Quantifying Total Water Productivity for Multiple-Use Small Reservoirs in Mzingwane Catchment, Zimbabwe

by

Geoffrey C. Mamba

A thesis submitted in partial fulfilment of the requirements for the Masters Degree in Integrated Water Resources Management

DEPARTMENT OF CIVIL ENGINEERING
FACULTY OF ENGINEERING
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Supervisors

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ABSTRACT

The Government of Zimbabwe embarked on construction of small, medium and large multiple-use dams as a strategy to increase the level of water security in the country. Over 10,000 dams have been constructed in communal and large-scale-commercial farming areas. So far, the socio-economic contributions made by medium-to-large scale dams have been fairly documented, but those by small reservoirs are scantily documented. A study on total water productivity was conducted to determine total water productivity and apply this to value and allocate scarce water resources to uses that optimise societal benefits in semi-arid areas. Water productivity gives the value of a product that can be obtained from using a unit amount of water on alternative functions such as domestic use, livestock watering, crop production, fishery, brick making and related uses so that the resources can be wisely allocated to more productive sectors. Eight small reservoirs surrounding Avoca Business Centre in Mzingwane Catchment, Zimbabwe, were studied. Questionnaires were administered and physical measurements carried out on crops, livestock, thatching grass, bricks and fisheries. The results were that donkeys had the highest monetary water productivity of 145 US$/$m^3$ followed by bricks and cattle(32 US$/$m^3$), tomatoes (24 US$/m^3), sheep and goats(11 US$/$m^3$), small vegetables (8 US$/$m^3$), green maize(2 US$/m^3), dry beans (0.9 US$/$m^3$), fish (0.7 US$/m^3), wheat (0.2 US$/$m^3$), domestic water use (0.03 US$/$m^3$) and grass (0.02 US$/m^3). Formulation of an allocative strategy recognised scarcity of water resources in terms of dry season reservoir yield, individual-use water productivities and societal values. Two paths for increasing productivity per unit of utilizable water resources were considered for the strategy; (i) depleting developed primary water supply for beneficial purposes by increasing water savings and (ii) producing more output per unit of depleted water by increasing unit water productivity. By re-allocating water based on water productivities within and across sectors, income levels were increased by about 350% from current uses. The results of the study illustrated that water productivity can be used as a strategy for allocating scarce water resources for attaining optimum societal benefits. The water productivity strategy, however, should be complimented with wide stakeholder consultations to derive the optimum societal benefits.

Key words: Integrated water resources management; Livelihood; Multiple-use; Small reservoirs; Water productivity; Mzingwane Catchment

DECLARATION

I stand to declare that this thesis emanates from my own work and, in as far as I am aware, all secondary sources used have been duly acknowledged by means of complete references.

I also declare that I have, hitherto, never submitted this thesis for award of any other academic qualification at any other institution than for the Masters Degree in Integrated Water Resources Management tenable at the University of Zimbabwe.

…..……………………………………………..
GEOFFREY CHIDZAMMBUYO MAMBA

DATE: ……………………………………..

DEDICATION

This thesis is fondly dedicated to my wife Ruth and our three children; Matilda, Chrispin and Naomi. I thank them collectively for their perpetual deep understanding especially when I broke the news that I was to spend six months doing research in Matebeleland, Zimbabwe, when opportunity for me to undertake similar research in my home country was available. I thank them, once again, for allowing me to undertake the research under close supervision of renowned researchers in the names of Dr. Aidan Senzanje of the Soil Science and Agricultural Engineering and Mr. Alexander Mhizha of the Department of Civil Engineering, University of Zimbabwe. I vouch that the knowledge gained is exceedingly invaluable.

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Mount Pleasant, Harare, Zimbabwe
June, 2007

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LIST OF ABBREVIATIONS

ASWRMR: Assessment of Surface Water Resources of Mzingwane Report
FAO: Food and Agricultural Organisation
GoB: Government of Botswana
GoZ: Government of Zimbabwe
GPS: Global Positioning System
GWP: Global Water Partnership
HIV/AIDS: Human Immune Deficiency Virus / Acquired Immune Deficiency Syndrome
IWMI: International Water Management Institute
IWRM: Integrated Water Resources Management
MDGs: Millennium Development Goals
MMAI: Malawi Government: Ministry of Agriculture and Irrigation
SADC: Southern African Development Community
TLU: Tropical Livestock Unit and is equal to 250 Kg of live weight
SPSS: Statistical Product Services Solution
UNICEF: United Nations International Children Emergency Fund
WEDC: Water, Engineering and Development Centre, United Kingdom
WRMS: Water Resources Management Strategy
ZINWA: Zimbabwe National Water Authority

CHAPTER ONE: INTRODUCTION

1.1 Study Background

The Mzingwane Catchment in Zimbabwe is less endowed with water resources because of erratic seasonal rainfall patterns, high evaporation losses and low rainfall-runoff conversion. Rainfall ranges from 250-550mm per annum, mean runoff varies between 17 mm per annum and 19 mm per annum and the mean evaporation is 1800 mm per annum (GoZ, 2000). Due to these factors, there is scarcity of water resources in Mzingwane catchment (Mazvimavi, 2003).

In order to improve availability of water resources, the Government of Zimbabwe (GoZ) embarked on construction of small, medium and large multiple-use dams as a strategy to increase the level of water security in the country (GoZ, 2000). Over ten thousand (10,000) dams were constructed in communal and large-scale commercial farming areas (Senzanje and Chimbari, 2002). Water impounded in dams contributes to the improvement of socio-economic well-being of communities through domestic and agricultural water supply, power generation, navigation, industrial production, recreation, environment and related uses. This assertion, though, is obvious when one evaluates the contribution made by medium-to-large dams as these can easily be quantified and are fairly documented in literature (WCD, 2000 and ADB, 2002). The socio-economic contribution of small reservoirs to improve human livelihood is, however, hardly appreciated and is scantily documented (GoB, 1993).

Small reservoirs provide multiple functions such as domestic use, small-scale irrigation and gardening, brick-making, building, fishery, livestock rearing, tree growing, food processing and related uses (Rusere, 2005). Livelihoods derived from small reservoirs contribute significantly to the socio-economic development of rural communities (GoB, 1993; Twikirize, 2005) and their environment. Unfortunately in semi-arid areas, the derived livelihoods are constrained by erratic seasonal rainfall patterns, high evaporation rates and low rainfall-runoff conversion. Lack of efficient management tools and procedures for assessing sustainable use and planning of water resources in small reservoirs (Sawunyama, 2005) exacerbate the situation. The challenge for water resources management, therefore, is to formulate strategies for effective utilization of scarce water resources (Molden et al., 2001). One of the most promising strategies for allocating scarce water resources is through quantification of water productivities of the multiple uses. Water productivity provides a diagnostic tool for identifying low or high water use efficiency and also provides a robust insight into opportunities for re-distributing water (Cook et al., 2006) within space and time. However, application of water productivity as a tool needs to be properly juxtaposed with societal values to produce expected optimum benefits.

In spite of the multiple functions which small reservoirs render to communities, recent studies carried out in Zimbabwe and other countries have critiqued the sustainability of small reservoirs on the basis of their high evaporative losses of 97 % (Mugabe et al., 2003), loss of capacity of 30% (over a period of 40 years) due to siltation (Zirebwa and Twomlow, 1999) and seepage losses ranging from 61 to 86% (Sur et al., 1999). In trying to find a solution to these challenges, a project called "Small Reservoirs Project" was launched to improve planning and evaluation of small multi-purpose reservoirs for smallholder livelihoods and food security within the Limpopo River Basin (Figure 3.2). The Limpopo Basin is an international river basin shared among the countries of Botswana, Mozambique, South Africa and Zimbabwe in Southern Africa.

This thesis, therefore, was aimed at contributing towards the objective of the project by finding out how total water productivity can be used to value and allocate scarce water resources for optimising societal benefits.

1.2 Main Objective

The main objective of this research was to determine total water productivity and apply this to value and allocate scarce water resources to uses that optimise societal benefits in semi-arid areas. The specific objectives of the research were to:

a) Determine the maximum dry-season yield of multiple use small reservoirs

b) Identify and classify multiple uses of small reservoirs

c) Quantify water productivities for the various multiple uses

d) Formulate an allocative strategy for scarce water resources in small reservoirs

1.3 Hypothesis

The study was based on the null hypothesis that water productivity can be used as a tool for formulating water allocative strategies for various uses. The alternative hypothesis was that current water allocation was based on value of uses.

1.4 Research Justification

Water impounded in dams contributes to the improvement of socio-economic well-being of communities through domestic water supply, irrigation, power generation, navigation, industrial production, recreation, environment and related uses (WCD, 2000). The socio-economic contributions made by large dams are fairly documented (WCD, 2000 and ADB, 2002). However, contributions made by small reservoirs are scantily quantified (GoB, 1993). The Fisheries Department of Botswana (GoB, 1993) reported that of the 331 small reservoirs which were studied, only 17 % were well documented on their physical characteristics. Senzanje and Chimbari (2002) informed that despite a long history (since 1920s) of dam usage in Zimbabwe, there has not been a comprehensive study on the multiple uses of small reservoirs. Lack of records on small reservoirs complicates water resources management decisions as communities do not know how much water is available for utilisation in a given season (Mugabe, 2005).

Despite high evaporation rates, small reservoirs provide a spectrum of livelihoods to rural communities which encompass domestic water supply, crop production, brick-making, building, fishery, livestock rearing, tree growing, food processing, reeds for weaving (Sawunyama, 2005) and related uses. Valuing these multiple uses using the concept of water productivity may assist in shedding light on the socio-economic contributions which small reservoirs make to livelihoods of riparian communities and can be used as a tool for allocating scarce water resources to uses that have potential of bringing maximum benefits to society.

Quantification of total water productivity for multiple use small reservoirs may assist in comparing gains obtained from using the same quantity of water on alternative purposes other than the current use. Allocative strategies based on the concept of water productivity may be compared against existing traditional methods for allocating scarce water resources on different uses in rural areas. Results of such comparison may enable sub-catchment water managers and dam management committees to allocate water to uses that bring maximum benefit to society especially when water resources become scarce. Considering that poverty is a function of water availability (Cook et al., 2006), the accrued benefits from the allocation may assist in reducing the multiple dimensions of poverty among rural communities especially in a country like Zimbabwe where an estimated 64% of the population live in rural areas (UNICEF, 2007), 69% live below food poverty line and the poverty index stands at 29% (WELL, 2005). Poverty index is an indication of the standard of living. It represents the quality and quantity of goods and services and the way these services and goods are distributed within a population (http://en.wikipedia.org, 2007). This study, therefore, aims at finding out how total water productivity can be used to value and allocate scarce water resources.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The finite water resources of the world are under increasing stress as human population and per capita demands increase. These two factors are predicted to exert more pressure on the available water resources necessitating at least 25% increase in water supply to meet basic water needs. It is likely that 78% of the world's population will live in areas facing physical or economic water scarcity by 2025 (IWMI, 2000). The uneven temporal and spatial distribution of the resource cause local water scarcity in arid and semi-arid regions of the globe. This is in spite of the resources being adequate to meet the needs of the present and future global populations (Cook et al., 2006). In Zimbabwe, about half the landmass faces water stress, seasonal drought and unreliable rainfall (WELL, 2005). Growing scarcity and rising value of water induce users to seek ways of increasing water productivity and economic efficiency (Barker et al., 2003). For instance, the agriculture sector in Zimbabwe was urged to consume less and less water so that more water could be released to other sectors such as urban, mining and industry (Senzanje et al., 2005).

The MDGs acknowledge the critical and multi-faceted role of water in realizing a world where prevalence of hunger is halved, universal primary education is attained, women are fully empowered, child mortality is significantly reduced, maternal health is improved, HIV/AIDS and other diseases are combated, and environmental sustainability is enhanced (van Koppen et al., 2006). The global water resource challenge, therefore, is to search for strategies that optimally match supply and demand of water resources for the attainment of maximum societal benefits. Knowledge of water productivity may assist in evaluating socio-economic contributions made by small reservoirs, which some technocrats perceive as unproductive because only 3% of the stored water resources can be productively utilised (Mugabe et al., 2003). A thorough understanding of the socio-economic contributions made by small reservoirs to riparian communities may initiate increased level of investment in the construction of small multiple-use reservoirs.

The foregoing scene demonstrates that information on water productivity can act as a benchmark indicator for water allocation, policy directions and costing of scarce water resources (Senzanje et al., 2005). Quantifying total water productivity and understanding factors influencing water productivity on multiple use small reservoirs can, therefore, be considered as one of the promising strategies for allocating scarce water resources.

2.2 Definition of a Small Dam

The Zimbabwe Water Resources Management Strategy (WRMS) document (GoZ, 2000) defines a small dam as a structure with an embankment height of less than eight (8) metres and a reservoir capacity of up to one million cubic metres ($1x10^6$ m^3). However, the Zimbabwe Water Act (GoZ, 1998) defines a small dam as a structure, whether constructed or proposed to be constructed, which, together with its abutments, appurtenant works and foundations, is capable of diverting or storing water and which:

a) has a vertical height of more than eight metres but less than fifteen metres measured from the non-overflow crest of the wall of such structure to the lowest point on the downstream face of such wall; or

b) is capable of storing more than five hundred thousand but less than one million cubic metres of water at full supply level; or

c) is declared as such by the Minister responsible for water affairs

Since the Act excludes small dams of sizes which were encountered in this study, the definition given by the WRMS (GoZ, 2000) was adopted as a working definition. The vertical height and capacity of most of the dams were less than 8 metres and 500 000 cubic metres, respectively. Typically, small dams are constructed on the far upstream part of a catchment often on small seasonal streams. A reservoir is a body of water impounded by a dam. A reservoir can be defined as small, medium or large depending upon the definition of a dam.

2.3 Definition of Water Productivity

Water productivity is considered from a number of perspectives; physical water productivity in agriculture refers to obtaining more crop production from the same amount of water while in socio-economics, water productivity refers to obtaining more value per unit of water used (Molden et al., 2001). Physical water productivity is simple but useful only for single product cases. Monetary (economic) indicators are useful where products or multiple uses of water are to be analysed (Hussain et al., 2007). Total water productivity enables prioritisation of water use for the attainment of maximum societal benefit. Prioritisation of water use is necessary especially in arid and semi-arid regions such as Mzingwane Catchment (GoZ, 2000) where water is scarce.

According to Molden et al. (2001), there are three paths of increasing productivity per unit of utilizable water resources as follows:

a) Developing and consuming more primary water by increasing the developed storage and diversion facilities

b) Depleting more of the developed primary water supply for beneficial purposes by increasing water savings

c) Producing more output per unit of water depleted by increasing unit water productivity

2.4 Definition of a Water Resources Allocative Strategy

A water resources allocative strategy is a set of measures taken to apportion water resources to uses that bring maximum or optimum societal returns from available scarce water resources.

2.5 Quantification of Water Productivities

There are a number of formulae for quantifying water productivities for multiple use products as follows:

a) Domestic water use

Water productivity for domestic use (water drawn directly from small reservoirs) may be estimated by halving the cost per cubic metre of treated domestic water (Kachapila, 2004) which is supplied by regulated services providers (i.e. ZINWA) nearest to the area under consideration. Water productivity is expressed in monetary units per cubic metre (i.e. US$/$m^3$).

b) Crops

Physical water productivity for crops is obtained by dividing yield obtained by the volume of water supplied during the entire growth period of the crop. Crop water productivity is expressed as kg/m^3. Monetary water productivity is obtained by dividing the total amount of money which can be obtained from the sale of produce (yield) by the volume of water applied to the field during the entire growth period of the crop. This may be expressed in US$/$m^3$. Physical water productivity is given as:

$$WP = \frac{Y_c}{(P_e + W_b)}$$ (Lemoalle, 2006)

Where;

	WP = *Water productivity*	[Kg/m^3]
	Y_c = *crop yield*	[Kg/ha]
	P_e = *effective rainfall*	[m^3/ha]
	W_b = *blue water applied to field*	[m^3/ha]

Blue water includes surface and groundwater (WaterNet, 2003). In this study, however, blue water denotes surface water resources drawn directly from the reservoir for use. Effective rainfall is calculated using CropWat 4 for Windows 4.3 (Clarke et al., 2000) as dependable rain. Clarke et al. (2000) gives the following equations for calculating effective rainfall (P_e) in arid and sub-humid climates:

$$P_e = 0.6 \times R_m - 10 \qquad \textit{(Total monthly rainfall < 70mm)}$$

$$P_e = 0.8 \times R_m - 24 \qquad \textit{(Total monthly rainfall > 70mm)}$$

Where; R_m*=total monthly rainfall [mm]. The units are converted to metres. Then, rainfall is multiplied by the irrigated area [*m^2*] to obtain volume of water applied to the field [* m^3*].*

c) Livestock

Water productivity for livestock is estimated as follows:

$$LWP = \frac{\sum(O+S)}{W_d}$$ (Peden and Tadesse, 2003)

Where; LWP *=Livestock water productivity* [US$/m^3]
O *=Livestock outputs cost* [US$]
S *=Livestock services cost* [US$]
W_d *=Depleted water* [m^3]

Livestock outputs and services include cost of meat, milk, manure and draught power. As for manure, one tropical livestock unit (TLU) produces 1026 Kg of dry-matter-dung per year assuming 20% losses in dung weight. Kraal manure (with litter) has, on average, the following nutrient contents; 1.4 % nitrogen, 0.52% phosphorus and 3.1% potassium (Defoer and Budelman., 2000). The nutrient content varies between type, breed, diet and management of livestock. The plant nutrients (manure) are evaluated as monetary values.

Depleted water is taken as livestock voluntary water intake by season and average temperature as provided in Table 2.1. Water requirement of livestock varies between species, breeds and even within the same species and breeds. It also depends on other factors such as food intake, quality of food, air and water temperatures. Voluntary intake of water is the quantity of water which has actually been supplied to livestock and corresponds to that part of the water requirement which can not be provided by the moisture content of the forage. This approach recognises that water depleted through drinking is the major limiting factor of livestock production and it has to be available in sufficient quantity and quality (Sonder et al., 2004). The table below provides indicative water requirements for livestock drinking. The range of temperature for Avoca in Southern Zimbabwe showed that the area experiences wet and dry seasons.

Table 2.1: Indicative Livestock Water Requirements (Source: FAO, 1986)

	Mean Live Weight (Kg)	**Voluntary Daily Water Intake by Season and Average Temperature (litre/tropical livestock unit)**		
Species		**Wet 15-21°C**	**Dry 27°C**	**Dry Hot 27°C**
Cattle	180	14.3	27.1	38.6
Sheep	25	20	40	50
Goats	25	20	40	50
Donkeys	105	5	27.4	40

d) Fisheries

Physical water productivity for fisheries is the ratio of mass of fish catch to volume of evaporation (Lemoalle, 2006) over a period (usually a year). Volume of evaporation is a product of the surface area of the reservoir and depth of evaporation. The average mass of fish catch within a given period is divided by the volume of water lost from the reservoir through open water evaporation. Water productivity is expressed in kg/m^3. As for monetary water productivity, the total amount of money which can be obtained from the sale of the fish catch is divided by the volume of evaporation. This is expressed in US$/m^3.

$$FWP = \frac{M}{W_e}$$ (Lemoalle, 2006)

Where; *FWP=Fish water productivity* [Kg/m3]
M =mass of catch *[Kg]*
W_e=volume of evaporated water *[m^3]*

e) Bricks

Physical water productivity for bricks is obtained by dividing the mass of bricks by the total amount of water used in moulding the bricks. This is expressed in kg/m^3. Monetary water productivity is obtained by dividing the total amount of money which can be obtained from the sale of the bricks by the total amount of water used for making those bricks. This is expressed in US$/m^3.

f) Grass

Determination of water productivity for (thatching) grass is adapted from the approach of calculating water productivity for crops. Total volume of water applied is estimated as crop evapotranspiration (within a cropped area) using the Food and Agricultural Organisation (FAO) Penman-Monteith Method as provided in the CropWat 4 for Windows 4.3 model (Clarke et al., 2000). Physical water productivity for thatching grass is obtained by dividing total mass of harvested standard grass bundles by the total volume of evapotranspiration from grass germination to harvest. This is expressed as mass per cubic metre of water (kg/m^3). Monetary water productivity is obtained by dividing the total amount of money which can be obtained from the sale of standard grass bundles by the total volume of evapotranspiration from grass germination to harvest. This is expressed in monetary units per unit volume of evapotranspiration (US$/m^3). Normally, the grass is not watered by communities but grows naturally within the buffer zone of the reservoir.

g) Recreation

Recreation of small reservoirs may include swimming, boating, quiet contemplation and refuge from stress (Rusere, 2005). Recreation water productivity on small reservoirs is very difficult to obtain because of lack of documented procedures. This study, however, proposed an approach for calculating recreation water productivity which appears in the chapter of Research Methods.

2.6 Water Productivity and IWRM Linkage

As a concept, water productivity is used to value multiple water uses. However, the concept is contextualised with socio-economic and environmental sustainability in line with the principles of integrated water resources management (IWRM) which aims at promoting the coordinated development of water, land and related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP, 2000). Water productivity for small reservoirs aims at promoting utilization of sustainable yield of water resources to uses that bring maximum benefit to society.

The means for improving water productivity are not always apparent because of interactions between uses and complex flow paths of water (Hussain et al., 2007). The development of tools for measuring water productivity is, therefore, important in exploring ways and means of enhancing the productivity and benefits of water resources. Multiple-use water services aim at achieving plans and designs that take people's multiple water needs as a starting point and searches for incremental improvements in access to water across the range of needs within informal settings and a highly variable water situation (van Koppen et al., 2006). Recent estimates of the value of (agricultural) water from 40 settings in 23 countries by Hussain et al. (2007) have deduced that:

a) Popular productivity indicators based on crop output do not capture the full range of benefits and costs associated with water use;

b) The value of water may not be as low as it is generally perceived when all major uses, direct and indirect benefits of water at various levels are properly accounted for;

c) The value of water varies across time, space and stakeholders at various scales. For instance, farm scale is more relevant for agricultural water charging policies but for water sector investments and allocations, the national scale is more relevant;

d) Efforts should be directed not only at increasing the productivity of water in terms of mass of output per unit of water but also the overall benefits or value of water at various levels for larger growth and poverty alleviation impacts considering the sustainability of systems.

Accounting for direct and indirect benefits of water resources at various scales is difficult especially in a country such as Zimbabwe where 69% of the population live below poverty line (WELL, 2005) and rural communities are involved in informal and mixed farming systems. Such set-ups require simple but robust and meaningful indicative water productivity estimates (Hussain et al., 2007) that are able to guide water allocation and investments.

2.7 Runoff and Yield Assessment

Molden et al. (2001) outlined three paths for increasing productivity per unit of utilizable water resources (section 2.3). Utilizable water resources can be determined through knowledge of catchment runoff and yield of a reservoir. Simple empirical approaches for estimating runoff and yield of small dams have been developed over the years (Mitchell, 1987). Complex approaches are generally less applicable in the context of small dams (MMAI, 1999) because most small dams are located in un-gauged catchments where data is scantily available and safety risks are assumed to be relatively lower than large dams.

2.7.1 Runoff Assessment

Assessment of mean annual runoff (MAR) provides a crude index of the available water resources in a catchment. A regional equation for calculating MAR for use in Malawi, Tanzania and Zimbabwe was developed by Bullock et al (1990) as follows:

$$MAR = 0.0000467 AAR^{2.204}$$

Where; AAR=Average annual rainfall

A more applicable equation for calculating MAR for Mzingwane catchment was developed through the ASWRMR (ZINWA, 2005) as follows:

$$MAR = -12.02 - 0.0936 AAR + 0.0003 AAR^{2}$$

(NB: In physical terms, runoff will only be generated in the catchment when rainfall is greater than 12.02 mm)

The ASWRMR found that the MAR for hydrological sub-zones IN1 and N3 (Figure 3.1) were 33mm and 31 mm, respectively (ZINWA, 2005).

Runoff coefficient, which gives the proportion of rainfall that is converted to runoff, is estimated from the relationship:

$$C = \frac{MAR}{AAR} \qquad \text{(Jones, 1988)}$$

Where; C=Runoff coefficient

2.7.2 Dry Season Reservoir Yield Assessment

Sustainable utilisation of water resources implies that the rate of resource withdrawal, use, consumption or depletion should always be balanced or exceeded by the rate of replenishment while maintaining the natural physical and chemical characteristics of the resource in terms of quality and quantity (GoZ, 2000). Since most small reservoirs in Sub-Saharan Africa are located in un-gauged catchments (Mutiro, 2006), the calculation of sustainable yield (renewable and utilisable water) of small reservoirs is difficult. In

Zimbabwe, the yield is determined through an approach described by Mitchell (1987) who assumed constant rates of draw-off and evaporation. A modified Mitchell's Method for estimating dry season yield is based on the following assumptions, that:

a) Reservoirs are full at the end of the wet season (i.e. end of March)

b) During the dry season (April to September), inflows into reservoirs are negligible

c) Draw-off and evaporation of water are at a constant rate

d) Reservoirs are non-carry-over (annual reservoirs)

There are three steps for estimating the dry season yield:

i) Since evaporation loss has a significant effect on the yield of the reservoir, determination of an evaporation index (EI) for the reservoir is done using the equation below:

$$EI = 0.001\left(\frac{E_D \times RA_{\max}}{RC_{\max}}\right)$$

where; E_D*=evaporation over the 6 months of the dry season [mm]*
RA_{max}*=surface area of the reservoir at full supply level [*m^2*]*
RC_{max}*=full supply capacity of the reservoir [*m^3*]*

ii) Determine a K-factor using the equation:

$$K = e^{-0.9EI}$$

iii) Determine the maximum dry season yield (Y_{max}) using the equation:

$$Y_{\max} = \left[\frac{0.9K}{1-K} - 0.15\right] EI \times RC_{\max}$$

K and u are parameters of variation between reservoir surface area (RA) and capacity (RC). For most reservoirs, this relationship closely follows a power law:

$$RA = K\left(RC\right)^u$$

where; Mean value of “K” is 0.523 while the average value for the power "u" is 0.667 for "average reservoirs" of capacities ranging from 11 to 1300 mega cubic metres.

2.8 Key Points on Literature Review

The literature review has highlighted both the significance and gaps of a water productivity strategy as follows:

2.8.1 Significance of a Water Productivity Strategy

The literature review has shown how water productivities for various uses can be determined on multiple-use small reservoirs. Water productivity links well with the concept of integrated water resources management through the socio-economic and environmental sustainability (utilization of sustainable yield and efficient use of scarce water resources). Hence, the water productivity strategy can be used as a tool for valuing and allocating scarce water resources on small reservoirs.

2.8.2 Gaps in Existing Literature

The literature review has highlighted gaps on the conceptual basis for calculating water productivity for grass and recreation. Similarly, a simple approach for estimating flows from un-gauged semi-arid catchments was also not readily available in the studied literature. In this chapter, attempts have been made to provide a conceptual basis for the quantification of grass water productivity. In the subsequent chapter, a simple method for estimating flows into small reservoirs for large time-steps (i.e. a month) has been provided.

CHAPTER THREE: RESEARCH METHODS

3.0 Introduction

This chapter presents various research methods which were used to collect data, quantify water productivities and formulate water allocative strategies based on water productivities. The chapter starts by giving the location and hydrology of the study area as follows.

3.1 Study Area

The study was carried out on eight small reservoirs located in the Mzingwane catchment, semi-arid southern Zimbabwe. Zimbabwe is one of the 14 states constituting the SADC bloc. The eight reservoirs surround Avoca Business Centre in Insiza District, Matebeleland South and fall into hydrological sub-zones BIN1 and BN3 (Figure 3.1).

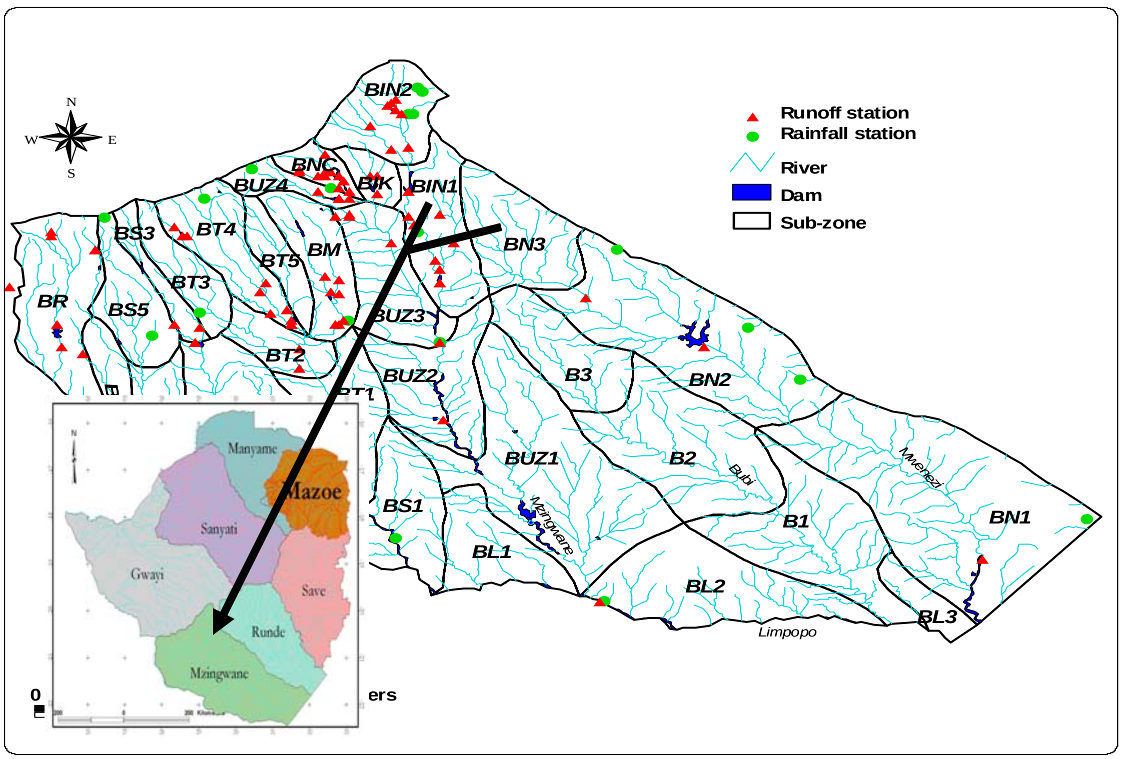

Figure 3.1: Mzingwane Catchment in Zimbabwe (Source: ZINWA, 2005)

Table 3.1 provides details of the eight reservoirs. Manzamhlophe was the furthest reservoir and was located at a direct distance of 16 kilometres from Avoca.

Table 3.1: Location of reservoirs

Reservoir	Year	Longitude(°E)	Latitude(°S)	Map Reference	CA(Km^2)
Avoca	1947	29.52	20.81	Masase 2029D_3	4.4
Bova	1980's	29.51	20.84	Masase 2029D_3	6.8
Denje	1958	29.58	20.79	Masase 2029D_3	10.6
Dewa	1954	29.52	20.79	Masase 2029D_3	4.4
Manzamhlophe	2002	29.41	20.71	Filabusi 2029C_2	16.9
Mashoko	1962	29.58	20.74	Masase 2029D_3 /Wanezi 2029D_1	29.5
Mzambani	1980	29.53	20.79	Masase 2029D_3	0.5
Sifinini	1980	29.56	20.83	Masase 2029D_3	3.6

NB: CA=catchment area

3.2 Hydrology

Mzingwane Catchment comprises Shashe, Upper Mzingwane, Lower Mzingwane and Mwenezi sub-catchments and has a total area of 62 451 km^2. The catchment is part of the Limpopo River Basin (Figure 3.2) located on longitude 25-34°E and latitude 24-26°S. Limpopo River forms an international river basin shared among the countries of Botswana, Mozambique, South Africa and Zimbabwe. The two hydrological sub-zones have a base flow index which varies from 0.14-0.18 (ZINWA, 2005). Base flow is the proportion of total river flow derived from stored catchment sources (MMAI, 1999). The catchment experiences frequent water shortages which induce considerable competition for water (Sawunyama, 2005).

Figure 3.2: Limpopo River Basin (Source: www.iwmi.cgiar.org, 2005)

3.3 Data collection

The determination of water productivities involved collection of data on multiple uses of small reservoirs through desk studies, reconnaissance survey (conducted in December 2006), and the main data collection exercise (conducted in February 2007). During desk studies, eight reservoirs were selected for study. Suitability of the reservoirs was assessed through physical inspection in the reconnaissance survey. The criteria for selection of the reservoirs included the definition of small reservoirs, variety of multiple-uses and continuation of research on reservoirs previously studied by other researchers on different aspects. Data was mainly collected through questionnaires, official records and physical measurements as given below:

3.3.1 Questionnaires

Questionnaires (Appendix 3.0) were administered in eight catchment areas of Avoca, Bova, Denje, Dewa, Manzamhlophe, Mashoko, Mzambani and Sifinini reservoirs in February, 2007. For each reservoir, key informants (village headmen, councillors and elderly members of the community) were initially interviewed for general information about a particular reservoir. Basing on information collected from the key informants, two persons per each water use (domestic, irrigation, livestock, fisheries, brick-making and thatching grass) were interviewed in all the reservoir catchments. The total sample size for the eight reservoirs was 104 which included key informants and interviewees. The questionnaires were administered in order to obtain the actual multiple-use nature of reservoirs. The collected data comprised quantity of water used for domestic purposes (drinking, food preparation, sanitation/hygiene and laundry); crop-watering methods, growth period and yields; livestock watering, products and services; fish catches; quantity of water used for brick making and brick prices; thatching grass harvests and prices. Data collected from questionnaires was supplemented by data collected from official records and physical measurements since it was difficult to capture some data types merely through interviews.

3.3.2 Official Records

Data on livestock statistics, hydro-meteorology and product prices were collected from various offices as follows:

a) Livestock Data

Livestock data was collected from Avoca and Sanali offices of the Department of Veterinary Services in February 2007. The data was based on statistics recorded at dip tanks located adjacent to reservoirs.

b) Hydro-Meteorological Data

Stream flow data for Kangesi Gauging Station (29.42^{o}E, 20.60^{o}S) located in hydrological sub-zone BIN1 was obtained from the ZINWA database. Meteorological data such as rainfall, pan evaporation and temperature were collected from Siwaze Dam (29.49^{o}E, 20.85^{o}S) located in hydrological sub-zone BIN1 and West Nicholson (29.37^{o}E, 21.06^{o}S) Meteorological Stations located in hydrological sub-zone UZ2. Eleven-years of rainfall and pan evaporation data was collected from Siwaze Dam office. Temperature and long-term reference crop evapotranspiration data for West Nicholson Meteorological Station was obtained from FAO archives. FAO calculates long-term reference crop evapotranspiration using Penman-Monteith Method available in CropWat 4.0 for Windows 4.3 model (Clarke et al., 2000).

c) Product Prices

Wholesale livestock prices were obtained through interviews with livestock-keepers as well as local butcheries. Prices for agricultural and related products were collected from farmers as farm-gate prices. Market prices were halved (Kachapila, 2004) in estimating farm-gate prices. The 2006/07-season wheat producer price (RBZ, 2007) was used as an estimate for wheat prices. Prices in Zimbabwe Dollars were converted to United States Dollars by using a shadow exchange rate of January / February 2007 whereby One Thousand Five Hundred Zimbabwe Dollars (1500) was equivalent to One (1) United States Dollar.

3.3.3 Physical Measurements

Physical measurements were carried out in order to compare and contrast with data collected through questionnaires and official records as follows:

a) Livestock Counts

Hourly livestock traffic counts (Figure 3.3) were undertaken from 09:00-16:00hrs on seven of the eight reservoirs. Smaller time-step-tallies were taken from 11:00-14:00hrs as livestock traffic to the reservoir increased. The traffic counts enabled comparison of the actual number of livestock that report to a particular reservoir against dip-tank statistics obtained from the Department of Veterinary Services.

Figure 3.3: Livestock Traffic Count

b) Grassed Areas and Gardens

Grassed areas buffering reservoirs and gardens were surveyed using a geographical positioning system (GPS) and a measuring tape. Grassed dimensions (extents) were measured as off-sets/insets from a GPS coordinate point taken at the water's edge. Areas were calculated using trigonometry relationships. The off-sets/insets had variable extent from the water's edge. Dimensions of gardens were measured using a tape and areas were calculated subsequently.

c) Mass of Products

Mass of vegetable bundles, fish and bricks were weighed on a balance. Four fishermen were hired to catch fish continuously around the reservoir from 08:00 to 16:00 hours so that the catch per unit effort (CPUE) could be compared with data recorded through interviews. Most of the fishermen used hook and line to catch fish. The catch was measured on a balance (Figure 3.4) and fish species were recorded.

Figure 3.4: Measurement of mass of fish

d) Water Discharges

Data related to water discharges on irrigation projects or nutritional gardens was collected through measurement of capacities of conveyance containers and noting the frequency of irrigation per area per day.

3.4 Formulation of a Water Allocative Strategy

The hypothesis of the study was to prove whether water productivity is a tool for formulating water allocative strategies for various uses. The alternative hypothesis was that current water allocation was based on value of uses. Hence, formulation of the strategy considered the second and third paths (section 2.3b and 2.3c) of increasing water productivity (Molden et al., 2001) through the re-distribution of water resources (Cook et al., 2006) from a catchment perspective of reservoir-use. In developing the strategy, a six-month dry season reservoir yield (April to September), average annual water productivities for different products (sub-sectors) and societal values of water use were considered. Figure 3.5 provided a framework for formulating the water allocative strategy as illustrated below:

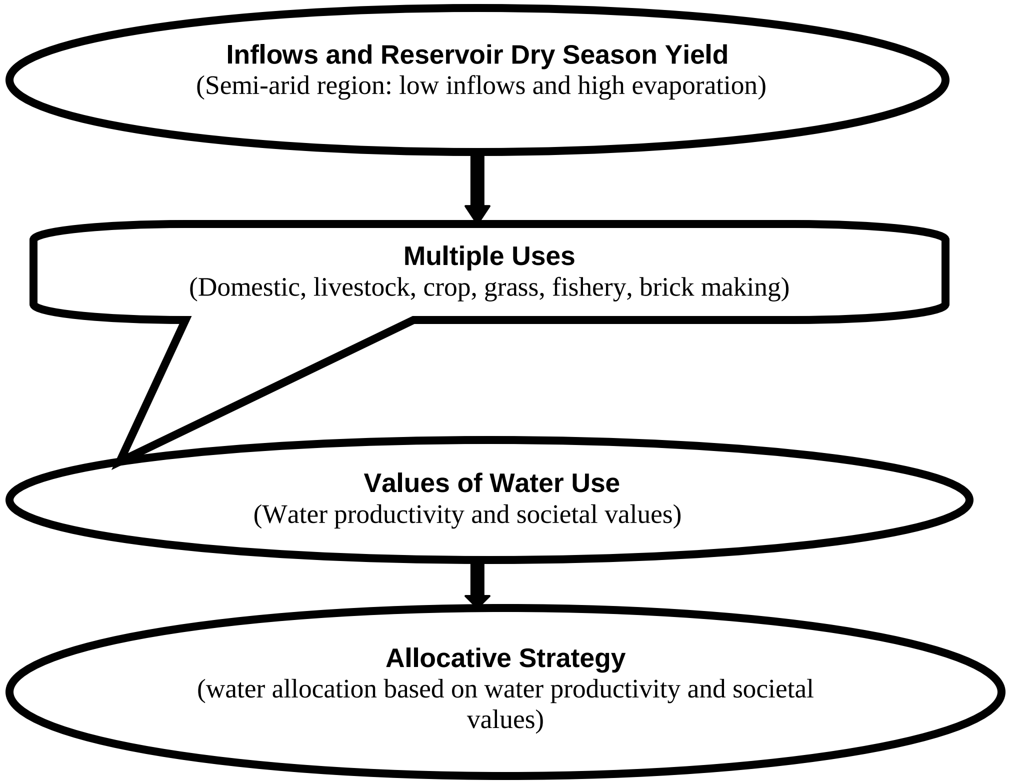

Figure 3.5: Framework for Water Allocative Strategy

a) Stream Inflow Characteristics

Estimation of stream inflow was done in order to characterise flows into the reservoirs. Stream inflows were determined on monthly-time steps using the inflow equations of runoff coefficient and catchment-area proportion given below. The formulae (runoff coefficient equation) assumed that the runoff coefficient was constant within a hydrological homogenous catchment at monthly or larger time-steps. Both equations were based on the fact that basin characteristics have potential to explain variability of flow statistics (Drayton et al., 1980). An average runoff coefficient of 0.11 was incorporated in the runoff co-efficient equation to estimate inflows into the eight reservoirs which had a combined catchment area of 76.603 km^2. The runoff coefficient, C, was obtained by averaging solutions from two equations as follows:

$$C = \frac{MAR}{AAR}$$

(NB: Average MAR for the two hydrological sub-zones was 32 mm which was divided by AAR i.e. 469 mm)

and;

$$C = \frac{Q_{yr}}{AAR}$$

Where; Q_{yr} = *Measured total annual runoff*

*(**NB**: Measured total annual runoff was for Kangesi gauging station for the period 1995/96 to 1999/2000)*

Values of MAR were obtained from the ASWRMR (ZINWA, 2005). Bullock et al. (1990) equation was not used in the calculations partly because it is a regional equation which should be used for rough preliminary estimates of MAR in an un-gauged catchment in the three countries. Monthly flows into reservoirs were estimated as follows:

$$Q_{in} = RxCxCA$$

Where; Q_{in}=*Monthly flow into reservoir* [m^3/month]
R=*Total monthly rainfall* [m]
C=*Runoff coefficient*
CA=*Catchment area of reservoir* [m^2]

Inflows were, alternatively, estimated using catchment-area-proportion method as given below:

$$Q_{in} = \frac{Q_f xCA_{uf}}{CA}$$

Where; Q_{in} =*Inflow in un-gauged stream* [m^3/month]
Q_f= *gauged flow* [m^3/month]
CA_{uf}= *catchment area of an un-gauged stream* [m^2]
CA=*catchment area of gauged stream* [m^2]

b) Reservoir Dry Season Yield

Utilisation of reservoir water for productive functions depends upon available dry season yield. Maximum reservoir dry season yield was determined using Mitchell (1987). Total reservoir evaporation for the six-month dry season period (April to September) was calculated from the eleven-year mean monthly pan evaporation data for Siwaze Dam. The total evaporation was multiplied by an evaporation pan coefficient of 0.7. Lecture notes on integrated water resources management (WaterNet, 2003) and WMO (2001) recommended a coefficient of 0.6 or less for dry seasons and arid areas where water temperature in the evaporation pan is less than air temperature, and 0.8 or above for humid seasons and climates where water temperature in the pan are higher than air temperature. 0.7 was used as an average pan coefficient because Mzingwane catchment is located in a semi-arid region (Mugabe, 2005).

In calculating the reservoir yield, surface area and volume data for six reservoirs was obtained from Sawunyama (2005) while surface area and capacity for Denje and Mzambani reservoirs were estimated from a joint relationship of grassed area and reservoir surface area in conjunction with a modified Sawunyama (2005) equation for capacity-surface area as given below:

$$A_G = 0.0145xRA^{1.251} \qquad r^2=0.98$$

$$RC = 0.0232xRA^{1.3269} \qquad r^2=1$$

Where; A_G=*grassed area* [m^2]

c) Multiple Uses

Multiple uses of small reservoirs such as domestic use, livestock watering, crop production, fishery, brick making and related uses were identified through interviews and physical observations. Classification of the multiple uses was done based on the nature of resource use, social contribution of the use and the water use-sector.

Nature of resource use was classified as either consumptive/depletive or non-consumptive depending on water utilisation. Water depletion was the removal of water (mostly by humans) from the reservoir which rendered it unavailable for further use.

Social contribution of use was obtained as an equal unit score per use. For instance, cattle can contribute to cash (wholesale), nutrition (milk), draught power and plant nutrients (equivalent of nitrogen in kraal manure, littered). The total score for cattle would be four. Scores of all products would be totalled and the percentage contribution score for each water use was worked out and ranked per reservoir. These scores were used as proxies for societal values in setting of criteria for the allocative strategy. The proxy societal values were factored in the allocative strategy through the prioritised use of cash (income). The method of ranking/prioritisation is adapted from the multi-criteria analysis approach which entails interviewing stakeholders about their perceived value on criteria (Nyagwambo, 2006). In this instance, however, societal values were deduced through analysis of the nature of water use and their related benefits to communities. Results from this approach compared well with societal values actually upheld by communities. Mugabe (2005) and Rusere (2005) separately alluded to the prioritised societal value of cash (income) as a principal use-value of small reservoirs by communities. The approach has its strength in that a strategy developed on this basis may introduce minimal changes to community's current uses of water whilst significantly increasing benefits. Hence, the strategy may have a high chance of being accepted by the community. The rational combination of products (sectors / sub-sectors) based on high water productivities and prioritised societal values may result in a strategy that has potential to improve health, power and plant nutrients (manure) since multiple benefits of water tend to mutually reinforce each other for the better (Van Koppen et al., 2006).

Classification of water-use sectors was an adaptation from the GoZ (2000) which identified the following sectors that must be considered in water allocation at the catchment planning stage: primary water; the environment; urban, industrial and mining; agriculture; and, reserve for future use. Sectors were classified based on water-use such as agriculture, domestic, industry and environment (WaterNet, 2003). For example, water-use for crops and livestock was classified under the agriculture sector. Domestic water use and brick making were classified under domestic and industry. Water use for fisheries and thatching grass was classified under the environment sector. Thatching grass was a non-process depletion (Molden et al., 2001) classified under environment because its growth and development was not human-intended as deduced from the interviews.

d) Quantification of Water Productivities

Water productivities of various products and services were quantified and expressed, mostly, as monetary units per unit volume of water used. All water productivities were calculated and deduced on annual basis as follows:

i) Livestock water productivity

The type of livestock that were considered in the calculation of water productivities was cattle, goats, sheep and donkeys. Quantification of livestock water productivity was based on total amount of money obtained from annual average livestock sales, dry and wet season milk production, equivalent nitrogen content in dry matter manure (with litter) and traction/draught power in terms of transport and ploughing (Appendix 2C). The total water productivity for livestock was found as a ratio of total cost of products and services to the amount of water consumed per annum for each type of livestock (FAO, 1986) and expressed as monetary water productivity (US$/$m^3$). The study adopted the approach of lumping livestock outputs and services in order to minimise complexities encountered in the informal and mixed farming set-up of Avoca Area. Livestock data obtained through traffic counts was used in the quantification of water productivities per reservoir because of its relevance to actual reservoir-use. However, descriptive statistics for livestock were deduced from dip-tank livestock records and questionnaires.

ii) Bricks water productivity

Quantification of water productivity for bricks involved measurement of mass of at least 10 finished bricks and finding the average mass of each brick at each reservoir. Quantity of water used in making 1000 bricks and prices for bricks were obtained through interviews. Water productivity was expressed either in terms of physical water productivity (kg/m^3) or monetary water productivity (US$/$m^3$). For bricks, the monetary water productivity values were more appropriate to use than physical water productivities.

iii) Crop water productivity

Quantification of crop water productivity covered tomatoes, small vegetables (covo), green maize cobs (maize grown using water from small reservoirs was sold at this stage of development), dry beans and wheat. Data required for calculating water productivities was obtained through interviews and physical measurements. The collected data included water quantities applied to crops, mass of crop yields (kg) and farm-gate prices of crops. For example, the average mass of one vegetable bundle (Figure 3.6) was 0.63 kg. This would be multiplied by the number of bundles harvested in a given period to find total mass of yield for the determination of physical water productivity. Quantities of water applied to crops were estimated from the volume of water applied per bed and the frequency of watering per week for the entire growing season (Lovell, 2000). These water quantities were compared with total crop evapotranspiration in order to check that physically applied water volumes obtained through interviews were higher than the calculated water quantities which crops use in transpiration. Allen et al. (1998) informed that transpiration processes use nearly all water taken by plants and only a negligible fraction is used within the plant. Both physical (kg/m^3) and monetary water productivities ($US\$/m^3$) were calculated.

Figure 3.6: Vegetables production, Hlanganani Nutritional Garden, Denje

iv) Fish water productivity

Quantification of the water productivity for fish involved conducting interviews on the average fish catch per day in the wet and dry seasons, respectively. The collected data was verified with trial fish catches which were conducted by four fishermen during the study period (wet season). Average price of fish bundles was found through interviews. The average weight and number of fish for each bundle were recorded. Productive water for fish was determined from the total volume of water that could evaporate from the reservoir during wet and dry seasons (Lemoalle, 2006). Water productivity was expressed either in terms of physical water productivity (kg/m^3) or monetary water productivity ($US\$/m^3$).

v) Domestic use water productivity

The monetary water productivity for raw reservoir water domestic use was found by halving the cost of treated water per cubic metre as supplied and charged by ZINWA at Avoca Business Centre. The productivity was expressed in $US\$/m^3$. The study did not cover the multiple benefits of domestic water use beyond the cost of supply.

vi) Grass water productivity

Thatching grass was harvested from the reservoir buffer area and made into standard bundles. The bundles were made by members of the community who were involved in grass harvesting and selling. The bundles were weighed on a hanging balance and mass recorded in situ (the average diameter and mass of the standard bundles were 900mm and 17 kg, respectively). Dimensions of the area where grass was harvested were measured

(Figure 3.7) in order to establish grass density. By using the grass density and measured areas of grassed buffer zones, the total number of bundles that would be harvested from the grassed buffer was estimated. Total mass of the bundles was calculated by proportional multiplication with the mass of a standard bundle. For monetary water productivity, selling prices of standard bundles were obtained through interviews. Volume of water depleted by grass was estimated by multiplying grass evapotranspiration which was obtained using CropWat 4.0 model for Windows 4.3 (Clarke et al., 2000) and the area of the grassed buffer. A cropping pattern of alfalfa grass was assumed in the determination of the evapotranspiration of the grass. Grass water productivity was calculated in physical (kg/m^3) and monetary terms (US$/m^3).

Figure 3.7: Measurement of harvested areas of grass

vii) Recreation Water Productivity

Water productivity for recreation was estimated from the number of man-hours spent by individuals whilst swimming, boating or contemplating at the reservoir. This was done through interviews. The man-hours were multiplied by the minimum average wage rate for casual labourers in rural areas assuming the time had an opportunity cost of being spent on such type of work. Water productivity was then expressed in monetary units per unit volume of available reservoir water. The assumption was that reservoir recreation is a function of the available water volume and is envisaged to maximise at full reservoir capacity. Recreation is a non-consumptive use.

3.5 Selection of the Water Allocative Strategy

Four scenarios were considered in the selection of the strategy: scenario one (1), scenario two (2), scenario three (3) and scenario four (4). These scenarios were based on the prioritised societal value of cash (income). Scenario one was a no-intervention scenario where the present water uses and allocations were analysed (zero scenario). Scenario two was aimed at re-allocating water across sub-sectors (uses or products) with high water productivities. Scenario three was aimed at re-allocating water across sectors with high water productivities. In this scenario, the allocation for environment sector was substantially reduced to allow for only 11 % of the yield which could be sufficient for other minor uses. Nguyen-Khoa et al. (2005) and Renwick (2001a) considered this portion of reservoir yield as minimum "dead" water reserve required for the enhancement of aquatic organisms. Scenario four was aimed at distributing sectorally re-allocated water of the second scenario across sub-sectors of the first scenario. Water was re-allocated to more productive sectors in order to optimise on incomes from the available dry season reservoir yield. In all the four scenarios, water allocation was done in a way that benefits could be realised without unsustainably utilising the maximum dry season reservoir yield. The scenarios were piloted on Avoca reservoir.

The scenarios considered three water-use sectors of agriculture (crops and livestock), domestic and industry (domestic water use and brick making) and environment (fish, grass and others). The scenario which yielded the highest income level was selected based on income per person per a six-month period (April-September). This was obtained by dividing total income resulting from a scenario by the total number of people using the reservoir. One hundred and forty-four (144) households used the reservoir and each household was estimated to comprise nine persons. Selection of the strategy was based on incremental benefits across the scenarios for the optimum societal benefit of cash (income). Income per sector or sub-sector was calculated from the relationship:

$$Income = Q_{wa} x WP$$

Where; Q_{wa}=*Water allocation* (m^3)
WP=*Water productivity* $(US\$/m^3)$

3.6 Quality Control, Calculations and Analysis

3.6.1 Quality Control

Data quality control was done through tabular comparisons, double mass analysis and statistical inference. For instance, rainfall data collected at Siwaze Dam was correlated with runoff recorded at Kangesi gauging station. Also, rainfall data was correlated with flows calculated separately using the runoff-coefficient equation method and catchment-area-proportion. This was done in order to select a more applicable equation for estimating flows into reservoirs.

3.6.2 Calculation and Data Analysis

Calculation and data analysis were executed using a number of equipment and tools as follows:

a) Crop and grass evapotranspiration were calculated using CropWat 4.0 for Windows 4.3 model (Clarke et al., 2000). The input was reference crop evapotranspiration data from West Nicholson Meteorological Station

b) Reservoir catchment areas were measured using a planimeter from 1:50 000 topographical maps

c) Areas for grassed buffers were calculated using geometry by converting GPS coordinates into horizontal distances using a Spherical Model Distance Calculator *(www/grapevine.abe.msstate.edu)*

d) Correlations were obtained using a Statistical Product Services Solution (SPSS 10.0 for Windows) package

e) Water productivities and hydrological variables such as inflows and yields were calculated and plotted in EXCEL spreadsheets using data collected from questionnaires and physical measurements.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.0 Introduction

This chapter presents results and discussion of analysed data which was collected through desk studies, physical measurements and questionnaires. The results and discussions follow the outline of the specific objectives, which was to: determine the maximum dry-season yield of multiple use small reservoirs; identify and classify multiple uses of small reservoirs; quantify water productivities for the various multiple uses; and formulate an allocative strategy for scarce water resources in small reservoirs. The chapter commences by giving the quality control which was performed on the most important data sets which were used in the study as follows:

4.1 Rainfall and Runoff

Results of the Pearson correlation between rainfall and total inflow estimated using the catchment-area-proportion method showed a correlation of 0.593 at a significance of 0.042 ($p<0.05$). Results of the paired sample correlation between rainfall and total inflow estimated using the runoff-coefficient equation (section 3.4a) showed a correlation of 0.929 at a significance of 0.001 ($p<0.01$). The results showed that both equations could be used for estimating flows into the reservoirs but the runoff-coefficient equation gave better estimates of flows and was, therefore, used in the study.

4.2 Livestock Distribution

Livestock data collected from the Department of Veterinary Services and through traffic counts was compared (Figure 4.1 and 4.2) in terms of percentage distribution of livestock and correlated using a paired sample correlation test. Generally, there was consistency in percentage distribution of cattle, goats and donkeys except for sheep.

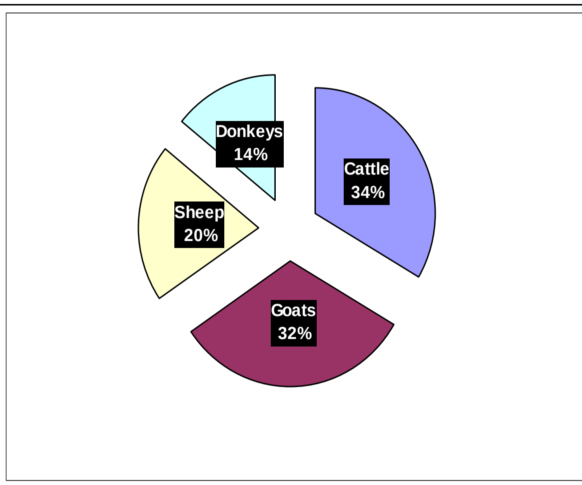

Figure 4.1: Livestock Distribution: dip tank

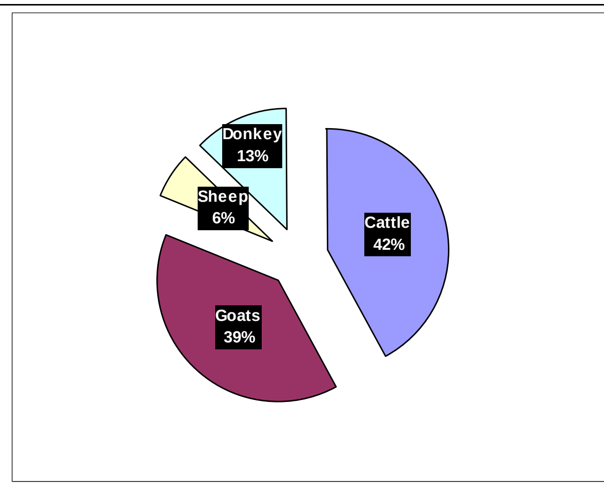

Figure 4.2: Livestock distribution: reservoir

Results of the paired sample correlation test of the two livestock data sets showed a correlation of 0.91 at a significance of 0.09 while the paired t-test showed $t(3)=6.5$, $p>0.001$ (0.007), two-tailed test. Therefore, there was no significant correlation between the two data sets. The means of the two data sets were significantly different from each other. The difference might have been caused by the incongruence of the catchment areas where the two data sets were collected. Data from the Department of Veterinary Services was based on the catchment area of a dip tank whereas livestock traffic count data was based on reservoir-use-catchment. Calculations for actual volumes of water consumed by livestock were, consequently, based on data which was collected at reservoir-use-catchment but statistical parameters related to livestock type and distributions were deduced from data collected from the dip-tank and interviews.

4.3 Assessment of Surface Water Resources

Assessment of surface water resources considered rainfall, runoff and evaporation characteristics of the study area.

4.3.1 Rainfall

Analysis of monthly rainfall from Siwaze Dam for the period 1995/96-2005/06 showed that rainfall regimes were low (Figure 4.3) and highly variable. Average monthly rainfall of less than 20mm per month was received in the months of April to October.

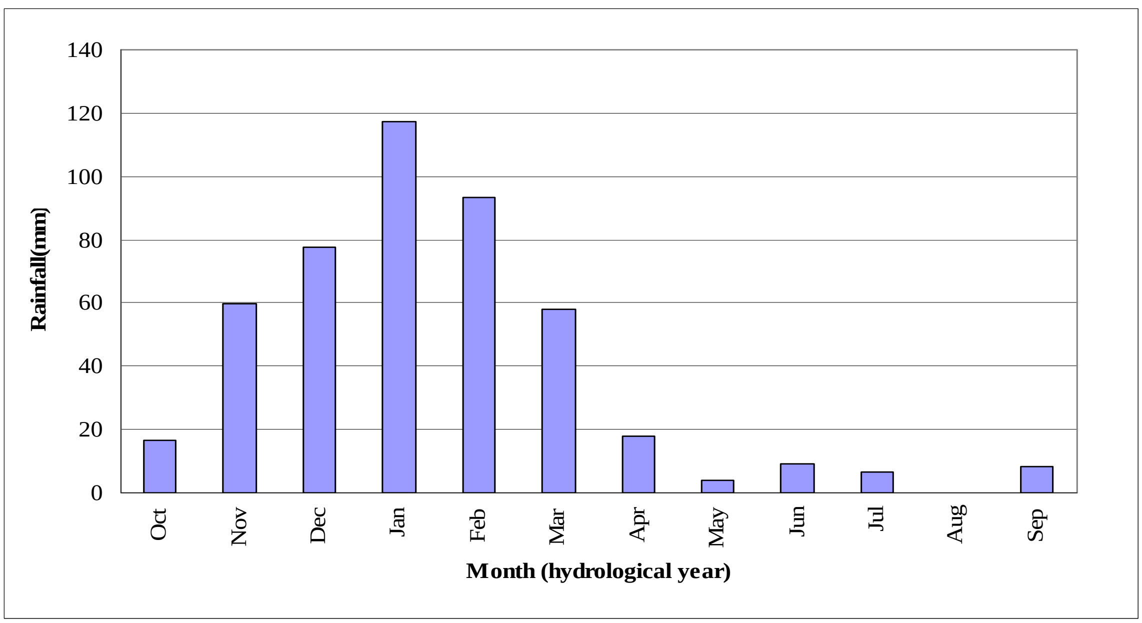

Figure 4.3:11-year (1995/96-2005/06) Mean Monthly rainfall: Siwaze Dam

4.3.2 Comparison of Rainfall, Runoff and Evaporation

Besides having low and variable rainfall regimes, Avoca area had low rainfall to runoff conversion and high evaporation rates. For example, in the month of January; rainfall, runoff and reservoir evaporation depths were 117 mm per month, 15 mm per month and 157 mm per month, respectively (Figure 4.4). Mean rainfall for the 11 year period was

469 mm per annum and the mean evaporation was about 2000 mm per annum. This represents a water deficit of about 1700 mm per annum in the area. Hence, small reservoirs are indispensable for storing the low runoffs. The reservoirs also act as supplementary sources of water during the dry season months (April to September). Well formulated water allocative strategies should, therefore, enable productive utilization of the available water in the reservoir before occurrence of significant evaporative losses.

Given these hydro-meteorological factors, small reservoirs enabled storage and distribution of scarce water resources in space and time in areas which would have, otherwise, been facing extreme water deficits. Small reservoirs were not only easily accessible but they also enhanced equity through the sharing of scarce water resources at sub-catchment level.

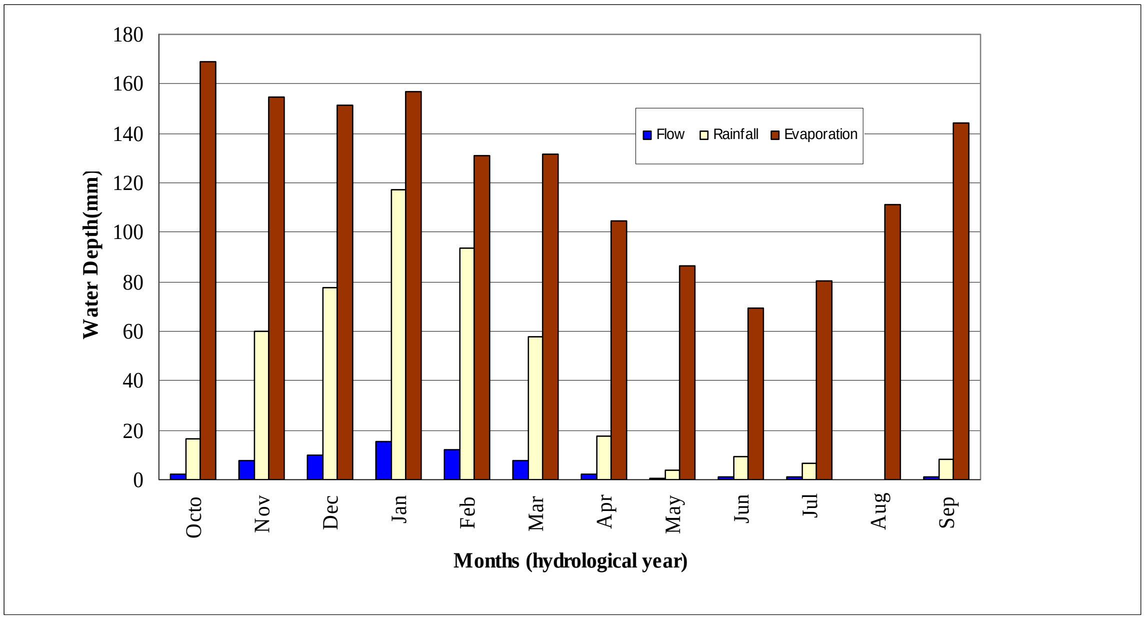

Figure 4.4: Rainfall, runoff and evaporation around Avoca (11-year monthly average)

4.3.3 Flow Estimation into Reservoirs

Flows into reservoirs were estimated by the runoff-coefficient-equation (section 3.4a) using an average runoff coefficient of 0.11 and plotted as combined flow in Figure 4.5 below. Calculated runoff coefficients from the two equations (section 3.4a) were 0.07 and 0.15, respectively. Inflows estimated using the catchment-area-proportion method were not representative mainly because of significant disparities in the magnitude of the parent catchment area and the reservoir catchment area which resulted in a low correlation coefficient of 0.593. The streams were found to be ephemeral in nature.

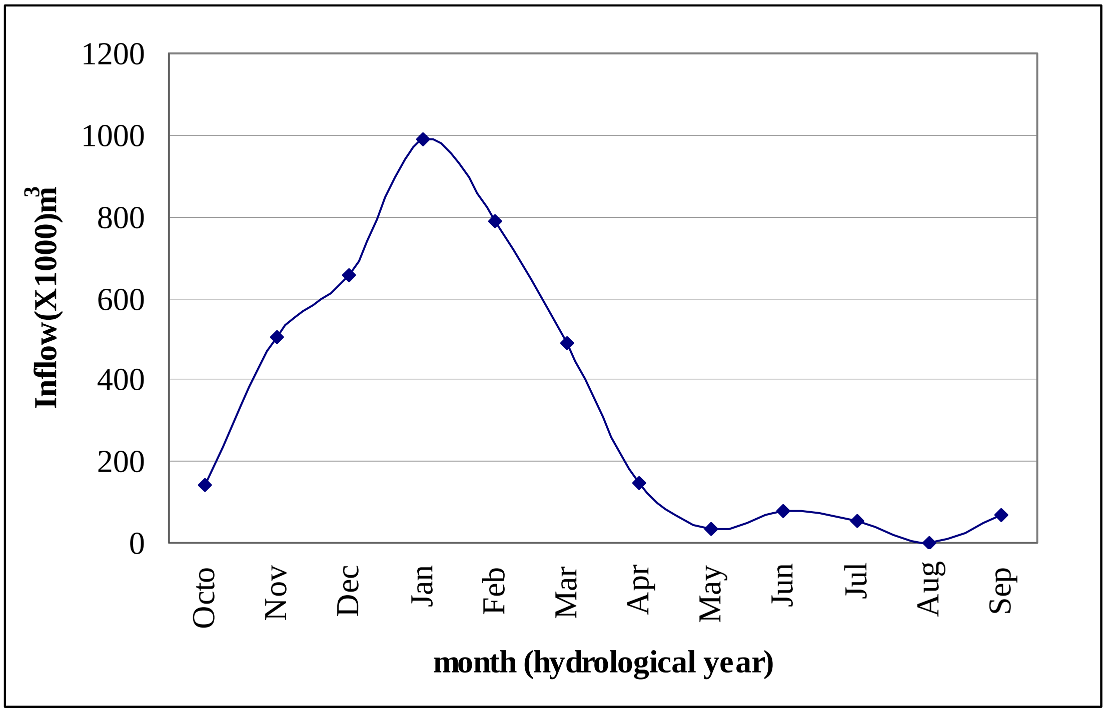

Figure 4.5: Estimated combined monthly flows into eight reservoirs

The results showed that the monthly flows (combined) in the eight reservoirs peaked in January while there was no flow in August. Flows of about one mega cubic metres ($1X10^6$ m^3) per month were registered in January while August had no flow. Inflows which occurred in June and July were as a result of winter season rainfall. Generally, the period between April and September was associated with insignificant inflows (low to zero flows) but high evaporation rates. Such inflow variability amplifies the significance of small reservoirs in storing part of the peak runoff for use during the dry season.

4.4 Determination of Maximum Dry Season Reservoir Yield

Table 4.1 presents maximum dry season reservoir yield determined using an approach by Mitchell (1987). The results show that reservoir storage ratios (SR) ranged from 0.03 to 0.46. Storage ratio is a fraction of reservoir capacity to the quantity of runoff generated in the reservoir catchment. Small SRs meant that the catchments had underdeveloped water resources potential (GoZ, 2000). On average, only 16% of the MAR was stored in the reservoirs. A catchment that has storage capacity which is greater than twice and less than or equal to thrice ($2<SR\leq3$) MAR is classified as developed (GoZ, 2000). Development of more storage capacities in such a catchment results in incremental yield reduction (i.e. diminishing yield). The results also show that the reservoirs had low maximum dry season yield of between 2 000 m^3 and 60 000 m^3 from capacities of between 7 000 m^3 and 90 000 m^3. On average, dry season yield in the reservoirs was 48 % of the full supply reservoir capacity. The low reservoir yields necessitate that users exercise prudent utilization of the scarce water resources. Otherwise, more reservoirs should be constructed in the catchment to reach the "developed" level in order to ease pressure on the dry season yield.

Table 4.1: Maximum Dry Season Reservoir Yield

Reservoir	MAR(m^3)	RC_{max}(m^3)	SR	RA_{max}(m^2)	EI	K_{factor}	Y_{dry}(m^3)	Remark
Avoca	146454	41593	0.28	51698	0.811	0.482	23194	
Bova	224136	12816	0.06	21276	1.083	0.377	5490	
Denje	350229	53930	0.15	62792	0.759	0.505	31444	Estimated RA
Dewa	146454	16592	0.11	25865	1.017	0.401	7614	
Manzamhlophe	553839	14423	0.03	23269	1.052	0.388	6381	
Mashoko	914159	86405	0.09	89684	0.677	0.544	53971	
Mzambani	15675	7243	0.46	13829	1.245	0.326	2575	Estimated RA
Sifinini	117975	11526	0.10	19658	1.112	0.368	4781	

NB: $SR = \frac{RC_{\max}}{MAR}$ =*storage ratio* (Sources for RC and RA: Sawunyama, 2005)

4.5 Identification of Multiple Uses of Small Reservoirs

Data collected through questionnaires and physical measurements showed that reservoir water was being used for domestic water supply, livestock watering, crop production, fishery, brick making and grass production. Recreation activities were insignificant.

Based on the uses, Table 4.2 classified the nature of resource use, social contribution of use and water use-sectors. The nature of resource use was either consumptive or non-consumptive. The social contributions of the water resources were on cash (income), health (nutrition/livelihood), shelter, power and plant nutrients (manure). Four water use-sectors were identified based on use. The sectors were agriculture (livestock/crop), domestic (drinking), industry (brick making), and environment (fishery, grass and others). The sectors of domestic and industry were merged to form one sector. Hence only three water use sectors of agriculture, domestic and industry, and environment were considered as shown in below:

Table 4.2: Multiple uses of small reservoir

Use	Nature of use	Social Contribution	Use-sector
Domestic use	Consumptive	Health (livelihood)	Domestic (primary) and Industry
Livestock	Consumptive	Cash, health (nutrition), power and plant nutrients (manure)	Agriculture (livestock)
Crops	Consumptive	Cash and health(nutrition)	Agriculture (crops)
Fishery	Non-consumptive	Cash and health (nutrition)	Environment (available water)
Grass	Consumptive	Cash and shelter	Environment (available water)
Bricks	Consumptive	Cash and shelter	Domestic and Industry

Figure 4.6 depicts use-percentage-score for the various social contributions. Most of the reservoir uses were aimed at cash (income generation), health and shelter for the society. These scores were used as proxies for social values.

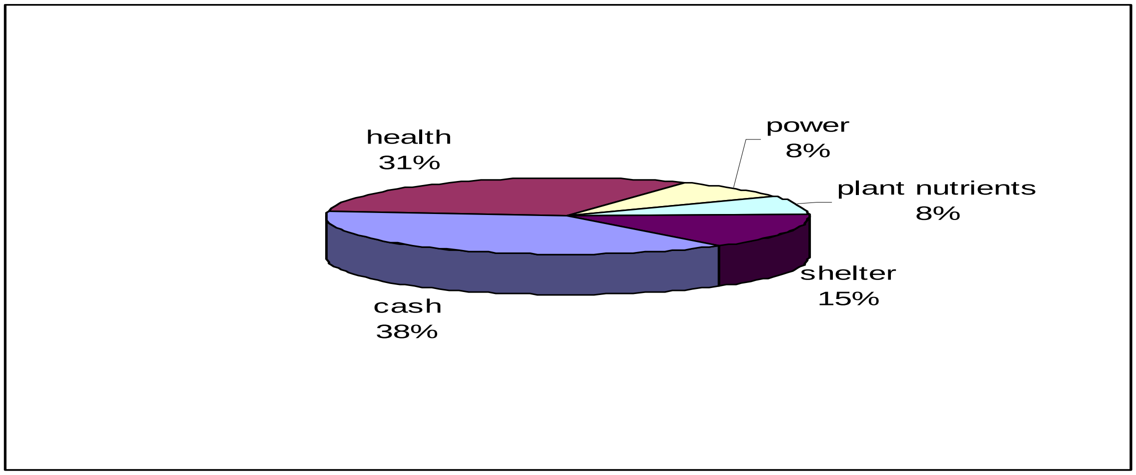

Figure 4.6: Use-percentage-score for social contribution

Most of the studied uses were consumptive in nature and only fishery had a non-consumptive use. Return flows from irrigated areas were assumed insignificant in an area where the most common method of watering was a bucket and high evaporation rates were experienced.

4.6 Water Productivities

Water productivities were calculated as physical and monetary water productivities as given below:

4.6.1 Physical Water Productivity

Physical water productivities were calculated for selected products (sub-sectors), especially crops. The results of the physical water productivities (Table 4.3) showed that most products such as dry beans and small vegetables were within the range of water use efficiencies (WUE) for harvested yield in tropic and sub-tropic regions (FAO, 1977). Water use efficiency represents the mass of (crop) product produced per unit amount of evapotranspiration at field or reservoir-use level. Water productivity is an indicator of water use efficiency.

The results showed that tomatoes had a slightly lower water productivity of 8.3 kg/m^3 than the WUE of between 10-12 kg/m^3 provided in the lecture notes on integrated water resources management (WaterNet, 2003). In the same area, however, a study done by Rusere (2005) found that tomatoes had a water productivity of between 4.5-9.7 kg/m^3. The two results are similar. The difference between these two results and the WUE values was attributed to differences in agronomic practices, efficiency of irrigation method and climatic factors such high evaporation rates.

The results also show that water productivity for wheat was higher (1.2 kg/m^3) than the WUE (0.8-1 kg/m^3) obtained by FAO (1977) at field level. However, Singh et al. (2005) found that water productivity of wheat ranged from 1.22 to 1.56 kg/m^3 among different farmer fields in Sirsa District, India. Senzanje et al. (2005) found that the mean water productivity for winter wheat, in the Middle Save estates in Zimbabwe, ranged from 0.33 to 0.49 kg/m^3. The results confirm the assertion that in areas of high evaporation, there is likely to be considerable spatial variation in water productivity values (Singh et al., 2005). Calculation of crop water productivity in semi-arid areas should, therefore, consider factors such as method of crop watering, evaporation and percolation losses, and also the scale at which water productivities are analysed (Hussain et al., 2007).

Table 4.3: Physical water productivity for selected products

Product	WP [Kg/m^3]	WUE [Kg/m^3]	Remark
Beans (dry)	0.4	0.3-0.6	
Green maize	2.4	0.8-1.6	WUE is for grain maize
Tomatoes	8.3	10-12	
Small vegetables	15.6	12-20	WUE if for cabbage
Wheat	1.2	0.8-1	
Grass	1.6		
Fish	0.124		

4.6.2 Monetary Water Productivity

Monetary water productivities were calculated for thirteen products (sub-sectors) as shown in Table 4.4 below. Monetary water productivities minimised the inevitable difficulties encountered in calculating physical water productivities for some products and services (Hussain et al., 2007). Comparison of monetary water productivities with similar research was difficult because there were very few documented studies on the subject. Also, the few previous studies done in Zimbabwe did not define the prevailing exchange rate between the Zimbabwe Dollar and the United States Dollar at the time to enable fair comparison.

a) Livestock Water Productivity

Analysis of questionnaires and livestock statistics showed that for a given population of cattle, 34% were oxen, 26% were cows and the rest were a combination of bulls, steers/heifers and calves. 27% of the cows were milked in the dry season and 32% were milked in the wet season. On average, during the dry and wet season a cow produced 2 and 2.34 litres of milk per day, respectively. A livestock-keeper would sell 11% of their cattle and 32% of goats/sheep in a given year while donkeys were rarely sold. Departure in the percentage distribution of sheep might have been caused by lack of data from Mashoko reservoir which was not collected because of time constraints.

On draught power, cattle (oxen) and donkeys were, on average, allowed to work four and three days in a week, respectively. Oxen worked intensively for three months during land cultivation while donkeys worked almost throughout the year. 89% of the donkeys were used for transporting people and goods. Donkeys were, on average, working as a team of two-pairs per activity while cattle (oxen) worked as a pair.

Calculation of voluntary water requirements was done using long-term mean monthly temperature data from West Nicholson. Figure 4.7 shows long-term mean monthly temperatures used in estimating livestock voluntary daily water intake by season (FAO, 1986). The temperatures depict that the area experiences wet (14-21^{o}C) and dry seasons (22-27^{o}C).

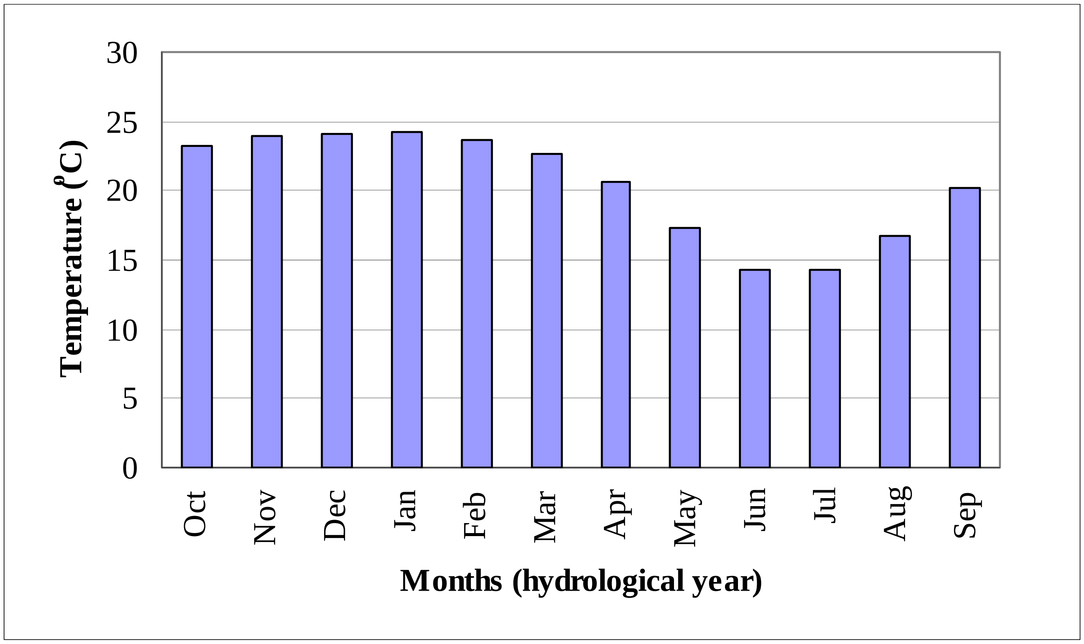

Figure 4.7: Long-term mean monthly temperature: West Nicholson

The results of water productivity (Table 4.4 and Appendix 2C) showed that donkeys had the highest monetary water productivity (145 US$/m^{3}) followed by cattle (32 US$/m^{3}) in the livestock sub-sector. Sheep had almost the same water productivity as goats (11 US$/m^{3}). The high water productivity of donkeys was largely attributed to the high cost of traction/draught power in an area where donkeys are extensively and intensively used throughout the year for transport and cultivation. Donkeys also have, on average, a lower voluntary daily water intake (by season and average temperature) of 16 litres whereas cattle and goats/sheep have 21 and 30 litres, respectively. However, in terms of societal preference, cattle, sheep and goats were kept in large numbers by riparian communities. The reason for keeping more cattle, goats and sheep might be the perceived added value of goods such as meat and milk which these livestock offered. Since donkeys were rarely sold, even their residual value was significantly reduced in the perception of society. The other reason might be that the long-term financial gains which may be obtained from hiring-out donkeys may be less than the accrued benefits obtained from the rearing of cattle, sheep and goats.

b) Bricks Water Productivity

Bricks had almost the same monetary water productivity as cattle (32 US$/m3). Bricks seconded donkeys in total water productivity magnitude (Table 4.4). However, analysis of questionnaires revealed that most reservoir management committees were ensuring that brick making was controlled because of environment concerns such as deforestation, erosion and siltation of reservoirs. Dam management committees should, therefore, ensure sustainable brick making so that it contributes to the improvement of livelihoods.

c) Crops and Grass Water Productivity

Crops such as tomatoes, small vegetables (covo), green maize, beans and wheat were also studied for their individual water productivities. These crops were grown extensively by farmers in their irrigation projects and nutritional gardens. The monetary water productivity (US$/m^3) of these crops showed that tomatoes had the highest productivity of about twenty-four (24) followed by small vegetables (8), green maize (2), beans (0.93) and wheat (0.17) as shown in Table 4.4. Green maize, beans, wheat and thatching grass, had low monetary water productivities. The results of water productivity militate against growing of green maize, beans, wheat and grass using scarce reservoir water resources. Dam management committees should, therefore, ensure that scarce water resources from their reservoirs are used on more productive uses such as the growing of tomatoes and vegetables. In order to serve societal values, low water productivity crops such as maize and beans may be grown during the rainy season when water resources are relatively abundant. Alternatively, crops such as maize, beans and wheat may also be imported from other parts of the country by using part of the income realised from the sale of the high value products within the concept of virtual water. Virtual water is the volume of water required to produce a commodity. The virtual water concept represents flows of water embedded in commodities used in global trading system such as beef, maize, rice, wheat, tea and power. It denotes water that is used to produce goods that a country imports. Effects of trends in producer prices over a longer period of time (more than one year) should, however, be taken into account in making decisions on water allocation.

Table 4.4: Monetary water productivities for thirteen (13) products

Product	WP(Monetary) [Zim$/m^3]	WP(Monetary) [US$/m^3]	Remark
Cattle	47273.87	31.52	Traction/sale/milk/manure
Goats	16392.52	10.93	Sale and manure
Sheep	16503.86	11.00	Sale and manure
Donkey	217902.20	145.27	Traction and manure
Beans(dry)	1391.00	0.93	
Green maize	3381.15	2.25	
Tomatoes	36206.90	24.14	
Small Vegetables	12006.58	8.00	
Grass	36.16	0.02	
Fish	977.74	0.65	
Wheat	260.50	0.17	Used 2006/07 producer price
Domestic use	45.00	0.03	
Bricks	47500.00	31.67	

NB: Z$ 1500 = 1 US$

d) Fish Water Productivity

Water productivity for fish was found to be low at US$0.65/m^3 (Table 4.4). The average number of fish caught per fisherman per day in the dry and wet season was 20 and 50, respectively. Fish were sold at 1 US$ per a bundle of five fishes whose average mass was 0.2 kg. The most common fish species caught were O*reochronis mossambicus* (cichlidae / Isikwaya / Gwaya) and *Clarias gariepinus* (African catfish / Umadevu / Muramba). In the Lower Shire river floodplains of Malawi, Chimatiro (2004) found out that these two species formed the bulk of the catch and together they accounted for an average mass percentage of 82 of total catch. Although total volume of evaporated water was used in the calculation of fish water productivity (Lemoalle, 2006), in the allocative strategy, 11% of full supply reservoir capacity could be sufficient as an allocation (reserve) for aquatic organisms including fish (Nguyen-Khoa et al., 2005; Renwick, 2001a). Hence, fish production should be integrated with all other uses in order to maintain sustainable water depth for fishery development.

e) Domestic Use Water Productivity

The water productivity for domestic water use was US$0.03/$m^3$ (Table 4.4). However, the study did not assess the multiplier effect of domestic water use beyond the supply cost. Domestic water plays primary functions in the livelihood of a society. These primary functions include food preparation, sanitation and hygiene, drinking and laundry. Results of this study showed that the average per capita-day reservoir water use on these functions was 14 litres. In the East African countries (Uganda, Kenya and Tanzania), the per capita-day of 20.5 litres was found for rural un-piped systems (WaterNet, 2003). Hence, water drawn from small reservoirs contributed 69% of all household primary water requirements for livelihood in Avoca. The balance of the water demand was fetched from boreholes and shallow wells. Mugabe (2005) reported that 97 % of available reservoir water is lost to evaporation and that only 3% of the stored water resources could be utilised. This study contends that the 3 %, apart from serving other multiple functions, contributes significantly to satisfying domestic water demand. Therefore, in semi-arid regions, small reservoirs are indispensable sources of water for domestic water which directly supports rural livelihoods. Hence, stakeholders in the water sector should consider investing in small reservoirs in areas where medium to large reservoirs are not feasible and cost-effective. The formulation of the allocative strategy, however, used 25 litres per capita-day of reservoir water as the upper threshold for rural un-piped water supply demand.

4.7 The Allocative Strategy

Results of the scenarios for selecting the water allocative strategy were as follows:

4.7.1 Scenario 1: Zero-Scenario

Table 4.5 gives the present water allocation per sub-sector (products). Crops depleted the highest share (8000 m^3) of the available yield followed by domestic use (6000 m^3), fish and others (6679 m^3). Calculation of the present water allocation was based on data such as total size of gardens, crop type, livestock statistics and population. Note that 11% of available yield allowed for other uses that may not have been captured in the study.

Table 4.5: Scenario 1: zero scenario

Sub-sector	Scenario 1 allocation[m^3]	Percentage allocation	WP [US$/m^3]
Livestock	1000	4.3	49.70
Crops	8000	34.5	7.10
Domestic	6000	25.9	0.03
Industry	15	0.1	31.70
Grass	1500	6.5	0.02
Fish & others	6679	28.8	0.65
Total yield	**23194**	**100.0**	

NB: WP= water productivity

Figure 4.8, which gives the percentage-use of yield per sector showed that agriculture sector consumed the largest share of reservoir yield (39 %) followed by environment (35 %), domestic and industry (26 %).

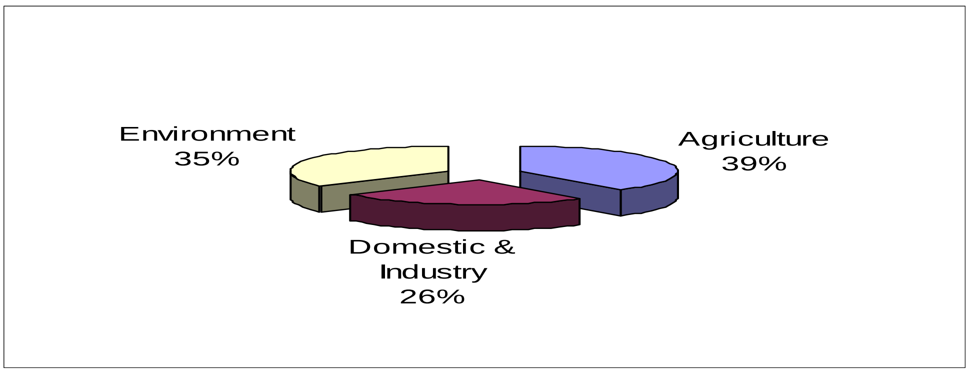

Figure 4.8: Percentage-use of reservoir yield per sector

Table 4.6 provides a six-month income per sector based on monetary water productivities. Average monetary water productivities (US$/m^3) which were used in the calculation of incomes for the sectors of agriculture, domestic and industry, and environment were 26, 15.9 and 0.3, respectively. By applying these water productivities, the agriculture sector had the highest income per allocation (106 500 US$) followed by environment (4371 US$), and domestic and industry (656 US$). Results of the water allocation in the agriculture sector showed that crops depleted 89 % of water allocation while livestock depleted 11 %. However, the water productivity of crops was 7.1 US$/m^3 while that for livestock was 49.7 US$/m^3. Within the domestic and industry, domestic use depleted 99.8 % while bricks depleted 0.2 %. The water productivity for domestic use was 0.03 US$/m^3 while the water productivity for bricks was 31.7 US$/m^3.

The results showed that despite the low reservoir yield, utilisation of the water resources was not being optimised as observed from the 35 % available to the environment sector which was more than adequate for grass, fish production and other micro-organisms. Lovell et al. (2005) suggested that there is need to quantify water resources potential of small catchments in order to identify appropriate (agricultural) development strategies. Mugabe (2005) also argued that water used for productive use on small reservoirs was insignificant such that use could be increased up to five-fold without drying-up the reservoir in most seasons. Through analysis of scenario one, the study found that total water allocation for agriculture, domestic and industry, could only be increased by 37 % from present allocations without jeopardising the environment sector. Hence, in the following scenario, part of the 35 % of the environment sector would be appropriated on more productive sectors leaving out just sufficient quantities for the environment (i.e. 11 % of available yield). The balance from the environment sector could be re-allocated within the sectors of agriculture, domestic and industry. For example, in the agriculture sector, more water may be allocated to livestock production than crops. This may be done through reduction of area under cultivation. However, production of livestock must be controlled to avoid impacting negatively on other natural resource bases. As for domestic water use, water allocation may be decreased by urging communities to fetch the balance of their per capita water demand, especially for drinking, from alternative safer water sources such as boreholes available in the area.

Table 4.6: Incomes for the zero-scenario

Sector	**Income** [US$]
Agriculture	106500
Domestic and Industry	656
Environment	4371

Furthermore, the results showed that sustaining scenario one (1) would result in water resources being inappropriately and inefficiently allocated to less productive sectors.

4.7.2 Scenario 2: Re-allocate Water across Sub-sectors

Scenario two (2) was aimed at re-allocating water across sub-sectors (products or uses) which had high water productivities as given in Table 4.7:

Table 4.7: Scenario 2: Re-allocate water across sub-sectors

Sub-sector	**Re-allocation percentage**	**Scenario 2 allocations**[m^3]	**WP**[US$/$m^3$]
Livestock	65	5850	49.70
Crops	35	3150	7.10
Domestic	80	4812	0.03
Industry	20	1203	31.70
Grass	15	1227	0.02
Fish & others	85	6952	0.65
Total yield		**23194**	

Table 4.8 shows that the allocative strategy could be improved if water were allocated only to those sub-sectors that had high water productivities within a sector. The resultant income in agriculture sector was 313 110 US$, domestic and industry was 38 279 US$ and environment was 4543 US$. Results show that incomes were increased by an overall 219 % from scenario one (1).

Table 4.8: Incomes for re-allocating water across sub-sectors

Sector	Scenario 1 [US$]	Scenario 2 [US$]
Agriculture	106 500	313 110
Domestic and Industry	656	38 279
Environment	4371	4 543
Total income	**111 527**	**355 932**
Overall increase (%)	**0**	**219**

4.7.3 Scenario 3: Re-allocate Water across Sectors

Scenario three (3) was aimed at re-allocating water across sectors that had high water productivities as given in Table 4.9:

Table 4.9: Scenario 3: Re-allocate water across sectors

Sector	**Scenario 1 allocation**[m^3]	**Scenario 3 allocation** [m^3]	**Avg. WP**[US$/$m^3$]
Agriculture	9000	12989	26
Domestic and Industry	6015	7654	16
Environment	8179	2551	0.3
Total yield	**23194**	**23194**	

Table 4.10 shows that the allocative strategy could be improved if water were allocated across sectors that had high water productivities. The agriculture sector had an income of 337 705 US$, domestic and industry had 122 464 US$ and environment had 765 US$. The allocation for environment sector was substantially reduced to allow for only 11 % of the reservoir yield which could be sufficient for other minor uses which were not captured in the study. The results showed that incomes were increased by an overall 313 % from scenario one.

Table 4.10: Incomes for re-allocating water across sectors

Sector	Scenario 1	Scenario 2	Scenario 3
Agriculture	106 500	313 110	337 705
Domestic and Industry	656	38 279	122 464
Environment	4371	4 543	765
Total income	**111 527**	355 932	**460 934**
Overall increase (%)	**0**	219	**313**

NB: Values in US$

4.7.4 Scenario 4: Distribute Sectorally Re-allocated Water

Scenario four (4) given in Table 4.11 was aimed at distributing sectorally re-allocated water of scenario three (3) to sub-sectors of scenario two (2):

Table 4.11: Scenario 4: Distribute sectorally re-allocated water

Sub-sector	Percentage-scenario 2	Scenario 4 allocation [m^3]	WP [US$/$m^3$]
Livestock	65	8443	49.70
Crops	35	4546	7.10
Domestic	80	6123	0.03
Industry	20	1531	31.70
Grass	15	383	0.02
Fish & others	85	2168	0.65
Total yield		23194	

Table 4.12 shows that incomes could be increased by an overall 350 % from scenario one. The agriculture sector had an income of 451 887 US$, domestic and industry had 48 710 US$ and environment had 1417 US$.

Table 4.12: Incomes from distributing sectorally re-allocated water

Sector	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Agriculture	106 500	313 110	337 705	451 887
Domestic and Industry	656	38 279	122 464	48 710
Environment	4371	4 543	765	1 417
Total income	**111 527**	355 932	460 934	**502 014**
Overall increase (%)	**0**	219	313	**350**

NB: Values in US$

4.7.5 Selection of the Allocative Strategy

Table 4.13 gives a summary of results of the four scenarios.

Table 4.13: Summary of scenarios

Scenario	Zero	First	Second	Third
Total Income (US$)	111 527	355 932	460 934	502 014
Income per person per six months (US$)	86	275	356	387
%age Increment from scenario one	0	219	30	9

Incomes were distributed per person per a six-month period (April-September). Percentage increments in income for each scenario have been presented in ascending order of magnitude. Moving from scenario two (2) to scenario four (4), the results show that there was diminishing percentage incremental benefit of 219, 30 and 9 over preceding scenarios. These results showed that scenario four (distributing sectorally allocated water across sub-sectors with high water productivities) was the ultimate strategy which could contribute optimally to the prioritised societal objective (value) of cash (income). This scenario considered the rearing of donkeys, cattle and goats; growing of tomatoes and small vegetables; brick making and domestic water use. 11% of reservoir yield was reserved for environmental use. The societal objectives of health, shelter, power and plant nutrients were expected to be served from increased livestock rearing, crop production and brick making since multiple benefits of water mutually reinforce each other for the better (Van Koppen et al., 2006). The selected strategy may lead to increased food security and reduced poverty which would eventually improve livelihood (Twikirize, 2005) through implementation of the virtual water concept.

Results of this study illustrate that knowledge of reservoir yield (Mugabe, 2005), sector water allocation and water productivities of sub-sectors for small reservoirs was an important tool for achieving societal objectives. The results of the scenarios confirm the null hypothesis that water productivity can be used as a tool for formulating water allocative strategies for various uses and that current water allocation was not based on value of uses.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.0 Introduction

This chapter presents conclusions and recommendations on how to determine total water productivity and apply this to value and allocate scarce water resources to uses that optimise societal benefits in semi-arid areas. The conclusions and recommendations culminated from results discussed in the previous chapter as given below:

5.1 Conclusion

The study established that most catchment areas where the reservoirs were located in Avoca were still underdeveloped and that the reservoirs had low dry season yield. These factors entail that the available water resources should be prudently allocated and utilised for productive functions. Otherwise, stakeholders in the water sector may have to consider developing more small reservoirs in most upper parts of the catchments in order to ease pressure on the current dry season reservoir yield and improve livelihoods. However, development of more reservoirs should be embarked on mindful that yield diminishes with development level. Dam development may also be an expensive option unlike the application of the water productivity-based allocative strategy.

In spite of high evaporation rates, the study has shown that small multiple-use reservoirs play an important role in the livelihoods of rural communities. Through the multiple uses, riparian communities acquire income and improve their health besides provision of shelter, draught power and plant nutrients (manure). These uses contribute integrally to the improvement of livelihoods of communities (Van Koppen et al., 2006). Hence, planning, design and management of small reservoirs should recognize and factor-in these integral uses in order that the accrued benefits should contribute to the reduction of poverty (WELL, 2005) prevalent among rural communities of semi-arid southern Zimbabwe. Small reservoirs can contribute to the attainment of the MDGs through prioritisation of water allocation based on water productivities.

The four scenarios (strategies) considered in the selection of the best water allocative strategy illustrated that water productivity can be used as a tool for formulating water allocative strategies for various uses and that current water allocation was not based on value of uses. The strategy that had ultimate significant contribution to the prioritised social objective of cash (income) was the distribution of sectorally allocated water across sub-sectors with high water productivities. Total income increased by 350% from the current situation. This strategy entailed rearing of donkeys, cattle and goats/sheep; growing of tomatoes and small vegetables; brick making and domestic water use. 11% of reservoir yield was reserved for environmental use. The study argues that products which had low water productivity values should be considered under the virtual water concept or should be produced during the rainy season when water resources are relatively abundant. Hence, scarce water resources should be allocated to sub-sectors (products) which have high water productivities without impairing environmental capacity and domestic water supply. The allocation strategy should also incorporate societal values since communities in different locations have different perceptions and appreciation for water which may mimic intrinsic elements of traditional experiences (Twikirize, 2005). Furthermore, value of water varies across time, space and stakeholders at various scales (Hussain et al., 2007). Hence, selection of the best allocative strategy should seek wide inputs from various stakeholders on the determination of societal values. Stakeholder consultations were not conducted extensively in the present study because of time constraints.

5.2 Recommendations

Scarce water resources should be allocated based on individual-use water productivities and societal values in order to optimise benefits. However, wide consultations with various stakeholders on societal preferences should be held in order that actual societal values are incorporated in the formulated strategy.

Water sector stakeholders should consider developing more multiple-use small reservoirs in semi-arid catchments in order to ease pressure on the available dry season reservoir yield and improve livelihoods.

Since the period of this study was short (less than six months), there may be need, in future, to carry out a longer study (1-5 years) to develop a variable-reservoir yield water productivity based strategy which will consider trends in crop yields, produce prices and actual reservoir yield variation with time. Further studies should also be carried on the conceptual basis for calculating water productivity for fish, grass and recreation at field level. Similarly, simple approaches for estimating flows from un-gauged semi-arid catchments into small reservoirs need to be studied further.

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APPENDICES

APPENDIX 1A: MONTHLY RAINFALL DATA (MM): SIWAZE DAM

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2006/07		148.7	78.5	23.0								
2005/06	12.3	21.7	143.0	110.1	85.8	39.1	4.0	12.0	2.5	1.5	0.0	0.0
2004/05	0.0	0.0	137.8	58.2	15.0	25.3	8.4	0.0	0.0	2.5	0.0	0.0
2003/04	12.3	17.3	10.4	299.4	119.3	166.9	23.0	0.0	0.0	0.0	0.0	0.0
2002/03	30.3	13.5	44.0	67.2	43.5	245.5	0.0	8.0	31.8	1.2	0.0	0.0
2001/02	16.9	153.4	124.3	9.0	7.0	5.5	89.5	0.0	13.5	13.7	0.0	2.5
2000/01	23.7	81.8	75.0	17.0	150.3	34.4	17.5	4.5	0.0	16.6	0.0	69.6
1999/00	11.2	87.5	48.9	146.1	314.1	19.3	0.0	8.2	54.3	6.0	0.0	0.0
1998/99	10.0	32.4	93.6	56.4	133.5	29.4	6.3	0.0	0.0	0.0	0.0	3.3
1997/98	9.5	25.3	9.5	157.8	5.6	7.8	0.0	0.0	0.0	0.0	0.0	0.0
1996/97	27.3	73.0	34.5	237.6	24.5	65.0	45.8	1.0	0.0	4.0	0.0	14.5
1995/96	29.0	153.5	133.0	132.3	130.0	0.0	0.0	8.7	0.0	26.5	0.0	0.0

Source: Zimbabwe National Water Authority, Siwaze Dam Office (Mr. Madebe)

APPENDIX 1B: MONTHLY EVAPORATION DATA (MM): SIWAZE DAM

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
2006/07		173.8	206.5	181.5								
2005/06	270.3	249.4	146.4	171.1	197.0	154.6	136.1	142.7	106.3	140.7	164.7	243.0
2004/05	323.6	306.7	216.7	235.7	213.8	189.9	162.8	150.9	120.8	124.2	202.1	238.1
2003/04	220.5	234.4	198.1	235.7	175.7	141.2	120.9	114.1	88.4	100.2	177.8	208.2
2002/03	244.1	231.2	245.2	268.6	241.8	181.7	178.3	142.1	147.0	113.2	173.1	204.4
2001/02	228.3	186.0	156.2	279.6	225.8	247.7	175.4	169.4	104.9	138.4	184.2	199.5
2000/01	244.7	194.5	207.3	227.8	134.8	145.8	155.3	145.0	134.1	110.2	182.6	229.7
1999/00	208.4	201.1	211.6	201.8	117.4	164.3	158.4	114.1	110.3	94.3	167.7	196.2
1998/99	207.2	203.7	174.9	193.3	118.6	166.2	147.3	154.7	129.8	133.5	183.8	203.7
1997/98	231.3	234.9	275.0	230.3	174.2	211.7	218.4	175.6	136.5	153.5	172.3	187.4
1996/97	238.4	202.0	204.7	237.6	195.2	233.3	134.4	139.2	126.5	121.4	214.6	183.8
1995/96	266.0	223.7	243.2	167.0	175.7	179.9	146.2	118.2	112.4	112.9	162.0	208.7
1994/95	236.4									130.1	199.8	226.5

Source: Zimbabwe National Water Authority, Siwaze Dam Office (Mr. Madebe)

APPENDIX 2A: DIP TANK LIVESTOCK DATA

Reservoir	Cattle					Total	Goats	Sheep	Donkeys
	Bulls	Oxen	Cows	Heifers/Steers	Calves				
Avoca	47	361	340	268	21	1037	1049	691	547
Bova						133	240	154	98
Denje	25	126	228	235	65	679	855	567	304
Dewa						107	115	101	95
Manzamhlophe	43	318	211	293	150	1015	545	243	125
Mashoko	38	294	124	238	112	806	355	195	80
Mzambani						130	103	89	90
Sifinini						112	178	110	98

Source: Dept. of Veterinary Services, Avoca and Sanali (Messrs: N.Sibanda, B. Ndhlovu)

APPENDIX 2B: LIVESTOCK TRAFFIC COUNT DATA

Reservoir	Cattle	Goats	Sheep	Donkeys
Avoca	246	139	21	46
Bova	148	127	30	38
Denje	99	100	14	68
Dewa	165	220	23	58
Manzamhlophe	17	69	0	8
Mzambani	17	13	4	4
Sifinini	134	107	27	30

APPENDIX 2C: CALCULATION OF LIVESTOCK WATER PRODUCTIVITY

Reservoir	Livestock	type	Cost(Z$/yr)	Traction(Z$)	Milk(Z$)	Nitrogen(Kg)	Cost Nitrogen(Z$)	cost(US$)	Water (m^3/yr)	WP(US$/$m^3$)
Avoca	cattle	246				2035.3	7584968.94		1334	31.37
	oxen	84		14400000						
	cows	64			22570500					
	Cattle sold	27	18225000					41853.65		
	Goats	139	1912500			159.7	595155.28	1671.77	152	11.03
	Sheep	21	297500			24.1	89813.66	258.21	23	11.23
	Donkeys	46		23985000		222	827329.19	16541.55	113	146.64
										200.27
Bova	cattle	148				1224.5	4563354.04		804	31.29
	oxen	51		8640000						
	cows	39			13753500					
	Cattle sold	16	10800000					25171.24		
	Goats	41	1742500			145.9	543726.71	1524.15	139	10.97
	Sheep	10	425000			34.5	128571.43	369.05	33	11.25
	Donkeys	34		19890000		183.4	683478.26	13715.65	94	145.60
										199.12
Denje	cattle	99				819.1	3052546.58		538	31.39
	oxen	34		5760000						
	cows	26			9169500					
	Cattle sold	11	7350750					16888.53		
	Goats	32	1360000			114.9	428198.76	1192.13	109	10.90
	Sheep	5	190400			16.1	60000.00	166.93	15	10.91
	Donkeys	68		35404200		328.2	1223105.59	24418.20	169	144.83
										198.02

Dewa	cattle	165				1365.2	5087701.86		897	31.64
	oxen	56		10098000						
	cows	43			15129000					
	Cattle sold	18	12251250					28377.30		
	Goats	220	2992000			252.8	942111.80	2622.74	241	10.90
	Sheep	23	312800			26.4	98385.09	274.12	25	10.88
	Donkeys	58		30197700		279.9	1043105.59	20827.20	144	144.83
										198.25
Manzamhlophe	cattle	17				140.7	524347.83		92	31.64
	oxen	6		1040400						
	cows	4			1558500					
	Cattle sold	2	1262250					2923.67		
	Goats	69	938400			79.3	295527.95	822.62	76	10.90
	Sheep	0	0			0	0.00	0.00	0	
	Donkeys	8		4165200		38.6	143850.93	2872.70	20	145.09
										187.62
Mzambani	cattle	17				140.7	524347.83		92	31.64
	oxen	6		1040400						
	cows	4			1558500					
	Cattle sold	2	1262250					2923.67		
	Goats	13	176800			14.9	55527.95	154.89	14	10.91
	Sheep	4	54400			4.6	17142.86	47.70	4	10.84
	Donkeys	4		2082600		19.3	71925.47	1436.35	10	145.09
										198.47
Sifinini	cattle	134				1108.7	4131801.24		728	31.64
	oxen	46		8200800						
	cows	35			12286500					
	Cattle sold	15	9949500					23045.73		
	Goats	107	1455200			123	458385.09	1275.72	117	10.89
	Sheep	27	367200			31	115527.95	321.82	30	10.91
	Donkeys	30		15619500		144.8	539627.33	10772.75	74	144.80
										198.24

APPENDIX 3: QUESTIONNAIRE

A: Basic Identification Data *(Enumerator)*

Reservoir		Hydro-zone	
GPS: Easting		Village	
: Northing		Ward Number	
River		Date	

B: Reservoir Data *(Key Informant)*

B1			
Respondent	***Sex*** *(tick)*	***Age(yrs)***	***Position*** *(tick)*
	Male / Female		Village Head / Councillor / Chairman / Other

B2	For how many years have you lived in this area?
B3	When was the dam (reservoir) constructed?

B4	***Who constructed the Dam***	***Who sets rules during water shortages/ low level***
Government		
ZINWA		
Dam Committee		
Village Head		
Councillors		
Others (specify)		

B5	***Dam Purpose****(tick)*	***Current use***	***Uses during shortages/ low level*** *(Rank)*
Livestock watering			
Domestic use			
Watering crops			
Fisheries			
Recreation			
Others (specify)			

B6								
Reservoir water level	Feb	March	April	Aug	Sept	Octo	Nov	Other
A) Which month is water level highest?								
b) Which month is water level lowest?								

B7	How many households use water from the reservoir? …………………………………………………………………………………………….
B8	What rules guide daily water use from the reservoir?
B9	What rules guide water use during low water levels or shortages in the reservoir?
B10	What information / basis are used in setting the rules during water shortages or low water levels?
B11	How are rules of using water enforced on users?
B12	What can be done to improve the rules of using water from the reservoir?

B13	What problems are faced when using water from the reservoir? a) ………..………………………………………………………………………………………………….. b) ……… c) …………..………………………………………………………………………………………..............

C: Domestic Water Use *(Household)*

C1			
Respondent	***Sex***	***Age(yrs)***	***Position***
	Male / Female		Husband / Wife / Single / Other

C2	Once	Twice	Thrice	Four times	Other
In a day, how many times do you go to draw water from the reservoir?					

C3	How much water do you draw each time you go to the reservoirs?

C4	Food preparation	Sanitation/hygiene	Drinking	Others (specify)
a) In a day, how many times do you use water for:				
b) In a day, how much water do you use for:				
c) What are the main uses of water when it is scarce:				

C5	How many times in a week do you do laundry (washing clothes)
C6	How much water do you use each time you do laundry?

C7	Borehole	Well	Tap	Other
Do you have other water sources?				

C8	How many people are there in your household?
C9	How much money would you be willing to pay per month if water from the reservoir was charged? ……………………………………………………………………………………………(Z$)
C10	What problems are faced when using water from the reservoir for domestic use? a) ………..……………………………………………………………………………………… b) ………………………………………………………………………………………………. c) …………..………………………………………………………………………………………

D: Irrigation (Irrigation/nutritional garden farmers)

D1			
Respondent	***Sex***	***Age(yrs)***	***Position***
	Male / Female		Chairman / Committee Member / Farmer / Other

D2	Once	Twice	Thrice	Four times	Other
In a day, how often do you water your crops using reservoir water?					

D3	*2 litre*	*5 litre*	*10 litre*	*20 litre*	*100 litre*	
What size of containers are used in drawing water from the reservoir						

D4	How many households use reservoir water for irrigating crops?

D5	*Furrow*	*Basin*	*Strip*	*Other*
What irrigation method is used in watering your crops?				

D6	*Sprinkler*	*Bucket*	*Drip*	*Surface*	*Other*
What irrigation system is used in irrigating your crops?					

D7	For Drip Irrigation a) What is the number of emitters per lateral length………………………………………………. b) What is the emission rate………………………………………………………………………..
D8	How long do you irrigate (irrigation duration)? ……………………………………………………………………………………………....(hours)
D9	How often do you irrigate (irrigation interval)? …………………………………………………………………………………….....(days)
D10	How big is the garden that you irrigate? ……………………………………………………………………………………………(hectares)

D11	Maize	Vegetables	Spice	Millet/Sorghum	Wheat	
What portion (hectares) of your garden do you grow?						

D12	Do you practice crop rotation? a) Yes………………………………………………………………………………………. b) No………………………………………………………………………………………..
D13	How do you rotate the crops?
D14	In which month do you plant your main crop? *(Identify the crop)*
D15	In which month do you harvest your main crop? *(Identify the crop)*

D16	Maize	Vegetables	Spices	Millet/Sorghum	Wheat	
How much money do you get per year from:						

D17	What problems are faced when using water from the reservoir for irrigating your crops? a) ………..………………………………………………………………………………… b) …………………………………………………………………………………………

E: Livestock Keeping *(Household Level)*

E1			
Respondent	***Sex***	***Age(yrs)***	***Position***
	Male / Female		Husband / Wife / Single / Other

E2			
Livestock	***How many available***	***How many sold in a year***	***Cost of full-grown livestock (Z$)***
Cattle			
Donkeys			
Goats			
Sheep			
Pigs			
Rabbits			
Chickens			
Other			

E3	What is the distance to the source of water during dry and wet season a) Dry season..……………………………………………………………………………(Km) b) Wet season.………………………………………………………………………… (Km)
E4	How do you water your livestock? a) Drinking direct from the reservoir…….………………………………………………... b) Drinking away from reservoir using buckets or old tyres………………………………………

E5	Once	Twice	Thrice	Four times	Other
a) How often do you take your livestock to the reservoir for watering in a day					

E6	Borehole	Well	Tap	Other
Do you have other sources of water for your livestock?				

E7	What type of benefits (goods and services) do you get from your livestock? a) Meat……………………………………………………………………………..*(tick)* b) Milk.…………………………………………………………………………….*(tick)* c) Draught/traction or transport power………………………….………………………*(tick)* d) Hides………..……………………………………………………………...*(tick)* e) Money………..…………………………………………………………….*(tick)* f) Manure……………………………………………………………………..*(tick)* g) Other……………………………………………………………………….*(tick)*

E8	Dry season (Apr-Octo)	Wet season(Nov-Mar)
a) How many livestock do you milk during:		
b) How many litres of milk do you get during:		

E9	How many livestock assist you with draught / traction/ transportation? a) Cattle……………………………………………………………………….*(Number)* b) Donkeys…………………………………………………………………….*(Number)* c) Other……………………………………………………………………..*(Number)*
E10	How many times in a week do your livestock work? a) Cattle………………………………………………………………………………………… b) Donkeys………………………………………………………………………………………. c) Other……………………………………………………………………..
E11	How much can it cost to hire livestock to cultivate on a farm for one day?
E12	How much can it cost you to hire livestock to cultivate one hectare of land?
E13	How much manure do you apply in your garden in a year? …………………………………………………………………………………………………
E14	What problems do you face when using water from the reservoir for irrigating your crops? a) ………..……………………………………………………………………………………… b) …………………………………………………………………………………………………

F: Fisheries *(Fishers)*

F1				
Respondent		***Sex***	***Age(yrs)***	***Position***
		Male / Female		Husband / Wife / Single/ Other
F2	What type of fish is available in the reservoir? a)……………………………………………………………………………………………………. b)…………………………………………………………………………………………………… c)……………………………………………………………………………………………………			
F3	At what scale are you operating in your fishing? a) small-scale…………………………………………………………………………………….. b) large-scale			
F4			Dry season (Apr-Nov)	Wet Season(Dec-Mar)
	a) How many fish do you catch?			
	b) How often do you fish?			
F5	How many fishermen (fishers) operate on the reservoir?			
F6	What are the regulations for fishing in the reservoir?			
F7	What water problems do you face as fishermen on the reservoir? a) …………….……………………………………………………………………………………. b) …………..…………………………………………………………………………………... c) …………..…………………………………………………………………………………….			

G: Brick Making *(Brick Makers)*

G1			
Respondent	***Sex***	***Age(yrs)***	***Position***
	Male / Female		Husband / Wife / Single /Other
G2	How many bricks do you mould in a day or year? a) Day…………………………………………………………………………….*(bricks)* b) Year……………………………………………………………………………*(bricks)*		
G3	How much water do you use to mould 1000 bricks?		
G4	How much does one brick cost? …………………………………………………………………………………………(Z$)		
G5	How many households/villages are involved in brick making? a) Households………………………………………………………………………… b) Villages…………………………………………………………………………….		
G6	In which months do you make bricks?		
G7	What problems are faced when using water for brick making? a) ………..……………………………………………………………………………… b) ………………………………………………………………………………………. c) …………..…………………………………………………………………………….		

H: Grass Harvesting *(Grass harvesters)*

H1			
Respondent	***Sex***	***Age(yrs)***	***Position***
	Male / Female		Husband / Wife / Single /Other
H2	In which month do you start harvesting grass around the reservoir?		
H3	In which month do you stop harvesting grass around the reservoir?		
H4	How many bundles of grass do you harvest from the reservoir during this period?		
H5	How many households harvest grass from the reservoir?		
H6	What do you use grass harvested from the reservoir for? a) Fencing gardens...…………………………………………………………………… b) Thatching houses……………………………………………………………………… b) Others…………………………………………………………………………………		
H7	What is the cost of each bundle of grass? ……………………………………………………………………………………………(Z$)		
H8	How many bundles of grass do you need to thatch one kitchen? ………………………………………………………………………………………………		
H9	What problems are faced when using water for brick making? a) ………..…………………………………………………………………………… b) ………………………………………………………………………………………. c) …………..…………………………………………………………………………		

I: Recreation

I1						
Respondent	***Sex***	***Age(yrs)***	***Position***			
	Male / Female		Husband / Wife / Boy / Girl / Other			
I2			Once	Twice	Thrice	Other
a) How often do you come to the reservoir for recreation (i.e. relaxing, chatting, canoeing, swimming) in a week?						
I3			30 min	1 hrs	2 hrs	Other
How long do you stay at the reservoir (i.e. relaxing, chatting, canoeing, swimming) in a week?						
I4	How many people come to the reservoir to chat, swim or canoe?					
I5	How much money can one earn when hired to do casual work by government, NGOs or private person for one hour/ half-day or one day? 1 hr……………………………………………………………………………………..*(Z$)* Half-day…………………………………………………………………………..*(Z$)* One day..……….………………………………………………………….............*(Z$)*					
I6	What water problems do you face when recreating at the reservoir? a) ………..…………………………………………………………………………… b) ………………………………………………………………………………………. c) …………..…………………………………………………………………………					