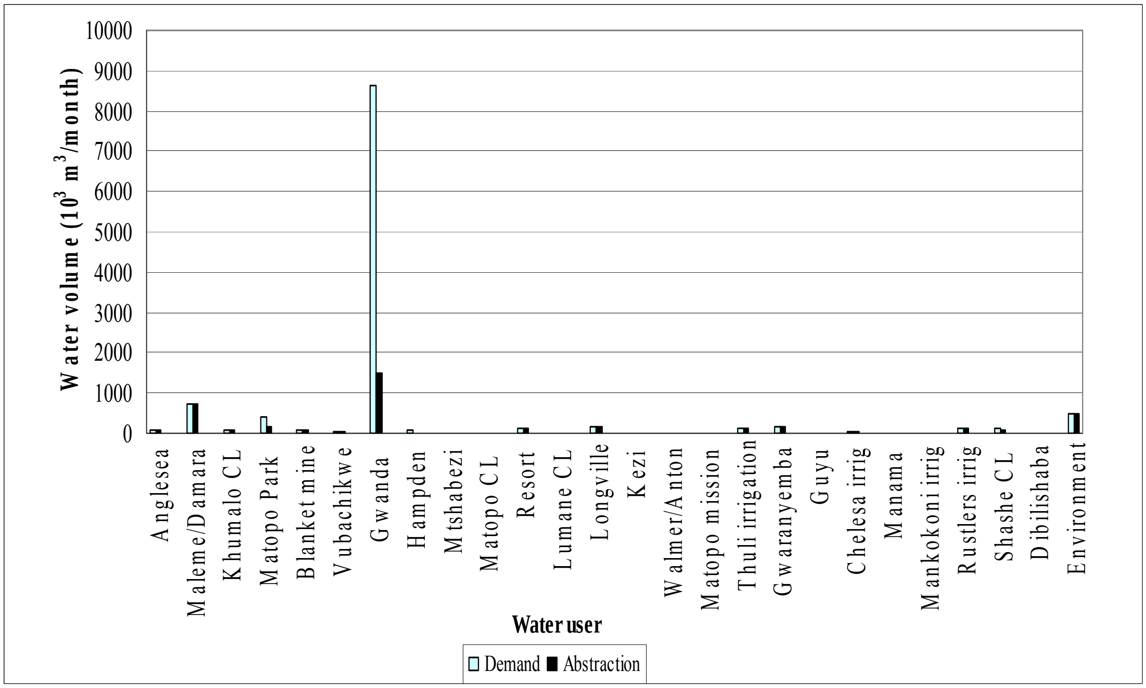

Figure 5.4.18: Water demand and abstraction after increase in urban demand

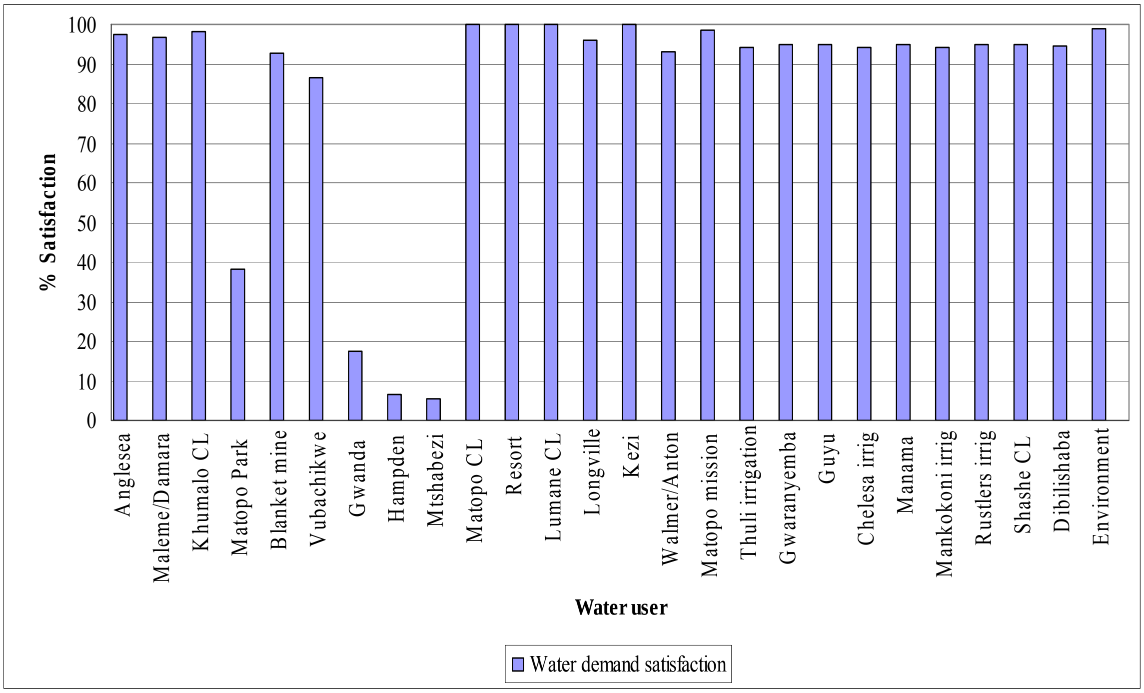

Figure 5.4.19: Water demand % satisfaction after increase in urban demand

The results indicated that the projected future water demand due to increase in demand for Gwanda town would reduce the water demand satisfaction for Gwanda, Hampden farm , Blanket mine, Vubachikwe mine, and Mtshabezi mission to 17%, 7%, 93%, 87% and 5%, respectively.

Run 10: Implementation of all the proposed plans

The scenario considered the proposed IBWT, Irrigation schemes, Environmental water requirements and proposed dams implemented. The results of the run from the model are shown in Figures 5.4.20 and 5.4.21 below.

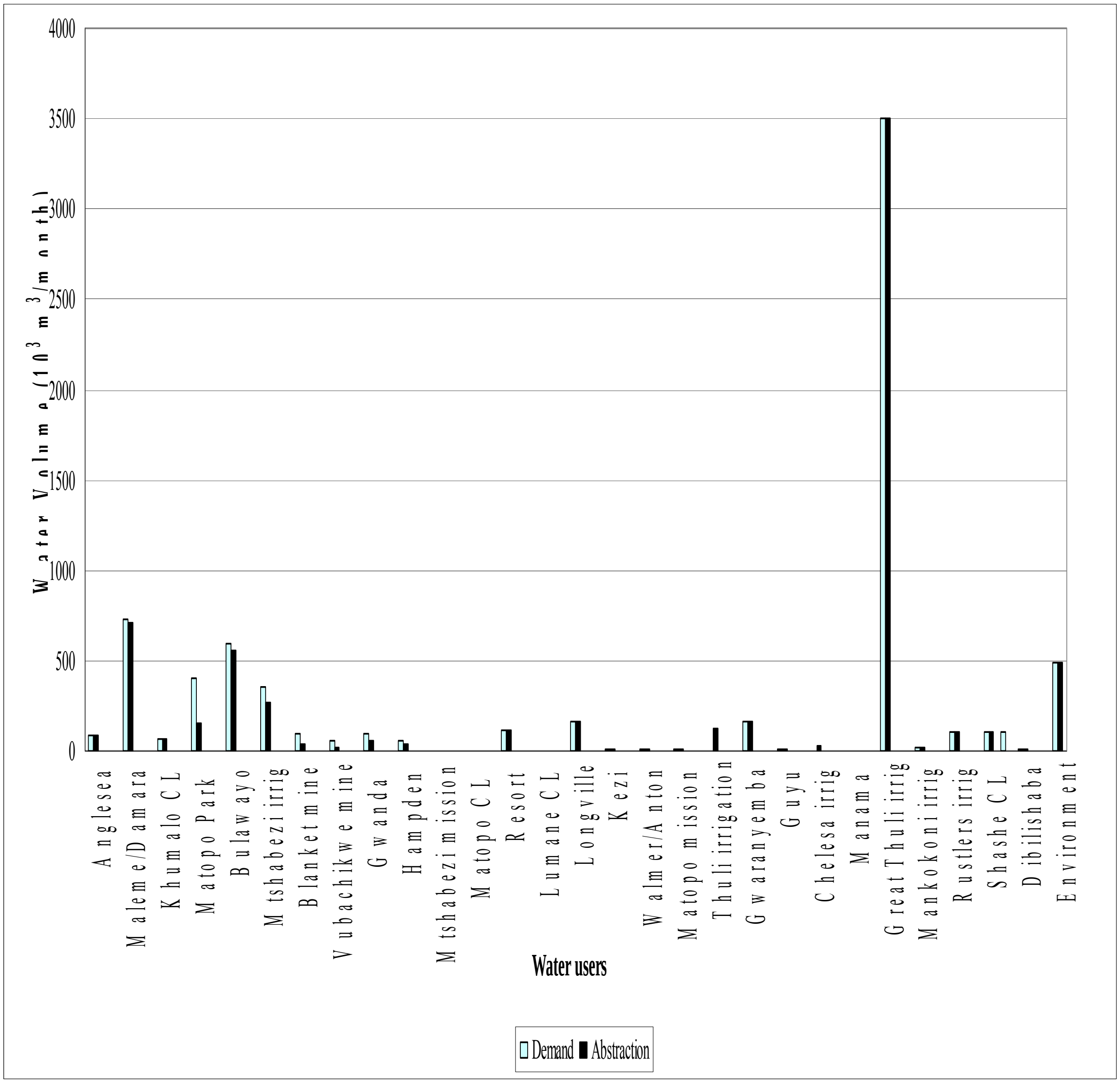

Figure 5.4.20: Water demand and abstraction after implementing all proposed plans

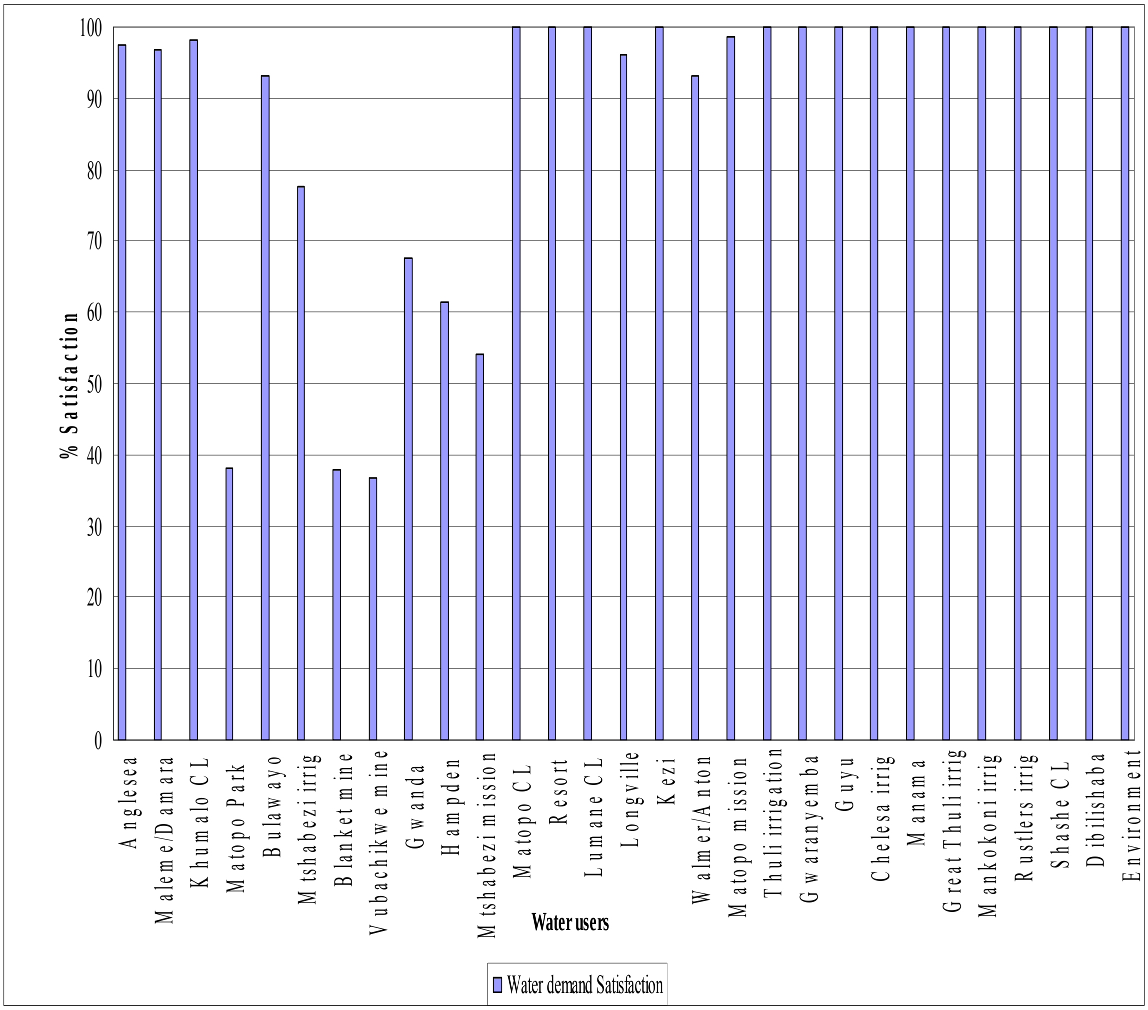

Figure 5.4.21: water demand %satisfaction after implementing all the proposed plans

The results showed that the implementation of all proposed development plans would reduce the water demand satisfaction of Mtshabezi irrigation scheme to 78%, Blanket mine to 38%, Vubachikwe mine to 37%, Gwanda town to 67%, Mtshabezi mission to 54%, Hampden to 61%, Bulawayo to 93%,. However the developments would not affect sub zone BT2/BT3 water users. The results further revealed that the implementation of the proposed plans would reduce the water demand satisfaction of Thuli-Makwe to 62% and Great Thuli Irrigation to 49% and would significantly reduce the water demand satisfaction of all downstream users.

6 CONCLUSION AND RECOMMENDATIONS

The following conclusions can be drawn from the results analysed in the preceding chapter:

- The current water uses in the river basin are agriculture, urban domestic, National park, rural domestic and Mining. The current total surface water demand in the river basin was estimated to be 28 Mm^3/a. The future surface water uses are Mtshabezi irrigation scheme, Inter basin water transfer to Bulawayo city and Great Thuli irrigation scheme would demand 49.5 Mm^3/a of surface water. Current water demand in the sub zones is lower than the MAR in the respective zones therefore the current water availability can satisfy the demand.

- Spatial surface water availability in the hydrological sub zones BT1, BT2/BT3, BT4, BT5 and BM is 161.4Mm^3/a, 22.8 Mm^3/a, 151.8 Mm^3/a, 31.4 Mm^3/a and 34.1 Mm^3/a, respectively. Coefficient of variation of runoff is high indicating that there is a wide variation in temporal surface water availability in the river basin.

- Current water allocation in the river basin is arbitrary and though the environment is recognized as the user, currently the water allocated to the environment is no sufficient.

- Application of easily accessible model, like Waflex, can be useful for the simulation of the physical processes taking place in the catchment and can be used in coming up with management decision for example in water allocation among competing users.

- Implementation of IBWT to Bulawayo reduced the demand satisfaction levels of downstream users. Increasing efficiency of irrigation schemes (90%) increased level of water demand satisfaction to some users but did not change the level of satisfaction of other users. Reserving water for the environment satisfied the downstream users but failed to do so to the users downstream of Mtshabezi dam. Implementing all the proposed developments at once reduced the levels of downstream user's water demand satisfaction significantly. Implementing the planned irrigation schemes without dams reduced level of satisfaction to down stream users. However implementation of the planned Great Thuli irrigation scheme, Thuli-Elliot and Thuli-Moswa dams and allocating 5% of runoff in the river basin to the environment would result into high levels of water demand satisfaction to downstream water users.

The study recommends that further research be carried out to determine the transmission and seepage losses in the river basin especially on the lower reaches which have alluvial aquifers.

The gap identified by this research work is that of data quality since most of the gauging stations are affected by siltation, therefore further research work is recommended to carry out a detailed analysis of the runoff data quality control.

The study recommends the following allocation mechanism to the catchment council for the proper management of the river basin:

- The constitutional obligation to provide a basic amount of water to the population also called primary water should be handled with care and seriously considered.
- The likely economic and social benefits of the proposed use so that water is put to the right use
- Principle of equity should be adhered to promote fairness in water allocation.
- . The legal (or treaty) obligation to consider downstream requirements beyond the area being considered for water allocation for example at the confluence of the Thuli river and Shashe is a trans frontier conservation area which will require a certain proportion of water to be allocated to the area.
- The legal obligation to provide for environmental water requirements should be properly determined
- Allocation principles should include clear provisions for (extreme) drought situations
- Allocation principles should promote water users' willingness to invest in water infrastructure and to improve efficiency.

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8 APPENDIX

8.1 APPENDIX A: Water users, water demand and purpose of water use.

RIVER	USER	PURPOSE	WATER DEMAND (10^3 m^3)/Year
Hove	Anglesea	Agriculture	1068
Lumane	Longueville	Agriculture	1404
	Insindi ranch	Agriculture	1992
	Matopo CL	Domestic rural	24
	Nswazi CL	Domestic rural	24
Maleme	Matopo National Park	Environment	2928
	Maleme Estate	Agriculture	72
	Ebenezer Agric Centre	Agriculture	1908
	Damara Estate	Agriculture	1080
	est Acre Creek	Agriculture	4320
Mtshabezi	Blanket Farm	Agriculture	96
	Blanket Mine	Mining	1123
	Gwanda Town	Domestic urban	1068
	Hampden	Agriculture	157
	Deneys Farm	Agriculture	82
	Rem of Timber	Agriculture	72
	Terrington	Agriculture	12
	Mtshabezi Clinic/schools	Domestic rural	528
	Georgia Ranch	Agriculture	360
	Vubachikwe Mine	Mining	648
Mtsheleli	Malaje	Agriculture	276
	Wenlock CL	Domestic rural	293
Mwewe	Kezi Growth Centre	Domestic rural	144
	Walmer	Agriculture	36
	Anton Ranch	Agriculture	36
	Hannayvale	Agriculture	72
Thuli	Shashi CL	Domestic rural	1236
	Matopo Mission	Domestic rural	72
	Gwanda CL	Domestic urban	24
	Thuli Makwe Irrigation scheme	Agriculture	2596
	Dibilishaba CL	Domestic rural	108
	Guyu	Domestic rural	60
	Thuli River Farm	Agriculture	89
	Gwaranyemba	Domestic rural	1944
	Chelesa Irrigation Scheme	Agriculture	284
	Manama Mission	Domestic rural	36
	Mankokoni irrigation	Agriculture	358
	Rustlers irrigation	Agriculture	1308

8.2 APPENDIX B: Run off records of the gauging stations in Thuli river basin

Monthly run off
Summary

River: Thuli
Location: Thuli Gorge
Date opened: 14/11/58
R/T Code No: 2031 01
Notch capacity: 365 m^3/s

Station No: B31
Zone: BM
Latitude: 2105S
Longitude: 2850E
Grid Reference:
Area: 4140 Km^2

MONTHLY RUNOFF IN THOUSANDS OF CUBIC METERS

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
58/59	0	249	44110	152269	34182	24649	4192	1206	484	289	81	105	261816
59/60	0	493	1537	112	6192	1451	906	69	0	0	0	0	10760
60/61	0	6543	6052	8007	6679	6802	4846	1464	800	577	278	64	42112
61/62	0	144	1341	36039	5375	439	71	319	0	0	0	0	43728
62/63	0	36155	43446	26990	20114	12930	21569	3032	2322	927	159	0	167644
63/64	0	0	12740	865	1040	60	0	0	0	0	0	0	14705
64/65	0	0	42437	11943	996	187	0	0	0	0	0	0	55563
65/66	0	0	592	39304	210505	17286	2130	511	0	0	0	0	270328
66/67	0	11916	60380	123192	132632	29333	8609	4088	910	294	39	226	371619
67/68	0	0	0	0	9185	12	2153	1	0	0	0	0	11351
68/69	0	1077	6894	475	510	87760	13812	1286	111	0	0	0	111925
69/70	13963	2427	1651	245	19	135	0	0	0	0	0	0	18440
70/71	0	0	4307	71918	545	1416	1429	0	0	0	0	0	79615
71/72	0	94	362	82575	25745	16993	15246	2741	648	205	0	0	144609
72/73	0	0	1775	1254	3119	923	0	0	0	0	0	0	7071
73/74	0	0	54913	145819	148351	115759	38292	12019	3766	2186	1127	363	522595
74/75	0	1623	86656	43660	329943	98448	34994	11719	5653	2995	1353	154	617198
75/76	1	0	10922	8296	21624	87000	62585	44264	11316	7136	3130	1381	257655
76/77	1628	10712	1221	419	172243	178519	31317	11444	5147	2915	1659	395	417619
77/78	1972	2	68399	239368	233017	106905	47253	20571	12223	6997	2978	3100	742785
78/79	2316	11843	41977	9272	202630	13215	2937	625	289	359	184	80	285727
79/80	1168	11602.5	29330	50854	232983	45889	12736	7251	2941	1487	703	253	397194.5

80/81	20	11362	16683	92435	263335	78562	22535	13876	5593	2614	1221	426	508662
81/82	956	8416	1971	42	55	65	11	1	0	0	0	0	11517
82/83	0	301	1112	0	11393	4022	8953	143	83	124	51	34	26216
83/84	36	4413	7961	3521	3218	22080	6225	239	369	256	18	20	48356
84/85	0	3843	16855	49452	67142	6155	409	303	182	111	58	20	144530
85/86	263	2924	6278	1738	324	0	11999	1209	184	94	0	0	25013
86/87	2432	2352	17901	2349	37	164	0	0	0	0	0	0	25235
87/88	0	4	50394	27911	63107	3050	2866	118	207	1347	173	66	149243
88/89	1173	11	73	503	14305	2735	55	36	10	17	64	21	19003
89/90	0	754	195	11003	19013	711	429	0	0	0	0	0	32105
90/91	17	3	2503	5830	67481	17491	3311	161	10	2	1	0	96810
91/92	0	0	0	0	0	0	0	0	0	0	0	0	0
92/93	0	3227	19875	21843	15386	914	0	0	0	0	0	0	61245
93/94	0	12161	26102	7341	8203	44	0	0	0	0	0	0	53851
94/95	0	0	235	2971	3391	8177	3648	26	6	0	0	0	18454
95/96	240	6199	4497	116735	81328	33933	4009	1785	424	304	50	0	249504
96/97	102	1759	1076	22732	9272	4164	26241	1402	274	78	2	0	67102
97/98	0	720	116	8253	15133	731	1	0	0	0	0	0	24954
98/99	788	1182	872	600	8007	797	30	4	10	1	0	263	12554
99/00	57	2323	7316	26367	189914	110672	42822	15543	10689	1463	2316	309	409791
00/01	11	0	303	896	53478	67872	18443	5066	1729	797	297	31	148923
01/02	233	7068	26215	12624	851	0	0	0	0	0	0	0	46991
02/03	0	0	0	0	0	15422	91	0	0	0	0	0	15513
03/04	3158	1	3309	17040	16778	23714	24310	4362	962	221	65	19	93939
04/05	0	0	7653	13753	1931	13	0	0	0	0	0	0	23350
05/06	0	0	2841	38999	17391	54377	5177	793	0	0	0	0	119578
MEAN	650	3487	15756	31890	57675	26545	10244	3551	1433	719	341	156	152445
MAX	13963	36155	86656	239368	329943	178519	62585	44264	12223	7136	3130	3100	742785
MIN	0	0	0	0	0	0	0	0	0	0	0	0	0
DAYS	1394	1377	1418	1412	1270	1399	1380	1426	1372	1426	1426	1380	16680
ST.DEV	2138	6252	21649	51036	81206	41805	15160	7841	3046	1582	768	498	180302
SKEW	5.732	3.584	1.646	2.348	1.986	1.923	1.761	3.679	2.616	3.167	2.646	5.141	1.754
C.V.	3.59	1.888	1.4	1.621	1.942	1.6	1.488	2.259	2.176	2.253	2.309	3.238	1.264

Mean Flow m^3/s	0.227	1.28	5.81	11.9	20.7	9.94	3.93	1.3	0.543	0.262	0.124	0.059	4.55

Monthly run off Summary													
River: Mtsheleli												Station No: B54	
Location: Freda L/F Weir												Zone: BT4	
Date opened: 19/06/65												Latitude: 2058 S	
R/T Code No: 2054 02												Longitude: 2858 E	
Notch capacity: 16.7 m^3/s												Grid Reference:	
												Area: 1813 Km^2	
					MONTHLY RUNOFF IN THOUSANDS OF CUBIC METERS								
YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
75/76	29	5	3398	3630	10188	15266	11514	8615	3005	1764	1316	1994	60724
76/77	498	1910	417	331	31300	35000	6940	2850	1450	943	682	408	82729
77/78	168	36	13887	40238	38924	14170	5796	3867	2372	1626	907	561	122552
78/79	658	4110	2690	5560	2730	6200	1240	585	361	285	172	53	24644
79/80	73	3351	3797	2040	8437	9521	2373	921	511	368	197	77	31666
80/81	0	2789	3795	7666	16931	4069	167	94	41	21	11	5	35589
81/82	424	479	232	1723	51	44	0	0	0	0	0	0	2953
82/83	0	3	575	0	1125	2	162	0	0	0	0	0	1867
83/84	0	6	3	0	0	0	4	0	0	0	0	0	13
84/85	0	541	6	380	678	69	0	0	0	0	0	0	1674
85/86	0	0	0	0	0	0	2306	0	0	0	0	0	2306
86/87	0	0	0	0	0	0	0	0	0	0	0	0	0
87/88	0	0	612	76	306	1097	143	48	17	5	2	0	2306
88/89	0	0	0	0	217	27	10	2	0	0	0	0	256
89/90	0	0	0	32	158	197	5	1	0	0	0	0	393
90/91	0	0	0	35	56	111	2	0	0	0	0	0	204
91/92	0	0	0	0	0	0	0	0	0	0	0	0	0

92/93	0	0	69	83	104	16	0	0	0	0	0	0	272
93/94	0	9	114	132	65	0	0	0	0	0	0	0	320
94/95	0	0	0	0	0	0	0	0	0	0	0	0	0
95/96	0	36	12	168	579	105	10	3	0	0	0	0	913
96/97	0	0	0	20	11	0	16	1	0	0	0	0	48
97/98	0	0	0	2	5	0	0	0	0	0	0	0	7
98/99	24763	19	0	133	422	0	0	0	0	0	0	0	25337
99/00	60	238	67	119	1686	2527	2772	1196	1071	480	26	0	10242
00/01	0	0	0	0	0	1198	1814	118	42	16	0	0	3188
01/02	691	517	439.5	343	227.5	728.5	907	59	21	0	706	1215	5854.5
02/03	1382	1034	879	686	455	259	0	0	0	0	0	0	4695
03/04	0	0	2	1247	3234	16441	5587	2232	124	0	0	0	28867
04/05	0	0	0	984	1296	67	0	0	0	0	0	0	2347
05/06	0	899	3022	12385	10008	12368	1611	232	0	0	0	0	40525
MEAN	927	516	1097	2517	4168	3854	1399	672	291	178	130	139	15887
MAX	24763	6394	18400	40238	47700	35000	11514	8615	3005	1764	1316	1994	122551
MIN	0	0	0	0	0	0	0	0	0	0	0	0	0
DAYS	1320	1281	1349	1345	1224	1351	1304	1364	1291	1333	1352	1292	15806
ST.DEV	3687	1391	4067	7422	11268	7089	2643	1556	675	431	294	355	30297
SKEW	6.652	2.658	2.535	3.384	2.386	2.609	1.925	3.441	2.465	2.337	2.499	4.293	1.949
C.V.	5.702	2.088	1.945	2.115	1.987	1.853	1.628	2.118	1.985	1.996	2.134	3.187	1.548
Mean Flow m^3/s	0.255	0.271	0.807	1.36	2.41	1.47	0.648	0.281	0.137	0.084	0.053	0.045	0.645

MONTHLY
RUN OFFS
SUMMARY UNOFF S UMMARY

RIVER: MCHABEZI
LOCATION: GWANDA
DATE OPENED: 10/7/1965
R/T CODE NO: 2055
01
NOTCH CAPACITY: 12.8 m^3/s

STATION NUMBER: B55
ZONE: BM
LATITUDE: 2058 S
LONGITUDE: 2859 E
GRID REFERENCE:
AREA: 987 km^2

MONTHLY RUN OFFS IN THOUSANDS OF CUBIC METERS

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
65/66	0	0	0	4230	21568	5806	724	295	80	18	0	10	32731
66/67	0	7566	23608	31260	41224	13319	3474	1768	601	322	226	172	123540
67/68	67	139	141	22	184	0	6	84	84	107	103	32	969
68/69	6	83	333	263	23	10249	3722	403	33	0	0	94	15209
69/70	956	462	343	303	501	248	328	429	637	358	356	88	5009
70/71	22	2587	23017	2164	2	944	1	0	23	1	0	0	28761
71/72	0	832	1419	26206	11279	6439	6864	942	226	58	20	4	54289
72/73	22	50	63	54	559	46	154	59	95	94	103	26	1325
73/74	16	156	10800	28082	25794	26338	8800	3406	1246	767	256	44	105705
74/75	43	1197	26641	11182	51757	26804	10424	3126	1880	1060	541	50	134705
75/76	53	67	3185	2584	4232	25740	16059	11369	4487	2044	901	200	70921
76/77	340	2284	194	139	16354	9715	10443	3447	1549	946	591	173	46175
77/78	66	52	17600	52800	55400	25300	11300	6250	3220	2000	878	691	175557
78/79	851	10344	5446	10329	4681	7637	1381	449	153	191	39	74	41575
79/80	157	1927	5441	2998	7362	13756	2729	788	340	280	242	200	36220
80/81	123	2179	6680	27486	57058	22512	6014	3996	1802	996	409	133	129388
81/82	83	214	116	111	9	11	16	91	129	36	13	3	832
82/83	42	312	669	0	1562	127	1620	5	1	10	9	16	4373
83/84	187	427	243	1	0	191	517	1	0	0	2	20	1589
84/85	2	3006	3132	8640	12367	3360	243	21	40	41	36	22	30910
85/86	3	133	230	63	48	8	320	104	3	1	0	0	913

86/87	516	611	1795	571	10	3	0	0	0	17	68	36	3627
87/88	0	13	18314	4155	15876	20514	5082	1532	410	259	3	0	66158
88/89	0	0	0	0	3039	818	0	0	0	0	0	0	3857
89/90	0	9	4	4520	8311	650	266	1	1	6	0	0	13768
90/91	0	0	854	487	2707	2041	213	1	0	0	0	0	6303
91/92	0	0	0	0	0	0	0	0	0	0	0	0	0
92/93	0	423	2998	7380	3966	167	0	0	0	0	0	0	14934
93/94	0	2261	6836	1549	4808	0	0	0	0	0	0	0	15454
94/95	0	0	419	21	224	691	403	4	3	0	0	0	1765
95/96	0	792	948	19069	20634	5684	744	330	64	729	30	10	49034
96/97	124	12	34	2448	2816	772	3355	480	141	8	8	15	10213
97/98	14	6	10	74	1047	53	1	0	8	12	8	0	1233
98/99	1487	530	18	0	592	0	0	0	0	0	0	0	2627
99/00	0	122	352	3645	3758	24043	14184	5334	7136	1149	1025	35	60783
00/01	0	7	853	1355	3748	20226	5198	1955	644	65	25	213	34289
01/02	334	1511	7611	1339	0	0	0	0	20	0	289	266	11370
02/03	213	58	36	0	359	3462	78	0	0	0	0	0	4206
03/04	150	0	0	2210	1515	7832	5452	1681	346	41	0	41	19268
04/05	0	0	2708	871	32	0	0	0	0	0	0	0	3611
MEAN	147	1009	4327	6465	9635	7138	3003	1209	635	290	155	67	34080
MAX.	1487	10344	26641	52800	57058	26804	16059	11369	7136	2044	1025	691	175557
MIN.	0	0	0	0	0	0	0	0	0	0	0	0	0
DAYS	1240	1200	1240	1240	1111	1221	1192	1240	1200	1240	1240	1182	14546
ST.DEV	306	2054	7273	11498	15695	9358	4351	2277	1412	524	273	125	43849
SKEW	3.078	3.405	2.005	2.463	2.096	1.117	1.571	2.88	3.335	2.205	2.044	3.562	1.715
C.V.	2.085	2.035	1.681	1.778	1.629	1.311	1.449	1.884	2.223	1.804	1.766	1.869	1.287
Mean Flow m^3/s	0.055	0.389	1.62	2.4	1 4.0	2 2.71	1.17	0.45	1 0.24	5 0.10	8 0.058	0.026	1.08

MONTHLY RUNOFF SUMMARY

RIVER: Thuli : TULI
LOCATION: THULI MAKWE DAM D/S
DATE OPENED:
4/10/1966 OPENED: 4/10/'1966

R/T CODE NO: 2067 02
NOTCH CAPACITY: 320 m^3/s

STATION NUMBER: B67
ZONE: BT5
LATITUDE: 2058 S
LONGITUDE: 2848 E
GRID REFERENCE:
AREA: 767 Km^2

MONTHLY RUNOFF IN THOUSANDS OF CUBIC METRES

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP
66/67	0	5303	25137	35022	31664	9326	2590	1310	266	89	66	80
67/68	83	101	126	114	870	7	873	83	70	70	61	50
68/69	39	66	3574	224	431	25847	5225	536	99	83	83	80
69/70	84	76	79	68	56	54	62	59	64	83	78	14
70/71	62	36	27	22031	1147	53	35	48	39	41	35	7
71/72	21	49	2564	27454	16488	8288	4077	909	95	54	54	52
72/73	54	52	39	14	7	3	27	27	26	36	30	18
73/74	15	0	12488	79235	71061	21259	8987	2908	1077	575	99	15
74/75	27	56	22299	12916	75569	19673	9651	2911	1383	696	291	29
75/76	27	26	4219	2863	7481	21078	8782	12180	3213	1694	625	97
76/77	27	41	13259	7890	41525	20376	9217	7546	2298	1195	458	63
77/78	27	33.5	8739	5376	24503	20727	8999	9863	2756	1445	542	80
78/79	14	17	4370	2688	12252	11227	4511	4931	1378	722	271	40
79/80	0	0	0	0	0	1728	23	0	0	0	0	0
80/81	0	0	0	0	0	1152	15	0	0	0	0	0
81/82	0	0	0	0	0	2304	31	0	0	0	0	0
82/83	0	0	0	0	0	0	0	0	0	0	0	0
83/84	0	0	0	0	0	4608	61	0	0	0	0	0
84/85	0	0	132	876	408	18	0	0	0	0	0	0
85/86	0	0	422	438	204	9	0	0	0	0	0	0
86/87	0	0	711	0	0	0	0	0	0	0	0	0
87/88	0	0	24	35	5464	4789	71	0	0	0	0	0

88/89	0	0	0	149	24	2395	36	0	0	0	0	0
89/90	0	0	0	231	144	0	0	0	0	0	0	0
90/91	0	0	0	29	196	357	1	0	0	0	0	0
91/92	0	0	0	0	0	0	0	0	0	0	0	0
92/93	0	0	2	126	57	0	0	0	0	0	0	0
93/94	0	37	248	53	846	0	0	0	0	0	0	0
94/95	0	0	0	0	0	318	27	0	0	0	0	0
95/96	0	0	0	1497	855	458	0	0	0	0	0	0
96/97	219	736	761	806	49	39	581	0	0	0	0	0
97/98	0	0	0	4303	3131	275	0	0	0	0	0	0
98/99	0	0	0	0	3442	0	0	0	0	0	0	0
99/00	0	0	37	10755	68262	43492	4555	414	375	0	0	0
00/01	0	0	0	0	64542	90937	609	0	0	0	0	0
01/02	0	1461	6224	831	0	0	0	0	0	0	0	0
02/03	0	0	0	0	0	1762	0	0	0	0	0	0
03/04	0	0	0	0	2242	22797	2316	0	0	0	0	0
04/05	0	0	0	0	0	0	0	0	0	0	0	0
05/06	0	0	0	4286	3314	10270	98	0	0	0	0	0
MEAN	17	202	2637	5508	10906	8641	1786	1093	328	170	67	16
MAX.	219	5303	25137	79235	75569	90937	9651	12180	3213	1694	625	97
MIN.	0	0	0	0	0	0	0	0	0	0	0	0
DAYS	992	960	992	973	894	961	930	961	930	961	961	930
ST.DEV	44	964	6140	15875	23453	18373	2872	2229	628	329	120	27
SKEW	3.399	5.008	3.003	3.624	2.145	3.334	1.98	4.789	4.047	4.139	4.14	2.062
C.V.	2.227	3.858	2.497	2.545	2.117	2.135	1.894	3.335	2.997	3.076	2.705	1.971
Mean Flow m^3/s	0.007	0.096	0.918	2.37	4.59	3.32	0.604	0.258	0.083	0.041	0.017	0.005

MONTHLY RUNOFF SUMMARY

RIVER: Thuli
LOCATION: U/S Shashe Thuli Confluence
DATE OPENED:
13/05/71
R/T CODE NO. :2085 02
NOTCH CAPACITY: 175 m^3/s

STATION NO.: B85
ZONE : BT1
LATITUDE: 2145 S
LONGITUDE: 2903 E
GRID REFERENCE:
AREA : 7670 km2

MONTHLY RUN OFF IN THOUSANDS OF CUBIC METERS

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
71/72	5065	5160	9987	9579	52362	28998	22064	2630	1096	62	0	0	137003
72/73	0	160	842	876	6478	3725	1406	0	0	0	0	1855	15342
73/74	237	699	349181	218064	171374	129018	44489	13822	4266	1859	507	264	933780
74/75	0	9885	114887	59377	212834	122785	58090	17072	7152	4339	1264	141	607826
75/76	0	0	14754	23467	22751	114863	72035	54631	16094	9242	3423	708	331968
76/77	1485	21053	355	854	81643	244612	45085	13484	5785	3190	1505	349	419400
77/78	743	10527	7555	12161	52197	179738	58560	34058	10940	6216	2464	529	375684
78/79	1114	15790	3955	6507	66920	212175	51823	23771	8362	4703	1985	439	397542
79/80	9977	8904	9726	3395	33729	106567	26820	11885	4181	2352	992	219	218747
80/81	18840	2018	15497	282	539	959	1817	0	0	0	0	0	39952
81/82	12560	1459	29367	560	360	640	1520	0	0	0	0	0	46464
82/83	25120	2578	1627	5	718	1279	2114	0	0	0	0	0	33441
83/84	0	339	57106	1114	1	0	926	0	0	0	0	0	59486
84/85	0	1181	249	60834	8730	1399	11073	0	0	0	0	0	83466
85/86	132	2619	2620	4115	617	1465	21220	3372	0	0	0	0	36160
86/87	3147	17508	46211	5110	1674	1099	0	0	0	0	0	0	74749
87/88	0	0	121150	25595	190175	97800	26287	8955	603	0	0	0	470565
88/89	0	0	0	0	21807	7350	15	0	0	0	0	0	29172
89/90	476	0	0	24729	5938	1189	0	0	0	0	0	0	32332
90/91	0	182	27846	26175	32764	79968	6432	207	0	0	0	0	173574
91/92	0	0	0	771	0	4889	44	0	0	0	0	0	5704
92/93	0	0	18670	4617	0	0	0	0	0	0	0	0	23287
93/94	0	39846	41953	25229	21246	0	0	0	0	0	0	0	128274

94/95	0	22471	5	0	5133	4	450	0	0	0	0	0	28063
95/96	0	26419	16252	40160	7671	19590	4172	162	104	64	42	0	114636
96/97	0	2020	6047	26064	10209	2486	9372	1288	234	37	0	0	57757
97/98	0	1	21	11968	11882	278	0	0	0	0	0	0	24150
98/99	0	0	2649	3889	7594	461	90	4	0	0	0	0	14687
99/00	0	3306	10648	66649	27766	95666	42483	35604	47791	509	38059	1461	369942
00/01	196	0	0	35269	17680	48063.5	21287	17804	23896	255	19030	731	184209
01/02	142	4302	15954	7683	518	0	0	0	0	0	0	0	28599
02/03	0	0	0	0	0	9386	55	0	0	0	0	0	9441
03/04	1922	1	2014	10371	10211	14432	14795	2655	585	135	40	12	57171
04/05	0	0	4658	8370	1175	8	0	0	0	0	0	0	14211
05/06	0	0	1729	23735	10584	33094	3151	483	0	0	0	0	72775
MEAN	2636	6471	30305	23247	35760	50236	17656	7958	4350	1094	2309	223	161416
MAX.	25120	39846	349181	218064	212834	244612	72035	54631	47791	9242	38059	1855	933780
MIN.	0	0	0	0	0	0	0	0	0	0	0	0	5704
DAYS	755	733	723	711	628	719	690	681	718	727	713	690	8488
ST.DEV	5073	10663	73712	45300	61937	62720	21478	13073	9940	2074	7594	473	232055
SKEW	4.608	1.943	3.632	3.534	2.157	1.878	1.459	2.819	4.123	3.348	4.922 2	0.847	2.015
C.V.	3.537	1.715	2.186	1.847	1.733	1.635	1.505	2.161	2.989	2.686	4.238 2	0.476	1.395
Mean Flow m3/s	0.55	2.45	13.5	9.98	16.5	15.4	5.98	2.57	1.34	0.307	0.727 0	0.08	5.67

MONTHLY RUNOFF SUMMARY

RIVER:	MWEWE			STAT	ION NUM	BER: B87
LOCATI	ON : GW	ARANYEMB	A TTL	ZONE	: BT2	
DATE O	PENED:	12/10/1972		LATI	TUDE: 2	110 S
R/T CO	DE NO.:	2087 12		LONG	ITUDE:	2850 E
NOTCH	CAPACIT	Y : 240	m^3/s	GRID	REFERE	NCE:
				AREA	: 1386	.00km2

MONTHLY RUNOFF IN THOUSAN DS OF CUBIC M ETRES

YEAR	OCT	NOV	DEC	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	TOTAL
72/73	0	0	348	1540	2700	2	0	0	0	0	0	0	4590
73/74	0	0	26700	42600	30900	14500	1680	1710	797	0	0	0	118887
74/75	0	2970	21900	13200	105000	14600	7340	2220	1430	611	74	24	169369
75/76	27	27	1541	4762	5094	30256	12021	6424	715	306	37	17	61226
76/77	20	663	95	109	4337	28580	2718	14	0	0	0	9	36545
77/78	0	43	5254	79966	43181	25060	6100	1196	274	0	0	170	161244
78/79	176	1711	2319	0	21591	10	29	10	0	0	0	0	25845.5
81/82	0	2548	473	0	0	0	0	0	0	0	0	0	3021
82/83	2837	0	3	0	1442	269	2140	0	0	0	0	0	6691
83/84	0	79	398	26	7	0	0	0	0	0	0	0	510
84/85	0	16	164	253	640	0	0	0	0	0	0	0	1073
85/86	0	447	3869	621	0	0	3768	55	0	0	0	0	8760
86/87	420	8733	7392	0	0	0	0	0	0	0	0	0	16545
87/88	0	152	7057	1275	2010	1063	293	2	0	0	0	0	11852
88/89	0	0	0	540	3717	24	0	0	0	0	0	0	4281
89/90	0	50	107	13358	4545	34	9	0	0	0	0	0	18103
90/91	0	0	197	167	214	1759	17	0	0	0	0	0	2354
91/92	0	0	0	0	0	0	0	0	0	0	0	0	0
92/93	0	29	898	58	72	0	0	0	0	0	0	0	1057
93/94	27	147	139	28	41	0	0	0	0	0	0	0	382
94/95	0	0	0	824	3416	2994	690	0	0	0	0	0	7924
95/96	0	0	35	2352	1138	45	0	0	0	0	0	0	3570
96/97	0	185	2	145	30	0	40	0	0	0	0	0	402

97/98	0	0	0	1586	16816	0	0	0	0	0	0	0	18402
98/99	0	0	0	106	0	0	0	0	0	0	0	0	106
99/00	0	0	0	53	0	0	179.5	44	0	0	0	0	276.5
00/01	0	0	0	0	0	0	359	88	0	0	0	0	447
01/02	0	588	123	1	251	1	0	0	0	0	0	0	964
02/03	0	0	0	0	541	531	0	0	0	0	0	0	1072
03/04	0	0	0	0	9	0	0	0	0	0	0	0	9
04/05	0	348	1741	14963	4453	0	0	0	0	0	0	0	21505
													0
MEAN	113	604	2605	5759	8134	3862	1206	379	104	30	4	7	22807
MAX.	2837	8733	26700	79966	105000	30256	12021	6424	1430	611	74	170	274222
MIN.	0	0	0	0	0	0	0	0	0	0	0	0	0
DAYS	930	900	917	908	799	916	900	913	870	899	899	869	10720
													0
ST.DEV	520	1702	6254	16358	20746	8943	2749	1259	296	112	14	31	58984
SKEW	5.279	4.12	3.137	3.815	4.02	2.236	2.802	4.202	3.971	5.477	5.477 5	0.299	39.358
C.V.	4.45	2.725	2.323	2.75	2.7	2.241	2.217	3.224	3.555	5.477	5.477 4	0.601	32.263
MEAN													
Flow													
m3/s	0.044	0.241	1.02	2.2	8 3.3	4 1.51	0.478	0.14	9 0.03	3 0.008	0.001	0.003	0.739

8.3 APPENDIX C: Reservoir storage records

DAM SUMMARY

DAM NAME	TULI MAKWE	FS. LEVEL	100.99	M		Area	147	Ha
PROVINCE	FS. CAPACITY		7.663	ML				
SUBCATCHMENT	TOWN SUPPLIED							
CATCHMENT	PURPOSE. ID							

Capacities in Millions of Cubic Metres

	Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
	1970	*	*	*	7.245	5.736	6.078	7.543	7.507	6.676	6.838	6.594	6.276	60.492
	1971	5.882	1.357	2.01	7.094	8.254	7.848	7.651	7.258	6.8	6.564	6.280	5.932	72.929
	1972	5.542	5.882	7.52	8.213	8.256	7.753	7.435	7.756	6.551	7.113	6.909	6.619	85.548
	1973	6.222	3.620	4.765	5.662	7.565	7.657	7.218	8.254	6.302	6.014	5.65	5.245	74.174
	1974	4.861	4.454	5.149	8.245	8.245	8.247	8.254	8.254	8.202	8.212	8.168	7.993	88.284
	1975	7.583	7.202	8.235	8.252	8.254	8.254	8.254	8.254	8.235	8.214	8.196	8.068	97.001
	1976	7.698	7.242	7.677	8.239	8.254	8.249	8.254	8.254	8.254	8.242	8.212	8.116	96.691
	1977	8.139	8.157	8.212	8.077	8.254	8.254	8.254	8.254	8.242	8.223	8.169	8.051	98.286
	1978	7.927	7.582	8.239	8.254	8.254	8.254	8.254	8.254	8.254	8.24	8.202	8.175	97.889
	1979	7.909	7.870	8.226	8.166	8.254	8.254	8.254	8.200	8.180	8.071	7.914	7.626	96.921
	1980	7.207	6.819	8.156	8.269	8.085	7.7	7.244	8.145	8.105	7.901	7.626	7.076	92.332
	1981	6.505	6.008	8.263	8.338	8.514	8.333	8.295	8.254	8.247	8.147	8.101	7.788	94.793
	1982	7.297	7.629	8.048	8.2	7.656	7.067	6.193	5.627	5.144	4.682	4.242	3.605	75.39
	1983	4.146	6.509	6.62	5.979	7.743	8.04	8.172	7.659	7.102	6.685	6.198	5.638	80.491
	1984	5.092	6.543	7.657	8.032	7.797	7.516	8.225	7.762	7.29	6.799	6.353	5.71	84.776
	1985	5.1	5.541	8.338	8.275	8.422	8.231	8.084	7.478	6.94	6.476	5.753	5.209	83.847
	1986	4.595	3.925	4.422	6.569	6.494	5.836	6.002	8.198	7.88	7.536	6.921	6.289	74.667
	1987	5.72	5.072	8.23	8.154	7.75	7.247	6.531	5.83	5.226	4.622	4.208	3.699	72.289
	1988	3.096	2.399	5.828	7.427	7.345	7.636	7.298	7.222	7.164	7.136	5.988	5.828	74.367
	1989	5.371	5.42	4.684	6.311	6.963	7.163	6.48	6.018	5.377	4.784	4.207	3.454	66.232
	1990	2.756	2.787	3.282	3.755	7.347	6.974	6.684	6.205	5.539	5.015	4.436	3.704	58.484
	1991	3.004	2.143	4.101	6.631	7.187	7.208	7.178	6.595	6.056	5.545	4.958	4.258	64.864
	1992	3.566	2.938	2.496	1.744	1.398	1.131	0.994	0.808	0.661	0.561	0.474	0.397	17.168

	1993	0.333	3.861	4.964	7.118	7.243	7.062	6.461	5.788	5.148	4.774	4.205	3.636	60.593
	1994	3.142	3.535	7.243	7.221	7.157	6.701	5.869	5.135	4.627	4.208	3.67	3.1	61.608
	1995	2.372	1.735	1.107	1.678	4.638	6.712	7.149	6.817	6.498	5.897	5.31	4.642	54.555
	1996	3.902	4.425	7.224	6.638	7.256	7.256	6.328	6.098	6.078	6.028	5.848	5.215	72.296
	1997	4.4	4.262	5.087	6.122	6.107	6.081	6.068	6.078	6.011	5.756	5.179	4.713	65.864
	1998	3.994	3.508	3.867	3.733	6.114	6.034	5.565	4.801	4.134	3.621	3.029	2.647	51.047
	1999	1.858	1.386	1.681	4.052	5.614	6.034	5.504	4.829	4.186	3.73	3.163	2.508	44.545
	2000	1.562	1.569	4.66	6.229	7.039	6.393	6.549	6.145	6.143	6.107	6.085	6.045	64.526
	2001	5.677	5.278	5.934	5.859	5.99	6.32	6.124	6.107	6.092	6.075	6.034	5.865	71.355
	2002	5.799	6.046	6.247	5.293	5.917	5.261	4.556	4.14	3.567	3.178	2.741	2.229	54.974
	2003	1.915	2.275	1.987	2.047	6.029	6.164	5.695	5.251	4.769	4.413	3.911	3.261	47.717
	2004	2.762	3.02	3.206	5.709	6.141	6.303	6.198	6.081	6.042	5.853	5.341	4.73	61.386
	2005	4.18	3.49	4.741	5.78	5.775	5.115	4.425	3.669	3.121	2.696	2.272	1.774	47.038
	2006	1.222	0.852	3.878	5.84	6.16	6.219	6.113	6.016	5.79	5.355	4.826	4.242	56.513
	2007	3.656	3.336	4.024	4.894	4.386	5.637	*	*	*	*	*	*	25.933
	Maximum	8.139	8.157	8.338	8.338	8.514	8.333	8.295	8.254	8.254	8.242	8.212	8.175	98.286
	Minimum	0.333	0.852	1.107	1.678	1.398	1.131	0.994	0.808	0.661	0.561	0.474	0.397	17.168
	Average	4.648	4.478	5.568	6.404	6.937	6.901	6.739	6.568	6.179	5.927	5.551	5.118	69.681

IR = IRRIGATION WS = WATER SUPPLY MI = MINING IN = INDUSTRIAL HY = HYDRO ELECTRICITY

Dam capacities processed by ZINWA, Research and Data Division, BOX CY726, Causeway, Harare

DAM SUMMARY

DAM NAME	MTSHABEZI	FS. LEVEL	35	M	Are	378	Ha
PROVINCE	Matabeleland South	FS. CAPACITY	51.996	ML			
SUBCATCHMENT	Shashe	TOWN SUPPLIED					
CATCHMENT	Mzingwane	PURPOSE. ID	IRWS				

Capacities in Millions of Cubic Metres

	Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
	1996	*	*	*	3.834	15.281	26.492	29.55	30.73	31.317	31.56	31.778	31.579	232.125
	1997	31.215	31.086	31.65	32.602	35.74	37.467	41.322	42.83	43.162	43.208	43.272	43.089	456.645
	1998	42.849	42.434	42.061	40.155	45.263	45.751	43.294	45.09	44.113	40.523	43.406	42.469	517.411
	1999	38.512	33.096	33.686	34.416	34.387	34.396	34.314	33.93	33.556	33.13	32.493	32.257	408.177
	2000	32.322	31.642	31.498	34.465	49.286	53.521	56.198	56.06	53.071	52.063	52.033	51.977	554.137
	2001	51.764	51.59	51.765	51.747	51.544	52.42	52.436	52.56	43.886	52.008	51.942	51.744	615.408
	2002	51.881	51.83	52.241	50.001	51.898	51.281	50.612	50.52	49.356	48.512	47.309	45.213	600.65
	2003	43.743	42.376	41.763	41.682	47.273	43.485	43.531	43.3	43.063	42.55	42.657	42.289	517.714
	2004	41.948	41.672	41.431	41.348	42.648	46.147	51.819	52.04	51.996	51.983	51.878	51.741	566.653
	2005	51.244	50.897	50.78	50.761	51.817	51.598	51.062	50.58	50.076	49.74	49.383	48.906	606.839
	2006	48.19	46.85	47.628	49.587	52.147	52.535	52.147	52.09	51.996	51.971	51.769	51.49	608.4
	2007	51.05	50.904	51.273	51.336	51.006	51.644	*	*	*	*	*	*	307.213
	Maximum	51.881	51.83	52.241	51.747	52.147	53.521	56.198	56.06	53.071	52.063	52.033	51.977	615.408
	Minimum	31.215	31.086	31.498	3.834	15.281	26.492	29.55	30.73	31.317	31.56	31.778	31.579	232.125
	Average	44.065	43.125	43.252	40.161	44.024	45.561	46.026	46.340	45.054	45.204	45.265	44.796	499.281

IR = IRRIGATION WS = WATER SUPPLY MI = MINING IN = INDUSTRIAL HY = HYDRO ELECTRICITY

Dam capacities processed by ZINWA, Research and Data Division, BOX CY726, Causeway, Harare

LOWER MUJENI	FS. LEVEL	102.4	M	Area	271	Ha
Matabeleland South	FS. CAPACITY	10.45	ML			
Shashe	TOWN SUPPLIED	Gwanda				
Mzingwane	PURPOSE. ID	IRWS				

Season	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1990	3.15	2.617	3.013	3.320	3.239	3.213	3.205	5.483	5.04	4.572	4.198	3.73	44.7785
1991	3.336	2.833	4.01	5.311	5.549	5.585	5.727	5.353	4.816	4.304	3.881	3.458	54.163
1992	2.964	2.401	2.015	1.328	0.928	0.841	0.683	0.499	0.357	0.365	0.256	0.15	12.787
1993	0.334	3.025	3.983	5.6	5.635	5.635	5.359	4.949	4.363	4.036	3.551	3.182	49.652
1994	2.641	2.501	5.565	5.835	5.635	5.635	5.635	5.635	5.635	5.635	5.635	5.635	61.622
1995	5.701	5.492	5.196	5.103	4.986	4.996	5.349	4.897	4.5	4.094	3.66	3.177	57.151
1996	2.637	3.978	9.202	10.42	10.45	10.45	10.42	10.333	10.286	10.17	10.177	10.143	108.666
1997	9.982	9.794	9.684	9.684	10.348	10.288	10.45	10.437	10.37	10.261	10.167	9.966	121.431
1998	9.82	9.705	10.45	8.682	10.449	10.411	10.362	10.337	10.17	9.88	9.685	9.398	119.349
1999	9.95	10.256	10.16	10.155	10.164	10.154	9.914	9.758	7.816	6.755	6.204	5.608	106.894
2000	5.06	4.585	5.102	6.165	8.973	10.63	10.672	10.648	10.648	10.559	10.53	10.474	104.046
2001	10.192	9.905	9.79	9.648	9.792	10.628	10.555	10.512	10.492	10.452	9.405	7.775	119.146
2002	7.754	7.925	10.014	9.674	10.416	10.26	10.26	10.164	8.76	7.257	7.128	7.136	106.748
2003	7.124	6.565	5.993	6.262	5.587	6.852	6.262	5.832	5.267	4.794	4.2	3.613	68.351
2004	3.176	2.95	2.746	3.523	7.926	9.812	10.418	10.245	10.081	9.682	9.211	8.874	88.644
2005	8.536	7.829	7.371	8.36	10.1	9.581	9.084	8.536	7.982	6.555	5.917	5.452	95.303
2006	5.033	4.646	5.223	6.078	8.823	10.377	10.16	9.838	9.605	9.191	8.653	7.932	95.559
2007	7.328	6.866	6.518	5.934	5.403	5.056	*	*	*	*	*	*	37.105
Maximum	10.192	10.256	10.45	10.42	10.45	10.63	10.672	10.648	10.648	10.559	10.53	10.474	121.431
Minimum	0.334	2.401	2.015	1.328	0.928	0.841	0.683	0.499	0.357	0.365	0.256	0.15	12.787
Average	5.818	5.771	6.446	6.727	7.467	7.800	7.913	7.850	7.423	6.974	6.615	6.218	80.633

IR = IRRIGATION WS = WATER SUPPLY MI = MINING IN = INDUSTRIAL HY = HYDRO ELECTRICITY

Dam capacities processed by ZINWA, Research and Data Division, BOX CY726, Causeway, Harare

8.4 APPENDIX D: Naturalised flows

B15	B29	B31	B54	B55	B56	B67	B80	B81	B83	B87	B85
288	432	439		757	6	916	731	89	70	24	397
370	236	4816		852	342	2572	733	1506	243	103	760
599	553	8364		898	408	723	1088	1631	185	422	57607
426	546	3924		649	164	0	755	6474	427	50	1605
288	486	3621		605	6	2010	811	7584	109	31	400
288	456	22483		775	6	5344	833	890	621.5	24	466
343	337	6628		1013	6	506	2404	3035	858	24	1419
293	344	642		450	77	0	773	249	134	24	403
288	276	772		400	8	0	740	89	96	24	425
288	295	659		415	6	0	737	89	71	24	456
288	451	421		528	6	260	734	89	70	24	457
288	626	423		726	74	48	731	89	70	24	425
705	621	403		707	167	0	732	89	70	24	397
2115	1183	4246		3726	4246	1894	734	2922	325	40	1602
2759	518	17258		3759	5576	1924	1057	3172	1634	188	750
5055	1028	49855		9362	9126	2061	779	12858	2240	277	61325
3411	1167	67545		12975	17606	460	890	14829	4714	664	9129
1836	516	6558		3938	3536	95	935	1373	454	24	1865
606	306	812		720	599	1012	2202	2122	244	24	11566
439	324	706		456	262	0	778	93	102	24	403
353	228	585		405	98	0	748	89	120	24	425
316	267	514		436	42	0	743	89	104	24	456
288	401	461		526	10	282	736	89	91	24	457
288	502	423		639	6	0	732	89	93	24	425
288	600	666		693	16	0	731	89	87	24	529
288	402	3327		681	11	750	733	89	96	471	3040
759	449	6681		812	1246	3820	1118	89	221	3893	3121
845	422	2141		622	292	946	731	89	269	645	4606
442	299	727		519	259	522	731	339	124	24	1016
288	379	403		537	13	138	731	407	130	24	1931

1497	2630	12402		810	4737	163	2606	3947	3237	3792	21713
550	263	1612		494	1040	0	768	404	532	79	3775
337	116	587		288	1589	0	731	89	207	24	425
294	339	497		447	62	0	731	89	111	24	456
288	419	403		503	8	12	731	89	126	24	457
288	339	403		500	6	0	731	89	122	24	425
290	530	2835		1156	18	0	732	1996	106	444	3544
1610	559	2755		1272	5570	0	734	621	131	8757	17929
838	483	18304		2401	3042	2016	996	29005	1026	7416	46712
288	437	2752		1142	965	2624	827	2934	283	24	5601
288	443	440		585	195	454	1050	638	259	24	2073
288	515	567		630	200	0	1138	498	218	24	1565
288	281	403		458	6	464	1798	2099	143	24	493
288	290	403		410	6	2398	788	251	83	24	403
288	287	403		407	6	0	765	89	70	24	425
288	361	403		479	6	111	754	92	70	24	456
288	437	403		585	6	134	742	89	70	24	457
288	539	403		679	6	0	732	89	70	24	425
288	529	403		639	6	0	731	13371	70	24	397
680	512	407		640	13	0	731	7445	284	176	421
5351	1024	50797		18869	21867	3727	1240	57921	6589	7081	121651
1540	429	28314		4665	24782	437	923	5779	3528	1299	26086
11987	868	63510		16536	23674	5480	1368	936	3193	2034	190574
15035	1636	3453		21157	8967	4670	1545	588	3088	1087	98266
1983	598	3269		5665	3364	0	990	250	2724	317	26780
892	410	521		1994	1661	0	807	97	1823	26	9358
624	340	610		844	1902	0	799	95.5	970	24	1028
499	347	1750		707	1406	0	777	94	1387	24	456
368	393	576		486	140	311	752	89	1050	24	457
295	551	469		652	26	0	733	89	230	24	425
446	629	1576		711	69	0	733	7684	77	24	397
406	657	414		731	16	0	736	3767	78	24	421
346	340	476		504	23	3937	752	39688	141	24	501

470	512	906		624	1732	2561	748	3160	70	564	491
2745	560	14708		3542	3944	161	1053	654	80	3741	22206
1049	365	3138		1317	4165	2972	731	97	171	48	7816
562	303	458		467	268	46	731	102	85	24	508
435	256	439		384	137	111	731	102	77	24	403
292	224	413		362	11	168	731	102	73	24	425
288	277	420		401	9	382	731	93	70	24	456
288	347	467		452	7	0	731	89	70	24	457
288	580	424		673	6	360	731	89	70	24	425
288	459	403		589	6	0	732	3886	70	24	873
566	543	1157		658	546	376	734	89	402	74	421
1266	419	598		564	1053	0	959	21455	138	131	501
2648	501	11406		5113	2146	2436	1015	542	492	13382	25220
3776	489	19416		8805	5477	1086	738	371	977	4569	6337
712	582	1114		1183	892	762	1138	103	176	58	1655
645	307	832		739	714	0	861	89	217	33	493
310	267	403		393	98	0	769	89	93	24	403
288	226	403		365	17	0	765	89	75	24	425
288	265	403		399	6	0	754	89	70	24	456
288	399	403		489	6	150	742	89	70	24	457
288	479	403		600	6	0	732	89	70	24	425
288	290	420		3618	6	0	731	89	70	24	397
292	452	406		206	6	368	731	89	70	24	603
972	465	2906		1898	1212	1029	1165	17182	923	221	28347
2044	351	6233		1425	2856	1007	1282	995	370	191	26666
1563	507	67884		3250	3026	4014	744	654	1315	238	33163
1175	546	17894		2655	3264	336	731	117	4783	1783	80434
408	377	3714		739	828	45	731	89	1162	41	6925
302	305	564		2700	686	0	731	89	293	24	610
288	239	413		0	858	0	731	89	144	24	425
288	271	405		0	499	0	731	89	74	24	456
288	372	404		95	44	138	731	89	70	24	457
288	478	403		131	6	0	731	89	70	24	425

288	544	403		286	6	0	731	89	70	24	397
288	508	403		317	316	0	731	89	70	24	421
288	535	403		2234	142	2713	731	25728	70	24	501
288	406	403		2094	6	3123	731	89	70	24	1262
288	377	403		978	87	845	731	89	70	24	399
604	391	403		576	329	320	731	89	70	24	5355
288	311	403		663	123	297	731	89	70	24	537
288	277	403		27	6	0	731	89	70	24	403
288	228	403		0	24	0	747	89	70	24	425
288	253	403		0	14	0	731	89	70	24	456
288	451	403		103	7	160	731	89	70	24	457
288	377	403		127	6	0	731	89	70	24	425
288	544	403		179	6	0	731	89	70	24	397
291	447	3630		918	438	0	731	89	110	53	421
1885	562	20278		3576	5857	265	918	34274	1240	922	19171
1302	610	22246		7385	1989	0	1053	1900	564	82	5108
1870	675	15789		4349	3018	23	738	1218	1166	96	399
369	502	1317		686	1238	67	731	145	109	24	466
323	447	403		420	1045	221	731	89	70	24	493
288	345	403		266	467	33	731	89	70	24	403
288	252	403		264	20	103	739	89	70	24	425
288	277	403		409	6	310	731	89	70	24	456
288	345	403		341	6	619	731	89	70	24	457
288	477	403		493	6	402	731	89	70	24	425
288	450	403		902	6	331	1070	254	70	51	397
2777	417	12564		5578	19353	3840	2548	1284	71	171	40267
3725	542	26505		8626	10655	1984	1609	1186	2280	163	42454
2800	504	7744		3846	3550	2739	1375	505	1978	52	25720
1727	330	8606		5632	7113	1287	744	8210	1148	65	21645
319	378	447		950	80	340	731	89	186	24	466
288	402	403		273	6	0	731	89	140	24	493
288	329	403		80	6	0	731	89	83	24	403
288	406	403		0	6	0	731	89	70	24	425

288	383	403		173	6	89	731	89	70	24	456
288	358	403		0	6	142	731	89	70	24	457
288	432	403		221	6	0	731	89	70	24	425
288	564	403		208	6	0	901	89	70	24	397
288	389	403		541	6	698	1640	89	70	24	22892
288	386	638		4143	6	4248	1207	89	70	24	506
364	308	3374		1273	740	673	1446	92	74	848	491
984	323	3794		991	6483	348	921	1077	133	3440	5532
1078	437	8580		1291	2775	193	733	3871	78	3018	470
508	415	4051		972	1082	0	1158	994	159	714	943
288	333	429		513	1302	0	731	219	109	24	403
288	276	409		403	788	0	731	95	72	24	425
288	249	403		465	1220	0	731	89	333	24	456
288	385	403		479	1017.5	184	731	89	163.5	24	457
288	484	403		605	646.5	0	731	89	95.5	24	425
402	554	643		921	6	0	731	89	70	24	397
1810	531	6602		1251	2929	0	731	104	71	24	26840
1408	477	4900		1287	1073	0	805	385	95	59	16753
11646	581	117138		20075	27036	2827	1517	27609	380	2376	40651
11939	944	81731		21081	11673	4009	1098	9457	6816	1162	8070
3490	453	34336		6472	7678	2960	735	8083	5038	69	20056
1048	317	4412		1597	3284	753	1585	270	1583	24	4665
656	199	2188		238	3225	0	732	160	1162	24	565
514	191	827		6	2418	0	731	113	648	24	529
431	236	707		695	2434	0	731	89	596	24	520
422	352	453		51	2029	122	731	89	257	24	499
288	452	403		131	1287	0	731	89	121	24	425
291	598	505		273	597	0	731	89	211	24	397
375	585	2162		2032	2281	1563	731	122	374	209	2441
480	723	1479		6036	2152	4164	733	252	173	26	6548
5995	4595	23135		4454	7219	810	1229	17065	496	169	26555
3315	11964	9675		3466	4955	891	1067	654	687	54	10608
1401	11613	4567		1317	4194	340	738	139	197	24	2952

4289	3376	26644		3799	19887	0	2438	401	1457	64	9865
1196	1371	1805		728	3685	0	732	89	136	24	1691
683	788	677		443	3164	199	731	89	75	24	659
501	447	481		242	3017	331	731	89	70	24	493
341	508	405		426	2735	505	731	89	70	24	457
335	225	403		542	2064	0	731	89	70	24	425
288	166	403		493	1074	0	731	89	70	24	397
288	401	1123		458	1996	145	731	139	238	24	422
288	1488	519		822	1033	1507	877	119	71	24	522
3284	1372	8656		631	21355	5803	1804	6520	1526	1610	12459
2487	3867	15536		2487	16104	3425	1128	2897	589	16840	12281
680	2113	1134		527	2705	544	731	92	94	24	744
310	4120	404		610	1228	274	731	89	108	24	493
288	1746	403		358	565	187	731	89	113	24	403
288	552	403		302	74	158	731	89	87	24	425
288	245	403		248	6	124	731	89	79	24	456
288	439	403		386	6	141	731	89	73	24	457
288	169	403		309	6	0	731	89	70	24	425
288	25038	1191		1970	6	0	731	89	70	24	397
288	146	1585		1063	805	0	731	89	70	24	421
635	419	1275		1591	4379	990	731	243	81	24	3150
336	0	1003		0	2354	390	868	268	226	130	4380
983	6107	8410		3030	2941	6074	941	2392	1075	24	7993
362	831	1200		465	2543	198	731	357	231	24	927
288	0	433		392	1461	0	731	89	83	24	583
288	2079	407		377	6	0	731	89	80	24	407
288	0	413		188	6	0	731	89	70	24	425
288	0	404		66	6	0	731	89	70	24	456
288	0	403		266	6	120	731	89	70	24	457
288	0	666		238	6	57	731	89	70	24	425
288	0	460		1158	6	0	731	89	70	24	397
414	0	2726		1099	3612	0	733	101	70	24	3727
531	1503	7719		1122	6275	984	748	913	70	24	11149

5456	1436	26770		4318	9119	13656	5305	3631	70	77	67140
9072	2322	190317		4501	18397	70110	7949	163593	70	24	28165
14437	2917	111075		24563	19639	44205	11812	17796	70	24	96132
2764	3003	43225		14425	6187	4331	5743	5079	70	204	42976
2074	1096	15946		5580	3605	0	2749	1605	70	68	36007
10681	913	11092		5554	3331	-44	2019	3259	1374	24	48216
1848	279	1866		452	1921	0	1461	594	1309	24	965
827	0	2719		899	1727	126	871	137	650	24	38516
530	139	712		0	289	0	746	89	273	24	1886
327	535	414		49	1079	0	736	89	70	24	593
319	-82	403		221	4512.5	317	744	1011	70	24	421
288	668	706		2212	7070	3730	731	4535	79	24	501
288	3485	1299		3046	7436.5	2072	731	3295	147	24	35760
4242	15370	53881		7207	2386	65593	2148	81932	372	24	18079
6469	5746	68275		22364	12362	90558	5920	8943	767	24	48530
1551	4706	18846		5651	7153	1033	2182	2584	357	383	21780
1089	240	5469		2319	3525	0	1007	847	238	112	18207
737	0	2132		946	2874	192	813	1674	179	24	24321
782	0	1200		297	288	330	796	89	175	24	711
506	251	700		401	2850	659	787	131	163	24	19487
626	274	434		651	2226	382	744	89	80	24	1156
582	934	636		639	2152	-45	731	89	70	24	539
1771	925	7471		1901	5413	1365	993	1921	232	612	4723
4261	1438	26618		8346	7865	7523	3610	8157	600	147	16455
1717	1065	13027		1985	5754	1346	2654	2959	329	25	8174
742	582	1254		801	1727	375	1105	270	175	275	917
622	1940	403		1333	489	605	739	89	70	25	466
444	1159	403		353	441	80	731	89	70	24	493
315	409	403		319	6	155	731	89	70	24	403
298	0	403		350	6	204	731	89	70	24	425
288	8319	403		304	6	362	731	89	70	24	456
288	936	403		0	6	646	731	89	70	24	457
288	1454	403		0	6	295	731	89	70	24	425

288	1904	403		728	6	230	731	89	70	24	397
288	1469	403		838	6	513	731	89	70	24	421
288	2059	403		2936	6	823	731	89	78	24	501
288	0	403		433	6	0	731	89	119	24	491
2315	3156	403		1935	6	964	731	89	80	565	399
1577	186	15825		3953	6	1462	731	680	374	555	9852
417	0	494		547	6	0	731	89	104	24	548
289	164	403		292	6	0	731	89	70	24	403
304	0	403		0	6	0	731	89	70	24	425
316	0	403		0	6	-9	731	89	70	24	456
288	0	403		282	6	248	731	89	70	24	457
288	0	403		497	6	0	731	89	70	24	425
290	0	3561		740	6	18	738	89	77	24	2319
288	0	404		102	6	655	731	89	70	24	422
352	187	3712		260	6	345	743	310	165	24	2515
12254	1889	17443		3254	6	643	749	98	1304	24	10862
3447	9578	17181		1637	6	6544	886	352	927	33	10610
19613	13059	24117		9645	6	23235	3189	7659	8943	24	14898
4439	5911	24713		5319	6	2139	3493	2466	4729	24	15288
1969	2229	4765		1615	6	0	1208	300	1953	24	3058
1029	19	1365		79	6	0	875	89	1246	24	1010
787	0	624		0	6	19	796	89	643	24	591
562	391	468		0	6	181	741	89	471	24	497
340	0	422		0	6	0	731	89	359	24	437
288	70	403		117	6	0	731	89	75	24	397
288	74	403		285	6	471	731	89	137	372	421
1981	122	8056		3024	91	650	781	89	173	1765	5159
699	1211	14156		2128	208	2926	846	405	77	14987	8861
780	2894	2334		4906	168	575	732	89	70	4477	1574
288	3697	416		2237	6	358	731	89	70	24	474
288	5853	403		993	6	149	731	89	73	24	493
288	439	403		184	6	52	731	89	70	24	403
288	128	403		163	6	168	731	89	70	24	425

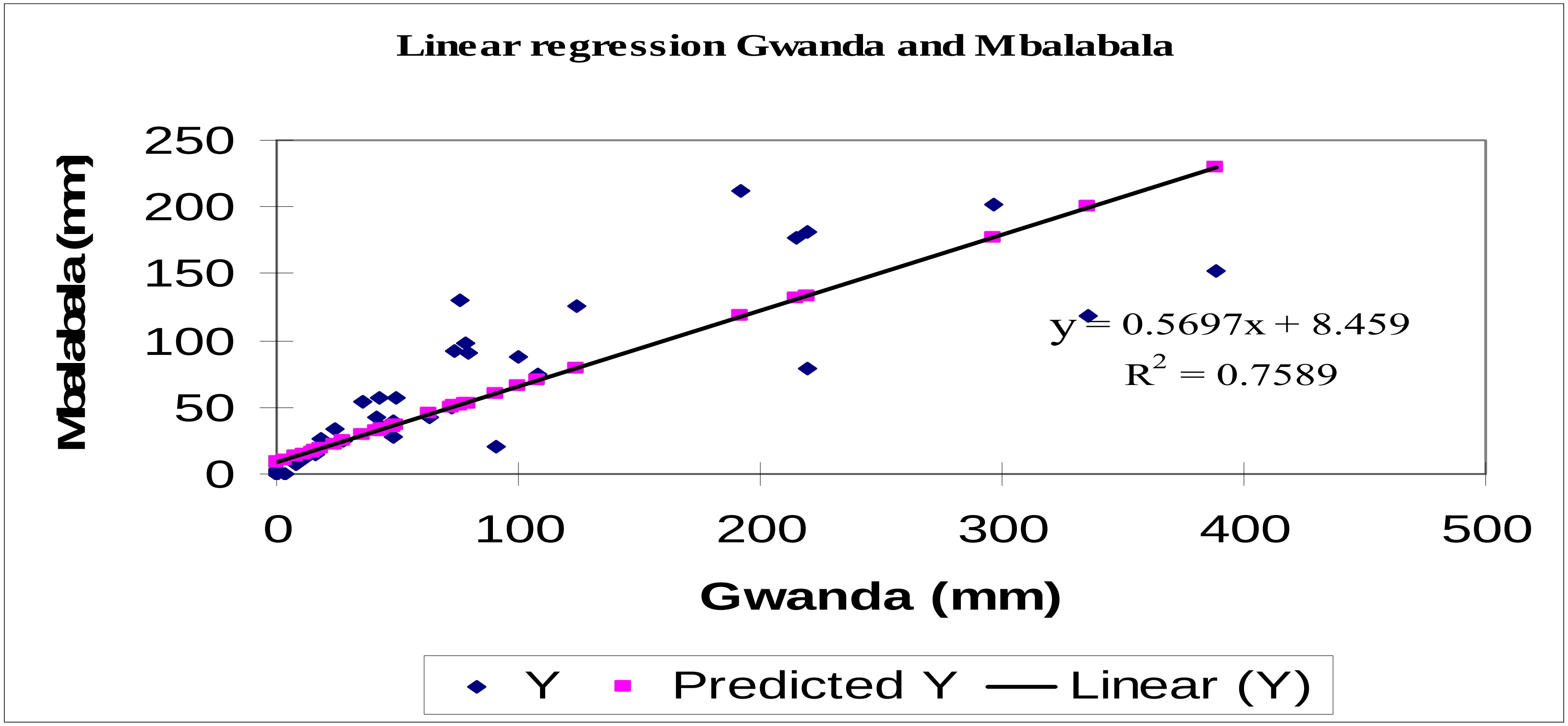
288	184	403		0	6	190	731	89	70	24	456
288	197	403		0	6	177	731	89	70	24	457
288	216	403		173	6	0	731	89	70	24	425

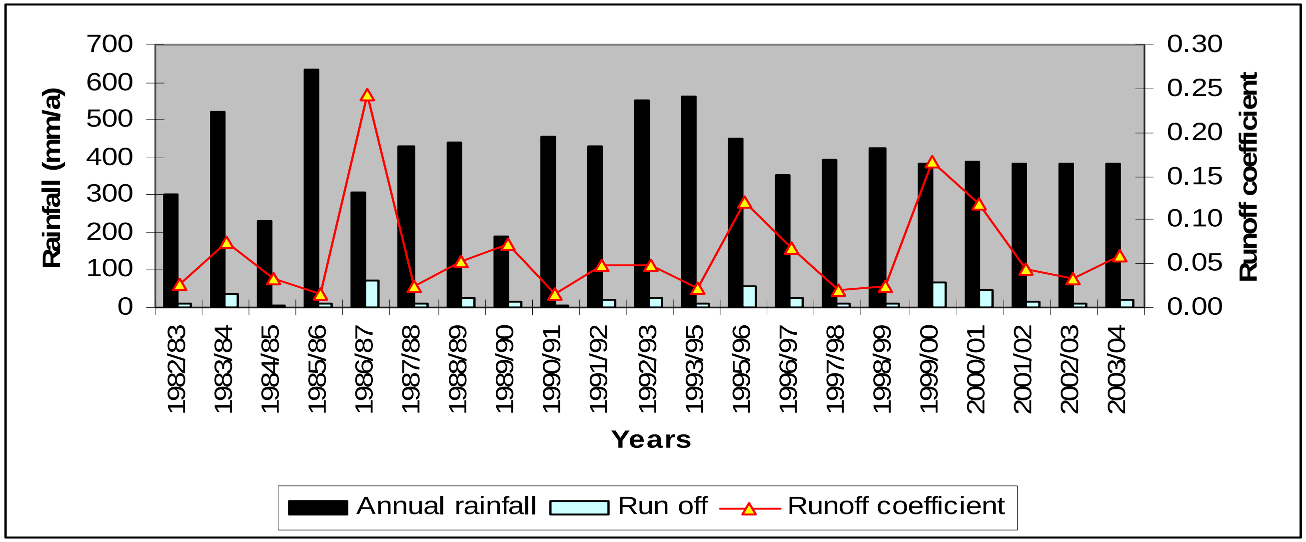
8.5 APPENDIX E: Water permit details

PURPOSE	RIVER_NAME	SUBZONE	PRI_DATE	Flow m^3	Store m^3	TOTAL_m^3	m^3/month
Gvt	MALEME TRIB	BT4	22-Apr-25	0	4315660	4315660	359638
Government	Mchabezi	BM	23-Oct-57	1818	0	1818	152
Government	MCHABEZI Q	BM	29-Sep-39	0	143182	143182	11932
Government	MCHABEZI Q	BM	01-Oct-42	0	1213636	1213636	101136
Agriculture	MCHABEZI Q	BM	11-Dec-72	14500	0	14500	1208
Agriculture	MCHABEZI Q	BM	19-Apr-47	24047	0	24047	2004
Agriculture	MCHABEZI Q	BM	14-Nov-49	0	70000	70000	5833
Agriculture	LUMANE	BM	30-Mar-88	0	1399000	1399000	116583
Government	MALEME	BT4	01-Apr-50	0	272727	272727	22727
Government	HAMBAMESILUMA TRIB	BT4	01-Apr-51	0	45455	45455	3788
Government	HAMBAMESILUMA TRIB	BT4	01-Apr-51	0	90909	90909	7576
Government	HAMBAMESILUMA	BT4	01-Apr-51	0	90909	90909	7576
Government	HAMBAMESILUMA TRIB	BT4	19-Feb-51	0	63636	63636	5303
Government	CHINTAMPA	BT4	19-Feb-51	0	204545	204545	17045
Government	MPOPOMA	BT4	19-Oct-51	0	2159091	2159091	179924
Government	MCHABEZI Q	BM	01-May-51	0	5818182	5818182	484849
Government	MTSHELELE Q	BT4	07-Feb-53	0	1909091	1909091	159091
Government	GADZIVUMBA	BM	02-May-53	0	81818	81818	6818
Government	Mchabezi	BM	04-May-53	0	0	0	0
Agriculture	HOVE TRIB	BT4	12-Feb-54	0	90909	90909	7576
Agriculture	MWEWE	BT2	22-Dec-54	33600	0	33600	2800
Agriculture	MALUNDI	BT4	02-Mar-56	0	82000	82000	6833
Agriculture	MANZIVUMVU TRIB	BT4	29-Jul-57	0	77273	77273	6439
Agriculture	MALONGA	BT4	30-Dec-57	0	31818	31818	2652
Government	MALEME	BT4	08-Jan-58	2273	0	2273	189
Agriculture	MCHABEZI Q	BM	09-Mar-67	0	363636	363636	30303
Agriculture	MCHABEZI TRIB	BM	09-Sep-58	6165	0	6165	514
Government	TULI Q	BT1	02-Dec-59	185000	0	185000	15417
Agriculture	MTSHELELE Q	BT4	12-Oct-60	0	272727	272727	22727
Agriculture	TULI TRIB	BT5	30-Dec-60	0	68182	68182	5682
Agriculture	MWEWE	BT2	27-Feb-64	34000	0	34000	2833
Government	TULI Q	BT5	30-Dec-64	0	8318182	8318182	693182
Government	TULI Q	BT1	31-Dec-64	1233046	0	1233046	102754

Agriculture	MCHABEZI	BM	29-Jun-65	98644	0	98644	8220
Government	MALEME	BT4	04-Jul-66	0	500000	500000	41667
Agriculture	LUMANE	BM	25-Jun-82	0	1974000	1974000	164500
Agriculture	MWEWE TRIB	BT3	21-Oct-69	8000	68000	76000	6333
Government	TULI Q	BT1	09-Jul-70	1295	0	1295	108
Agriculture	MCHABEZI Q	BM	10-Nov-70	0	37000	37000	3083
Agriculture	TULI Q	BT1	26-May-71	12000	0	12000	1000
Agriculture	TULI Q	BT1	09-Jul-71	25000	0	25000	2083
Agriculture	LUMANE	BM	18-Apr-77	24000	0	24000	2000
Institutional	MCHABEZI	BM	10-Sep-84	0	528000	528000	44000
Agriculture	HOVE	BT4	01-Aug-90	66000	0	66000	5500
Agriculture	Mchabezi Trib	BM	24-Apr-90	0	12100	12100	1008
Agriculture	Mpopoma	BT4	28-Apr-94	0	964	964	80
Agriculture	LUMANE	BM	03-Sep-91	26300	0	26300	2192
Agriculture	Malame	BT4	28-Feb-92	0	1077000	1077000	89750
Township	Mwewe Trib	BT3	30-Aug-94	140000	0	140000	11667
Township	Mchabezi	BM	05-Oct-94	1050000	0	1050000	87500
Agriculture	Sihaulane	BT1	27-Apr-95	0	113000	113000	9417
Agriculture	Tuli Trib	BT1	27-Apr-95	0	94000	94000	7833
Agriculture	Matsheni Trib	BT5	27-Apr-95	0	50000		0
Agriculture	Mukwatshana	BT5	27-Apr-95	0	100000	100000	8333
Agriculture	Mtshelele Trib	BT4	27-Apr-95	0	61000	61000	5083
Agriculture	Ove Trib	BT4	27-Apr-95	0	120000	120000	10000
Mine	TULI Q	BT5	19-Jan-78	28800	0	28800	2400
Mine	TULI Q	BT5	24-Mar-76	60000	0	60000	5000

8.6 APPENDIX F: (a) Simple Linear regression of Gwanda and Mbalabala rainfall stations





(b) Rainfall and runoff per hydrological year and runoff coefficient

8.7 APPENDIX G: Crop water requirements calculation tables

CROP WATER AND IRRIGATION REQUIREMENTS FOR IRRIGATION SCHEME Mankokoni

Month	Jan	Feb	March	April	May	June	July	August	Sept	October	Nove	Dec	Total
Mean Reference Crop Evapotranspiration. Eto (mm/day)	5.1	4.7	4.3	3.5	2.8	2.3	2.6	3.6	4.80	5.5	5.2	4.9	49.30
Effective Rainfall (mm/month	93	76	47	27	6	10	1	1	6.00	20	57	81	425.00

ETc (mm/month)													
Maize Grain	176.4	82.7								24	80.9	172	536.00
Beans		27.7	109.75	114.7	22.52								274.69
Wheat					16.2	43.1	58.95	103.6	39.00				260.80
Corrected ETc (mm/month)													
Maize Grain	194	83								24	81	189	570.84
Beans		28	121	126	23								297.14
Wheat					16	43	65	114	39.00				277.05
Net Irrigation Requirement (mm/month)													
Maize Grain	101	7								4	24	108	243.84
Beans		0	74	99	17								189.44
Wheat					10	33	64	113	33				253.05
Total Net Irrigation Requirement (mm/month per ha)	101	7	74	99	10	33	64	113	33	4	24	108	669.81
Gross Irrigation Requirement (mm/month per ha) (45% efficiency)	225	15	164	220	23	74	142	251	73	9	53	240	1488.46
Project Gross Irrigation Requirement for 24 ha (m³)	**53888**	**3573**	**39320**	**52902**	**5440**	**17653**	**34051**	**60216**	**17600**	**2133**	**12747**	**57707**	**357230.40**

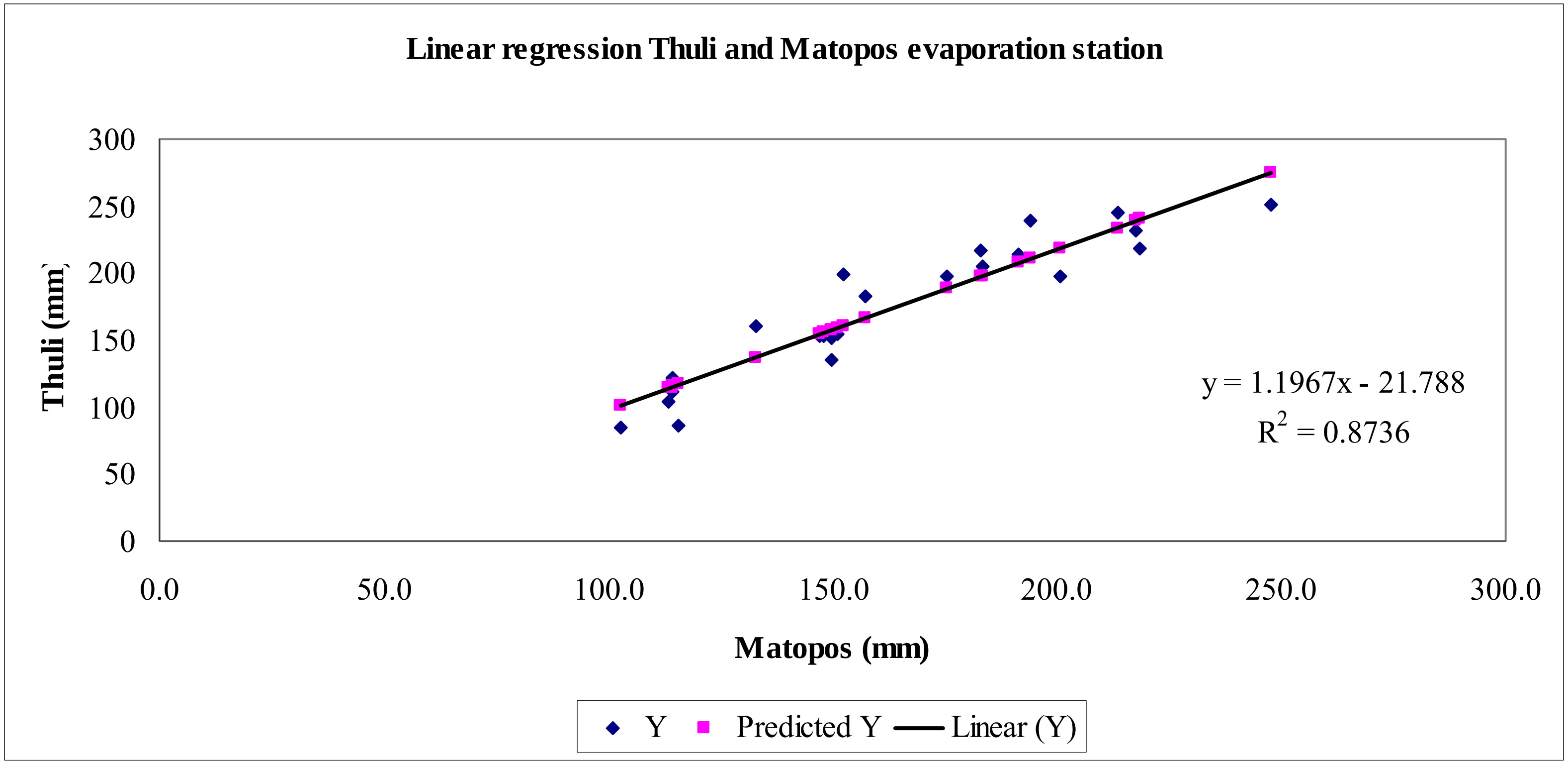
1.2 **APPENDIX H:** Crop water requirements at 90% effeciency

CROP WATER AND IRRIGATION REQUIREMENTS FOR IRRIGATION SCHEME Mankokoni

Month	Jan	Feb	March	April	May	June	July	August	Sept	October	Nove	Dec	Total
Mean Reference Crop Evapotranspiration. Eto (mm/day)	5.1	4.7	4.3	3.5	2.8	2.3	2.6	3.6	4.80	5.5	5.2	4.9	49.30
Effective Rainfall (mm/month	93	76	47	27	6	10	1	1	6.00	20	57	81	425.00

ETc (mm/month)													
Maize Grain	176.4	82.7								24	80.9	172	536.00
Beans		27.7	109.8	114.72	22.52								274.69
Wheat					16.2	43.1	58.95	103.6	39.00				260.80
Corrected ETc (mm/month)													
Maize Grain	194	83								24	81	189	570.84
Beans		28	121	126	23								297.14
Wheat					16	43	65	114	39.00				277.05
Net Irrigation Requirement (mm/month)													
Maize Grain	101	7								4	24	108	243.84
Beans		0	74	99	17								189.44
Wheat					10	33	64	113	33				253.05
Total Net Irrigation Requirement (mm/month per ha)	101	7	74	99	10	33	64	113	33	4	24	108	669.81
Gross Irrigation Requirement (mm/month per ha) (45% efficiency)	112	7	82	110	11	37	71	125	37	4	27	120	744.23
Project Gross Irrigation Requirement for 24 ha (m^3)	**26944**	**1787**	**19660**	**26451**	**2720**	**8827**	**17025**	**30108**	**8800**	**1067**	**6373**	**28853**	**178615.20**

8.8 APPENDIX I: Linear regression of Thuli and Matopos Evaporation stations



8.9 APPENDIX J: Calculations of water demand satisfaction levels

Gwanda		Manama		Walmer/Anton		Anglesea		Maleme/Damara		Thuli-Makwe irr
92	92	2.6	2.6	12	10.8	89	89	731	695	177
92	92	2.6	2.6	12	12	89	89	731	697	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	717	106
92	92	2.6	2.6	12	12	89	89	731	731	47
92	92	2.6	2.6	12	10.8	89	89	731	731	79
92	92	2.5	2.5	12	10.8	89	89	731	731	171
92	92	2.6	2.6	12	10.8	89	89	731	731	339
92	92	2.6	2.6	12	10.8	89	89	731	703	172
92	92	2.6	2.6	12	10.8	89	89	731	700	84
92	92	2.5	2.5	12	10.8	89	89	731	697	42
92	92	2.6	2.6	12	10.8	89	89	731	695	190
92	92	2.6	2.6	12	10.8	89	89	731	695	177
92	92	2.6	2.6	12	12	89	89	731	697	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	731	106
92	92	2.6	2.6	12	12	89	89	731	731	47
92	92	2.6	2.6	12	10.8	89	89	731	731	79
92	92	2.5	2.5	12	10.8	89	89	731	731	171
92	92	2.6	2.6	12	10.8	89	89	731	731	339
92	92	2.6	2.6	12	10.8	89	89	731	711	172
92	92	2.6	2.6	12	10.8	89	89	731	705	84
92	92	2.5	2.5	12	10.8	89	89	731	699	42
92	92	2.6	2.6	12	10.8	89	89	731	695	190
92	92	2.6	2.6	12	10.8	89	89	731	694	177
92	92	2.6	2.6	12	12	89	89	731	696	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	694	106
92	92	2.6	2.6	12	10.8	89	89	731	694	47
92	92	2.6	2.6	12	10.8	89	89	731	694	79
92	92	2.5	2.5	12	12	89	89	731	731	171
92	92	2.6	2.6	12	12	89	89	731	730	339
92	92	2.6	2.6	12	10.8	89	89	731	694	172
92	92	2.6	2.6	12	10.8	89	89	731	694	84

92	92	2.5	2.5	12	10.8	89	89	731	694	42
92	92	2.6	2.6	12	10.8	89	89	731	694	190
92	92	2.6	2.6	12	12	89	89	731	695	177
92	92	2.6	2.6	12	12	89	89	731	697	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	10.8	89	89	731	731	106
92	92	2.6	2.6	12	10.8	89	89	731	731	47
92	92	2.6	2.6	12	10.8	89	89	731	731	79
92	92	2.5	2.5	12	10.8	89	89	731	731	171
92	92	2.6	2.6	12	10.8	89	89	731	731	339
92	92	2.6	2.6	12	10.8	89	89	731	727	172
92	92	2.6	2.6	12	10.8	89	89	731	716	84
92	92	2.5	2.5	12	10.8	89	89	731	704	42
92	92	2.6	2.6	12	10.8	89	89	731	695	190
92	92	2.6	2.6	12	10.8	89	89	731	694	177
92	92	2.6	2.6	12	12	89	89	731	694	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	731	106
92	92	2.6	2.6	12	12	89	89	731	731	47
92	92	2.6	2.6	12	12	89	89	731	731	79
92	92	2.5	2.5	12	12	89	89	731	731	171
92	92	2.6	2.6	12	12	89	89	731	731	339
92	92	2.6	2.6	12	10.8	89	89	731	731	172
92	92	2.6	2.6	12	10.8	89	89	731	731	84
92	92	2.5	2.5	12	10.8	89	89	731	714	42
92	92	2.6	2.6	12	10.8	89	89	731	696	190
92	92	2.6	2.6	12	10.8	89	89	731	696	177
92	92	2.6	2.6	12	10.8	89	89	731	699	12
92	92	2.5	2.5	12	10.8	89	89	731	714	83
92	92	2.6	2.6	12	12	89	89	731	711	106
92	92	2.6	2.6	12	12	89	89	731	731	47
92	92	2.6	2.6	12	12	89	89	731	694	79
92	92	2.5	2.5	12	10.8	89	89	731	694	171
92	92	2.6	2.6	12	10.8	89	89	731	694	339
92	92	2.6	2.6	12	10.8	89	89	731	694	172
92	92	2.6	2.6	12	10.8	89	89	731	694	84
92	92	2.5	2.5	12	10.8	89	89	731	694	42

92	92	2.6	2.6	12	10.8	89	89	731	694	190
92	92	2.6	2.6	12	10.8	89	89	731	695	177
92	92	2.6	2.6	12	12	89	89	731	697	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	731	106
92	92	2.6	2.6	12	12	89	89	731	701	47
92	92	2.6	2.6	12	12	89	89	731	731	79
92	92	2.5	2.5	12	12	89	89	731	731	171
92	92	2.6	2.6	12	10.8	89	89	731	731	339
92	92	2.6	2.6	12	10.8	89	89	731	727	172
92	92	2.6	2.6	12	10.8	89	89	731	716	84
92	92	2.5	2.5	12	10.8	89	89	731	704	42
92	92	2.6	2.6	12	10.8	89	89	731	695	190
92	92	2.6	2.6	12	10.8	89	89	731	694	177
92	92	2.6	2.6	12	10.8	89	89	731	694	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	731	106
92	92	2.6	2.6	12	12	89	89	731	707	47
92	92	2.6	2.6	12	12	89	89	731	694	79
92	92	2.5	2.5	12	12	89	89	731	694	171
92	92	2.6	2.6	12	10.8	89	89	731	694	339
92	92	2.6	2.6	12	10.8	89	89	731	694	172
92	0	2.6	2.6	12	10.8	89	89	731	694	84
92	0	2.5	2.5	12	10.8	89	89	731	694	42
92	0	2.6	2.6	12	10.8	89	89	731	694	190
92	0	2.6	2.6	12	10.8	89	89	731	694	177
92	0	2.6	2.6	12	10.8	89	89	731	694	12
92	0	2.5	2.5	12	10.8	89	89	731	694	83
92	0	2.6	2.6	12	10.8	89	89	731	694	106
92	0	2.6	2.6	12	10.8	89	89	731	694	47
92	92	2.6	2.6	12	10.8	89	89	731	694	79
92	0	2.5	2.5	12	10.8	89	89	731	694	171
92	0	2.6	2.6	12	10.8	89	89	731	694	339
92	0	2.6	2.6	12	10.8	89	89	731	710	172
92	0	2.6	0	12	10.8	89	89	731	694	84
92	0	2.5	0	12	10.8	89	89	731	694	42
92	0	2.6	0	12	10.8	89	89	731	694	190

92	0	2.6	0	12	10.8	89	89	731	694	177
92	0	2.6	2.6	12	12	89	89	731	694	12
92	92	2.5	2.5	12	12	89	89	731	731	83
92	92	2.6	2.6	12	12	89	89	731	731	106
92	92	2.6	2.6	12	12	89	89	731	701	47
92	92	2.6	2.6	12	10.8	89	89	731	694	79
92	92	2.5	2.5	12	10.8	89	89	731	694	171
92	58.637378	2.6	2.6	12	10.8	89	89	731	694	339
92	19.80698	2.6	2.6	12	10.8	89	89	731	702	172
92	0	2.6	2.6	12	10.8	89	89	731	694	84
92	0	2.5	2.5	12	10.8	89	89	731	694	42
92	0	2.6	2.6	12	10.8	89	89	731	694	190
92	0	2.5763077	2.5763077	12	12	89	89	731	731	177
92	92	2.576547	2.576547	12	12	89	89	731	731	12
92	92	2.5767863	2.5767863	12	12	89	89	731	731	83
92	92	2.5770256	2.5770256	12	12	89	89	731	731	106
92	92	2.577265	2.577265	12	12	89	89	731	707	47
92	15.05	2.5775043	2.5775043	12	10.8	89	89	731	694	79
92	0	2.5777436	2.5777436	12	10.8	89	89	731	694	171
92	14.20154	2.5779829	2.5779829	12	10.8	89	89	731	694	339
92	92	2.5782222	2.5782222	12	10.8	89	89	731	694	172
92	0	2.5784615	2.5784615	12	10.8	89	89	731	694	84
92	0	2.5787009	2.5787009	12	10.8	89	89	731	694	42
92	0	2.5789402	2.5789402	12	10.8	89	89	731	694	190
92	0	2.5791795	2.5791795	12	10.8	89	89	731	731	177
92	0	2.5794188	2.5794188	12	10.8	89	89	731	731	12
92	0	2.5796581	2.5796581	12	10.8	89	89	731	731	83
92	57.8	2.5798974	2.5798974	12	12	89	89	731	731	106
92	92	2.5801368	2.5801368	12	12	89	89	731	731	47
92	92	2.5803761	2.5803761	12	12	89	89	731	696	79
92	92	2.5806154	2.5806154	12	12	89	89	731	731	171
92	0	2.5808547	2.5808547	12	10.8	89	89	731	695	339
92	5.20238	2.581094	2.581094	12	10.8	89	89	731	694	172
92	0	2.5813333	2.5813333	12	10.8	89	89	731	694	84
92	0	2.5815726	2.5815726	12	10.8	89	89	731	694	42
92	0	2.581812	2.581812	12	10.8	89	89	731	694	190
92	92	2.5820513	2.5820513	12	10.8	89	89	731	694	177

92	92	2.5822906	2.5822906	12	10.8	89	89	731	694	12
92	92	2.5825299	2.5825299	12	12	89	89	731	731	83
92	92	2.5827692	2.5827692	12	12	89	89	731	731	106
92	92	2.5830085	2.5830085	12	12	89	89	731	731	47
92	92	2.5832479	2.5832479	12	12	89	89	731	698	79
92	92	2.5834872	2.5834872	12	10.8	89	89	731	731	171
92	92	2.5837265	2.5837265	12	10.8	89	89	731	695	339
92	92	2.5839658	2.5839658	12	10.8	89	89	731	694	172
92	92	2.5842051	2.5842051	12	10.8	89	89	731	694	84
92	92	2.5844444	2.5844444	12	10.8	89	89	731	694	42
92	0	2.5846838	2.5846838	12	10.8	89	89	731	694	190
92	0	2.5849231	2.5849231	12	10.8	89	89	731	694	177
92	68.25	2.5851624	2.5851624	12	12	89	89	731	694	12
92	92	2.5854017	2.5854017	12	12	89	89	731	696	83
92	92	2.585641	2.585641	12	12	89	89	731	731	106
92	92	2.5858803	2.5858803	12	12	89	89	731	731	47
92	92	2.5861197	2.5861197	12	10.8	89	89	731	701	79
92	92	2.586359	2.586359	12	12	89	89	731	731	171
92	92	2.5865983	2.5865983	12	10.8	89	89	731	695	339
92	92	2.5868376	2.5868376	12	10.8	89	89	731	694	172
92	92	2.5870769	2.5870769	12	10.8	89	89	731	694	84
92	92	2.5873162	2.5873162	12	10.8	89	89	731	694	42
92	92	2.5875556	2.5875556	12	10.8	89	89	731	694	190
92	92	2.5877949	2.5877949	12	10.8	89	89	731	694	177
92	92	2.5880342	2.5880342	12	10.8	89	89	731	694	12
92	92	2.5882735	2.5882735	12	10.8	89	89	731	731	83
92	92	2.5885128	2.5885128	12	12	89	89	731	731	106
92	92	2.5887521	2.5887521	12	12	89	89	731	731	47
92	92	2.5889915	2.5889915	12	10.8	89	89	731	694	79
92	92	2.5892308	2.5892308	12	10.8	89	89	731	694	171
92	92	2.5894701	2.5894701	12	10.8	89	89	731	694	339
92	92	2.5897094	2.5897094	12	10.8	89	89	731	694	172
92	92	2.5899487	2.5899487	12	10.8	89	89	731	694	84
92	92	2.590188	2.590188	12	10.8	89	89	731	694	42
92	92	2.5904274	2.5904274	12	10.8	89	89	731	694	190
92	92	2.5906667	2.5906667	12	10.8	89	89	731	694	177
92	92	2.590906	2.590906	12	10.8	89	89	731	694	12

92	92	2.5911453	2.5911453	12	10.8	89	89	731	694	83
92	92	2.5913846	2.5913846	12	12	89	89	731	731	106
92	92	2.5916239	2.5916239	12	10.8	89	89	731	731	47
92	92	2.5918632	2.5918632	12	10.8	89	89	731	694	79
92	92	2.5921026	2.5921026	12	10.8	89	89	731	694	171
92	92	2.5923419	2.5923419	12	10.8	89	89	731	694	339
92	92	2.5925812	2.5925812	12	10.8	89	89	731	694	172
92	92	2.5928205	2.5928205	12	10.8	89	89	731	694	84
92	92	2.5930598	2.5930598	12	10.8	89	89	731	694	42
92	92	2.5932991	2.5932991	12	10.8	89	89	731	694	190
92	92	2.5935385	2.5935385	12	10.8	89	89	731	694	177
92	92	2.5937778	2.5937778	12	10.8	89	89	731	696	12
92	92	2.5940171	2.5940171	12	10.8	89	89	731	711	83
92	92	2.5942564	2.5942564	12	12	89	89	731	731	106
92	92	2.5944957	2.5944957	12	10.8	89	89	731	731	47
92	92	2.594735	2.594735	12	10.8	89	89	731	731	79
92	92	2.5949744	2.5949744	12	12	89	89	731	731	171
92	92	2.5952137	2.5952137	12	12	89	89	731	731	339
92	92	2.595453	2.595453	12	10.8	89	89	731	731	172
92	92	2.5956923	2.5956923	12	10.8	89	89	731	731	84
92	92	2.5959316	2.5959316	12	10.8	89	89	731	731	42
92	92	2.5961709	2.5961709	12	10.8	89	89	731	709	190
92	92	2.5964103	2.5964103	12	10.8	89	89	731	699	177
92	92	2.5966496	2.5966496	12	10.8	89	89	731	707	12
92	92	2.5968889	2.5968889	12	10.8	89	89	731	694	83
92	92	2.5971282	2.5971282	12	10.8	89	89	731	694	106
92	92	2.5973675	2.5973675	12	10.8	89	89	731	731	47
92	92	2.5976068	2.5976068	12	10.8	89	89	731	731	79
92	92	2.5978462	2.5978462	12	12	89	89	731	731	171
92	92	2.5980855	2.5980855	12	12	89	89	731	731	339
92	92	2.5983248	2.5983248	12	10.8	89	89	731	731	172
92	92	2.5985641	2.5985641	12	10.8	89	89	731	731	84
92	92	2.5988034	2.5988034	12	10.8	89	89	731	731	42
92	92	2.5990427	2.5990427	12	10.8	89	89	731	707	190
92	92	2.5992821	2.5992821	12	10.8	89	89	731	694	177
92	92	2.5995214	2.5995214	12	12	89	89	731	731	12
92	92	2.5997607	2.5997607	12	12	89	89	731	731	83

92	92	2.6	2.6	12	11.75	89	89	731	731	106
92	92	2.6002393	2.6002393	12	12	89	89	731	731	47
92	92	2.6004786	2.6004786	12	11.75	89	89	731	702	79
92	92	2.6007179	2.6007179	12	10.8	89	89	731	694	171
92	92	2.6009573	2.6009573	12	10.8	89	89	731	694	339
92	92	2.6011966	2.6011966	12	10.8	89	89	731	694	172
92	92	2.6014359	2.6014359	12	10.8	89	89	731	694	84
92	92	2.6016752	2.6016752	12	10.8	89	89	731	694	42
92	92	2.6019145	2.6019145	12	10.8	89	89	731	694	190
92	92	2.6021538	2.6021538	12	10.8	89	89	731	694	177
92	92	2.6023932	2.6023932	12	10.8	89	89	731	694	12
92	92	2.6026325	2.6026325	12	10.8	89	89	731	694	83
92	92	2.6028718	0	12	10.8	89	89	731	694	106
92	92	2.6031111	2.6031111	12	12	89	89	731	694	47
92	92	2.6033504	2.6033504	12	12	89	89	731	694	79
92	92	2.6035897	0	12	10.8	89	89	731	694	171
92	92	2.6038291	0	12	10.8	89	89	731	694	339
92	92	2.6040684	0	12	10.8	89	89	731	694	172
92	92	2.6043077	0	12	10.8	89	89	731	694	84
92	92	2.604547	0	12	10.8	89	89	731	694	42
92	92	2.6047863	0	12	10.8	89	89	731	694	190
92	77.662284	2.5827735	2.4639068	12	11.167917	89	89	731	708.24617	125.16667
84		95		93		100		97		94
Demand	Abstraction	Demand	Abstraction	Demand	Abstraction	Demand	Abstraction	Demand	Abstraction	Demand
	77.662284		2.4639068		11.167917		89		708.24617	
92		2.5827735		12		89		731		125.16667

8.10 APPENDIX K: Rural domestic water demand figures for Zimbabwe

Description	Water demand (l/person/day)
Individual connection in a rural area	60
Communal taps within 300 m of homestead	40
Communal taps greater than 300 m from the homestead	25
Boreholes with handpumps less than 300 m from the homestead	30
Wells less than 300 m from the homestead	30

Description	Water demand
Rural clinics	10 l/outpatient/day 60 l/inpatient/day
Rural hospitals	200 l/patient/day
Rural shops	200 l/shop/day

Source: Handbook for assessment of catchment water demand (DFID, 2003)