UNIVERSITY OF ZIMBABWE

ASSESSING UPSTREAM AND DOWNSTREAM INTERACTIONS IN CHALIMBANA RIVER CATCHMENT, ZAMBIA

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

Department of Civil Engineering

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ABSTRACT

Chalimbana river originates from forest reserve number 27 east of Zambia's capital city, Lusaka. From its headwaters to the confluence with Chongwe river, Chalimbana river meanders through the farming and rural community over a distance of approximately 51 kilometers. The extent of the catchment is 680 km^2 and it lies between latitudes 15º 19′ and 15º 32′ south and longitudes 28º 21′ and 28º 45′ east.

Chalimbana catchment has good arable soils for agriculture and receives mean annual rainfall of 832.5mm. Its proximity to Lusaka city has attracted settlers, peasant and commercial farmers. Over the years, agricultural development in the catchment has led to the construction of hydraulic structures (weirs and dams) in the upper and middle parts of the catchment. Currently there are 9 privately owned dams on Chalimbana river. This development on one hand has contributed to food security for the local community, surrounding areas and the city of Lusaka. Agricultural produce such as horticultural products are also exported to the international market. Agriculture has therefore contributed to the livelihood for the local people within and outside the catchment. On the other hand, construction of hydraulic structures in the catchment has changed the flow regime of the river from a perennial to an intermittent river especially in the downstream section of the catchment. Furthermore, water demands for both commercial farmers and downstream community has increased significantly over the years resulting in conflicts among themselves as well as with the downstream community.

This study was therefore carried out to assess the upstream and downstream interactions in terms of water demands. The data inputs to this study included historical hydrological and climatic data, irrigation and domestic water demand and area-capacity curves for the reservoirs. A spread sheet river basin simulation model called Water Allocation and Flow Model in Excel (WAFLEX) was developed for the catchment to evaluate different water demand alternatives. This was done to determine water demand satisfaction levels for both upstream and downstream water demands. The main water demand management alternatives evaluated in this study based on current water demand were; management of catchment as a complete system, expansion of irrigation areas and improvement of irrigation efficient system.

The study concludes that runoff and the storage in the reservoirs is able to sustain both irrigation and domestic water demand. Furthermore, the simulated results indicate that management of the catchment as a complete system is an initial step to the resolution of upstream-downstream water conflicts. Water availability for the downstream community and environmental flows also improves under this management option. The study also concludes that the current water demand is sustainable if the water resources are managed in an integrated manner. Expansion of irrigation area by 30% is also sustainable if irrigation efficient system is improved.

The study thus recommends that downstream water demand must be provided for in the water allocation system and manage the catchment as a complete system. For optimal water use, efficiency in irrigation system must be improved.

DECLARATION

I declare to the Registrar of Examinations at the University of Zimbabwe that this dissertation is my own, unaided work. With the exception of tables, graphs and maps which were made, drawn or compiled by me, all secondary sources used in this thesis have been duly acknowledged by means of complete references. This thesis is hereby submitted for the Master of Science degree in Integrated Water Resources Management (IWRM), Civil Engineering Department in the Faculty of Engineering, University of Zimbabwe. To the best of my knowledge it has not been submitted before for any degree or examination in any University.

Name:……………………………………………………………………………………

Signed:…………………….. …………. day of …………………………..2008

DEDICATION

To
my beloved family

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LIST OF ABBREVIATIONS AND ACRONYMS

CWR	Crop Water Requirement
DWA	Department of Water Affairs
EUD	Effective Uniform Depth
EWR	Environmental Water Requirements
FAO	Food and Agriculture Organisation
FNDP	Fifth National Development Plan
GRZ	Government of the Republic of Zambia
GWR	Ground Water Recharge
IWRM	Integrated Water Resources Management
JICA	Japanese International Cooperation Agency
MDG's	Millennium Development Goals
MEWD	Ministry of Energy and Water Development
MTENR	Ministry of Environment, Tourism and Natural Resources
SADC	Southern African Development Community
WAFLEX	Water Allocation Flow Model in Excel
WDM	Water Demand Management
WUA	Water User Association
ZINWA	Zimbabwe National Water Authority
ZWP	Zambia Water Partnership

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CHAPTER ONE

INTRODUCTION

1.1 General Background

Over the last 50 years, changes in the way humans use water have been enormous. Major driving factors have been a growing population, economic development, improved living standards and increasing demands (Abernethy, 2000). Irrigation agriculture has played a significant role in changing the face of water resources utilization as dams, diversion, delivery and drainage structures have been developed to store and distribute water for irrigation and to drain out surplus water supplies (Abernethy, 2000).

It is widely recognized that many countries are entering an era of severe water shortages (Seckler *et al*, 2005). In particular, many southern African countries are facing the challenge of effectively managing the available water resources to meet the needs of the growing population (Hirji *et al*, 2002). Conflicts between different water uses and users have over the years become common, as increasing demands are placed on the limited resource (Gustard *et al*, 2002). In recognition of the complexity of water resources management, different management strategies have been developed to effectively manage the finite resource. Integrated Water Resources Management (IWRM) is one concept which has led to the shift of water resources management from the traditional supply oriented approach to one which takes into account the needs of different stakeholders, scarcity and sustainability of water resources (Savenije *et al*, 2003). This concept thus recognises the interests of water users in different sectors of society and further promotes the management of water resources at catchment level.

Planning and management of water resources at catchment level requires appropriate approaches and tools to balance the demands of different stakeholders. The basis of planning and management is the understanding of the catchment input-output relationship because a water resources system is the whole set of water generation, conservation, abstraction, conveyance, distribution and utilization of infrastructure and its environment (including people) both natural and manmade within a given temporal and spatial boundary (Mhizha, 2004). The application of models in the assessment of water resources is one approach that enhances the understanding of the inputs and outputs of the catchment. Models are therefore decision support tools which can be applied in different situations such as water allocation, reservoir operation, environmental flow analysis, conflict resolution among others.

Chalimbana catchment, located in south-central Zambia in Lusaka Province, is one such catchment where agriculture is a predominant and socio economic activity. Thus, both large-scale agro-business, smallholder and subsistence agriculture is practiced and the Chalimbana River provides much of the required water resources for irrigation agriculture (ZWP, 2007). Over the years, water demand has increased resulting in reduced flows for the downstream community.

1.2 Problem Statement

Increased agricultural water demand in the Chalimbana catchment has resulted in increased surface water abstractions through dam construction and direct pumping from the upper and middle reaches of the river. Abstractions by upstream users have not only caused competition and conflicts among themselves but have also resulted in the change of the flow regime from a perennial to an intermittent river. This change still remains a major concern for the downstream community despite interventions by Water Board and the Department of Water Affairs to balance water needs for upstream and downstream water users. The problems of surface water use in the catchment is also acknowledged by Nyambe (2003) that competition for available water resources among the farming community has manifested itself in the Chalimbana catchment and this is expected to increase with the economic development in the country.

Furthermore, forest cover in the headwaters of the Chalimbana river has been diminishing due to deforestation arising from charcoal burning and clearance of land for agriculture (ZWP, 2007). Thus, while water demand has been going up, available water resources have been diminishing. Now the issue is how to optimize the limited available water resources for upstream and downstream users in view of increasing demand for water resources in the catchment.

1.3 Justification

Availability of water to all stakeholders in the Chalimbana catchment is key to food production, sustenance of livelihood for the local community and sanitation. Furthermore, water availability is also needed for the sustainability of the aquatic ecosystems. This is in line with integrated water resources management which calls for optimal economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Zambia is in the transition of changing the water resources management system from the traditional approach to integrated management of the resource at catchment level. Therefore assessment of water availability and demand at catchment level is key to the contribution of the effective management of water resources once the new management system is implemented. Additionally Zambia through the Fifth National Development Plan (FNDP) is also set to improve access to water through improved management and development (GRZ, 2006).

This study is therefore carried out to assess the catchment's water availability and upstream-downstream interactions in terms of water demand. A model has been applied to evaluate how the upstream water use affects the downstream water availability. The findings of this study will therefore contribute to the integrated management of water resources at catchment level.

1.4 Objective of the study

The main objective of this study is to assess upstream and downstream water use interactions in Chalimbana catchment.

1.5 Specific Objectives

(i) To determine surface water availability in the catchment
(ii) To quantify water abstractions in the catchment by upstream and downstream water users
(iii) To asses the existing water allocation system for primary, secondary water uses and how it takes into account the environmental flows
(iv) To apply a model to analyze the effect of different water demand management options on the downstream water availability

CHAPTER TWO

LITERATURE REVIEW

2.1 Definition of Water Demand and Water Use

The terms water demand and use are often used interchangeably though they have different meanings (Wallingford, 2003). In a simplified way, water demand is considered equal to water consumption although conceptually the two terms do not have the same meaning. Wallingford (2003) therefore defines water demand as the volume of water requested by users to satisfy their needs. Savenije *et al* (2003) defines water demand as the amount of water required at a certain point. In contrast, water use refers to water that is actually used for a specific purpose, such as for domestic use, irrigation, or industrial purposes (USGS, 2008). Water use is subdivided into two categories; offstream and instream use. Offstream use mainly depends on water which is diverted or withdrawn from surface water while instream use does not depend on diversion or withdrawal from surface water or groundwater sources and conveyed to the place of use (WMO, 1994). In this study the focus is on offstream use because this category is mainly consumptive in comparison to instream use which is non-consumptive. The extent of water demand and use at global, regional, national and catchment level is driven by several factors and further depends on the extent of economic development, population growth, irrigation use, among others.

2.2 Agricultural Water Demand-The Global Perspective

It has been estimated that about 250 million hectares are irrigated worldwide today, nearly five times more than at the beginning of the 20th century and currently agriculture uses 70% of world water withdrawals, while domestic, municipal and industrial uses collectively account for the remaining 30% (Thekabail *et al*, 2006). The comparison of past global agricultural water demands to the present shows a remarkable increase and is an indication that the demands will continue to rise. The world population estimated at six billion is expected to near eight billion by 2025 and to meet future food demand for the growing population, at least 2000 Km^3 of water will be needed (Thekabail *et al*, 2006). Similar estimates by Cashman *et al* (2006) indicate that by 2025 global water withdrawals for agriculture will rise to $3200Km^3$ more than the withdrawals for domestic and industrial uses (Table 2.0). These projections illustrate that the increasing global water demand for agriculture is likely to affect food production considering that water resources are finite and unevenly distributed.

Irrigation in many river systems is the main water user and mainly accounts for at least 80% of the total use in a water resource system (Savenije and van der Zaag, 2003). Due to its predominant proportion of water use, agricultural water demand brings about competition with other users and subsequently causes conflicts over the use of water. In an effort to manage and develop the scarce world water resources and balance the demands of different water users, various interventions have been formulated. In recent years integrated water resources management (IWRM) has come to the fore as means of resolving water conflicts, balancing the water needs for different water users, inclusive of the environment.

Table 2.0. Historical and Projected Global Water Withdrawal and Consumption

Use	1900	1950	1995	2025
Agriculture				
Withdrawal	500	1100	2500	3200
Consumption	300	700	1750	2250
Industry				
Withdrawal	40	200	750	1200
Consumption	5	20	80	170
Domestic				
Withdrawal	20	90	350	600
Consumption	5	15	50	75
Total				
Withdrawal	600	1400	3800	5200
Consumption	300	750	2100	2800

Adopted from Cashman et al, 2006 (Units in Km^3)

2.3 Water Availability and Agriculture Water Demand in Southern African

Southern Africa is a water-scarce region where water is distributed unevenly in time and space. With an increasing population and its legitimate demand for an improved standard of living, requiring increased economic development and agricultural production, the region faces an enormous challenge on how to allocate, use and protect this limited resource (Rothert, 2000). It has also been reported that in most catchments in southern Africa water availability is frequently less than the demand for it (Wallingford, 2003). This is usually the case in catchments where agriculture is more developed considering that agriculture consumes more water than other users.

On a regional basis, water resources seem abundant: SADC's renewable freshwater resources are estimated to be 650 billion m^3 per year (excluding the Democratic Republic of Congo) which is equivalent to approximately 15 000 litres per person per day (Rothert, 2000). In southern Africa, agricultural water demand is estimated at 70% of the regions water resources with an irrigated area of 1.8 million hectares (Wallingford, 2003). Surface water resources remain the major source to meet the agricultural water demands. However, in southern Africa water is already scarce in a number of local basins and that water availability underpins the social and economic fabric in the region which is characterized with widespread poverty (Hirji *et al*, 2002). Water scarcity in some parts of the region is attributed to the uneven temporal and spatial distribution of water.

The rising demand for increasingly scarce water in the drier parts of southern Africa is leading to growing concern about future access to water (World Water Forum, 2000). Wallingford (2003) reports that the demand for water in the SADC region is projected to rise by at least 3 % annually till 2020, a rate equal to the region's population growth rate.

2.4 Zambia's Water Resources -Availability, Demand and Management

2.4.1 Agricultural Water Demand

The National Water Resources Master Plan of Zambia of 1995, estimates that Zambia generates 100Km^3 per year of surface water and an estimated annual renewable groundwater potential of 49.6 Km^3 per year (MEWD/JICA, 1995). As much as it is highly generated, surface water is the most utilized source of water due to its easy accessibility in comparison to groundwater which requires high costs to abstract especially in the urban areas of the country.

Over 60% of Zambia's population derives its livelihood from agriculture and reside in rural areas. Currently the estimated land under cultivation is 100 000 hectares, comprising 52 000 under commercial farming and 48 000 under subsistence farming. The current land under cultivation is expected to increase to 200 000 by the year 2010(GRZ, 2006; GRZ, 2007). The estimated expansion means more water will be required to meet the demand. Since agriculture remains the key priority in the growth and poverty reduction programmes, the governments key interventions through the Fifth National Development Plan (2006-2010) are to improve agricultural productivity especially for small scale farmers, development of irrigation and support services, and opening up of new farming blocks.

In order to meet the water demand for agricultural development, the Zambian National Water Policy (GRZ, 2007) is set to develop and manage water resources through the establishment of a fair, efficient and transparent water allocation system. This is also a basis for resolving water conflicts that mainly occur between agricultural and domestic uses particularly at catchment level.

2.4.2 Domestic Water Demand at Catchment Level

Estimating domestic water demand and use at catchment level for rural areas in southern Africa is problematic owing to the lack of measured data. Rural water demand in Zambia, as estimated in the National Water Master Plan, is 35 litres per capita per day. Zambia's rural water demand lies in the same range as that of Zimbabwe whose rural per capita water demand is between 30 and 40 liters for unpiped water supply (Appendix A). This is also the case in the majority of rural areas of Southern Africa, where domestic water use varies from 20 litres per person per day to 40 litres per person per day.

In a study carried out in South Africa in Mkonimazi river catchment, primary water demand was estimated at 30.8 litres per person per day. In a related study in Mbuluzi catchment of Swaziland, domestic water demand was estimated at 15.7 litres per person per day (Wallingford, 2003). On the basis of these studies as well as the Zambian and Zimbabwean cases, the estimated rural domestic water demand is less than the World Health Organisation (WHO) recommended minimum standard of 50 litres per capita per day for rural areas.

2.4.3 Water Resources Management and Allocation

The ownership of all water in Zambia is vested in the republican president. This implies that there is no right of private property in water. The use, diversion, and impoundment of water must be made in terms of the Water Act Cap 198 of the laws of Zambia (Water Board, 2005). The Water Act (1948) recognizes three uses of water namely: *Primary, Secondary and Tertiary*. Primary uses include use of water for domestic and livestock watering. Under this category every person is lawfully entitled to use water from the natural channel for the outlined purposes, thus one can freely abstract water without a water right or permit. However the free use of water does not extend to any abstraction or distribution of water by mechanical or motorized means (Water Board, 2005). In contrast to primary water use, secondary use of water includes irrigation of land and for fish farming. For this category, the user is by law required to obtain a water right or permit to abstract a specified volume of water either directly or by impoundment. Tertiary water use refers to the use of water for industrial purposes and for the generation of power (Water Board, 2005).

Under the current water law, Water Board under the Ministry of Energy and Water Development is the sole institution mandated to manage water resources in the country. Through the provisions of the amended Water Act (1948), CAP 312 of the laws of Zambia, Water Board is given the mandate to control the abstraction and use of surface water resources through the issuance of water rights and water permits. A water right is defined as an entitlement to impound, abstract or divert a specified quantity of water from any public stream. A water right is valid for five years upon which it is renewed (Water Board, 2005). In contrast, a water permit is not a water right but rather it is a letter from the Water Board to the applicant authorizing the temporary use of water for a limited period. Thus, a water permit is not registered and does not receive any priority of interest and does not even guarantee the eventual granting of a water right (Water Board, 2005). However, water rights and permits are not issued to abstract water on international shared rivers such as the Zambezi river, Luapula river and part of the Luangwa river portion which borders Zambia and Mozambique.

Under the Statutory Instrument No. 20 of 1993 of the Water Act, a person who intends to abstract water for secondary purposes on land exceeding 250 hectares shall pay for the first 500m^3/day and a minimum cost for every excess cubic metre of water per day. The flat fee for the abstraction up to 500m^3/day has cushioned small scale farmers because their daily water demands are usually less or equivalent to 500m^3/day. Currently, water allocation is based on crop water requirements (CWR) as determined by climatic factors, crop type and rainfall. Previously the crop water duty used in water allocation 70m^3/hectare per day (Mondoka and Kampata, 2000). While the Water Act provides for the regulation of surface water use, it does not provide for the regulation of groundwater abstraction through drilling of boreholes (Water Act, 1948).

Zambia's Water Act of 1948 has been amended over the years and is currently under review to realign it with the current developments in integrated water resources management, and also to improve the overall management of water resources in the country. The new Water Act is expected to introduce the catchment and sub catchment subdivisions as units for water resources management. Under the existing Water Act, environmental water requirement is not explicitly defined and thus is not considered in the water allocation system. In Zimbabwe under the new catchment council, 7 water uses have been identified and the environment is allocated 5% of the mean annual runoff (Herbertson *et al* 2001). The allocation system also apportions 10% of mean annual runoff for downstream users. Table 2.1 shows the water use sectors for Zimbabwe.

Table 2.1. Water allocation in Zimbabwe

Water Use Sectors in Zimbabwe Catchments	**Typical Catchment Allocation (%)**
Primary and environmental	5
Urban, industrial and mining (UIM)	5
Not accessible (with present state of resource development)	25
Reserve for future use	5
Downstream	10
Power generation and tourism	5
Agriculture	45
Total use of available water (mean annual runoff)	**100**

Source: Adopted from Herterson et al, 2001

2.5 Upstream-Downstream Water Conflicts

In its simplest and broadest sense, the term "water conflict" has been used to describe any disagreement or dispute over or about water, where social, economic, legal, political or military intervention has been needed, or will be required, to resolve the problem (Ashton, 2000). Water conflicts, particularly those involving upstream and downstream water users, are not only common at transboundary level but also at local level with varying degrees of intensity and scale. Ashton (2000) points out that water related conflicts have existed for millennia and many of the contributing reasons or causes of these conflicts continue today and will continue to exist in the future.

Carius *et al* (2007) reports that water conflicts arise not due to lack of water but due to the inadequate way the resource is governed and managed. This is acknowledged by Makali and Kiteme (2005) that inconsistent water allocation procedures also contribute to water conflicts. However in most cases this cause is not perceived as a main cause for conflicts but rather the actual lack of water. In a study carried out in Ewaso Ng'iro Basin in Kenya it was concluded that conflicts between upstream and downstream are due to reduced or no flow at the lower reaches and over utilisation at the upper reaches (Makali and Kiteme, 2005). Similarly Vyagusa (2005) reports that in Pangani basin of Tanzania causes of water conflicts vary from increase in demand and uses of water to upstream users who deny water people in the lower slopes, prolonged drought, poor maintenance of furrows and insufficient design of furrows. In some cases illegal abstractions, over abstractions beyond permitted levels contribute to upstream-downstream conflicts. This is in line with Mondoka and Kampata (2000) who reports that in times of water stress, conflicts have arisen in Chalimbana catchment because upstream farmers would abstract lump sum amounts of water allocated to them since they had rights spread through out the year.

Upstream-downstream conflicts take a different dimension when they occur during dry season with an already low level of river flows (Gichuki, 2004). This situation brings about negative effects not only on the downstream communities but also on water-dependent ecosystems. For the downstream community water availability for primary use is a major externality while for the ecosystems it's mainly loss of aquatic life.

2.6 Water Conflict Resolution- The IWRM Approach

Integrated Water Resources Management (IWRM) has emerged in recent years as a response to the so-called "water crisis". IWRM seeks to tackle some of the root causes of this management crisis, namely the inefficiencies and conflicts that arise from un-coordinated development and use of water resources (Smits *et al*, 2008). Un-coordinated management of water resources in most cases exacerbate existing conflicts in catchments where water is highly utilized. Pallet et al (1997) points out that usually decision makers neglect to view the catchment as whole, from upstream to downstream and in most cases individuals use the available water in their part of the catchment to their own best advantage, ignoring everyone downstream and the ecological processes that water supports. This is contrary to the principles of IWRM which promotes the use of available water resources to satisfy the needs of all stakeholders and the environment. Allocation of water on the basis of crop water requirements (CWR) is one approach for efficient water use which ultimately contributes to resolution of conflicts because abstractions are limited to the requirements.

Levite *et al* (2003) reports that water management in the Steelpoort River Basin of South Africa is characterised by local tensions and conflicts between a number of different water users, including mines, large-scale farmers, municipalities and rural communities. The author further acknowledges that participation of users in management of water in the basin is constrained by lack of information on the state of the rivers and water use, as well as the absence of any history of dialogue about issues relating to the management of natural resources. On the basis of the findings by Levite *et al* (2003), the availability of historical hydrological data of the river is a key prerequisite to conflict resolution because once the water resources' potential and availability is known, planning and allocation can be done to satisfy the needs of the users in a catchment.

Makali and Kiteme (2005) further suggest that Water User Associations (WUA) is one of the means of conflict resolution. The authors also points out that various water users within the upper Ewaso Ng'iro basin in Kenya adopted a WUA strategic approach as means of sustainable resource use conflict resolution through the formation of an all inclusive (multi level and multi-stakeholder) inter-catchment forum to oversee allocation and utilisation of water resources in the basin. In the same study it was realized that conflict resolution based on institutions and organisations rooted in the concerned communities and involving all major stakeholders are important components in a strategy for more sustainable water use and management.

2.7 Surface Water Modelling

With the realization that water resources are finite amidst increasing demands, much effort has gone into developing tools for effective planning and management. Various water assessment models have been developed to mimic natural water systems for decision making, development, allocation and management of water resources.

Models are invaluable tools for resource management which help resource managers develop a shared conceptual understanding of complex natural systems, allow testing of management scenarios, predict outcomes and set priorities (Caminiti, 2000). A model is thus defined as a replica of the actual existing system behaving in respect to certain properties and functions as the prototype (Caminiti, 2007). According to Makurira *et al* (2004) a model is a package that facilitates the simulation of a system out of a conceptual framework of the system. Makurira *et al* (2004) further elaborates that models identify and evaluate alternatives and help to predict and better understand trade-off among goals, objectives and interests.

There are a wide variety of hydrological models available and the choice of which to employ can depend on several factors. Hughes *et al* (1994) identified some of these and referred to the type and resolution of output required, catchment response and climate characteristics and the amount of information available for defining the input data and quantifying model parameter values. Schulze (1995) acknowledges that different models are used for different purposes depending on the purpose of the model and data availability. He further emphasized that in order to attain good results from the model, 80% of the time must be spent on the model input to ensure uncertainties associated with inaccuracies in rainfall and runoff measurements, missing data, inadequate instrument design and maintenance are considered.

Water Allocation Flow Model in Excel (WAFLEX) is a river basin simulation model that makes use of the spreadsheet environment for the computations of graphical windows to communicate with the user. The model is transparent and efficient as an indicator in the decision making process (Makurira *et al*, 2004). Spreadsheets also have a ready-to-use graphical interface, can easily import and export data to other software, have simple data base management facilities and built in statistical packages and can be programmed using macro language (Savenije, 1995). Savenije (1995) further points out that application of spreadsheet modelling approach to river basins in Mozambique, Trinidad, Zambia and Ecuador have demonstrated the ease with which individual, case specific components for a decision-support system may be developed.

WAFLEX model has been applied in several studies in some SADC countries as a decision support tool. In Zimbabwe, WAFLEX has been applied in many studies. Makurira (1997) applied the model on integrated water management and supply for Kunzwi and Manyame while Mhizha (2001) applied it on reservoir operation in Manyame catchment. Khosa (2007) simulated different water demand scenarios and the effect on the downstream water availability in Thuli river basin.

Other applications of the model include the analysis of water availability and use under current and future demands in the Komati basin by van der Zaag *et al* (2003) and also the assessment of in stream flow requirements in Ngwavuma river in Swaziland by Shongwe (2003). Symphorian et al (2002) studied environmental water requirements and concluded that WAFLEX model can provide practical guidelines to catchment managers and dam operators to implement environmental water requirements. Overall, the application of WAFLEX model in these studies has shown that the outputs are reliable based on its accuracy in terms of the observed and simulated mean annual runoff (MAR) and coefficients of variation (CV). The simulated results and outputs further confirm that WAFLEX can provide practical guide to the management of water resources.

2.8 Scenarios and Water Demand Management Alternatives

Scenarios refer to sets of events and conditions, which describe an interruption, disruption or disaster. (www.state.mn.un/portal/mn/jsp.content). Scenarios are therefore events or natural phenomenon for which man has no control and includes population growth, natural disasters, climate change, among others. Scenarios are based on 'what if' options which includes questions like: what if population increases? what if ecosystem requirements are tightened? (Cour *et al,* 2002). The purpose of scenario analysis with regards to water resources management according to Siebert *et al* (1997) is to estimate the influence of growth in population, economy and changing climate on future water use and availability. The results derived from scenarios are useful for analysts and decision makers. Groves *et al* (2005) thus acknowledges that scenarios generate new ideas for successful policies, but he notes that scenarios are not predictions but they instead reflect multiple plausible views of the future.

On the basis of assumed scenarios, models are applied to serve as inputs in decision making for improved management of the available water resources. Therefore, to arrive at suitable options, water demand management measures or alternatives are developed. Savenije and van der Zaag (2002) define water demand management (WDM), as one of the tools that ensures that water resources are properly managed in order to achieve the three key cross cutting issues of Integrated Water Resources Management (IWRM), which are equity, efficiency and ecological integrity. Similarly Global Water Partnership (GWP), as quoted by Savenije and van der Zaag (2002), defines water demand as the development and implementation of strategies aimed at influencing water demand in order to achieve water consumption levels that are consistent with the equitable, efficient and sustainable use of the finite water resource.

From the two definitions, it is clear that water demand management focuses on increasing the economic, social and ecological benefits from the finite water resources. Water demand management alternatives can either be structural or non structural alternatives which are aimed at maximising the satisfaction of all stakeholders either for urban or rural water demand. These measures are thus developed to mitigate the consequences brought about by scenarios such as climate change, population growth, among others.

In a study carried out in a water stressed basin in South Africa using Water Evaluation and Planning (WEAP) model, three water demand management alternatives were simulated. The study concluded that without introducing water demand management options, the demand for 15 users could not be met even in a normal hydrological year (Cour *et al,* 2002). In a related study Downing *et al* (2003) applied climate change and socio economic scenarios on the effect of water demand. His results indicated that the frequency of droughts would require water saving technologies and associated reductions in demand. Similarly socio economic reference scenarios showed that future water demand for 2024/25 would rise from 118 to 203 litres per head per day as compared to 162 litres per head per day in 1997/8.

2.9 Environmental Water Requirements

The flows of the world's rivers are increasingly becoming modified through impoundments such as dams and weirs, abstractions for agriculture and urban supply, maintenance of flows for navigation, drainage return flows and structures for flood control (Hirji *et al,* 2003). These interventions have had significant impacts on the flow regimes of rivers. In particular, modifications on rivers have adversely affected the ecological and hydrological services provided by water ecosystems which in turn have increased the vulnerability of people-especially the poor-who depend on such services (Hirji *et al,* 2003). There is now an increasing recognition that modification to river flows need to be balanced with maintenance of essential water dependent ecological services. In view of this development, international organizations such as the World Conservation Union (IUCN) are promoting environmental flow as a key element to integrated water resources management (Dyson *et al*, 2003). According to the World Bank's recently approved Water Resources Sector Strategy, "the environment is a special 'water-using sector" in that most environmental concerns are a central part of overall water resources management (Hirji *et al*, 2003). Many countries have therefore demonstrated their commitment to implement environmental flows in their water resources management plans.

Environmental water requirements are given priority with regards to water allocation under many recent pieces of water legislation implemented in southern Africa (Wallingford, 2003). In Tanzania, laws and policies were developed recently that gave priority of water use to river ecosystem once basic human needs are met (Dunbar *et al*, 2004).

The assessment of environmental water requirements is done by a range of methods based on simple hydrological indices, historic data analysis, hydrological simulations, habitat simulation methods and consensus and discussion based approaches (Wallingford, 2003). The methods include Tennant, Flow duration curve, Texas, Building block methodology among others.

The flow duration curve is used in assessing stream flow compatible for meeting water supply, water quality and environmental instream flow requirements. The flow duration relationship shows the frequency or percentage of time that stream discharge falls within various ranges (Wurbs *et al*, 2002). Naturalised flows or present day historical flow data over specific durations are usually used in the flow duration analysis. In some cases the 90 percentile flow (Q_{90}) may be set as the minimum environmental flow (Wallingford, 2003). The 90 percentile flow is the flow that is equaled or exceeded 90 percent of the time. In other cases 95 pecentile (Q_{95}) is used in regulating abstractions and as an index to define the environmental flow as is the case in the United Kingdom (Barker *et al*, 1998 as referenced by Dunbar *et al*, 2004). Figure 2.0 illustrates typical flow duration with Q_{90} flow.

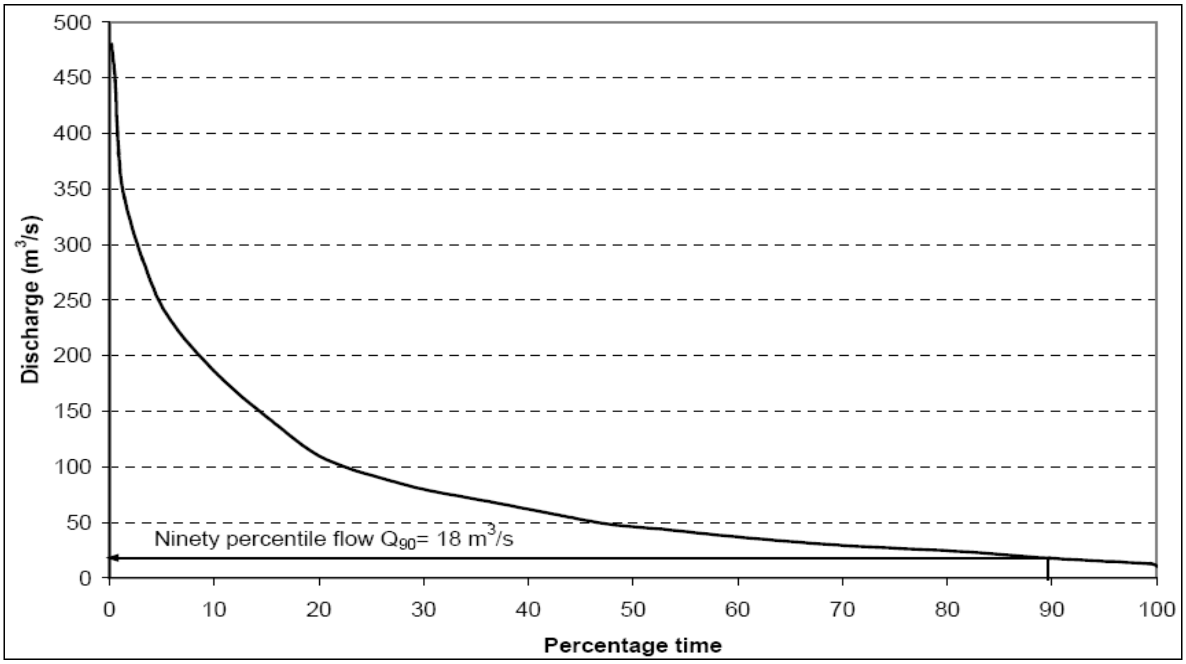

Fig. 2.0 Typical Flow Duration Curve (Source: Wallingford, 2003)

2.10 Groundwater Recharge

At the land surface recharge is affected by the topography and land cover in addition to the magnitude, intensity duration and spatial distribution of precipitation (Nyagwambo, 2006). Groundwater recharge rates therefore vary from place to place. Groundwater recharge in semi arid areas is more susceptible to near surface conditions as compared to humid areas (Nyagwambo, 2006).

A linear relationship shown in equation 2.0 is often used to estimate annual average recharge as a function of average annual rainfall.

$$R = k_1 * (P - k_2) \quad \ldots\ldots(2.0)$$

where *R= Annual Recharge*
k_1=constant of proportionality
P=Annual rainfall

k_2=*threshold annual rainfall*

The constant k_1 represents the fraction of net rainfall that actually becomes recharge and k_2 represents the threshold annual rainfall below which rainfall is not expected to result in significant recharge. This is the rainfall that goes into interception and direct evaporation and never enters the groundwater medium. Nyagwambo (2006) established that for Nyundo catchment recharge is 12% of annual rainfall and threshold value of 270mm per annum (equation 2.1)

$$R = 0.12 * (P - 270) \quad \text{……(2.1)}$$

According to Bredenkamp *et al* (1997) as referenced by Nyagwambo (2006), SADC region threshold annual rainfall values range between 200 and 400mm/a. Maseka (1994) established that Chalimbana catchment receives a recharge of about 300-400mm per year. The Zambian Water Resources Master Plan of 1995 established that groundwater recharge ranges from 8% to 9% of annual rainfall for different parts of Zambia. In particular Lusaka which is mainly underlain by crystalline dolomitic limestone, schist and gneiss has 8% of rainfall as recharge (MEWD/JICA, 1995).

2.11 CROPWAT Software and Applications

CROPWAT is a decision support system developed by the Land and Water Development Division of FAO for planning and management of irrigation. It is a practical tool that is used to carry out standard calculations for reference evapotranspiration, crop water requirements and irrigation requirements (Berejena *et al*, 2007). CROPWAT uses the recommended FAO Penman-Monteith method for estimating crop evapotranspiration.

This model has been used in several studies to determine crop water requirements. Mtshali (2001) applied CROPWAT to determine crop water requirement for sugarcane in Swaziland and acknowledged that estimates from the model were more realistic than the estimates derived from pan evaporation and pan factor coefficients. In Zambia CROPWAT was applied to assess the potential and actual crop water use of selected cropping patterns in the two districts of Chongwe and Chipata (CEEPA, 2006)

Determination of crop water requirements is important to establish whether the source of water can satisfy the demand (Makadho *et al*, 1989). These authors established from the crop water requirements (CWR) areas that can be irrigated from a given amount of water following a given cropping programme. In a study conducted in Zambia on promoting water use efficiency on Kafue, Ngwerere and Chalimbana rivers by Mondoka and Kampata (2001) revealed that allocating water based on crop water requirement reduces water demand as opposed to allocating water based on a fixed quantity. In a related study on equitable water allocation, Mtshali (2001) concluded that using crop water requirement in water allocation gives room to accommodate new water right applicants.

CHAPTER THREE

STUDY AREA

3.1 General Background to Zambia

3.1.1 Geographic Location and Extent

Zambia is a landlocked sub Saharan African country bordering eight southern African countries- Zimbabwe, Malawi, Mozambique, Botswana, Angola, Namibia, Tanzania and the Democratic Republic of Congo (fig 3.0). The country is 752,614 km^2 in extent and lies between latitudes 8º and 18º south and longitudes 22º and 28º east. Zambia administratively consists of 9 provinces with 72 districts spread across the country.

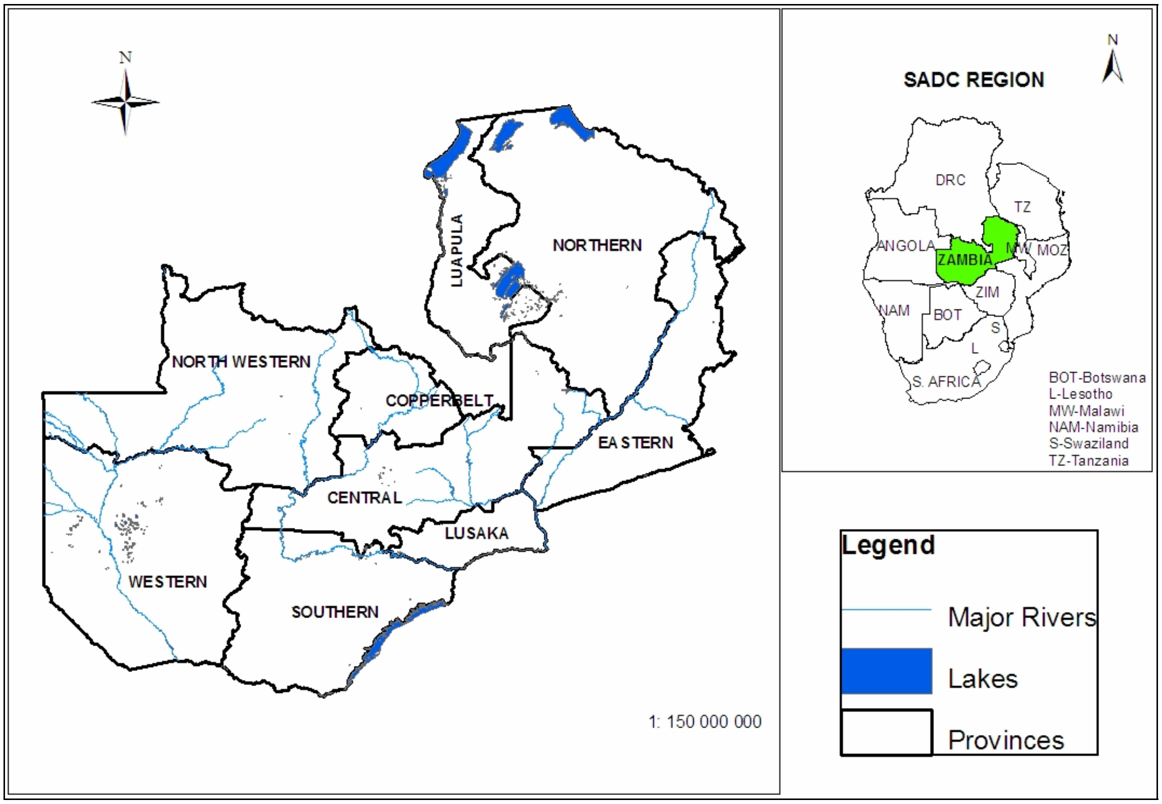

Fig. 3.0 Geographic Location of Zambia in the SADC Region (Adopted from Zambezi Atlas)

3.1.2 Climate and Agro-Ecological Regions

Zambia has a subtropical climate with two distinct halves in a year, a dry half from May to October and a wet half from November to April (MEWD/JICA, 1995). However, the year is divided into 4 unequal seasons as follows:

(i)	Winter season	:	June to August
(ii)	Pre-rainy season	:	September to October
(iii)	Rainy season	:	November to March

(iv) Post rainy season : April and May

Rainfall in Zambia is unimodal and is influenced by the movement of the Inter-Tropical Convergence Zone (ITCZ). The rainfall increases from an annual average of 600mm in the lower south to 1300mm in the upper north of the country. Based on 30 year rainfall records, the highest rainfall amount in Zambia is received in January. The annual variation of monthly rainfall for the country is illustrated in figure 3.1.

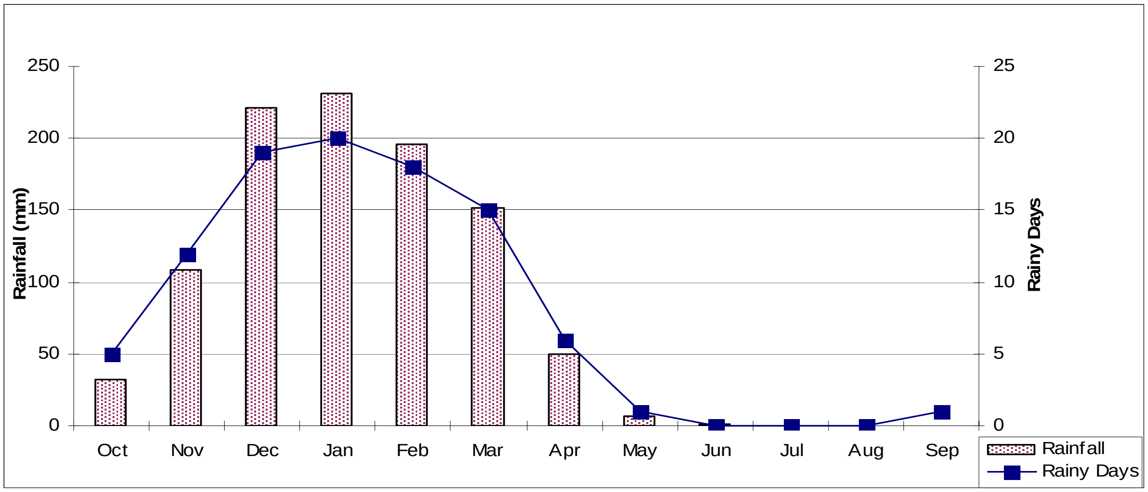

Fig. 3.1 Annual Variation of Monthly Rainfall in Zambia (Source: MEWD/JICA, 1995)

On the basis of rainfall amount and spatial distribution, Zambia is divided into three agro-ecological regions (fig 3.2).

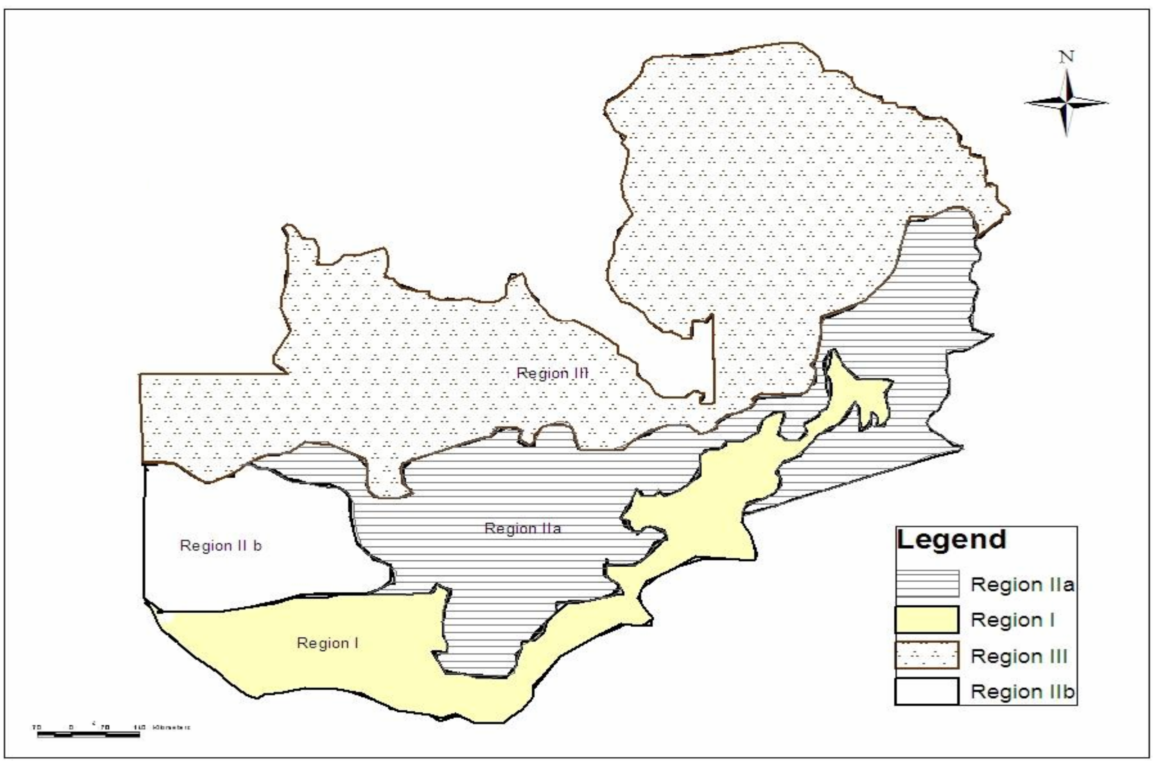

Fig. 3.2 Agro-ecological regions of Zambia (Adopted from GRZ, MTENR, Zambia)

Zone-I covers the southern half of Western and Southern Provinces, eastern half of Lusaka Province and the narrow band along the Luangwa river in Eastern Province. This region receives 700 to 800mm of rainfall per annum.

Zone-II covers the northern half of Western and Southern Provinces, almost the whole Central Province western part of Lusaka Province and Eastern Province except the narrow band of zone I. The annual rainfall in this zone is between 800 and 1000mm.

Zone-III covers North-Western Province, Coppebelt, Luapula, Northern Province including the northern part of Central Province. This region receives between 1000mm and 1400mm annual (MEWD/JICA, 1995).

Apart from rainfall, agro-ecological zones are characterized by temperature and evaporation variations. Annual mean temperature is around 21º C through out all the zones. Evaporation amount differs by zones, and it amounts to about 2300mm in Zone-I and 1900mm in Zone- III in year. In Zone-II and III, rainfall amount generally exceeds evaporation during rainy season, but rainfall is generally lower than evaporation in Zone-I (MEWD/JICA, 1995).

3.1.3 River Basins and Surface Water Resources

Zambia has a well distributed system of perennial rivers, streams, lakes and swamps through out its territory. There are five river basins in Zambia namely: Zambezi, Kafue, Chambeshi/Luapula, Luangwa and Tanganyika. The Zambezi basin is the largest basin within Zambia and it is 261 000 Km^2 in extent. Thus it constitutes 77% of Zambia's total surface area (GRZ, 2004). The Zambezi basin within the Zambian territory contributes 41.7% to the entire Zambezi basin in comparison to the neighbouring countries whose contributions range from 1.2% to 16%.

The average yield of the natural water resources of Zambia is approximately 3 200 m^3/s or 135mm over the surface area of the country each year. Runoff figures and areas of the five river basins are shown in Table 3.0 (MacDonald, 1990).

Table 3.0. Major rivers of Zambia

River	Basin Area (within Zambia) Km^2	Mean Annual Runoff	
		(m^3/s)	(mm)
Zambezi	261 000	19000	135
Kafue	152 000	350	70
Luangwa	165 000	500	95
Chambeshi	34 000	230	210
Luapula	124 000	690	175
Lake Tanganyika	17 000	330	600

Adopted from MacDonald and Partners, 1990

In Zambia annual average potential evapotranspiration ranges from 1394mm to 1892mm while the country average is 1574mm. Potential evapotranspiration is therefore larger than precipitation and this means that Zambia is in a hydrological condition of precipitation deficit that amounts from 100 mm to 1100mm per year. This situation has implications on water availability and management in Zambia, particularly in agro-ecological Regions I and II (MEWD/JICA, 1995).

3.2 Specific Study Area

3.2.1 Geographic Location

The Chalimbana river catchment lies within the Zambezi river basin between latitudes 15º 19´ and 15º 32´ south and longitudes 28º 21´ and 28º 45´ east. It is located east of Zambia's capital city, Lusaka. The catchment extends from the eastern periphery of Lusaka district into Chongwe district to the east of Lusaka (fig 3.3). The catchment falls under Agro-ecological region IIa.

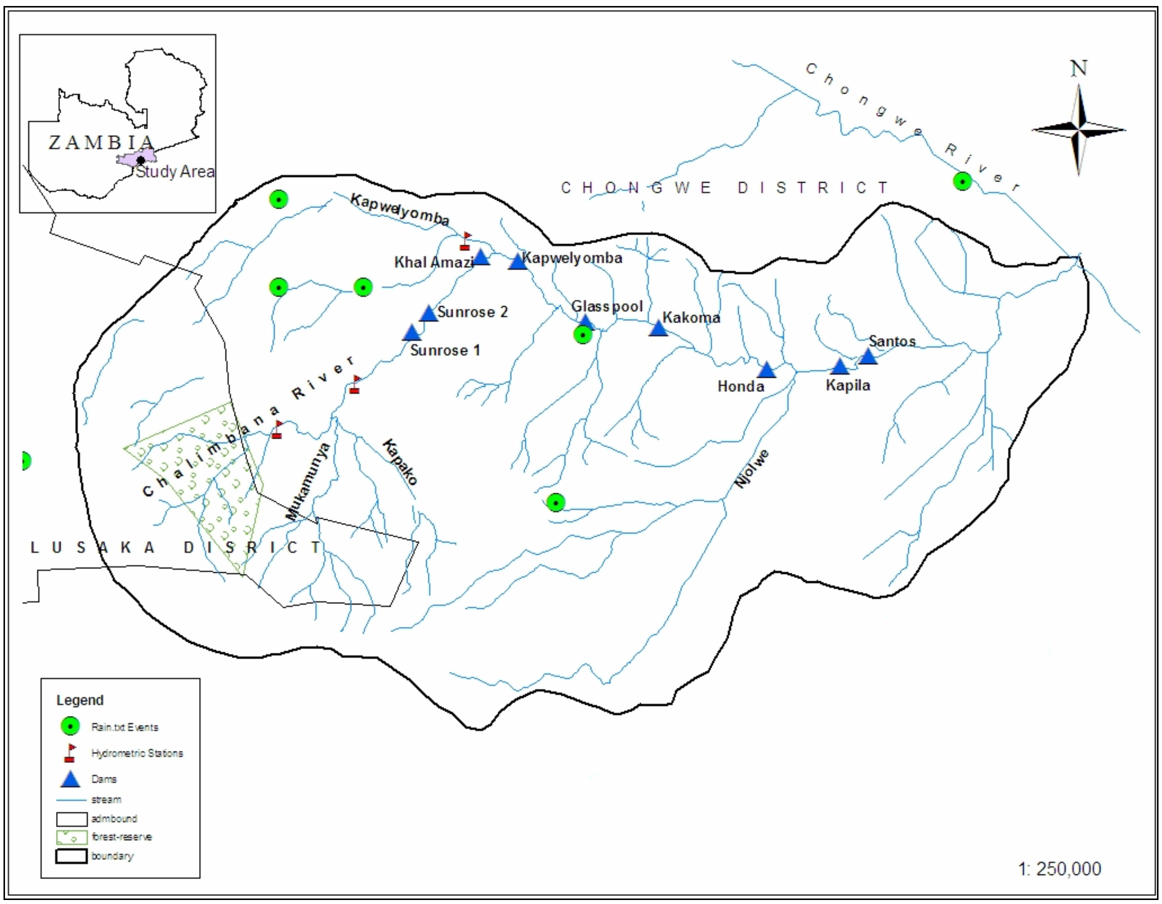

Fig. 3.3 Location of Chalimbana River Catchment

3.2.2 Hydrology and Water Resources

The Chalimbana river is one of the rivers that radiates from the Lusaka plateau area. Its headwaters lie in local Forest Reserves No. 26 and 27 in the south eastern part of Lusaka city (fig 3.3). From the source to the confluence with the Chongwe river, the Chalimbana river meanders through the farming community over a distance of about 51 kilometers. Its catchment area at the confluence with Chongwe river is 680 km^2. There are several intermittent tributaries flowing into the main Chalimbana river from the northerly and southern directions. Currently the catchment has only one operational gauging station located in the upper part of the catchment and a non operational station on the Kapwelyomba tributary.

The density of perennial and non perennial tributaries is high in the upper and middle parts of the catchment. This is where the 9 dams are located. The main sub catchments of Chalimbana are the Kapwelyomba, Muyuni and Mukamunya tributaries. The Chalimbana river is one of the main sub catchments of Chongwe river which is also a sub catchment of the Zambezi river basin.

The average rainfall for Lusaka inclusive of the Chalimbana catchment area based on the 30 year average period is 857mm although there is usually a degree of variation spatially (MEWD / JICA, 1995). The average temperature is about 20^o C with a minimum of 15^o C and a maximum of 26^oC.

3.2.3 Water Resources Management in the Catchment

Water Board under the Ministry of Energy and Water Development (MEWD) is mandated to manage water resources in the catchment as is the rest of Zambia. Therefore Water Board is responsible for the allocation and monitoring of water use in the catchment. The Chalimbana catchment is divided into three parts, the upper, middle and lower catchment. Water User Associations (WUA) were formed in conjunction with Zambia Water Partnership (ZWP) with representatives in each of the three sections of the catchment to help address the challenges of water resources management in the catchment.

3.2.4 Agriculture and Land use

Commercial farming is the predominant land use in the catchment whose source of water is the Chalimbana river. Commercial farming is mainly concentrated in the upper and middle catchment while small scale farming is mainly in the lower catchment. The main crops grown by the commercial farmers are wheat, tobacco, maize, cotton and horticultural crops

In the lower catchment, river bank cultivation by the local riparian community is a common agricultural practice which serves as source of food security and livelihood. Under small scale farming the main crops grown are groundnuts, maize, vegetables.

3.2.5 Geology and Topography

The Chalimbana catchment lies in the Chainama Hills area bounded by latitudes 15^o 00' and 15^o 30' south and longitude 28^0 30' and 29^o 00' east. About two third of this area is underlain by the Basement Complex and over half of it is occupied by the Gneiss Group (Garrard, 1968).

The Geology of the upper Chalimbana catchment river basin is characterized by three rock types: Chlorite (Muscovite, Quartz and Muscovite Schist), Crystalline dolomitic limestone and Quartz (Muscovite and Biotite Schist). Carbonate rocks, mainly dolomitic limestones and dolomites, are exposed in the Chalimbana river. The dissected cretaceous surface gives the Chalimbana headwaters region its present hilly topography. The elevation in the basin ranges from 1342m to 1235m above sea level (Garrard, 1968).

CHAPTER FOUR

MATERIALS AND METHODS

4.1 Data requirements

The data requirements for this study included the following:

i) Historical flow and climatic data,
ii) Past and present water demands for commercial irrigation,
iii) Water Allocation guidelines,
iv) Domestic water use,
v) Crop hectarages, planting dates and irrigation methods,
vi) Crop Water Requirements, and
vii) Reservoir area-capacity values.

The data was collected from public institutions, commercial farmers and the downstream community. The methods of collection and analysis are presented in the proceeding sub sections:

4.2 Calculation of Inflows for the Model

Flow data was collected from the Department of Water Affairs in Lusaka. The available flow at Romor station (5-029) has time series records of 38 years (Appendix G). The data at this station represent natural flows of the river as there are no hydraulic structures upstream of the station.

The flows for the ungauged tributaries (Mukamunya and Kapako) were generated using the Hot-Deck infilling method. The flows were an input into the WAFLEX model. Equation 4.1 shows the Hot-Deck infilling method used for estimation of flows for the ungauged tributaries.

Estimated Flow (X) = (Measured Flow)(Drainage Area (A)/Drainage Area (B)……(4.1)*

Where X= Estimated flow (m^3/sec) of the ungauged stream
A= Area (km^2) of the ungauged stream
B= Area (km^2) of the gauged stream

This method has been used in different studies (Hirsh, 1979; Parrett *et al*,1994) for extending streamflow records against base station records. The performance of the drainage area method may improve with an increased similarity of the two watersheds in terms of morphology, land use, imperviousness, and drainage area. This is the case in the Chalimbana catchment where the tributaries lie within the area with similar land use and geologic formations.

Other methods that are used for data infilling are Intra-station interpolation, regression infilling, mean value infilling and interpolation equations. For this study the Hot-Deck infilling method was adopted because of its simplicity and wide application by hydrologists (Boogard *et al*, 2007). Additionally, this method has also been recommended by Rantz *et al*. (1982) for the infilling of missing flow data for a stream in a period of fluctuating discharge.

4.3 Estimation of Environmental Flow

This was determined from the available 30 year historical flow. The flow duration curve is one of the common methods which are used in determining environmental flows using the 90 percentile flow (Q_{90}) as the minimum environmental flow (Wallingford, 2003). In this study Q_{90} was used to determine the minimum flow which is exceeded 90% of the time.

4.4 Calculation of Catchment Area Rainfall

The monthly rainfall data was collected from the Meteorological Department in Lusaka as well as from individual farmers within the catchment. The rainfall data from individual farmers had short period records of data ranging from 8 to 10 years in comparison to the main weather station at Lusaka International Airport which has 32 years of records.

The spatial variability of rainfall within the catchment was determined by using the Thiessen polygon method. This method defines the zone of influence of each rainfall station (Wilson, 1990).The analysis was done by the proximity analysis tool ArcView 3.2. The effective uniform depth (EUD) of rainfall for the catchment was determined by the summation of weighted precipitation values for each rainfall station. This method was used in this study because it provides for the non-uniformity distribution of rainfall stations (Fetter, 1994). This is the case for the Chalimbana catchment because the rainfall stations are not uniformly distributed.

Rainfall data was also an input in the calculation of runoff using the mean annual rainfall for the sub hydrological zones. It was also an input in the WAFLEX model as inflows and for the calculation of monthly evaporation from the reservoirs.

4.5 Calculation of Catchment of Runoff

Using areal rainfall, runoff for the sub hydrological zones for the catchment was calculated using equations 4.2.

$$Q = (P - E)A \quad \text{...} \quad (4.2)$$

where Q= *Discharge at the end of the catchment in* m^3
E= *Evapotranspiration in mm*
A= *Catchment area in* km^2
P=*Precipitation in mm*

4.6 Calculation of Evapotranspiration

Evapotranspiration ‘loss’ was calculated using Turc’s formula as shown in equation 4.3 (MEWD/JICA, 1995). The calculated evapotranspiration value was used as an input in equation 4.2 for calculating the runoff. The mean temperature used was 20.7^{o}C.

$$Et = \frac{P}{(0.9 + (P/L)^2)^{1/2}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.3)$$

where *Et= actual annual evapotranspiration (mm/year)*
P=mean annual precipitation (mm)
L=function of temperature, where $L=300+25T+0.05T^3$
T=mean air temperature (ºC)

4.7 Estimation of Groundwater Recharge

Groundwater recharge was estimated using equation 4.4. This method has been used by Nyagwambo (2006) to estimate groundwater recharge for Nyundu catchment in Zimbabwe.

$$R = k_1 * (P - k_2) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.4)$$

where *R= Annual Recharge (mm/a)*
k_1*= Constant of proportionality*
P= Annual rainfall (mm/a)
k_2*= Threshold annual rainfall (mm)*

For Chalimbana catchment k_1 used was 0.08 in line with the Water Resources Master Plan for Lusaka while k_2 was 400mm.

4.8 Water Demand

4.8.1 Water Demand for Commercial Irrigation

Secondary water demands for commercial irrigation were collected from commercial farmers and from Water Board office in Lusaka. Both expired and valid water rights were collected to make comparisons on how the historical water demands compare to the present demands.

The present water demand represents the water allocated to each farmer based on crop water requirements as opposed to the previous allocation criterion which was based on the lump sum water allocation of $70m^3$/day per hectare. Furthermore, present actual abstractions were also collected from the commercial farmers and then a comparison was made with the granted volumes of abstractions as stated in the water rights.

4.8.2 Domestic Water

Per capita rural water consumption of 35 liters was used in this study based on the National Water Resources Master Plan of 1995. This amount was used in the calculation of water demand for the downstream community using an indirect method as recommended by Wallingford (2003). The method is based on the given population and per capita water consumption as shown in equation 4.5.

Water Demand = Per capita water consumption (l/s/d) x population………………… (4.5)

4.8.3 Calculation of Crop Water Requirements

Crop water requirements (CWR) for commercial irrigation were also an input into the model (Appendix F). The calculations were done using CROPWAT software-version 4.3. The inputs for the calculations were crop types, planting dates and irrigation efficiencies. Climatic data from the nearest weather station to Chalimbana catchment (Lusaka Airport) was used in the calculation of CWR (Appendix B). The calculation of crop evapotranspiration (*ETc*) uses equation 4.6 which takes into account crop coefficient and potential evapotranspiration.

$$ET_{crop} = Kc * ETo \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4.6)$$

Where Kc = Crop coefficient (dimensionless)
ETo = Potential evapotranspiration (mm/d)

Crop coefficients vary over the growing period of the crop. As the crop develops, the ground cover, crop height and leaf area changes. As a consequence, the evapotranspiration of crop will change during its growing period. The majority of the crops have four growth periods (Wallingford, 2003).

4.9 WAFLEX Model – Development for Chalimbana Catchment

WAFLEX model was used to simulate different water demand management alternatives for the assessment of upstream and downstream interactions in terms of water demand and use. The model was built by linking modular system elements together in directly visible worksheets. The main system elements were precipitation, evaporation, stream inflows, demands and outflows. The development of the model for the Chalimbana river system was based on the schematic diagram shown in figure 4.0.

4.9.1 Model Structure

The WAFLEX model applied in this study consisted of the following Microsoft excel worksheets for the analysis of inputs.

(i) User Interface : This worksheet contains command buttons which are used to run the model and navigate to other worksheets containing inputs and outputs

(ii) Supply Mode : This sheet contains the representation of the river system with all the tributaries, dams and demand nodes.

(iii) Demand Mode: The demand mode also represents the river system but with the quantities of abstraction at each demand node.

(iv) Series Sheet : This sheet contains all the data inputs (rainfall, evaporation, inflows and water demands)

(v) Dams Sheet : The sheet contains specifications for each reservoir (area-capacity relationships, flood and dead storage capacities)

The other worksheets contain outputs on reservoirs' storage changes, inflows, releases, volumetric shortages and shortages in time.

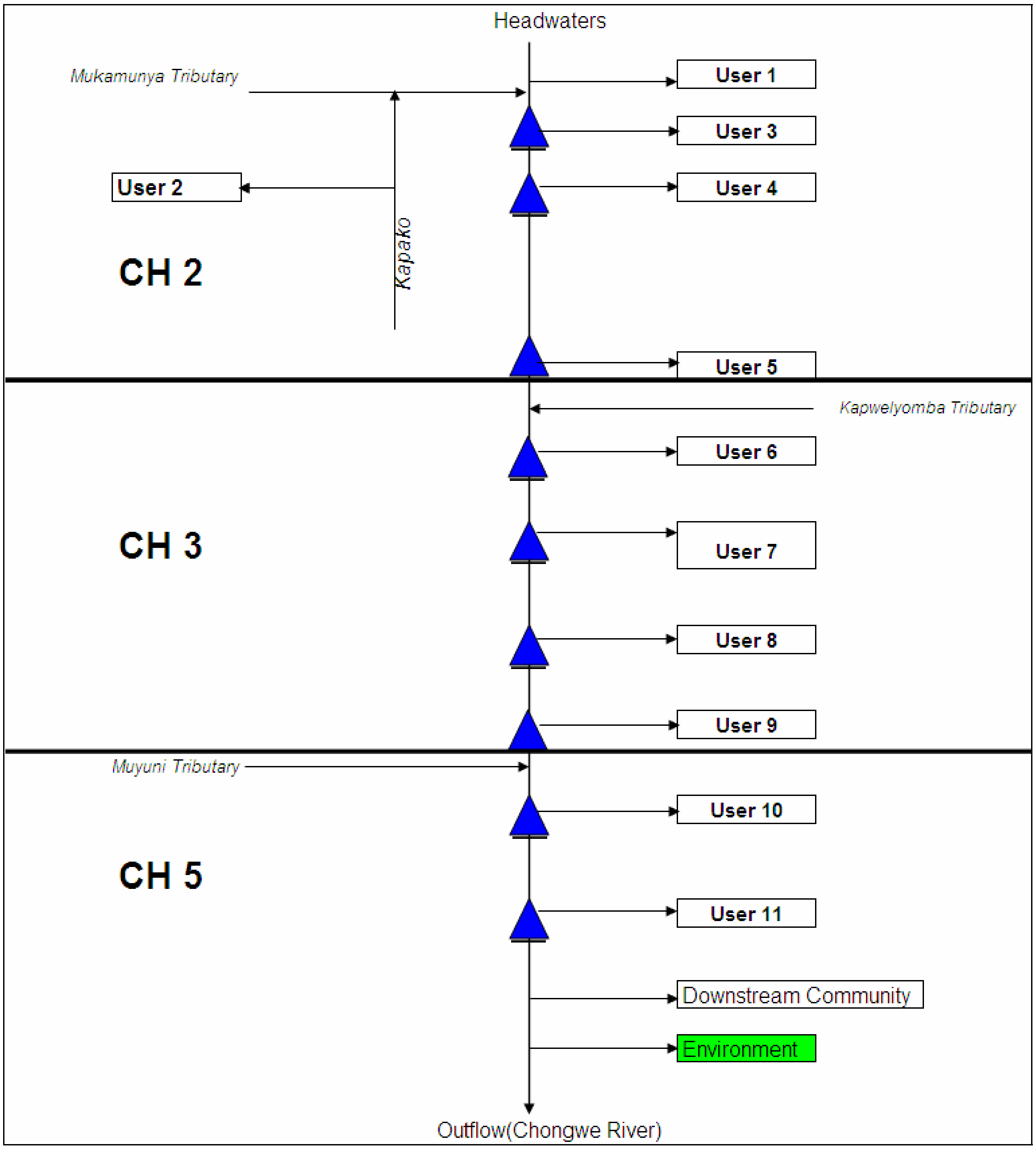

Fig. 4.0. Chalimbana river system conceptualization

The computations of the model inputs are calculated by Visual basic macros which give time step results. The macros used in the model computed water releases based on the actual demand. The following algorithm illustrates the macros which governed the operation of the first reservoir on the river, Dam A and the rest of the downstream dams.

```
Sub Res_a ()
Range ("infl1_a").Value = Range ("infl_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 ("infl1_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 ("URC1_a").Value Then
    Range ("Stor1_a").Value = (stor1_a + Range ("Rat1_a").Value * 1 / 100 * Range ("Req1_a").Value)
    Range ("Rel1_a").Value = (1 - Range ("Rat1_a").Value / 100) * Range ("Req1_a").Value
End If

If stor1_a < Range ("URC2_a").Value Then
    Range ("Stor1_a").Value = (stor1_a + Range ("Rat2_a").Value * 1 / 100 * Range ("Req1_a").Value)
    Range ("Rel1_a").Value = (1 - Range ("Rat2_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
```

The model also calculated the evaporation losses at each step from each reservoir based on the area-capacity curves. The algorithm applied for this operation is illustrated below.

```
Application. Calculate
Range ("evaploss1_a").Value=(Range ("p_a").Value – Range ("e_a").Value) * Range("area_a").Value
Range ("stor1_a").Value = Range ("Stor1_a").Value + Range ("evaploss1_a").Value

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

End Sub
```

- **Model Water Management Alternatives**

  The water management alternatives run in the model for Chalimbana river catchment included the following:

  (i) Existing situation under the current granted water rights with reservoir evaporation incorporated,
  (ii) Zero abstraction scenario,
  (iii) Management of the catchment as a complete system,
  (iv) Expansion of hectarage of cultivation by 30% and 50% based on the current water demands, and
  (v) Improvement on the irrigation system efficiency.

4.9.2 Model Water Balance

A water balance for the river system was done to ensure that all the water within the system was accounted for. This was done on all the nine reservoir and the water balance was based on the inflows and outflows from the reservoirs, change in the storage volumes and evaporation losses from the reservoirs. Equation 4.4 was used for the calculation of the system water balance.

$$I - O + \Delta S + E = 0 \qquad (4.4)$$

Where I *= Reservoir inflow*
O *= Reservoir outflow (Release)*
ΔS *= Change in Storage*
E *= Evaporation from the reservoir*

CHAPTER FIVE

RESULTS AND DISCUSSION

5.1 Water Availability in Chalimbana Catchment

The availability of water in the catchment is dependent on the amount of rainfall received, catchment characteristics and the prevailing climatic conditions. Therefore, the understanding of rainfall amount, its variability in time and space is an important prerequisite to the analysis and determination of available water in a catchment.

5.1.1 Spatial Rainfall in Chalimbana Catchment

The spatial annual rainfall of Chalimbana catchment ranges from 775mm to 885mm. This analysis was based on the available 8 year rainfall records from 1980 to 1988 at 7 rainfall stations (Appendix C). Figure 5.0 shows the distribution of rainfall stations in the catchment and the spatial rainfall as determined by Thiessen polygon method using ArcView 3.2 version.

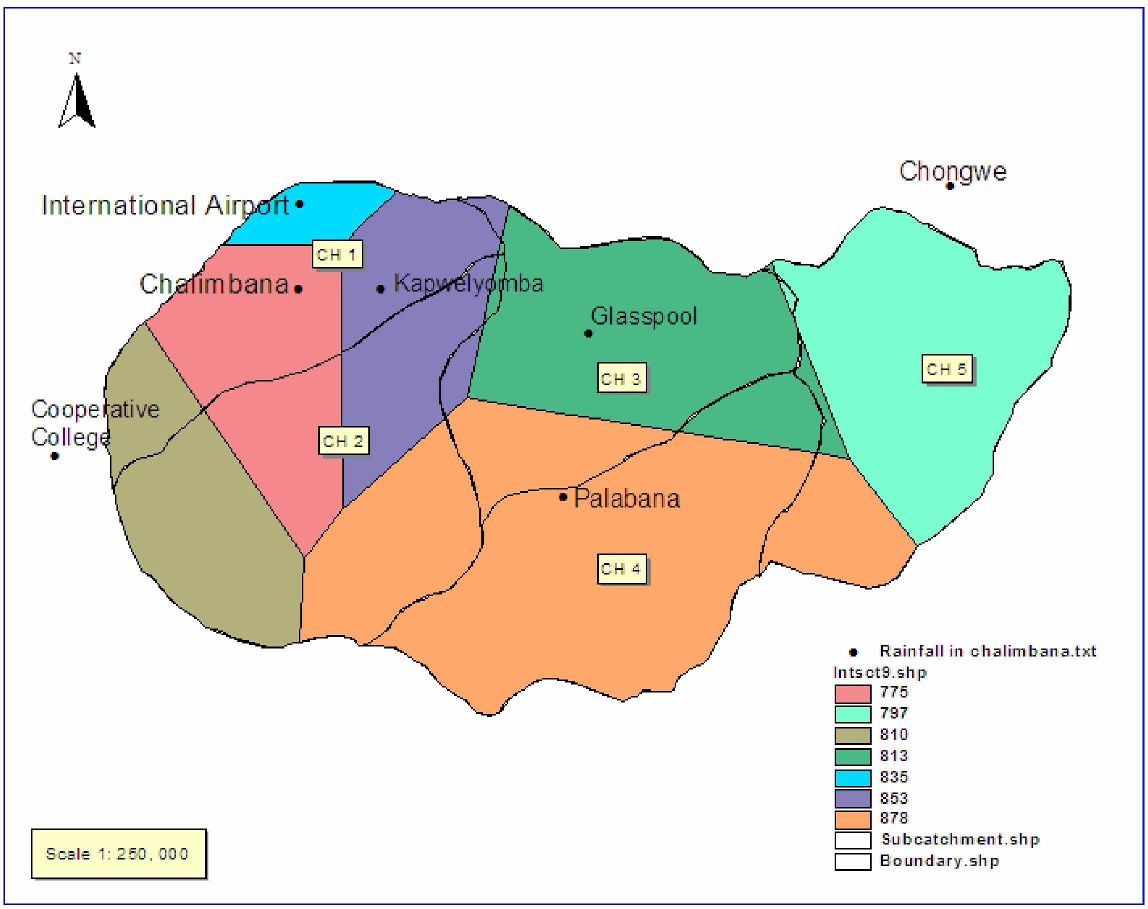

Fig 5.0. Spatial rainfall in Chalimbana Catchment

The mean annual rainfall as illustrated in fig 5.0 shows that rainfall varies spatially and temporally within the catchment. The results indicate that the annual rainfall received in the west half of the catchment is mainly influenced by four rain stations- Cooperative College, Chalimbana, Kapwelyomba, Lusaka International Airport and partly by the Palabana station. The eastern half of the catchment is equally influenced by rainfall recorded at three rain stations – Glasspool, Palabana and Chongwe station. Based on the mean annual rainfall and area of influence of each rainfall station, the effective uniform depth (EUD) was estimated to be 832.5mm (Table 5.0). This represents the mean areal rainfall for the entire Chalimbana catchment.

Table 5.0. Effective Uniform Depth of Rainfall in Chalimbana Catchment

	A	**B**	**C**	**D**
Station Name	**Station Precipitation (mm)**	**Net Area (km^2)**	**Percentage of Total Area (%)**	**Weighted Precipitation(mm) A*C**
International Airport	835	14.0	2.1	17.2
Glasspool	813	111.0	16.3	132.9
Kapwelyomba	853	67.8	10.0	85.1
Chalimbana	775	74.9	11.0	85.5
Cooperative College	810	69.5	10.2	82.9
Palabana	878	231.9	34.1	299.7
Chongwe	797	110.3	16.2	129.4
	Total	**679.5**	**100.0**	**832.5**

Based on the spatial rainfall amounts in Fig. 5.0, rainfall distribution in the 5 sub hydrological zones within the catchment is presented in table 5.1. The results show that more rainfall is received in the middle part of the catchment with an average of 862mm per annum in comparison to the upper catchment which receives less rainfall amounting to 818mm per annum. The mean annual rainfall for the extreme western half of the catchment is 824mm. The spatial rainfall over Chalimbana catchment reflects the average rainfall (800-100mm per annum) typical to Agro-ecological zone IIa (Fig. 3.2).

Table 5.1. Spatial rainfall distribution per zone

Sub Zone	CH 1	CH 2	CH 3	CH 4	CH 5
Area (Km^2)	108	158	136	143	147
Average Rainfall (mm/a)	818	829	846	878	838

The consistence of rainfall recorded at the 7 rainfall stations in the Chalimbana catchment was checked by plotting a double mass curve (fig 5.1). The cumulative total annual rainfall of Lusaka International Airport and the cumulative mean annual total of the 6 nearby rainfall stations (Chalimbana, Kapwelyomba, College, Palabana, Glasspool and Chongwe) did not show any apparent divergence in the trend. The results in figure 5.1 thus give a straight line, an indication of consistence in the rainfall data for both the Lusaka International Airport and the nearby stations. Therefore the spatial rainfall distribution in the catchment reflects the meteorological conditions of the catchment.

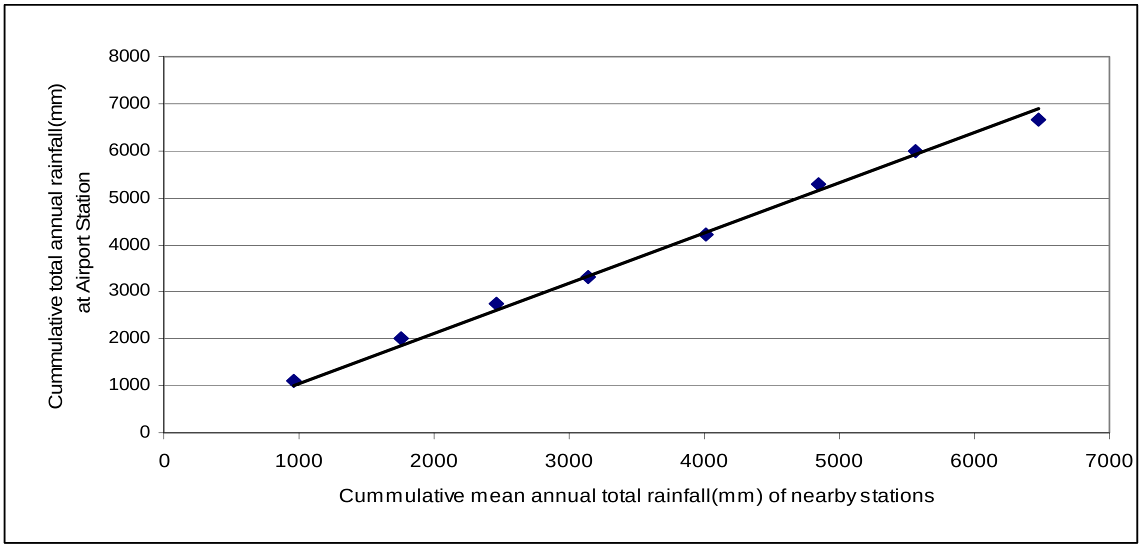

Fig 5.1. Double mass curve for the rainfall stations in Chalimbana Catchment

5.1.2 Long Term Rainfall Pattern

Based on the long time series of rainfall data (1970 to 2006) recorded at the Airport rainfall station (fig 5.2), a statistical analysis using the Analysis of Variance (ANOVA) was done to determine the variation and distribution of rainfall from 1970 to 2006. The analysis was done based on 10 year periods (1970-1979, 1980-1989, 1990-1999). The period from 2000 to 2006 was also included in the analysis.

The analysis revealed that the annual rainfall between 1970 and 2006 is normally distributed. This conclusion was based on the derived *p* value of *0.248* which shows that there was no significant difference in the 10 year periods of rainfall from 1970 to 2006.

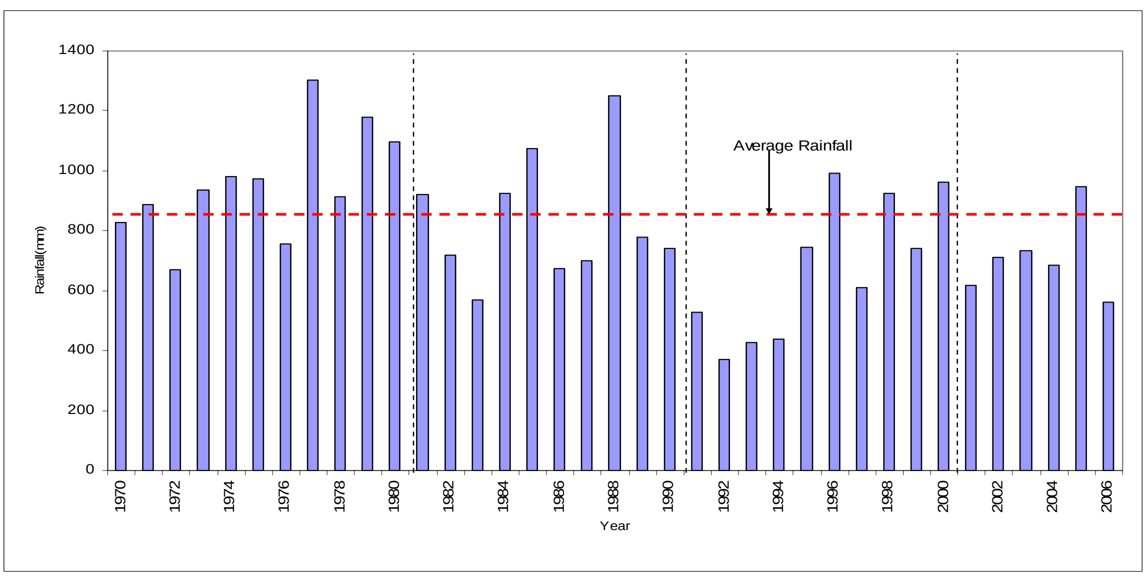

Fig 5.2.Long term temporal variation of annual rainfall (Meteorological Department)

5.1.3 Catchment Runoff and Spatial Water Availability

Catchment runoff for the Chalimbana catchment was calculated based on the five sub zones in which the catchment was divided. Mean annual rainfall, evapotranspiration and ground water recharge were used in calculating runoff for each sub zone. Evapotranspiration and groundwater recharge were calculated using equations 5.1 and 5.2 respectively.

$$Et = \frac{P}{(0.9 + (P/L)^2)^{1/2}} \qquad \text{(5.1)}$$

$$R = k_1 * (P - k_2) \qquad \text{(5.2)}$$

Runoff for each sub zone was calculated using equation 5.3 below. Table 5.2 shows the runoff results for the catchment.

$$Q = (P - E)A \qquad \text{(5.3)}$$

The total annual runoff for the catchment was estimated to be 53Mm^3. The estimates of runoff by the Department of Water Affairs (DWA, 2006) for the Chalimbana catchments is 56Mm^3 per annum. The difference in the runoff figures can be attributed to component of groundwater recharge which this study has taken into consideration as a "loss" in additional to evapotranspiration. Groundwater recharge of 8% as considered in this study is taken as the groundwater potential (total recharge) which is assumed to infiltrate to the aquifers and thus does not to contribute to the base flow.

Table 5.2. Runoff per sub zone

	Catchment Area	**Rainfall**		**Evapotranspiration**		**GWR**	**Runoff**	
Sub Zone	(Km^2)	(mm)	Mm^3	(mm)	Mm^3	Mm	(mm)	Mm^3
CH 1	108	818	88	708	76	33	77	8
CH 2	158	829	131	717	113	34	78	12
CH 3	136	846	115	732	100	36	78	11
CH 4	143	878	126	760	109	38	80	11
CH 5	137	838	115	725	99	35	78	11

An analysis of runoff figures in Table 5.2 indicates that the sub zones with larger areas generate more runoff in comparison to sub zones with smaller areas. The results further reveal that Sub zone CH 2 generates the highest runoff of magnitude 12Mm^3. The least amount of runoff is generated in the upper sub zone CH1 amounting to 8Mm^3 while CH4 and CH5 generate 11Mm^3 each.

The results further show that 59% of the catchment runoff is generated in CH1, CH2 and CH3 which constitutes the upper and middle parts of the catchment where agriculture is more developed. Therefore 31Mm^3 of the total 53Mm^3 is drained into the dams. The remaining 22Mm^3 generated in CH4 and CH5 drains into the downstream community and is eventually emptied into Chongwe river (fig 5.3).

5.1.4 Temporal Water Availability

The temporal water availability based on 46 hydrological years of runoff records (1959 - 1995) shows variations from one hydrological year to another (Fig 5.4). The runoff trend shows a return of peak runoff values of 107mm in 1977 and 1991. The peak runoff of 1977 corresponds to the highest rainfall amount of 1300mm which was recorded in that year on one of the rainfall stations in the catchment. Similarly the low runoff of 1986 corresponds to the 1986 below average annual rainfall. The results however show that more runoff was generated between 1976 and 1980 in comparison to the period before 1975. From 1991, runoff varied significantly and the low runoff of 1992 was attributed to the drought that affected most parts of Zambia and many countries in the southern African region.

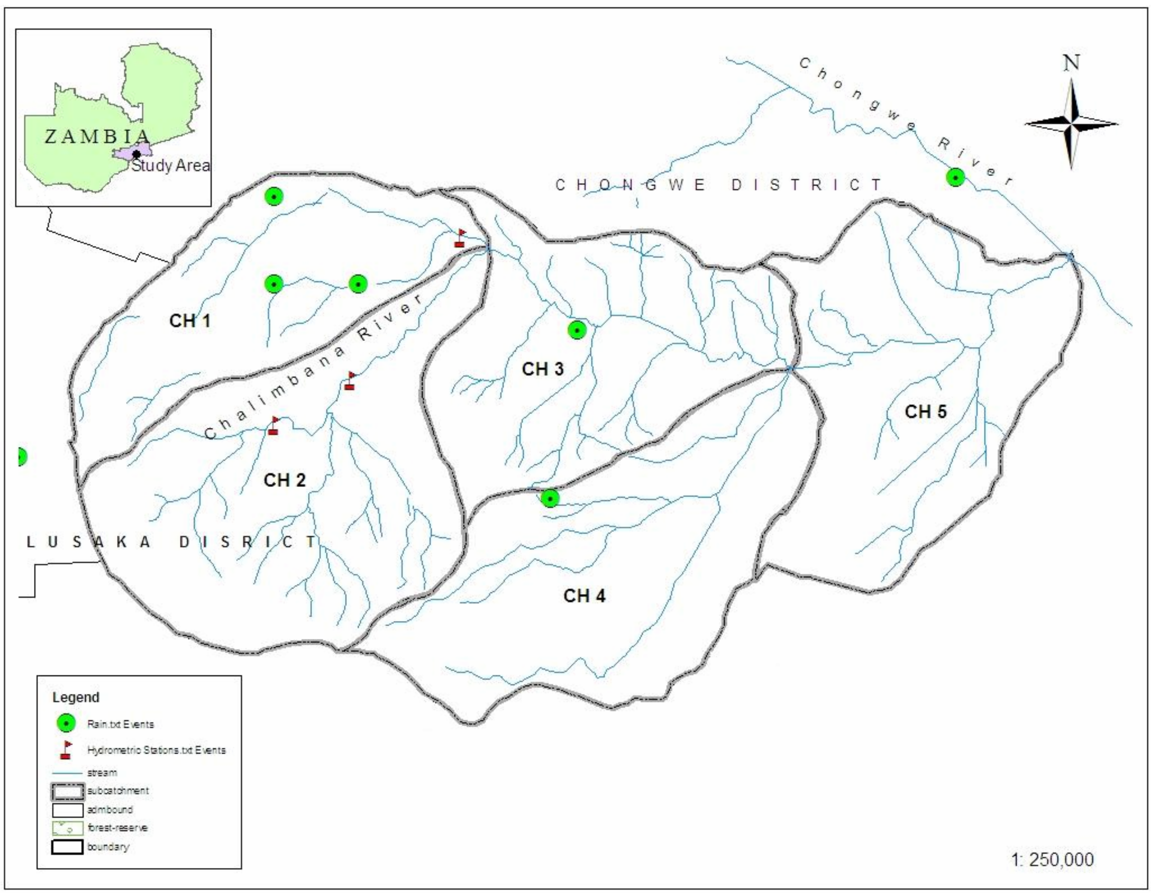

Fig 5.3. Sub catchments of the Chalimbana River Catchment

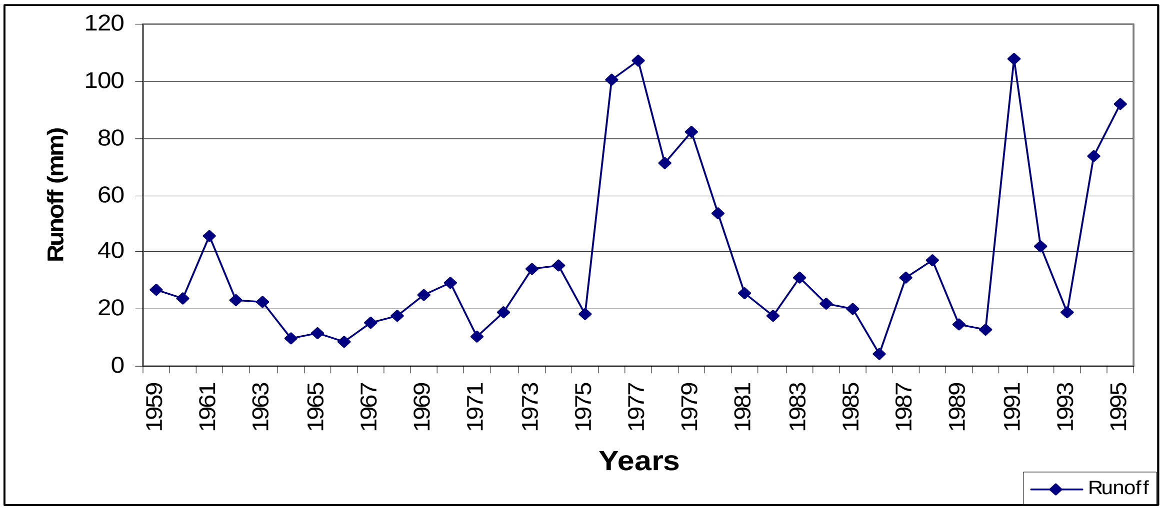

Fig 5.4. Long term runoff for Chalimbana catchment (Source: DWA)

5.1.5 Environmental Flows

In Zambia the minimum environmental flow has not been established as is the case in Zimbabwe where 5% of mean annual runoff is allocated to the environment. The National Water Policy however recognizes the need for protection of water resources and the environment. In this study a flow duration curve was used to determine the minimum flow based on 30 years of daily discharge. The flow duration curve is one of the methods recommended by DFID (2003) for determining environmental flow. The 90 percentile flow (Q_{90}) was used to determine the minimum environmental flow for the Chalimbana river (fig 5.5).

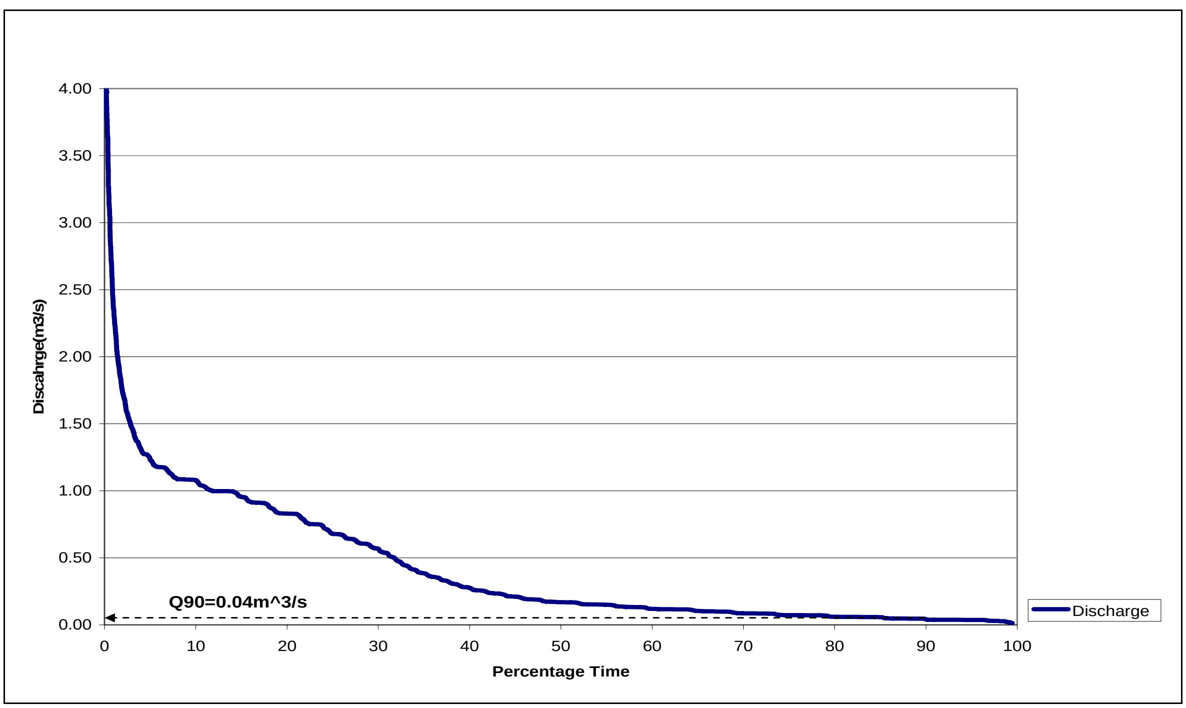

Fig 5.5. Flow duration curve for Chalimbana River

The curve was derived by ranking the daily flow and the percentage of time the flow is exceeded. From the flow duration curve in Fig 5.5 the 90 percentile flow was estimated as $0.04m^3$/sec. This flow is equivalent to 103 680 m^3 per month which is exceeded 90 % of the time. For this study this was set as the minimum flow and was therefore used in the model for the analysis of water requirement for the environmental flow.

5.1.6 Existing Reservoirs and Storage Capacities

There are nine reservoirs in the catchment with capacities ranging from $0.0104Mm^3$ to $2.54Mm^3$ (Table 5.3). These structures are all located in the middle section of the catchment. The cumulative total storage of the reservoirs at full supply level is $9.36Mm^3$. This capacity is 18% of the $53Mm^3$ total runoff generated in the entire catchment. Furthermore it also indicates that the total storage of $9.36Mm^3$ is almost more than the runoff generated in sub zone CH 3.

The nine reservoirs are spread over three sub zones, CH2, CH3 and CH5 (Fig 5.6). The first two reservoirs (Dam A and B) drain $12Mm^3$ of runoff from CH 2. These reservoirs thus receive 23% of the total catchment runoff. The rest of the six reservoirs downstream of the first two dams receive 8 Mm^3 of runoff generated from CH 1.

The overall impoundment ratio (*storage/mean annual runoff*) for the catchment based on the total impoundment of $9.36Mm^3$ with respect to the mean annual runoff of $53Mm^3$ is 0.18 (18%). This is an indication that there is room for more storage by means of construction of weirs and dams. Impoundment of more water in the downstream reach of the catchment can help address water shortages experienced in this part of the catchment.

Table 5.3. Reservoir capacities and surface areas

Dam Name	Full Capacity (Mm^3)	Area(Mm^2)	Year of Construction
Dam A	0.507	0.134	-
Dam B	0.311	0.075	1981
Dam C	1.589	0.422	1998
Dam D	1.300	0.290	2005
Dam E	0.104	0.380	2003
Dam F	1.605	0.250	1984
Dam G	1.080	0.080	1983
Dam H	0.325	0.420	1985
Dam I	2.538	-	1990
Proposed Dam	0.130	0.022	-

Source: Water Board

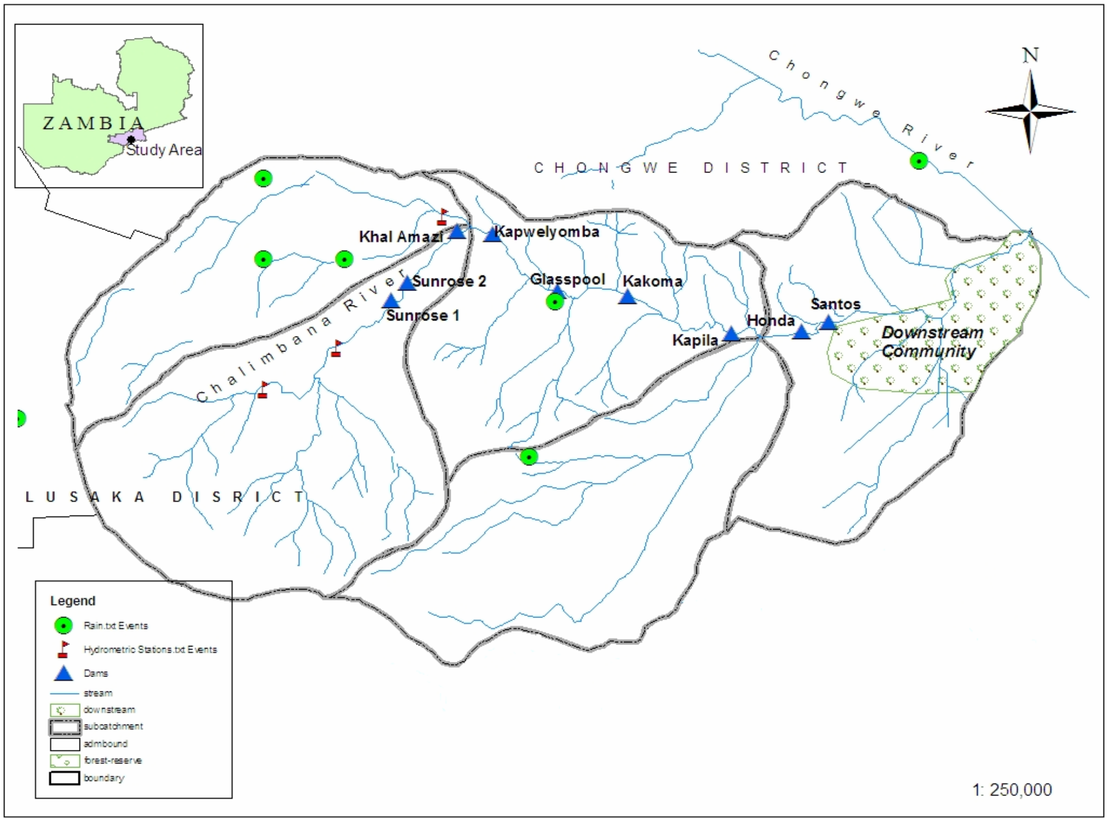

Fig 5.6. Location of dams and the downstream community in the Chalimbana Catchment

5.2 Historical Irrigation Water Demand and Conflicts

The study revealed that irrigation water demand on Chalimbana river has increased from 1.0Mm^3 per annum in 1968 to 6.06 Mm^3 per annum in 2006 (Appendix D). Figure 5.7 illustrates that significant increase of water demand was experienced between 1983 and 2006. This is the period in which construction of dams and weirs took place to impound more water to meet the growing water demand for agriculture. The conflicts among the upstream users and also with downstream users manifested and escalated in this period.

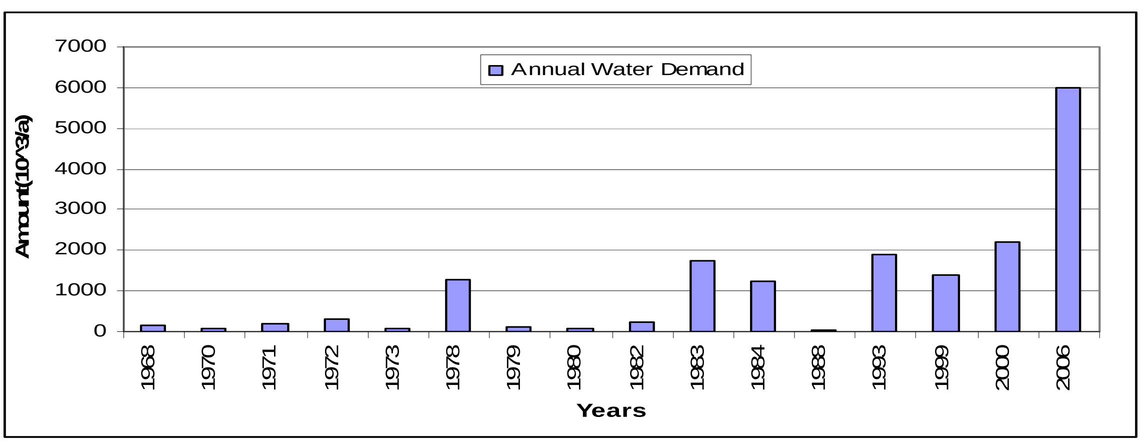

Fig 5.7. Historical agriculture water demand in Chalimbana Catchment

5.3 Current Agricultural Water Demand

Agriculture in Chalimbana catchment is the largest consumer of surface water. The current annual water demand, based on the existing valid water rights of 2006 was estimated to be 40 420 m^3 per day (Appendix H). The granted water rights are permitted to abstract water from the main Chalimbana river and the two tributaries- Mukamunya and Kapako.

The results presented in figure 5.8 illustrate the comparison of granted volumes of abstractions and the actual abstraction volumes. The volumes of abstractions for each farmer are readings taken from extraction pump on daily water usages. Installation of meters on extraction pumps has been a requirement by Water Board in recent years to monitor abstractions with respect to the permitted volumes of abstractions. Transmission losses in this study are assumed to be minimal and the analysis of water use is based on the actual recorded pump figures.

The results show that the actual water abstractions by 5 users exceeded the requested demand. The other 6 users' actual water abstractions were within the limits of the granted water demand in accordance with the water rights. The combined actual water use by the users amounted to 6.15Mm^3 more than the granted volume of 6.06Mm^3. Thus the actual abstractions exceeded the granted volumes by 15 %. The results also show that User 7 abstracted 1.45Mm^3 of water exceeding the granted volume of 0.194Mm^3 by seven times. This is attributed to the multiple use of the reservoir by three commercial farmers.

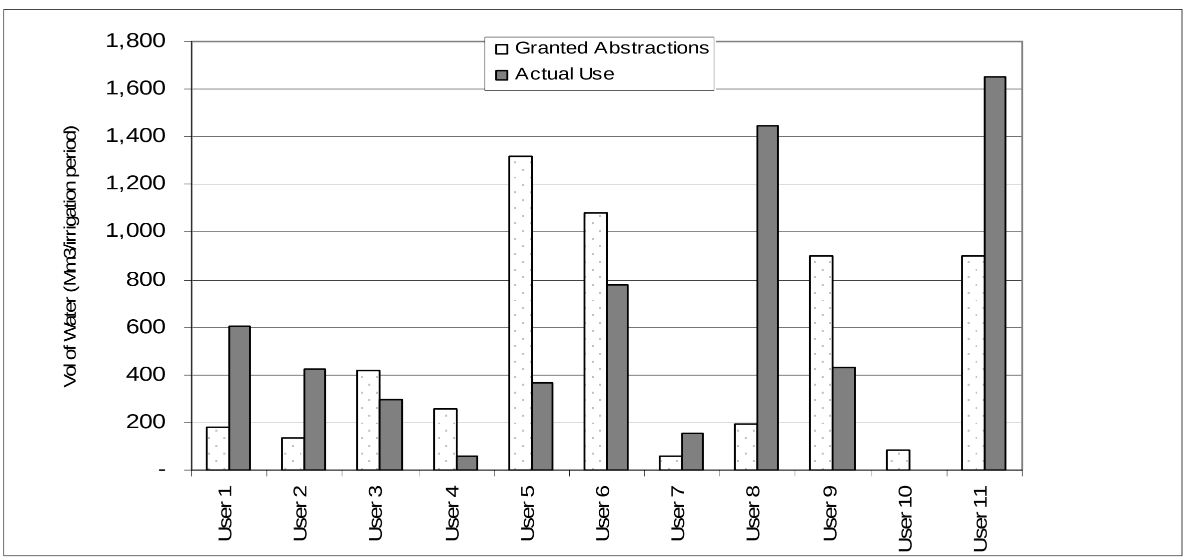

Fig 5.8. Granted volume of water and actual abstractions

5.4 Domestic and Irrigation Water Demand for the Downstream Community

The downstream riparian community consists of nine small villages: Kabeleka, Mukankaulwa, Kapumangoma, Maoma, Bundu, Kapuka, Kayombo, Mwampikanya and Chishiku. The total number of households in this area is 350 with an average family size of 8. The population was estimated to be 2800. Based on the population and per capita water demand, the downstream domestic water demand was estimated to be 40,241m^3 per year.

The analytical comparison of the downstream and upstream water demands reveals that the annual water demand of 40,241m^3 per year is almost equivalent to the daily water demand by the commercial farmers amounting to 40,420m^3(Appendix H). This scenario shows that agricultural water demand consumes more water than domestic use. This is actually the case at national level where 70% of water is used for agriculture.

The study further revealed that the reduction of river flows after the rain season is evident in the downstream reach of the river. By April 2008 the flow at Bimbe bridge, 5 kilometers downstream of the last dam, was below the culverts (Fig 5.8). According to the residents' observation, this is the common trend year after year since the construction of the dams.

The study further revealed that currently domestic water is supplied by the boreholes sunk by a charitable organisation for the villages (fig 5.9). The riparian downstream households of the Chalimbana river thus use the river water for irrigating small gardens along the river banks (fig 5.9).

Fig 5.8. Low downstream flow at Bimbe Bridge (April, 2008)

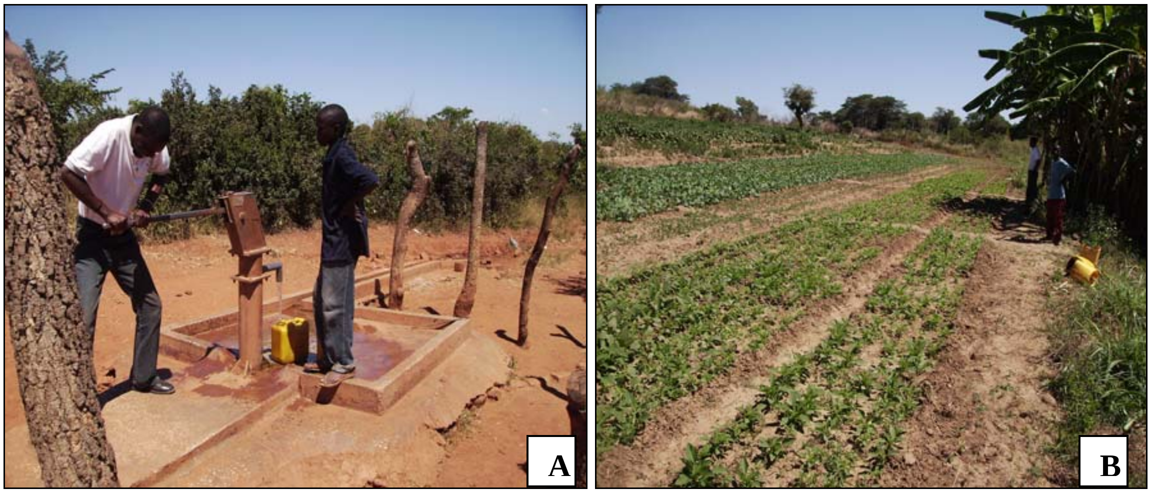

Fig 5.9. Village borehole for domestic use (A) and downstream river bank cultivation (B)

Majority of the peasant farmers on the banks of the river use 3.5 horsepower centrifugal pumps which pump about 3.5 to 5 litres per second. According to the local peasants, water abstraction for irrigation of gardens is done 3 hours per day in a week. The water abstractions in winter and summer are presented in Table 5.4.

Table 5.4. Water demand by peasant farmers

Abstraction Method	**Vol (l/s)**	**No of Users**	**Abstraction Frequency Per Week (3hrs/d)**		**Total Vol (m^3)**	
			Winter	Summer	Winter	Summer
Pump	3.5	5	1	2	3024	6480
Pump	5	4	1	2	3456	4147
Bucket	-	6	2	3	1920	2880
Total		**15**			**8400**	**13507**

The results in table 5.4 indicate that the total water demand for the irrigation of small gardens varies from 8400m^3 in winter to 13507m^3. Therefore the total water demand per annum was estimated to be 21907m^3. The table also shows that more water is used in summer than in winter and this is attributed to the higher evapotranspiration rate experienced in summer than in winter.

5.5 WAFLEX Model Application to the Chalimbana Catchment

5.5.1 Model Evaluation and Limitations

Chalimbana catchment has inadequate historical flow data. The only station with reliable long term flow data is along the main Chalimbana river. This station is located in the upper catchment upstream of the existing dams. The other station is on an intermittent tributary which is also upstream of the dams. Between the first and last dam on the river, there is no gauging station except for small V-notch weirs with very short period records of flow data. Furthermore, the catchment also lacks long term dam levels for appropriate model evaluation.

The evaluation of the model in this study was therefore not based on the observed and simulated flows or dam levels as is the case in catchments with long term and adequate hydrological data. In this study the model reliability was done by using a sensitivity analysis using input parameters. The model sensitivity was evaluated by making the water demand for upstream and downstream users constant. Increasing or decreasing water demand on some demand nodes showed a slight change in the downstream flow.

Furthermore errors on the model were also checked by doing water balance calculations to ensure that all water in the system was accounted for. The water balance calculations were based on the inflows (I), outputs (O), change in storage (ΔS) and evaporation losses (E) on each of the reservoirs. Therefore the reliability of the model outputs in this study was based on its sensitivity analysis and water balance checks to account for all the water in the system.

5.6 Model Water Demand Alternatives

The water demand alternatives applied in this study were aimed at assessing how the available water in Chalimbana catchment can be utilized to satisfy the water demand for both upstream and downstream users. The water demand management alternatives formulated in this study therefore takes into consideration the water resources management strategies of the National Water Policy (GRZ, 2007) which among other things aim at promoting and implementing the development of an integrated catchment management system to improve accessibility and utilization of water resources for various uses. Furthermore, in line with Zambia's Irrigation Policy Review and Strategy (GRZ, 2002), the country's natural resource potential (water, soil and land) guarantees the extent for intensified agricultural development and production. To date 400 000 hectares of irrigable land remain undeveloped. Increased demand due to agricultural expansion is a threat to water availability.

The following management alternatives were therefore evaluated under the following runs:

(i) Existing situation under the current granted water rights with reservoir evaporation incorporated,
(ii) Zero abstraction option,
(iii) Management of the catchment as a complete system,
(iv) Expansion of hectare of cultivation by 30% and 50% based on the current water demands, and
(v) Improvement on the irrigation system efficiency.

In this study the term "*water demand satisfaction level*", is used as the evaluation criteria for water demand alternatives and refers to the extent to which demands are satisfied in terms of percentage. It is the difference between full satisfaction (100%) and the shortages. Therefore for each user, a higher percentage represents less shortages and vise-versa.

5.6.1 Run 1: Current Water Demand

Under the current existing water demand and abstraction, shortages for each water right holder and the downstream users were calculated using the model. Water losses through evaporation from all the nine reservoirs were also incorporated in the calculation of volumetric shortages. The results showing the levels of satisfaction for the users are illustrated in figure 5.10.

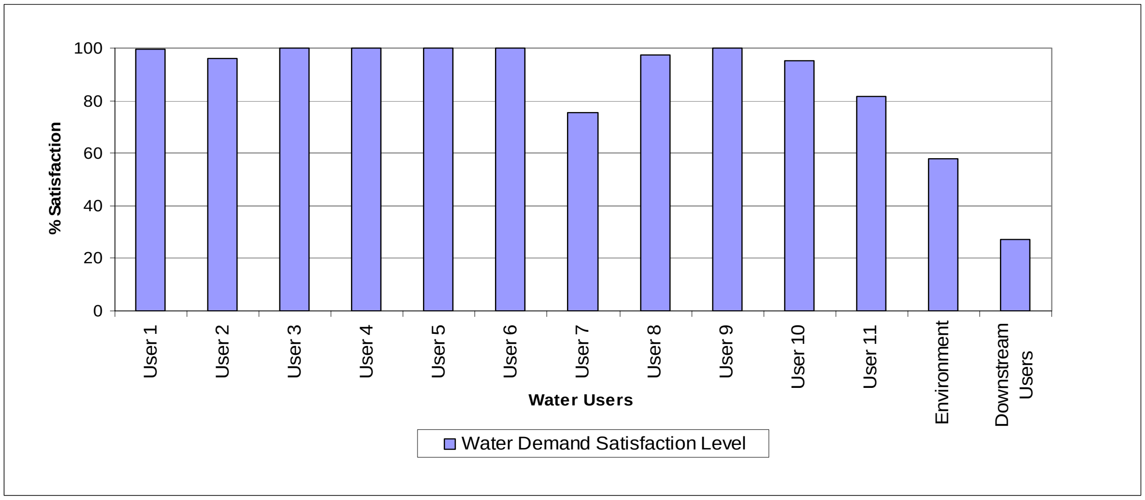

Fig 5.10. Current water demand satisfaction

The results shown in 5.10 illustrates that 9 out of 10 water right holders had their volumetric water demands met by more than 70%. Users 1, 3, 4, 5, 6 and 9 had satisfaction levels of 100%. This indicates that these users did not experience shortages in terms of the volume of water required for irrigation. The results presented in figure 5.8 also confirm that these users abstracted water within the limits of permitted volumes by Water Board.

Users 7, 8, 10 and 11 had satisfaction levels of 75%, 98%, 95% and 81% respectively. Due to the shortages experienced by these users, they abstracted more water than required as illustrated in figure 5.8. The shortages experienced by downstream users are due to the change in the flow regime from a perennial to an intermittent river as result of construction of hydraulic structures in the upper catchment. The results show that only 27% of the water demand is satisfied while the environment gets about 59% satisfaction level.

5.6.2 Run 2: Zero Abstraction and Water "Loss" by Evaporation

Under this run, mean annual evaporation from the 9 reservoirs was determined without any abstraction. The amount of water "lost" from each reservoir in comparison to the total storage capacity is presented in Table 5.5.

The results illustrate that the total water "loss" from the reservoirs without any abstractions is of magnitude 2.47Mm^3 per year. This represents an annual loss of 26% of water of the total storage of all the reservoirs. The amount of water lost if no abstraction take place is almost equivalent to the storage capacity of largest reservoir in the catchment with a storage capacity of 2.54Mm^3. The amount of water lost is also equivalent to irrigate about 300 hectares of wheat with an irrigation efficiency of 70%.

Table 5.5. Estimated annual evaporation from reservoirs

Dam Name	Full Storage Capacity (Mm^3)	Full Surface Area (Mm^2)	Mean Annual Evaporation (Mm^3/year)
Dam A	0.507	0.217	0.238
Dam B	0.311	0.093	0.101
Dam C	1.589	0.526	0.576
Dam D	1.300	0.340	0.372
Dam E	0.104	0.380	0.069
Dam F	1.605	0.250	0.025
Dam G	1.081	0.080	0.436
Dam H	0.325	0.420	0.096
Dam I	2.539	0.518	0.559
Total	**9.361**	**2.824**	**2.472**

The model results further shows that evaporation "loss" from reservoirs is slightly higher if no abstractions takes place in comparison to the "losses" from reservoirs where abstractions take place (figure 5.11). The higher "losses" in a situation where there are no abstractions is attributed to the fact that more water is "lost" through evaporation from a large surface area of water in comparison to a smaller surface area which is brought about by abstractions. The results thus illustrate that annually less water is "lost" from the reservoirs if abstractions are taking place.

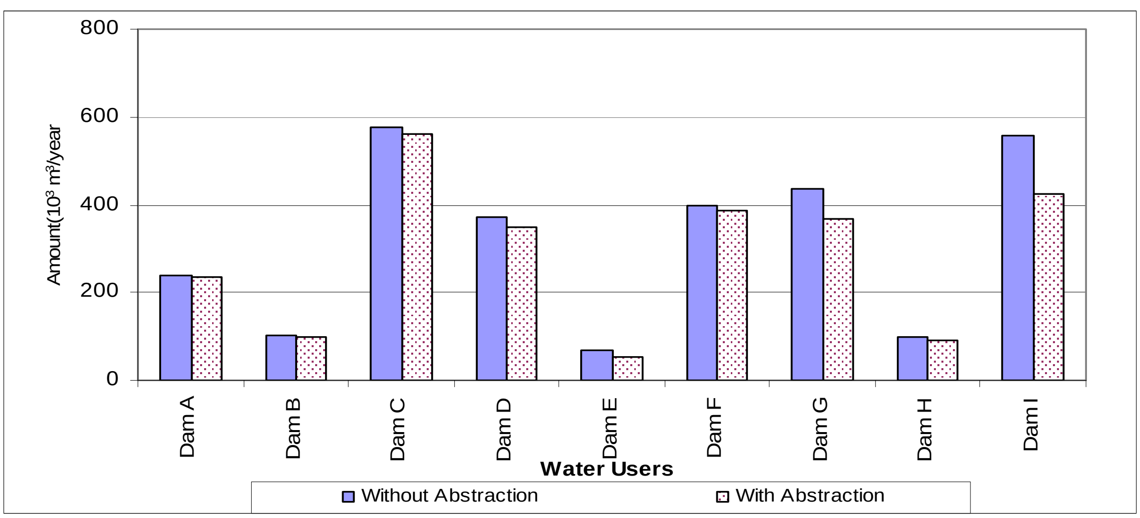

Fig 5.11. Evaporation from reservoirs with and without abstractions

5.6.3 Run 3: Management of the Catchment as a Complete System

Management and operation of the reservoirs as a system involves coordinated use of water in the catchment to satisfy the water demands of both the upstream and downstream users. This means releasing water from the upstream to the downstream reservoirs in order to ensure even distribution of water in the system. Under the current water demand situation, the results show that upstream reservoirs will be full while the downstream ones will have less water by the end of the hydrological year. The differences in storage between the upstream and downstream reservoirs is shown in figures 5.12 and 5.13

The comparison of the two reservoirs shows that the upstream reservoir will experience fewer fluctuations in the storage changes as compared to the downstream reservoir. The difference in storages of the two reservoirs is attributed to the continuous natural flow that the upstream reservoir receives as compared to the downstream reservoir which will receive regulated and highly intermittent flow from the upstream reservoirs. The comparison further shows that the upstream reservoir will experience fewer fluctuations in the storage changes as compared to the downstream reservoir. Furthermore the management alternative for this case was run with a factor incorporated in the water demand on each of the reservoirs to allow more water to flow to the downstream reservoirs.

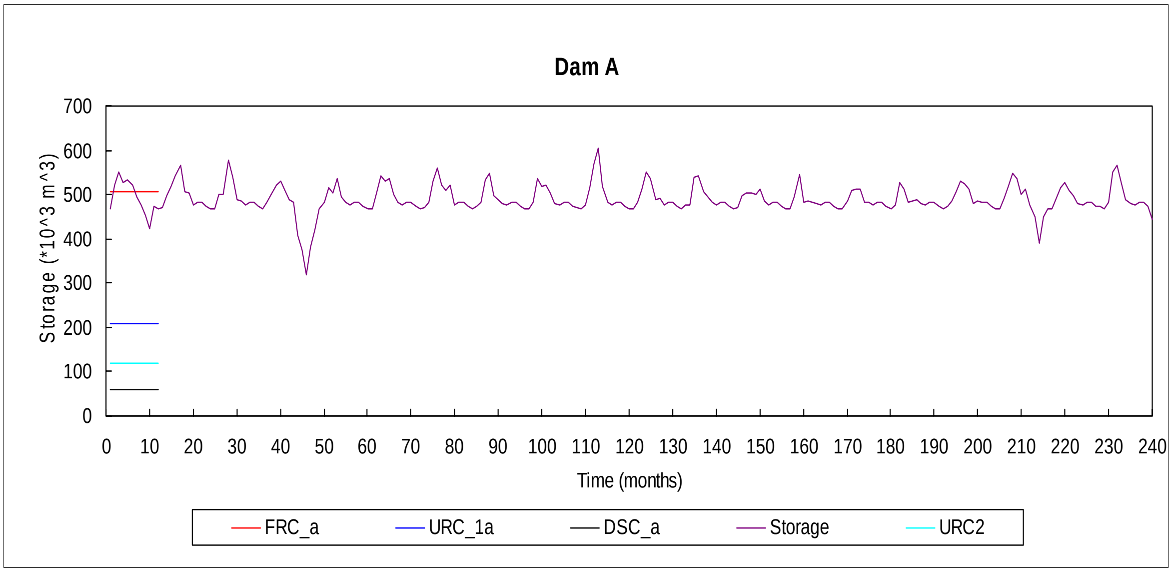

Fig 5.12. Temporal storage change of an upstream reservoir

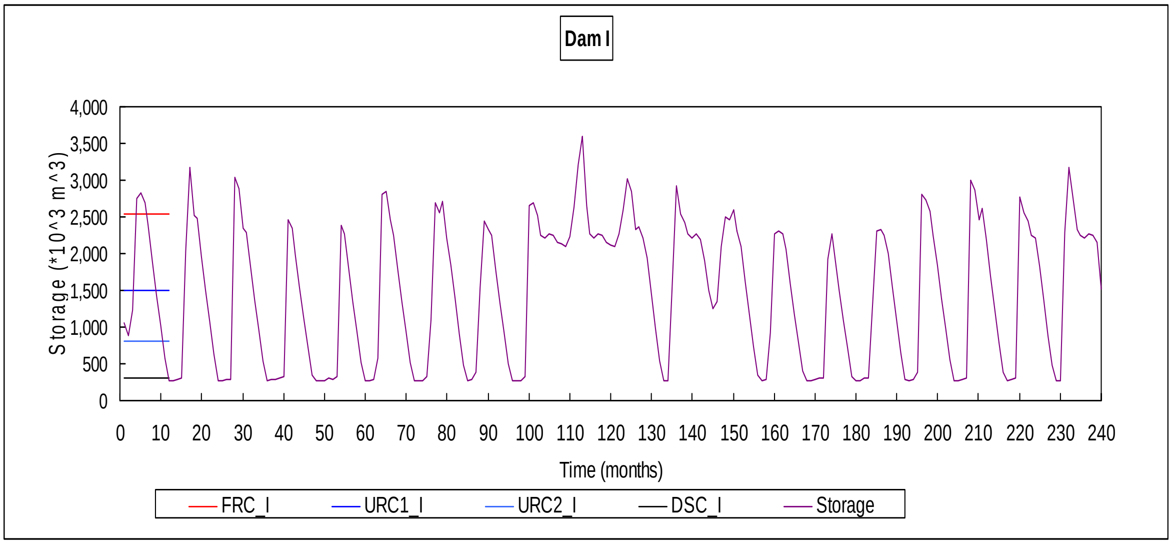

Fig 5.13. Temporal storage change of a downstream reservoir

By incorporating the release factor on each reservoir, the model results show that the water demand satisfaction level for the downstream users improve from 27% to 40% while that for the environment satisfaction level improves from 64% to 69%. In both cases although the improvement is not significant, the models result verifies that upstream releases enables the reduction of volumetric water shortages for the downstream users as well as that of the environment. While the water demand satisfaction improves for the environment and downstream community, satisfaction levels for upstream users reduce. For users 3, 4, 5, 6 and 8 the satisfaction level reduces from 100% to 97%, 80%, 90%, 70% and 53% respectively. Water demand satisfaction levels for users 7, 9, 10 and 11 further changes from 89%, 75%, 71% and 97% to 42%, 61%, 58% and 88% respectively. The resulting reduction in the satisfaction levels for upstream users is as a result of releasing more water from upstream reservoirs to flow downstream.

However, the water demand satisfaction levels for User 1 and 2 who abstract water direct from river are not affected by this requirement. This is attributed to the fact these users are in the upstream part where the natural flow has not been affected by any hydraulic structures. Fig 5.14 illustrates the water demand satisfaction levels from the model runs before and after the introduction of release factors.

The temporal change in the storage of an upstream reservoir before and after the releases from the reservoir are made is illustrated in figure 5.15. The results further indicate that despite the releases the reservoir is not emptied to the dead storage capacity but retains adequate volume over time.

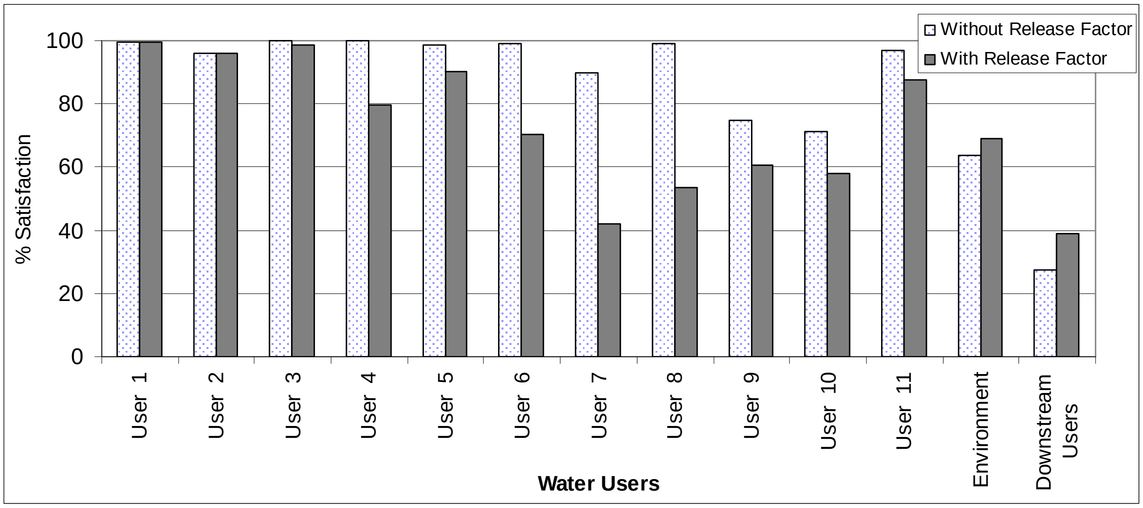

Fig 5.14. Water demand satisfaction after introducing release factors on the water demand

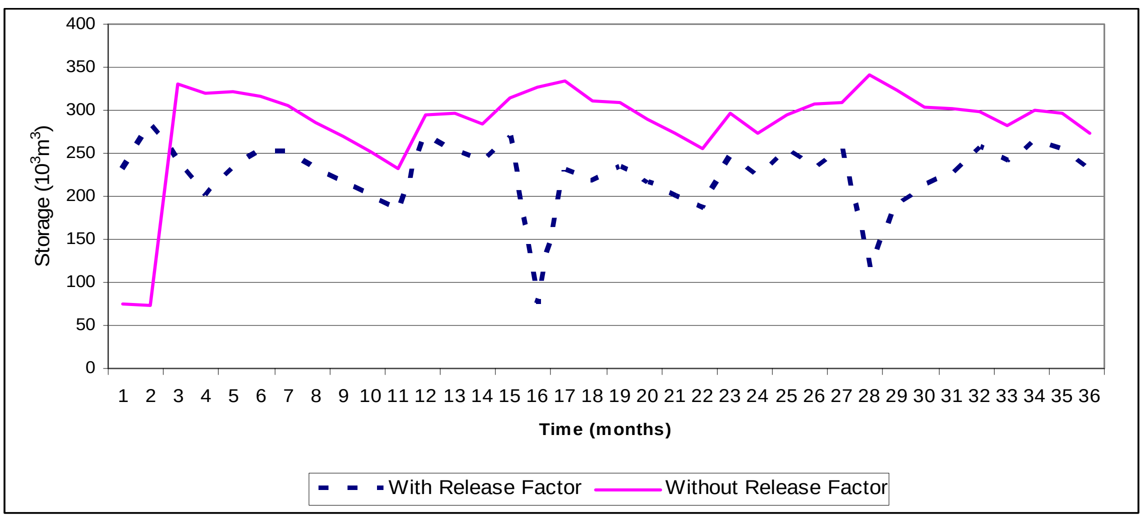

Fig 5.15 Change in storage before and after introducing release factor

5.6.4 Run 4: Expansion of Irrigation Area by 30%

This scenario was considered to evaluate the water demand satisfaction for all the upstream users by expanding the area of cultivation by 30%. Under this management alternative, evaporation "losses" were also considered with the environmental flow and downstream water demand remaining the same. Management of the catchment as complete system was also considered. The results before and after the expansion are presented in figure 5.16.

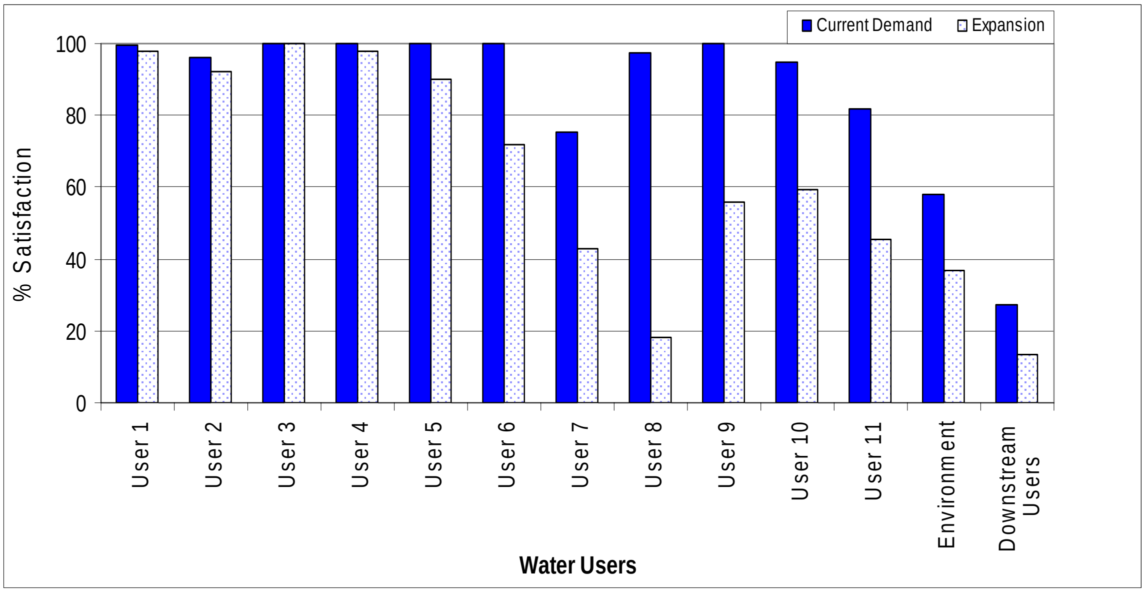

Fig 5.16. Water Demand satisfaction at 30% expansion of irrigation area

In comparison to the existing water demand satisfaction levels of 2006, the results show that expansion of irrigation area results in shortages for all the users. After expansion water demand satisfaction for 5 upstream users (users 1 to 5) remains above 90%. The water demand satisfaction levels for users 7 to 11 after expansion range between 18 and 59% except for user 6 whose satisfaction level is 72%. The results also reveal that the first two upstream users who abstract water directly from the river experience less shortages in comparison to others who have dams.

For the environmental flow, the expansion reduces the level of satisfaction from 58% to 37%. Similarly the downstream community experiences a reduction from 27% to 14%. In this case, the impact of water shortage is more on the downstream community and the environment. The volumetric shortages are 86% for the downstream community and 63% for the environment (Fig 5.16).

Overall, the expansion of agriculture by 30% does not result in significant changes for the upstream users but still affects the water demand satisfaction for the downstream community and the environment. Therefore this is a sustainable option for the upstream users and not for the downstream community and can give rise to conflicts. Furthermore the consequence of increasing to 30% is that reservoir storages decrease significantly up to the dead storage capacities especially for the downstream reservoirs. Fig 5.17 illustrates the change of storage for dam G. The results show that before expansion the volume of water at the beginning of the hydrological year is about 800,000 m^3 in comparison to the 200, 000m^3 for the same period if the expansion takes place. This means that although the increase to 30% can be sustainable the risk is that reservoirs will by the end of the hydrological year be almost empty with no capacity to release water for the downstream users.

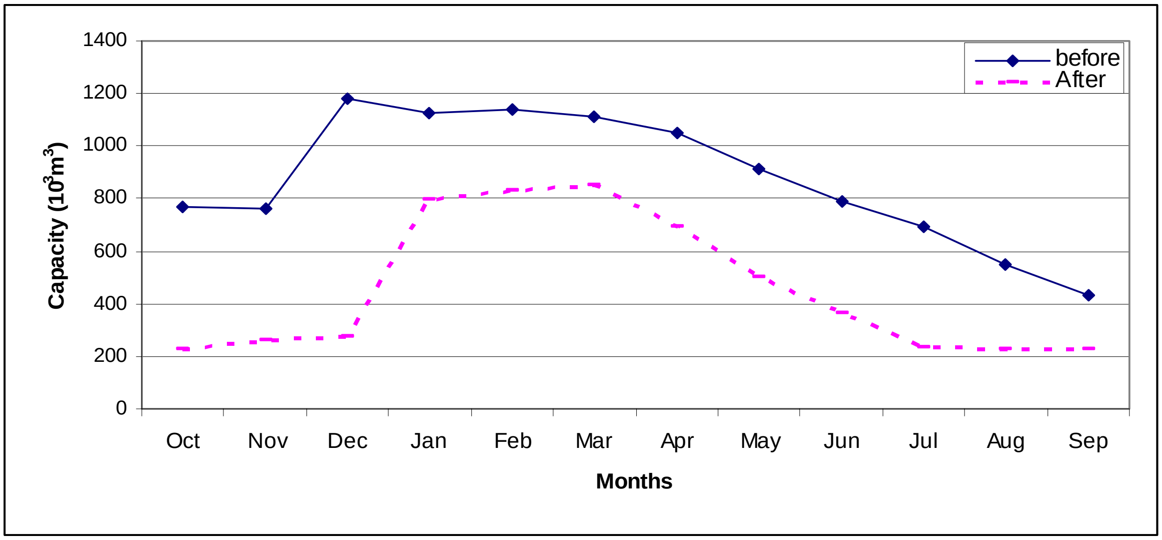

Fig 5.17. Comparison of storage for a downstream dam before and after expansion

5.6.5 Run 5: Expansion of Irrigation Area by 50%

The results from this run do not differ significantly as that of the 30% expansion alternative. The same conditions under which the 30% scenario was run were also considered for this option.

Under this case the 5 upstream water users experienced slightly more shortages than in the 30% scenario. In this scenario, 2 of the first upstream users had satisfaction levels less than 90%. For the downstream users there was no significant difference in the water demand satisfaction levels. User 8 under this scenario experienced a reduction of water demand satisfaction from 56% to 47%. This is attributed to the multi use of the reservoirs.

The environment and the downstream community experienced a further reduction in the water demand satisfaction. The shortages for the environment increased from 63% to 65% while that for the downstream community also increased to 87% from 86% (figure 5.18).

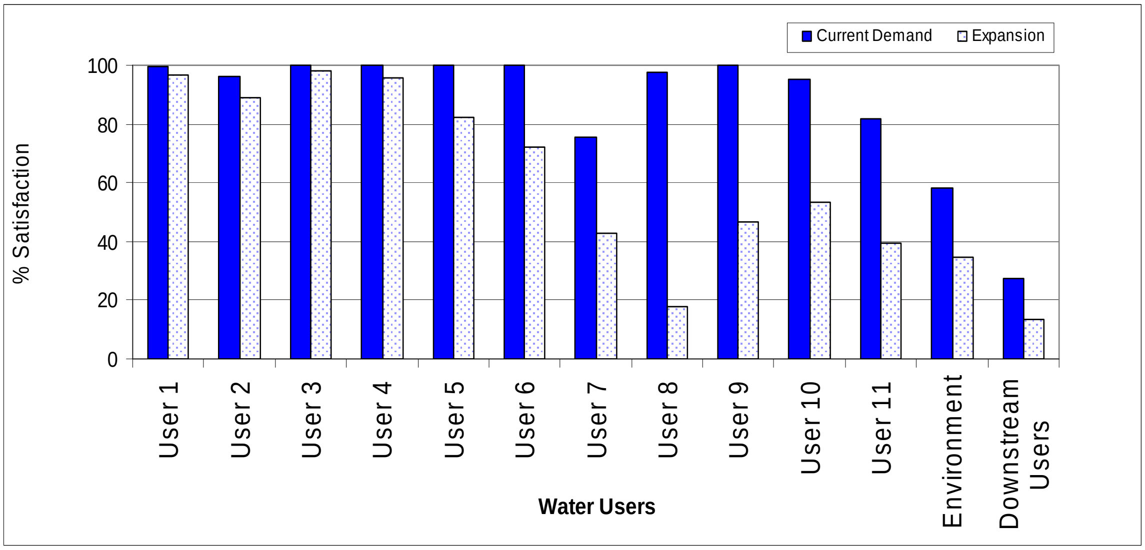

Fig 5.18. Water demand satisfaction at 50% expansion of irrigation area

5.6.6 Run 6: Improvement of Irrigation Efficiency System

Under this run, crop water requirements at 90% irrigation efficiency (Appendix E) were used to evaluate the water demand satisfaction for the upstream users and how it affected the downstream water availability. This management alternative did not affect the upstream users but improved water demand satisfaction for User 8, the downstream community and the environment (Fig 5.19). The results show that user 8 water demand satisfaction improved from 11% to 47%. The demand for the downstream community improved significantly from 58% to 91% while that of the environment improved from 27% to 90%.

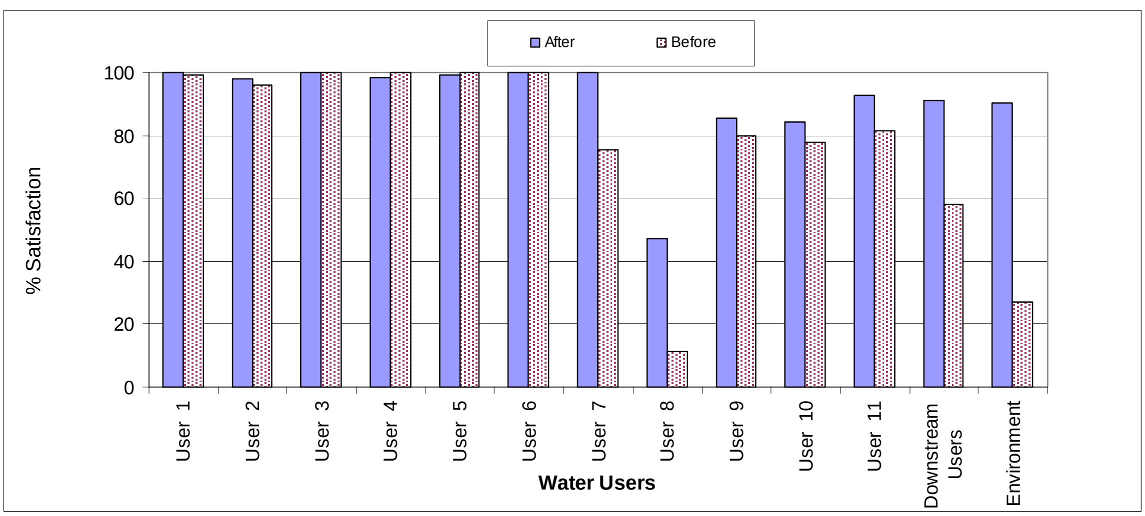

Fig 5.19. Water demand satisfaction after improving the irrigation system efficiency

Improvement in irrigation system efficiency illustrates that more is saved to meet the needs of other users in the catchment. This is in line with Mtshali (2001) who concluded that allocation of water based on crop water requirements in water allocation gives room to accommodate new water right applicants. However the irrigation system required to meet this scenario is expensive but more efficient. The results obtained in this run demonstrates and confirms that efficient use of water is a key prerequisite to integrated water resources management (IWRM) considering that water is a fugitive resource and has no substitute.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings of the study, the following conclusions were drawn:

(i) Water availability in Chalimbana catchment (53Mm^3 runoff) with an annual storage of 9.36Mm^3 is sufficient to sustain both upstream and downstream water demands. The study reveals that only 18% of total runoff is impounded thus giving leaving room for impoundment of more water especially in the downstream part of the catchment.

(ii) Under the current water demand situation, water demand satisfaction levels for upstream users range from 80% to 100% while for the downstream community it is 27%. The difference in the demand satisfaction levels is the main cause for the existing upstream-downstream conflicts as less water is made available for the downstream users. The study revealed that in some cases upstream users abstract more than the permitted quantities and this exacerbates downstream water shortages.

(iii) The existing water allocation system does not explicitly provide for downstream users in the catchment, except for the entitlement to primary water use which is not even adequately quantified. The same applies for the environmental flows. However, the allocation of water to upstream (secondary) users based on Crop Water Requirements (CWR) is an appropriate criterion because it promotes efficient use of water as is advocated for by integrated water resources management (IWRM) principles.

(iv) The model results show that the downstream demand satisfaction improves from 27% to 40% if the catchment is managed as a complete system with upstream reservoirs releasing water for the downstream users. This water demand measure balances and provides for both upstream and downstream users and is a basis for the resolution of the upstream-downstream conflicts. Under this run, water demand satisfaction for upstream users reduce slightly while that for downstream users increase, thus balancing the needs. The expansion of irrigation area by 30% and 50% reduces satisfaction levels for both upstream and downstream users. However the improvement of irrigation efficient system improves the demand satisfaction for both upstream and downstream users. The management alternatives of managing the catchment as a system and improvement of irrigation efficiency system balance the demand satisfaction levels for both upstream and downstream users.

In view of the findings and conclusions drawn, the study recommends the following:

(i) For balanced upstream-downstream water utilization based on the spatial water availability, the existing water allocation must consider allocating a percentage to the downstream community and the environment based on the catchments' mean annual runoff as is the case in the Zimbabwean water sector allocation. Once this is done, it can be achieved by regulation and inspection of upstream water demand and use to ensure that water is made available for the downstream users. The impoundment of more water by means of hydraulic structures particularly in the lower catchment is another option which can also address the water shortages experienced by downstream community. Ultimately this can resolve the upstream-downstream conflicts in the catchment.

(ii) From the results obtained from the model, this study recommends that the catchment be managed as a complete system as an initial step to improve the water demand satisfaction levels for the downstream users. Expansion of irrigation areas by 30% can be sustainable without causing significant shortages for the downstream community if the irrigation efficient system is improved to 90%.

(iii) Water User Associations in the catchment must be strengthened to promote multi-stakeholder (upstream-downstream) participation in the utilization of water resources.

(iv) This study should be repeated for the same catchment in future using WAFELX model after gathering adequate stream flow and dam data levels a The study should focus on reservoir operation and establishment of environmental flows of the catchment.

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APPENDICES

APPENDIX A. Unit Consumption Rates in Urban/Rural Areas for Zambia

Category	**Unit Consumption Rate**
Urban Area	
Large Urban Area	180 litres/capita/day
Small Urban Area	150 litres/capita/day
Rural Area	35 litres/capita/day

Source: Zambia National Water Resources Master Plan, 1995

APPENDIX B. Climatic Reference Data for Crop Water Requirement Calculations

Parameter	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Mean Max Temp	25	25.7	26	26.2	24.5	22.7	22.6	25.3	28.8	31.1	28.6	26.5
Mean Min Temp	17.1	17	16.2	14.8	12.1	10.1	9.5	11.6	14.6	17.7	17.7	17.2
Air Humidity (%)	80	82	77	72	62	59	57	49	43	41	60	75
Wind speed km/d @2m	138	130	216	251	251	268	268	294	311	259	199	164
Daily Sunshine(hrs)	5.6	5.1	7.2	8.4	9	8.6	8.6	9.2	9.4	9.1	6.6	5.5
ETo mm/day	3.93	3.7	4.26	4.37	4.13	3.84	3.98	5.18	6.55	6.9	5.18	4.17
Total (mm/month)	215	175	111	15	2	0	0	0	0	13	85	188
Effective Rainfall (mm/month)	141	126	91.3	14.3	2	0	0	0	0	12.7	73.4	131.4

Source : FAO, (CROPWAT Input Data)

APPENDIX C: Rainfall Station in the Chalimbana Catchment

Station 1	International Airport											
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Total (mm)
80-81	0	0	0	14	104.9	147	276.5	349.7	106.5	96.6	0	0	1095.2
81-82	0	0	0	0	116.4	78.4	433.7	232.7	34.9	17.9	7.9	0	921.9
82-83	0	0	0	74.1	118.6	171.9	218.3	97.9	32.9	3.5	0	0	717.2
83-84	0	0	0	2.4	36.5	145.9	98	221.4	50.7	10.5	5.4	0	570.8
84-85	0	0	0	0	133.6	260.7	221.6	222	82.3	3.7	0	0	923.9
85-86	0	0	0	21.3	34.2	201.1	347.2	156.1	123.3	187.6	0	0	1072.8
86-87	0	0	0	33.8	45.9	217.3	294.8	51.3	28.5	0	2.5	0	674.1
88-89	0	0	9.7	0	37.5	233.5	161.3	154	102.7	1	0	0.4	700.1
Average	**0**	**0**	**1.2**	**18.2**	**78.5**	**182.0**	**256.4**	**185.6**	**70.2**	**40.1**	**2.0**	**0.1**	**834.5**

Station 2	Exchange Farm												
	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Total (mm)
80-81	0	0	0	14.1	100	140.7	233.4	373.1	99.3	146.3	0	0	1106.9
81-82	0	0	0	0	148.3	0	235.1	185.3	9.2	295	10.1	0	883
82-83	0	0	0	87.1	45.7	81.4	77.4	114.5	268.3	4.3	0	0	678.7
83-84	0	0	0	30	77	117.3	56.1	109.5	42	10.7	0	0	442.6
84-85	0	0	0	0	87.5	179.9	311.9	188.7	77.8	3.9	1.6	0	851.3
85-86	0	0	0	22.3	40.4	184.8	319.2	140.7	176.8	198.1	0	0	1082.6
86-87	0	0	0	65.9	56.7	298.5	255.8	32.6	56.7	0	2	0	768.2
88-89	0	0	0	0	9.1	208.4	296.8	355	136.5	4	0	0	1009.8
Average	**0**	**0**	**0**	**27.4**	**70.6**	**151.4**	**223.2**	**187.4**	**108.3**	**82.8**	**1.7**	**0.0**	**852.9**

Appendix C continued

Station 3	Cooperative College											
Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Total (mm)
80-81	0	0	0	80.2	148.2	213.7	217	115	69.5	0	0	0	843.6
81-82	0	0	0	106.5	36.7	483	167.3	11	11	10.5	0	0	826
82-83	0	0	0	25.4	46	39.2	88.4	187.5	133.5	43.2	21.1	0	584.3
83-84	0	0	0	0	5	54	165.1	188.7	157	90	0	0	659.8
84-85	0	0	0	0	79.5	182.1	192	169.6	105.5	0.2	0	0	728.9
85-86	0	0	0	10	55.2	271.2	317.7	209.7	49.3	145.6	0	0	1058.7
86-87	0	0	0	47	73.5	284	210	35	20	0	0	0	669.5
87-88	0	0	0	0	0	118.2	422.5	422	142.5	0	0	0	1105.2
Average	**0**	**0**	**0**	**33.6**	**55.5**	**205.7**	**222.5**	**167.3**	**86.0**	**36.2**	**2.6**	**0**	**809.5**

Station 4	Palabana												
Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Total (mm)
80-81	0	0	2	19	76.5	156.5	289	305.5	141.5	88	0	0	1078
81-82	0	0	0	3	142.5	75	99	200.2	65	22	0	0	606.7
82-83	0	0	0	57.1	39	49.5	253.5	117	85	32.3	0	0	633.4
83-84	0	0	0	0	14.1	52	51	90	245	106	58	0	616.1
84-85	0	0	0	0	75.5	182	238.1	160	125.5	0	0	0	781.1
85-86	0	0	0	24.5	66.1	454.9	339	198	103.5	146	0	0	1332
86-87	0	0	0	52.2	70.7	200	410.9	61.4	36.7	0	0	0	831.9
87-88	0	0	0	0	161	394.5	395	188	2	0	0	0	1140.5
Average	**0**	**0**	**0.3**	**19.5**	**80.7**	**195.6**	**259.4**	**165.0**	**100.5**	**49.3**	**7.3**	**0.0**	**877.5**

Appendix C continued

Station 5	Chalimbana											
Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Total (mm)
81-82	0	0	0	1.9	145.7	31.1	256.3	153.7	8.5	0	0	0	597.2
82-83	0	0	0	125	129.7	78.2	199.5	68.3		0	0	0	600.7
83-84	0	0	0	2.5	34.6	170	48.1	162.6	56.6	11.5	0.9	0	486.8
84-85	0	0	0	0.7	102.4	223.5	336	179	45	1	0.8	0	888.4
85-86	0	0	0	16.1	40.5	246.1	272.3	186.7	187.8	151.2	0	0	1100.7
86-87	0	0	0	41.3	77	232.6	281.5	63	77.6	0	0.5	0	773.5
88-89	0	0	0	1.5	18.2	177.2	319.8	411.5	123.6	0	0	0	1051.8
89-90	0	1	0	0.3	62.6	91	299.3	204.4	10	33	0	0	701.6
Average	**0**	**0.1**	**0.0**	**23.7**	**76.3**	**156.2**	**251.6**	**178.7**	**63.6**	**24.6**	**0.3**	**0.0**	**775.1**

Station 6	Glasspool												
Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Annual Total (mm)
81-82	0	0	0	0	7.1	188.75	428.9	504	158	0	0	0	1286.75
82-83	0	0	0	8.2	52	190	316.25	259.25	31	1.75	0	0	858.45
83-84	0	0	0	20	33.5	421	292	251	92	9	0	0	1118.5
84-85	0	0	0	59.5	81	113	164	52	200.5	18	0	0	688
85-86	0	0	0	0	72.5	201.5	315.5	142	67.5	33.5	0	0	832.5
86-87	0	0	0	0	70.25	137	129.5	68	7.5	0	0	0	412.25
88-89	0	0	0	25.5	39	121	78	100.75	34.5	3.5	0	0	402.25
89-90	0	0	0	37	76.5	114.5	181	237	117	36.5	0	0	799.5
90-91	0	0	0	0	145.5	214.5	229	169.5	75	129	0	0	962.5
91-92	0	0	0	1.5	155	209	172.5	141	90	0	0	0	769
Average	**0**	**0**	**0**	**15.2**	**73.2**	**191.0**	**230.7**	**192.5**	**87.3**	**23.1**	**0.0**	**0.0**	**813.0**

Station 7					Chongwe Bridge							
Year	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	**Annual Total (mm)**
81-82	0.9	0.9	0.9	12.6	88.9	124.3	233.0	294.4	90.3	81.9	0.9	0.9	929.6
82-83	0.9	0.9	0.9	0.9	98.6	66.7	364.9	196.2	30.2	15.9	7.5	0.9	784.2
83-84	0.9	0.9	0.9	63.1	100.4	145.2	184.1	83.0	28.5	3.8	0.9	0.9	612.3
84-85	0.9	0.9	0.9	2.9	31.5	123.3	83.1	186.7	43.4	9.7	5.4	0.9	489.4
85-86	0.9	0.9	0.9	0.9	113.0	219.7	186.9	187.2	69.9	4.0	0.9	0.9	785.8
86-87	2.5	0.9	0.9	18.7	29.6	169.7	292.3	131.9	104.4	158.3	0.9	0.9	910.8
87-88	0.9	0.9	0.9	29.2	39.4	183.3	248.3	43.9	24.8	0.9	3.0	0.9	576.2
88-89	0.0	0.0	0.0	0.0	7.1	188.8	428.9	504.0	158.0	0.0	0.0	0.0	1286.8
Average	**1.0**	**0.8**	**0.8**	**16.0**	**63.6**	**152.6**	**252.7**	**203.4**	**68.7**	**34.3**	**2.4**	**0.8**	**796.9**

APPENDIX D. Historical Water Rights and Water Demand

WATER RIGHT HOLDER	RIVER	DATE APPLIED	VOL GRANTED (M3/DAY)	DATE GRANTED	DURATION(YRS)	STATUS
WR 1	Chalimbana	9/7/1957	682.00	Aug-68	10	Expired
WR 2	Chalimbana	5/16/1963	454.60	Aug-68	10	Expired
WR 3	Chalimbana	3/10/1964	500.06	Sep-70	10	Expired
WR 4	Chalimbana	12/1/1966	545.00	Nov-72	10	Expired
WR 5	Chalimbana	2/21/1972	340.00	Nov-72	5	Expired
WR 6	Chalimbana	8/24/1972	900.00	Nov-72	10	Expired
WR 8	Chalimbana	11/17/1971	200.00	Nov-72	10	Expired
WR 9	Chalimbana	3/24/1978	200.00	Apr-78	5	Expired
WR 10	Chalimbana	8/10/1977	230.00	Oct-78	10	Expired
WR 11	Chalimbana	8/18/1977	200.00	Oct-78	10	Expired
WR 12	Chalimbana	1/19/1978	8000.00	Oct-78	5	Expired
WR 13	Chalimbana	5/10/1979	400.00	Nov-79	5	Expired
WR 14	Chalimbana	9/19/1957	460.00	Nov-79	5	Expired
WR 15	Chalimbana	3/28/1979	600.00	Jan-80	5	Expired
WR 16	Chalimbana	4/14/1982	250.00	Nov-82	5	Expired
WR 17	Chalimbana	2/1/1977	1400.00	Nov-82	5	Expired
WR 18	Chalimbana	5/20/1983	1000.00	Jun-83	5	Expired
WR 19	Chalimbana	3/18/1983	850.00	Oct-83	1	Expired
WR 20	Chalimbana	6/28/1983	1200.00	Oct-83	5	Expired
WR 21	Chalimbana	12/15/1982	4000.00	Oct-83	1	Expired
WR 22	Chalimbana	4/12/1983	4000.00	Oct-83	5	Expired
WR 23	Chalimbana	2/3/1984	1000.00	Nov-84	5	Expired
WR 24	Chalimbana	3/14/1991	1080.00	Apr-93	1	Expired

Source: Water Board

APPENDIX E: Crop Water Requirements at 90% Efficiency (CROPWAT Results)

Crop	Wheat						
Planting Date	1-May						
Efficiency (%)	90						
Month	**ETo (mm/m)**	**Crop Kc**	**ET (CWR) mm/m**	**Pe (mm/m)**	**Irr Req (mm/m)**	**FWS (l/s/ha)**	**Irr Req (m^3/m)**
April	117.32	0.30	35.15	3.79	31.41	0.13	336.96
May	119.79	0.74	88.93	0	88.93	0.38	984.96
June	128.35	1.1.5	147.6	0	147.6	0.63	1632.96
July	142.22	0.95	134.49	0	134.49	0.58	1503.36
August	51.01	0.43	21.76	0	21.76	0.28	725.76
	558.69		427.93		424.2	0.84	2177.28

Crop	Soybean						
Planting Date	1-May						
Efficiency (%)	90						
Month	**ETo (mm/m)**	**Crop Kc**	**ET (CWR) mm/m**	**Pe (mm/m)**	**Irr Req (mm/m)**	**FWS (l/s/ha)**	**Irr Req (m^3/m)**
Nov	169.06	0.45	75.08	72.73	2.35	0.01	25.92
Dec	147.83	0.99	145.42	125.65	19.77	0.08	207.36
Jan	125.76	1.15	144.62	136.11	8.51	0.04	103.68
Feb	123.4	1.1	136.1	133.88	2.21	0.01	25.92
Mar	60.26	0.68	41.13	52.45	0	0	0
	626.31		542.35	520.82	32.84	0.03	72.576

Crop	Maize						
Planting Date	1-Nov						
Efficiency (%)	90						
Month	**ETo (mm/m)**	**Crop Kc**	**ET (CWR) mm/m**	**Pe (mm/m)**	**Irr Req (mm/m)**	**FWS (l/s/ha)**	**Irr Req (m^3/m)**
Nov	169.06	0.31	52.54	72.73	0	0	0
Dec	147.83	0.76	111.05	125.65	0	0	0
Jan	125.76	1.19	149.94	136.11	13.83	0.06	155.52
Feb	123.4	1.11	136.67	133.88	2.79	0.01	25.92
Mar	60.26	0.66	40	52.45	0	0	0
	626.31		490.2	520.82	16.62	0.01	181.44

Appendix E continued

Crop	Vegetables						
Planting Date	1-May						
Efficiency (%)	90						
Month	ETo (mm/m)	Crop Kc	ET (CWR) mm/m	Pe (mm/m)	Irr Req (mm/m)	FWS (l/s/ha)	Irr Req (m^3/m)
May	117.32	0.72	84.63	0	80.84	0.35	453.6
May	111.79	0.98	117.04	0	117.04	0.5	648
June	128.35	1.04	133.14	0	133.14	0.57	738.72
July	22.63	0.96	21.8	0	21.8	0.56	725.76
	415.63		356.61	0	352.82	0.50	2566.08

Crop	Potato						
Planting Date	1-May						
Efficiency (%)	90						
Month	ETo (mm/m)	Crop Kc	ET (CWR) mm/m	Pe (mm/m)	Irr Req (mm/m)	FWS (l/s/ha)	Irr Req (m^3/m)
May	117.32	0.51	61.22	0	61.22	0.24	311.04
May	111.79	0.93	120.36	0	120.36	0.48	622.08
June	128.35	1.15	163.56	0	163.56	0.63	816.48
July	142.29	1.06	166.92	0	166.92	0.64	829.44
Aug	51.01	0.81	45.42	0	45.42	0.53	686.88
			557.48	0	557.48		3265.92

Crop	Tobacco						
Planting Date	1-Apr						
Efficiency (%)	90						
Month	ETo (mm/m)	Crop Kc	ET (CWR) mm/m	Pe (mm/m)	Irr Req (mm/m)	FWS (l/s/ha)	Irr Req (m^3/m)
April	117.32	0.54	63.32	3.79	59.53	0.26	673.92
May	119.79	1.01	121.53	0	121.53	0.52	1347.84
June	128.35	1.13	144.76	0	144.76	0.62	1607.04
July	93.05	0.91	84.62	0	84.62	0.54	1399.68
	458.51		414.23		410.44		5028.48

APPENDIX F. Farm Areas, Crops Grown and Planting dates for Commercial Farmers

No.	Farm Name*	Farm Area (Ha)	Crops Grown	Hectares (Ha)	Planting Date
1	User 1	406	Wheat	80	1-May
			Soya Bean	40	Nov/Dec
			Maize	60	Nov/Dec
2	User 2	504	Wheat	50	April/May
			Vegetables	20	April/May
4	User 3	360	Wheat	80	20-Apr
	User 4		Soya Bean	80	20-Apr
5	User 5	2000	Maize	90	Nov/Dec
			Exp Vegetables	60	-
			Roses	20	-
			Wheat	100	April/May
6	User 6	1662	Wheat	30	20-Apr
			Soya Bean	30	20-Apr
			Maize	30	20-Apr
7	User 7	103	Soya Beans	50	April/May
			Vegetables	2.5	April/May
			Maize	50	April/May
8	User 8	1214	Tobacco	40	20-Apr
			Soya Bean	40	20-Apr
			Wheat	60	20-Apr
		1266	Wheat	50	April/May
			Maize	50	Rainfed
			Potatoes	15	April/May
			Wheat	60	April/May
			Tobacco	60	April/May
9		2985	Maize	30	April/May
(i)	User 9		Onion	40	April/May
			Potatoes	5	April/May
			Coffee	200	March
			Wheat	200	April/May
(ii)	User 10		Vegetables	40	April/May
(iii)	User 11		Maize	40	April/May

***(Actual Farm Names have been replaced with User Numbers)**

APPENDIX G. Historical Monthly Flow Data- Station No. 5-029

Summary of Monthly Flows at Romor Gauging Station (1955-2006) in Mm³/month													
No	Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
1	55/56	0.078	0.091	0.131	0.295	0.983	1.107	0.482	0.235	0.198	0.178	0.147	0.098
2	57/58	0.102	0.095	0.437	2.353	2.605	1.62	0.748	0.521	0.321	0.457	0.382	0.279
3	58/59	1.263	0.204	0.642	0.448	0.697	0.753	0.228	0.189	0.141	0.142	0.143	0.157
4	59/60	1.065	0.936	6.789	6.446	7.222	4.361	2.172	-	1.627	1.81	1.511	1.163
5	60/61	0.105	0.151	0.263	1.795	0.724	0.97	0.465	0.259	0.161	0.161	0.155	0.1
6	61/62	0.102	0.215	0.374	0.591	0.723	0.844	0.577	0.369	0.268	0.261	0.194	0.188
7	62/63	0.129	0.175	1.16	0.712	1.359	2.425	0.921	0.55	0.462	0.421	0.379	0.277
8	63/64	0.242	0.286	0.537	1.044	0.881	0.499	0.255	0.2	0.188	0.178	0.174	0.129
9	64/65	0.086	0.205	0.323	1.164	1.213	0.552	0.269	0.162	0.125	0.127	0.112	0.098
10	65/66	0.102	0.107	0.125	0.273	0.371	0.342	0.149	0.102	0.09	0.102	0.102	0.097
11	66/67	0.094	0.078	0.114	0.452	0.451	0.33	0.137	0.132	0.111	0.103	0.125	0.115
12	67/68	0.102	0.098	0.167	0.168	0.247	0.151	0.111	0.108	0.13	0.149	0.163	0.123
13	68/69	0.102	0.116	0.197	0.376	0.392	0.527	0.421	0.205	0.167	0.17	0.144	0.136
14	69/70	0.121	0.113	0.599	0.739	0.532	0.351	0.226	0.162	0.155	0.16	0.16	0.148
15	70/71	0.116	0.139	0.246	1.727	0.713	0.567	0.377	0.238	0.212	0.195	0.186	0.169
16	71/72	0.157	0.41	0.487	1.49	0.903	0.6	0.397	0.316	0.285	0.277	0.249	0.143
17	72/73	0.131	0.104	0.138	0.425	0.384	0.221	0.095	0.086	0.096	0.118	0.117	0.081
18	73/74	0.081	0.125	0.148	0.281	0.459	0.853	0.439	0.376	0.295	0.245	0.224	0.184
19	74/75	0.125	0.512	0.675	0.791	1.223	1.041	0.568	0.435	0.402	0.382	0.359	0.259
20	75/76	0.224	0.19	0.336	0.405	0.507	1.916	1.203	0.611	0.474	0.428	0.38	0.304
21	76/77	0.244	0.314	0.41	0.354	0.424	0.557	0.346	0.261	0.233	0.196	0.172	0.14
22	77/78	0.152	0.166	1.107	2.376	2.764	4.124	2.701	1.674	1.394	1.324	1.094	0.889
23	78/79	0.723	0.855	5.704	2.179	2.065	2.88	1.457	1.185	1.068	1.089	1.023	0.913
24	79/80	0.898	1.048	2.943	1.738	1.805	1.814	1.239	0.595	0.57	0.506	0.473	0.388
25	80/81	0.383	0.429	0.643	1.592	5.263	2.792	1.132	1.049	0.871	0.78	0.698	0.552
26	81/82	0.492	0.561	0.484	1.971	2.951	1.124	0.701	0.598	0.474	0.444	0.423	0.352
27	82/83	0.436	0.401	0.474	0.907	0.777	0.462	0.374	0.275	0.225	0.262	0.239	0.229
28	83/84	0.24	0.234	0.406	0.493	0.552	0.314	0.278	0.215	0.203	0.195	0.18	0.18
29	84/85	0.182	0.19	0.4795	1.072	1.67	0.874	0.468	0.386	0.361	0.341	0.295	0.233
30	85/86	0.236	0.274	0.553	0.825	1.1205	0.6085	1.086	0.457	0.312	0.287	0.204	0.141

31	86/87	0.2	0.216	0.839	0.9	0.571	0.343	0.269	0.158	0.154	0.127	0.116	0.083
32	89/90	0.338	0.317	0.471	1.524	2.142	0.747	0.459	0.42	0.333	0.292	0.143	0.141
33	92/93	0.05	0.455	1.769	2.95	2.71	2.661	2.443	1.871	1.516	1.637	1.595	1.546
34	97/98	1.62	1.73	2.68	5.259	3.439	3.293	2.421	2.121	1.974	2.09	1.84	1.52
35	98/99	1.85	1.824	2.751	3.442	4.453	3.84	2.842	2.673	2.587	2.673	2.673	2.45
36	99/00	2.384	2.256	2.642	3.243	3.257	5.545	3.322	2.912	2.817	2.85	2.673	2.517
37	01/02	2.615	2.501	2.71	2.643	2.323	2.324	2.244	2.212	2.15	2.192	2.12	1.899
38	02/03	1.788	1.805	2.049	2.604	3.027	4.035	2.805	2.669	2.42	2.463	2.295	2.117
	Average	**0.28**	**0.35**	**0.95**	**1.24**	**1.48**	**1.24**	**0.81**	**0.57**	**0.48**	**0.46**	**0.42**	**0.35**

APPENDIX H. Current Secondary Water Demands in the Catchment

User	River	Granted Abstraction Volume (m^3/d)	Abstraction Method
User 1	Chalimbana & Mukamunya	1200	Direct Pumping
User 2	Mukamunya/Kapako	4500	Direct Pumping
User 3	Chalimbana	2805	Pumping from Reservoir
User 4	Chalimbana	1720	Pumping from Reservoir
User 5	Chalimbana	8792	Pumping from Reservoir
User 6	Chalimbana	7193	Pumping from Reservoir
User 7	Chalimbana	365	Pumping from Reservoir
User 8	Chalimbana	1295	Pumping from Reservoir
User 9	Chalimbana	6000	Pumping from Reservoir
User 10	Chalimbana	550	Pumping from Reservoir
User 11	Chalimbana	6000	Pumping from Reservoir
Total Demand		**40,420**	