ABSTRACT

In Zimbabwe, sediment load has exceeded normal design limits in many reservoirs, thus reducing storage capacity and shortening their useful life for human benefit. The study sought to investigate the impact of land use and land cover change on reservoir sedimentation. Two reservoir catchments, Sebastopol Dam (MAR: 135 mm yr^{-1}) and Chesa Causeway Dam (MAR: 129 mm yr^{-1}) in the Upper Manyame and Upper Ruya subcatchments (Manyame and Mazowe Catchments), respectively, were studied. Sedimentation rates during the 2009-2010 rainfall season at both sites were quantified using hydrographic surveys and grab sampling methods. The study also examined the driving factors for land use and land cover change and how they have changed over time (1991 - 2009) using Landsat TM images. Sedimentation analysis showed that the current sediment specific yield at Sebastopol is 390 $tkm^{-2}yr^{-1}$-using the grab sampling method and 258 tkm^{-2} yr^{-1} from hydrographic survey while that at Chesa Causeway is 774 tkm^{-2} yr^{-1} from the grab sampling method and 503 tkm^{-2} yr^{-1}: from hydrographic survey. Projections based on current sediment loading indicate that Sebastopol dam will last for another 11 years while Chesa Causeway will be silted up in 9 years. Contrary to common belief, satellite images show that vegetated land is increasing while bare land is reducing at Chesa Causeway dam catchment. Both sediment quantification methods confirmed that Chesa Causeway dam is in a less conserved catchment than Sebastopol dam and also that Chesa Causeway is a small dam built in a large catchment area with a very small design gross storage ratio of 0.01; land use activities influence the lifespan of reservoir and, in this case, the less conserved Chesa site which is characterised by alluvial gold panning activities will have a much less useful lifespan of 25 years compared with Sebastopol Dam (40 years). From the projection made, if this trend continues at the current rate of sediment loading, alternative water sources need to be explored immediately at both study sites for the communities who depend on both dams for sustenance of livelihoods. The study recommends that hydrographic surveys and the grab sampling method should be both used for estimating sedimentation rates in reservoirs as they can be effective and useful tools for decision making in integrated catchment management; all catchment councils should adopt and enforce comprehensive catchment management plans.

Keywords: Land use, land cover, reservoir, sedimentation, specific sediment yield

DECLARATION

I declare that this dissertation is my own work. It is being submitted in partial fulfilment for the award of the degree of Master of Science in Integrated Water Resources Management (IWRM) to the senate of University of Zimbabwe. To the best of my knowledge, this work has not been submitted before for any other degree.

GODWIN. A. MAVIMA............................ ....

Name and signature Date

DEDICATION

This work is dedicated to my wife and other family members who have supported and encouraged me through my education. May God richly bless them.

Acknowledgements

I thank the Lord for the opportunity given to me to pursue this course. He has made me prevail over all the challenges that came my way.

I also thank Waternet for securing a full sponsorship for me so that I could pursue a Masters Degree in IWRM.

My sincere appreciations go to my supervisors: Dr M. J Tumbare and Eng. H. Makurira from the Department of Civil Engineering at University of Zimbabwe. It was a challenge coming up with this thesis but I managed through your constructive criticism and guidance. Thank you very much indeed may the Lord bless you abundantly.

I would also like to thank Mr Dzvairo of the ZINWA Planning Department for sponsoring me during the fieldwork of my thesis. Special thanks also to Messers: Kwashi, Madhina, Simanguwo, Nyatsambo, Mahoseni and Mutandwa all from ZINWA Data Section for their technical assistance during the hydrographic survey and grab sampling expeditions. It would have been impossible for one man to do it. I would want to sincerely appreciate the contribution and guidance from Mr I. Gwitira from the Geography department at University of Zimbabwe on the GIS part of my thesis.

Lastly, I would like to thank all lectures and fellow students who supported and encouraged me in various ways that have led to the completion of this thesis.

List of Abbreviations and Acronyms

AAR	Average annual rainfall
A_R	Reservoir surface area
B_f	Base Flow Index
E_v	Volume of evaporated water in a year
MAR	Mean annual runoff
mg/l	milligrams per litre
Mm^3	Million cubic metres
MWRD	Ministry of Water and Resources Development
S_c	Sediment concentration
S_{sy}	Specific sediment yield
S_y	Sediment yield
$tkm^{-2}yr^{-1}$	tonnes per square kilometre per year
V_{gross}	Gross dam capacity
V_{perc}	Reservoir volume as a % of average annual runoff
Y_N	Reservoir net yield
ZINWA	Zimbabwe National Water Authority

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CHAPTER ONE

1.0 Background

Sedimentation is a process whereby particulate matter is transported by fluid flow and deposited as a layer of solid particles on the bed or bottom of water bodies such as reservoirs or lakes (Sedimentation manual, 2006). Land use and land cover changes have been singled out as the main contributing factors to sedimentation of reservoirs. This has resulted in many reservoirs having a reduced useful lifespan for human benefit.

In Northwest China, a study was conducted investigating how the changes of land use and land cover influence soil erosion and reservoir siltation on the upstream of Shiyang reservoir (Zhou, 2002). The study found out that 43 % of woodland areas had been turned into agricultural land and soil erosion intensity was more severe on cropped land. The author concluded that anthropogenic activities were the main causes of land use changes and siltation in the Shiyang Reservoir (Zhou, 2002).

In Ghana, Burekese reservoir, a similar study was carried out. Landsat TM images from 1973, 1986 and 2000 were analysed using ArcGIS to assess the impact of land use and land cover changes on Burekese catchment. Hydrographic surveys conducted during the study period at the same locality showed a decrease in storage capacity of 45 % due to siltation. The changes in land use and land cover which caused the siltation of the reservoir were attributed to deforestation, population growth and lack of proper education of the communities in catchment management (Adjei et al., 2008).

Expanding population in Zimbabwe has led to the clearing of marginal lands for agricultural production and for settlement purposes. This has resulted in increased erosion, more rapid rates of sediment loading in reservoirs and reduced socio-economic benefits which they were built for (MWRD 1983, ZINWA, 2004).

Information on the upstream land use activities and land cover change, sediment yield within a catchment is required for controlling sediment accumulation in reservoirs (Kamtukule, 2008).

1.1 Problem Statement

In Zimbabwe sediment studies have only been conducted once for almost 90 % of the dams in Zimbabwe (ZINWA, 2004). Therefore the correlation between changes in land use and land cover (over given period of time) with sedimentation rates in reservoirs is least understood. This has resulted in sediment loads exceeding normal designed expectations in some reservoirs, thus reducing storage capacity and a shortened useful lifespan.

1.2 Research objectives

1.2.1 General objective

To investigate the impact of land use and land cover changes on the sedimentation rate of Chesa Causeway and Sebastopol dams in Upper Ruya and Upper Manyame sub-catchments respectively.

1.2.2 Specific objectives

1. To quantify the current sedimentation rates of Chesa Causeway and Sebastopol dams.

2. To determine whether the sedimentation rates are linked to land use and land cover change.

3. To predict the impact of sedimentation on the available water for use.

1.2.3 Research questions

The research is focussed on assessing the impact of different land use activities and land covers on reservoir sedimentation. The study attempted to answer the following questions:

1. What are the current sedimentation rates of Chesa Causeway and Sebastopol dams?

2. What are the driving factors for land use and land cover change and how have they changed over time?

3. What are the predictions on the impact of sedimentation on the available water for use?

1.3 Justification

In most reservoirs in Zimbabwe sediment load has exceeded normal designed expectations, thus reducing storage capacity and shortening their useful life for human benefit. This has resulted in socio-economic problems which include decreased agricultural productivity, increased water supply treatment costs, decreased power generating capacity and loss of storage capacity (Murty, 1998).

For effective control of the sedimentation problem due to land use and land cover change a holistic approach is needed. This requires involvement of all relevant stakeholders in the water sector including the water users, government and other non-state actors in integrated catchment management.

Spatial and temporal patterns of land use and land cover change within a catchment need to be known so that policy makers and scientists can make informed decisions in controlling excessive sedimentation of reservoirs. Therefore this research seeks to add more evidence to the challenges of loss of storage and hence compromised livelihoods as a result of changes in land use and land cover in Upper Ruya and Upper Manyame subcatchments respectively.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sedimentation of Reservoirs

Excessive sedimentation in many reservoirs has led to reduced expected useful lifespan for human benefit. The causes, the transport process, quantification of sediment in reservoirs, impact of sedimentation in reservoirs and responses to sedimentation by scientists and policy makers are discussed in detail in this section.

2.2 Causes of sedimentation

2.2.1 Catchment size

In Northern Ethiopia the size of the catchment was found to be positively contributing to the sediment loads in the reservoirs. The smaller the catchment the greater the chances of suspended load being carried by the flood to reach the reservoir in a relatively shorter distance without settling somewhere in the watershed (Aynekulu *et al.*, 2006). This results in sediment load rapidly filling up the dead storage zone therefore reducing the useful life of reservoirs.

2.2.2 Vegetal apron in a catchment

If catchment area is covered with a vegetal apron like grass, plants, forest area, the soils are held together by elaborate network of roots which underlies the forest floor. This results in reduced sediments into the rivers and reservoirs. The catchment area is also protected from the effects of wind and rain erosion by the forest canopy above (Hildyard and Goldsmith, 1984). In the Dominican Republic the main cause of sedimentation of the reservoirs in Nizao was mainly attributed to deforestation over the last 70 years. With, Valdesia reservoir completed in 1976 having a projected economic life of 69 years reported to be 26 % filled with sediments and 60 % of its dead storage capacity filled only after 13 years (Nagle, 2001).

2.2.3 Topography of catchment area

Although the sediment source can often be localised to the highly erodible hill slopes such as heavily used agricultural fields in the headwater catchments, the transport and storage processes in the river, thus linking the hill slopes with the reservoir, is not well understood (Muller, 2007). Steep and long slopes develop high velocity of flow, which will cause more erosion thereby making the river to carry subsequent amount of sediments. Eventually the sediments will be deposited into reservoirs where the river would be flowing into. In the Dominican Republic cultivation of erosive soils on steep slopes coupled with deforestation in the Nizao watershed has led to the sedimentation of reservoirs (Nagle, 2001).

2.2.4 Population increases

Rapid population growth led to fast land-use changes from forest to agricultural land. These changes together with the steep slope topography and inappropriate land-use practices in the catchment have resulted in severe soil erosion. Eroded sediment particles are then transported away by water. Nizamsagar in India is one of the heavily silted reservoirs constructed in 1931 with a live storage of 841 million m^3 but according to echo sounding technique done in 1965 it was found out that about 61% of live storage has been lost. This was attributed to increase in population density within the catchment which had increased from 116 to 174 per km^2. This along with intensive agricultural activities and cattle grazing in soils susceptible to erosion has led to severe erosion, which then results in sedimentation of reservoirs (Bowonder *et al.*, 1985).

2.2.5 Climatic effect

The climate also plays a significant role in the deposition of sediments in the reservoirs. For instance Northern New South Wales is characterized by a sub-tropical climate with a dry season (winter) and a wet season (summer). This annual cycle is, however, subjected to inter-annual climatic events: the El-Niño and La Nina In terms of soil erosion and sediment load, the most extreme hydrological events are exceptional floods following a long drought period (associated with an El-Niño). Dry conditions retard the growth of vegetation cover and the following wet conditions erode the bare unprotected soil. The following torrential rains easily wash away the soils and, as a result, the streams carry a large sediment load which will be deposited into the reservoirs (Chanson and James, 1998).

2.2.6 Agricultural practices

Cultivation of crops makes soil loose and run off will carry a lot of sediment into the river which will be subsequently carried into the reservoirs. According to the Chimanda Dam silt survey report (2004), it was found out that large part of the catchment is under cultivation. The soils are often disturbed and can be easily detached by runoff. In the last 15 years of operation, the dam has lost a storage capacity of 33.2 %. At this rate it might be silted up in 30 years against its designed lifespan of 50 years (ZINWA, 2004).

Overally land use and land cover change are the major causes of massive siltation of many dams. The spatial dimensions of land use and land cover need to be known based on remote sensing satellite data and DEM (using ArcGIS software). This can be achieved through frequent mapping of reserved forests and woodlands thus generation of information for governments informing them of the magnitude of encroachment.

According to Hill (1999) land use and land cover change in Africa is currently accelerating and causing widespread sedimentation problems in many river catchments and thus needs to be mapped. This is important because the changing pattern of land use and land cover reflect changing economic and social conditions. Monitoring such changes is important for coordinated actions at the national and international levels in integrated catchment as well as basin management (Bernard *et al.*, 1997).

2.3 Sediment transport process

The load transport characteristics have a significant bearing on water regime of any stream and they can influence its morphology. The majority of load transported in the streams is suspended load, and the suspended load transport processes are related to the contaminant transport. Therefore, changes in the suspended load transport regime, although usually not detected on time because their monitoring has been neglected, have far reaching consequences on a stream hydrologic system and sedimentation processes (Buselic and Rubinic undated)

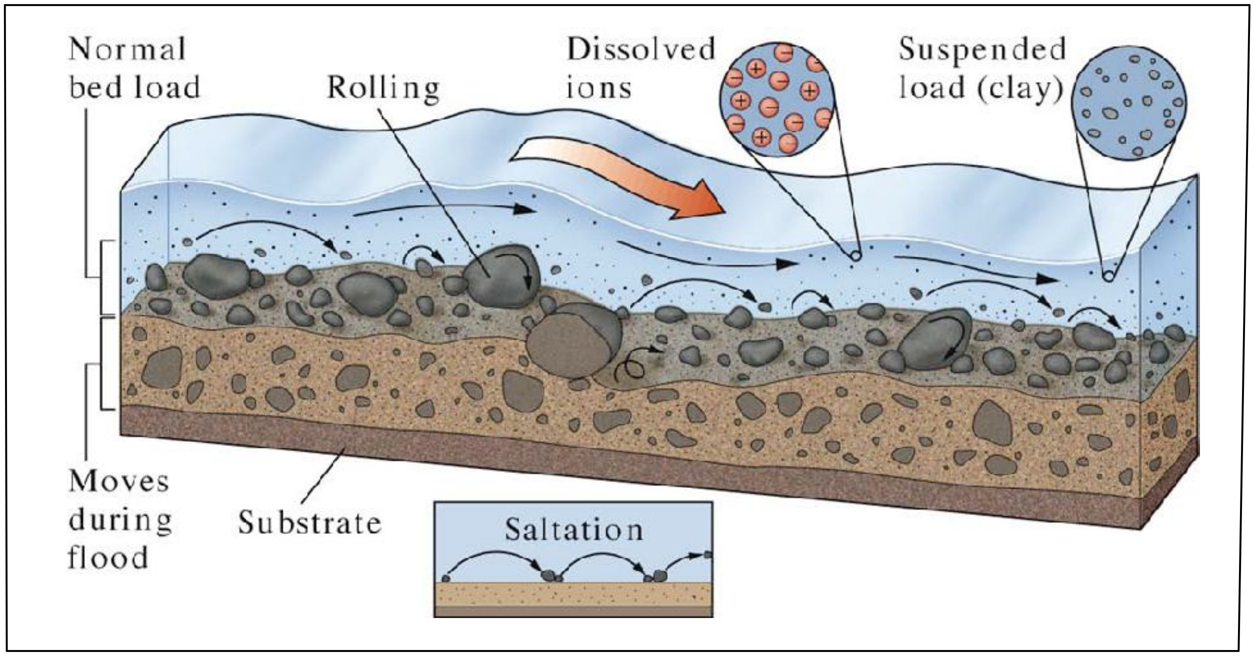

Figure 2.0 *Comparison of bed load and Suspended Load Transport Regime (Buselic and Rubinic undated)*

2.3.1 Suspended load

Suspended sediment is the finer particles (dissolved ions and clay particles) which are held in suspension by the eddy currents in the flowing stream, and which only settle out when the stream velocity decreases, such as when the streambed becomes flatter, or the stream discharges into a pond or lake (Abraham and Pratt, 2002).

2.3.2 Bed load

According to Abraham and Pratt (2002) bed load is the movement of particles whose successive contacts with the bed are limited by the effects of gravity. This means that the particles do not go into suspension or may be defined as sediment that is transported in a stream by rolling, sliding, or saltating along the bed and very close to it, the movement of the bedload normally takes place during flooding.

2.4 Impact of sedimentation on Reservoirs

Each year up to 1% of the world's reservoir capacity is lost to sedimentation (Howard, 2000). According to a report compiled by Ainworth (2005), loss of storage due to sedimentation exacerbates the problem of providing enough storage for the rising population with its rising aspirations and standards. The report noted that demand for additional storage is assumed to be 1.6% in 2000 falling 1.2% in 2030. Furthermore the reported noted that South America, Africa and Asia water storage demands would outstrip supply in the foreseeable future and the storage shortage is attributed to high sedimentation rates in these regions.

Halcrow (2001) noted there are positive and negative impacts of reservoir sedimentation. The positive impacts include;

- Generation of valuable wetland habitat with biological diversity;
- Reduction of fine sediment discharge and hence improved water quality.

Negative impacts of sedimentation include;

- Loss of reservoir water storage capacity;
- Decreased hydropower generation;
- Reduced agricultural production where reservoirs supply water for irrigation;
- Need for restrictions on draw down of reservoirs through bottom outlet valves to prevent sediment being mobilised during storms;
- Need for periodic operations of bottom outlet valves for safety reasons.

Furthermore, Kamtukule (2008) found out that generally in Malawi there is deterioration of ecosystem condition due to removal and transport of sediment deposits into reservoirs. This was according to findings of a study investigating the impact of sedimentation on availability of water on Chamakala dam.

In Zimbabwe previous silt survey studies done on major dams have concluded that dams are losing more than half of their design capacity in the first 11 to 12 years of operation. Therefore there is need for strategic interventions in order to address excessive sedimentation of reservoirs. Excessive sediment loading in reservoirs has impacted negatively on the livelihoods of communities' dependant on them as a water source (Mufure Causeway silt survey report, 2003).

2.5 Responses to the sedimentation problem

2.5.1 Land and catchment management

- Soil conservation practices

In the upstream watershed of a reservoir, three basic patterns of soil conservation measures are commonly taken to reduce sediment load entering the reservoir and these are: structural measures, vegetative measures and tillage practices. Structural measures include terraced farmlands, flood interception and diversion works, gully head protection works, bank protection works, check dams, and silt trapping dams. Vegetative measures include growing soil and water conservation forests, closing off hillsides, and reforestation. Tillage practice includes contour farming, ridge and furrow farming, pit planting, rotation cropping of grain and grass, deep ploughing, intercropping. These measures greatly reduce erosion on the land surface, channel bank cutting, and head-cutting (Sedimentation Manual, 2006).

2.5.2 Hydraulic methods

- Sluicing

This involves diverting sediment beyond the reservoir. In carrying out sluicing operations a substantial portion of the incoming sediment load is passed through the reservoir before the sediment particles can settle. This is achieved through operation of the reservoir at a lower level during the flood season to maintain sufficient sediment transport capacity through the reservoir (Sedimentation Manual, 2006).

- Flushing

Flushing technique can also be used whereby the flows velocities in a reservoir are increased to such an extent that deposited sediments are remobilised and transported through level outlets in the reservoir (Sedimentation manual, 2006).

2.5.3 Mechanical removal methods

The mechanical removal methods involve the elimination of sediment after it has settled in the reservoir, dredging (a barge is used to break-up consolidated sediments and pump out sediment-entrained water), dry excavation (the reservoir is drained and heavy machinery is used to excavate and remove sediment). Lastly removal of sedimentation by hydro suctiondredging which is an emerging removal strategy engineered to be environmentally friendly (Hotchkiss and Huffacker, 2006).

2.5.4 Dam design

In designing for dams allowance is made for sediment settling this is known as the dead storage zone, this has been the control measure for sediment accumulation so as not to reduce the dam storage capacity. Zimbabwe is a plateau country, on the watershed of the main river systems of the sub-continent where the internal rivers generally have comparatively small catchment areas and total sediment transport is not excessive. Therefore the allowance for dead storage to contain sediment deposits can be a viable solution in Zimbabwe (MRWD, 1983).

2.6 Methods for measuring sedimentation flow rates

Sediments are transported by the stream in different forms and different equipments are used to measure the sediment flow rates. There is need for sediment observation stations to be located along the stream with discharge observations.

- Bedload sampling

The rate of Bedload movement is determined by placing a sampler on the river bed and then measuring the amount of material collected in a given time. The most common bed load sampler is the basket type. The bed sampler has to be calibrated in laboratory flumes. The bed load collected in the sampler is dried and weighed. The dry weight when divided by the time taken for measurement and the width of the sampler gives the rate of Bedload movement per unit width of river bed per unit time at point of measurement (Murty, 1998).

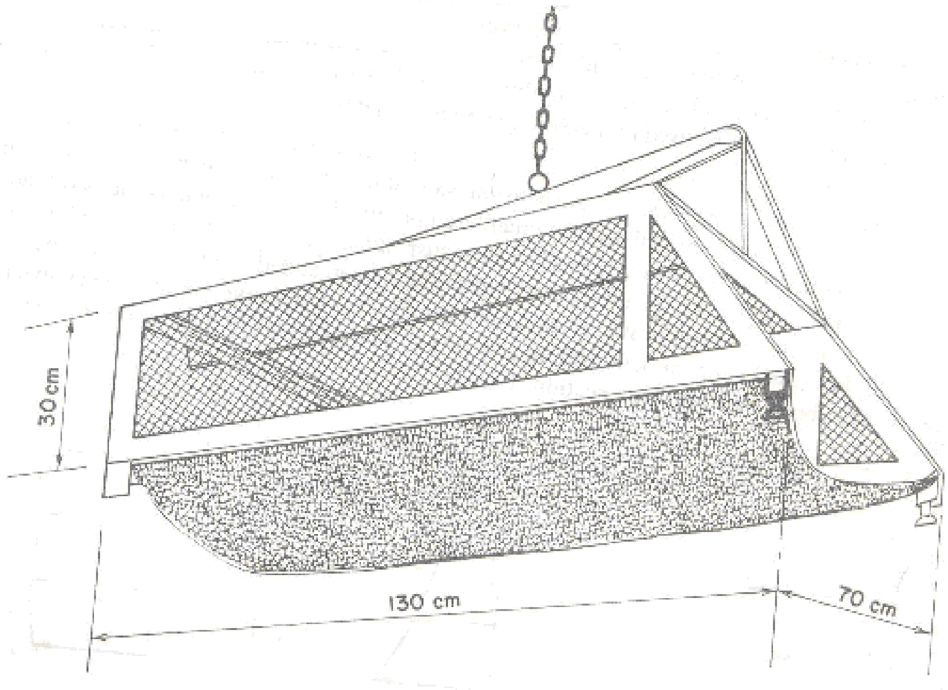

Figure 2.1: *Basket type Bedload sampler (Murty, 1998)*

- **Suspended load sampling**

  Grab samples

The simplest way of taking a sample of suspended sediment is to dip a bucket or other container into the stream, preferably at a point where it will be well mixed. Any type of bottle with sufficient volume (> 400 ml) can be used (Harlin and Liden, 1999). The sediment contained in a measured volume of water is filtered, dried and weighed. This gives a measure of the concentration of sediment and when combined with the rate of flow gives the rate of sediment discharge (Hildyard and Goldsmith, 1984).

For single samples taken by scooping a sample, a depth of 300 mm below the surface is recommended as better than sampling at the surface. If the single sample can be taken at any chosen depth, half the depth of flow is recommended as giving the best estimate of average sediment concentration. Where the sampling programme consists of samples on vertical sections at several points across the stream, the recommended pattern is to use six equally spaced sections as shown:

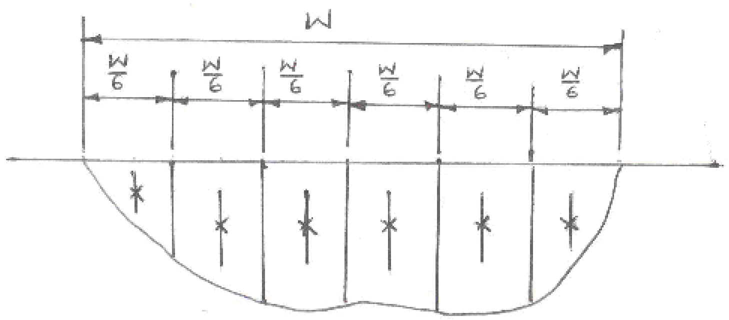

Figure 2.2: *Grab sampling-Recommended pattern for vertical sections (Hildyard and Goldsmith, 1984).*

The annual rainfall and runoff patterns in Zimbabwe are highly variable as a result the annual variation in sediment loads transported by rivers varies greatly. According to the then Ministry of Water Resources and Development (1983), the catchment areas are graded into the following three categories as shown in Table 3.0:

Table 2.0: *Classification of catchments according to sediment loads in Zimbabwe*

Catchment Description	**Sediment load (mg/l)**
Well conserved and moderate topography	3000
Prone to erosion through poor conservation and steeper slopes	5000
Highly susceptible to erosion	10 000

The following parameters need to be known in order to calculate the sedimentation rate in a reservoir per season:

Catchment Area (A): This is the total land area contributing runoff into the reservoir in km^2.

Mean annual Runoff (MAR): This the average net runoff expressed as a depth of water over the dam's catchment area in mm.

Gross dam capacity (V_{gross}): The volume of water the reservoir can store,

Sediment concentration (S_c) in mg/l or kg/m^3

Dry bulk density of deposited sediments (ρ) in kg/m^3.

Gross mean annual reservoir inflow (MAI) in m^3 = $A * MAR$ *Equation 2.1*

The dam's gross storage ratio is calculated from the formula below

$$S_{gross} = \frac{V_{gross}}{MAR}$$ *Equation 2.2*

Where: S_{gross} - gross storage ratio

V_{gross} - gross dam capacity (m^3)

MAI – Mean annual inflow (m^3 yr^{-1})

NB* Trap efficiency is assumed to be 100% for most reservoirs were the gross storage ratio > 0.1

The mass of sediments in the inflowing river per year in tonnes, $S_y = \frac{MAR * S_c}{1000}$

Equation 2.3

Where: S_y is the sediment yield in tyr^{-1}

Specific sediment yield (S_{sy}) = $\frac{S_y}{A}$ *Equation 2.4*

Specific Sediment Yield (S_{sy}) is a measure of mass of sediments per unit area per given time (measured in tkm^{-2} yr^{-1}).

Results of sampling and grading of total sediment deposits in large reservoirs around the world have shown that 90 % of the sediment load comprises fine particles carried in suspension, whose concentration at any time is a function of the catchment and rainfall variables. The remaining 10 % of the sediment load consists of a rolling bedload the transport rate of which is a function of river hydraulics (MWRD, 1983).

- Hydrographic Surveying

The method is a branch of surveying which is concerned with the measurement of a body of water. It includes operations such as the determination of contour lines under water, the cross sections and discharge of streams, the location of high and low water marks, the boundaries of lakes, the 'set' tides and the direction of currents (Balek *et al.*, 1988).

According to a previous hydrographic survey by ZINWA on Chesa Causeway dam in 2003, the dam had lost 46 % of storage (from the original) due to sedimentation during a 12 year period of operation. Figure 3.4 shows an Area/ Capacity Curve for the dam with the supply level taken at 100 m.

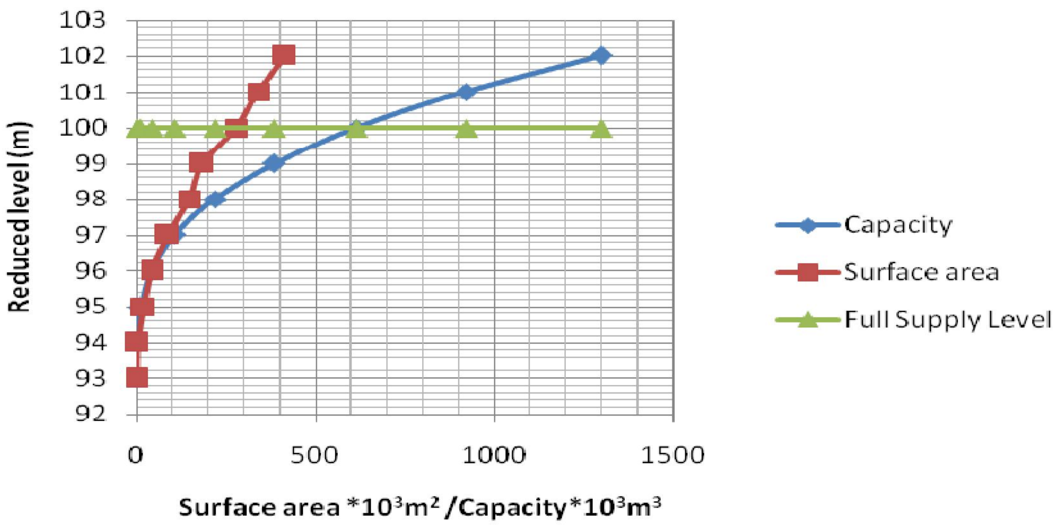

Figure 2.4: *Area/Capacity Curve (Chesa Causeway Silt Survey Report, 2003).*

Lastly a hydrographic survey of a reservoir is a good procedure for reconstructing sediment yield records of a drainage basin. It is therefore recommended that hydrographic surveys are carried out once after every five years for instance so that sediment yields can be computed in finer scales (Zarris *et al.*, 2002).

2.7 Trap efficiency

The amount of sediment deposited within a reservoir depends on the trap efficiency. Reservoir trap efficiency is the ratio of the deposited sediment to the total sediment inflow and depends primarily upon the fall velocity of the various sediment particles, flow rate and velocity through the reservoir (Ahmed and Bashar, 2008) it is also dependent upon the size, depth, shape, and operation rules of the reservoir. The following equation(s) can be used to calculate trap efficiency:

$$T_e = (0.1 + 9 * S_{gross}) * 100 \qquad \textit{Equation 2.5}$$

Where: S_{gross} is the gross storage

The trap efficiency can also be calculated from the formula below

$$T_e = \frac{(V_o - V)\,\gamma}{T \times 140 \times 10^6} \qquad \textit{Equation 2.6}$$

T_e = trap efficiency expressed as a % after T years of operation

V_0 = original reservoir volume, m^3

V = volume remaining after T year of operation

γ = average specific weight of deposited sediment over T years ($t\ m^{-3}$)

γ is calculated from the following equation (Miller, 1953)

$$\gamma = \gamma_i + 0.434\,\kappa\,[(T/(T-1))*(\mathit{Ln}T)-1] \qquad \textit{Equation 2.7}$$

Where γi the initial value of γi and is given by

$$\gamma_i = \gamma_{cl} P_{cl} + \gamma_{sl} P_{sl} + \gamma_{sa} P_{sa} \qquad \textit{Equation 2.8}$$

Where P_{cl}, P_{sl} and P_{sa} are fractions of clay, silt and sand respectively of the incoming sediment while γ_{cl}, γ_{sl} and γ_{sa} are coefficients of clay, silt and sand respectively which can be obtained from the tables prepared by USPR, 1982 for normally moderate to considerable reservoir drawdown (reservoir operation).

2.8 Rainfall and Run off Relationship

The ralationship between the mean annual run off and average annual rainfall was developed by Bullock *et. al*, using data from 102 ungauged catchments in Malawi, Tanzania and Zimbabwe, using the following equation:

$$MAR = 0.00000467AAR^{2.204} \qquad \textit{Equation 2.9}$$

The MAR is used to determine how easily the reservoir will fill by estimating the reservoir capacity as a proportion of the mean annual rainfall using the following equation:

$$V_{perc} = \left(\frac{Vgross}{MAR * A} \right) * 0.1 \qquad \textit{Equation 2.10}$$

Where V_{perc} = Reservoir volume as a % of average annual runoff

V_{gross} = Reservoir capacity (m^3)

MAR = Mean Annual Runoff (mm)

A = Catchment area (km^2)

2.8.1 Derivation of a flow duration curve

The proportion of time from which a certain flow discharge is exceeded or equalled is shown by a plot of a flow duration curve. It illustrates the relationship between the frequency and magnitude of stream flow. Flow duration curves have been widely used to solve problems in river and reservoir sedimentation, water use planning, flood control and scientific comparisons of stream flow characteristics across watersheds (Fennessey and Vogel, 2007). Kamtukule, 2008 adopted an approach developed by Mitchell in 1987 of developing flow duration curves in Zimbabwe based on the geometry of dams using the following steps:

Step 1: Estimating Average Daily Flows (ADF) using the following equation

$$ADF = \frac{MAR * A}{31600} \qquad \textit{Equation 2.11}$$

Where ADF = average daily flow (m^3s^{-1})

MAR = Mean annual run off (mm)

A = Catchment Area (km^2)

Step 2: Estimating the 50 percentile flow , Q_{50} (as a multiple of ADF)

The determination of the percentile flows for reservoir data analysis is done by first determining the 50 percentile flow using the equation:

Q_{50} = -0.234 + 0.000209 AAR + 0.649 B_f *Equation 2.12*

Where :AAR = Average annual rainfall (mm yr^{-1})

B_f = The catchment base flow index

Step 3: Estimating Q_{90}, Q_{80}, Q_{70}, Q_{60} and Q_{40} percentile flows and gross yields

Estimation of percentiles is done by using Standardised Regional Flow duration curves and a table of standardised values is used (Appendix 3A). The percentile flows are presented as a fraction of ADF and are then converted to volumes (gross yield) by multiplying with 31.6 $*10^6$.

2.8.2 Selecting a chosen acceptability of failure to a supply yield

From the gross yields obtained an acceptability of failure to supply a yield for each of the calculated storage stages was chosen. The choice of failure depends on the purposes of the particular reservoir and current capacity of the reservoir.

2.8.3 Estimating evaporation losses

Estimating the evaporation losses is done by assuming that the reservoir has a storage – area relationship given by the following formula:

$A_R = aV_r + b$ *Equation 2.13*

Where: A_R = reservoir surface area (m^2)

V_r = volume of reservoir (m^3)

a and b are constants

The values of constants in equation 2.13 can be derived if the area and volume of the reservoir at full supply level are known. With the known value of a and b , the reservoir surface areas for each of the six storage volumes determined in step 3 can be calculated.

The volume for each surface area was then estimated using the above relationship. The volume of evaporation losses for each storage stage were then estimated using an equation of open water evaporation given by the followng equation:

$$E_v = \left(\frac{A_R * E}{1000}\right) * \frac{2}{3}$$ *Equation 2.14*

Where : E_v = volume of evaporated water in a year (m^3)

E = open water evaporation (mm)

A_R = reservoir surface area (m^2)

2.8.4 Derivation of reservoir net yields

The reservoir net yield is calculated from the formula below

$Y_N = Y_G - E_v$ *Equation 2.15*

Where:

Y_N = Reservoir net yield

Y_G = Gross yields

E_v = volume of evaporated water in a year

The storage – yield relationship for a reservoir is determined by plotting the net yields against storage volumes. In the case that there is an already existing reservoir and that the storage at the full supply level is known or can be estimated, then the reservoir net yield can be read from the graph (Kamtukule, 2008).

CHAPTER THREE

RESEARCH MATERIALS AND METHODS

3.1 Introduction

This chapter describes in detail the research materials and methods used during data collection in order to investigate the impacts of land use and land cover change on sedimentation of reservoirs under study.

A number of methods were used to collect data for this study in order to achieve all the three specific objectives as outlined in chapter one. Section 3.3 describes the methods used to estimate the sedimentation rates of Chesa Causeway and Sebastopol dams. Section 3.4 describes the method used to determine whether the rates of sedimentation are linked to land use and land cover change, section 4.4 Projections on impact of sediments on the available water from both study areas**.**

3.2 Description of study area

The study was carried out in Mazowe and Manyame catchment areas focussing on two reservoirs Chesa Causeway and Sebastopol dams.

3.2.1 Chesa Causeway Dam

The dam is located in the Upper Ruya sub-catchment in Mt Darwin area, which falls under Mazowe Catchment. Chesa Causeway dam was built along the Mufure river approximately 2 km east of Mt Darwin, in the hydrological subzone DM2 (S16^{o} 46.375’ and E031^{o} 35.697’), and on map ref: 1631 D3. The dam was built in 1991 with an estimated capacity of $1150*10^3$ m^3 at full supply level and has a catchment area of 229 $km^{2.}$ The catchment area has a mean annual runoff (MAR) of 129 mm yr^{-1} and average annual rainfall of 786 mm yr^{-1}. The mean annual evaporation of the dam is approximated to be 1.85 m. The dam’s catchment area comprises of communal lands (Kandeya and Madziwa) and newly resettled A1 farmers. The main purpose of the dam is to supply Mt Darwin town with water and livestock watering.

According to the dam design report, the geology of Mt Darwin is of magmatic gneisses of Pre-Cambrian era with evidence of folding along Mufure river. The formation is of secondary permeability with low prospective borehole yields in the order of 10-50 m^3/day. The dam's catchment area has indigenous tree species mainly the Brachystegia Speciformis (msasa) and Colophospernum (mopane) and with shrubs and stargrass. The slope of the catchment is moderately gentle (2-5 %).

3.2.2 Sebastopol Dam

The dam lies in the Upper Manyame sub-catchment in Ruwa located on S17^{O} 53,144' and E031^{O} 16,894' along Ruwa river in the hydrological subzone CH5 (Map ref: 1731 C4). The dam was built in 1968 along Ruwa river with an estimated live capacity of $272*10^3$ m^3, on a catchment area of approximately 12 km^2. The mean annual run off is approximated to be 135mm and with average annual rainfall of 944 mm. The dam's catchment area comprises of Ruwa Estate, James farm and Sebastopol farm. The main purpose of the dam is to supply Sebastopol farm with irrigation water (permit number 3733 and abstractions are not to exceed 1219 mm yr^{-1} The geology of the area is made up of granitic bedrock, with rock outcrops which show a high degree of fragmentation. The soils consist of predominantly sandy clay loams with the depths averaging 15 cm – 90 cm. The vegetation of the area is predominantly grass (star grass and mopane trees) and the slope is also moderately gentle (2-5 %).

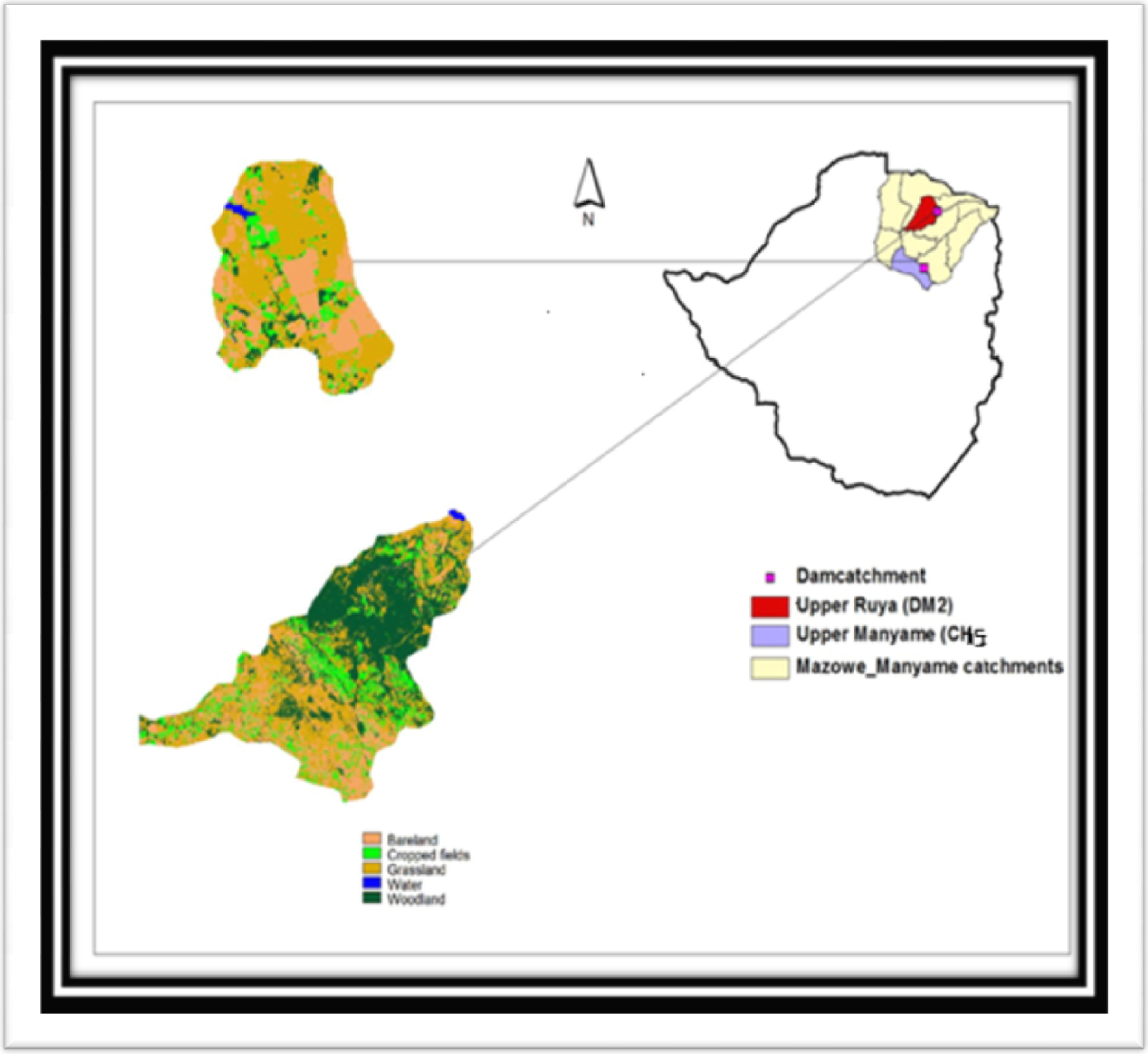

Figure 3.0: *Study Area*

3.2.3 Issues of Sedimentation at both reservoirs

- **Chesa Causeway Dam**

Over its 19 years in operation, the dam has been accumulating sediments in its basin. According to a ZINWA silt survey report of 2003 the main drivers for sediment accumulation in the reservoir included the following:

- ➢ Lack of enforcement of environmental laws by the local authority resulting in deforestation of the dam's catchment area;
- ➢ Alluvial gold panning activities taking place within the main tributary of the dam;

- Poor farming methods such as stream bank cultivation leading to erosion along Mufure river (the main tributary) and subsequent sediment deposition into the dam**.**

According to ZINWA Mazowe Catchment office, when the dam started operating in 1991 it used to cater for 80 % of water demand for Mt Darwin town. The current population is at 15100 taking 2002 as a base year, at a growth rate of 3 % per annum (Zimbabwe Central Statistical Office, 2002). Currently the percentage supply of water demand from the dam has reduced drastically (to about 30-50) mainly attributed to excessive sedimentation of the reservoir. This has impacted negatively on the communities who rely on the dam in sustaining their livelihoods. They are being forced to make do with the little quantities of water available for domestic use, being supplied by the dam.

- **Sebastopol Dam**

The dam is in a well grassed catchment where sedimentation is not a major issue. The dam is in a commercial farming area where agricultural activities are being carried out at a small scale, but large scale commercial poultry production projects are taking place in the dam's catchment area. The dam has been in operation for 42 years and according to information gathered from the local people the reservoir has not been desilted since 1968 (the year it was constructed).

3.2.4 Selection of the study areas

The two study areas were chosen so as to have a comparative analysis of a well a conserved catchment and a less conserved catchment (following the Zimbabwe catchment classification, Table 2.0). Hence the choice of the two dam catchment areas, the selection was conducted in consultation with ZINWA Data section.

3.3 Sediment quantification methods

Two methods were used to quantify the sedimentation rates of the study areas. The methods used were: grab sampling and hydrographic survey method**.**

3.3.1 Grab sampling

Water samples were taken by scooping (using a 500 ml plastic sampling bottle) at a sampling point. The water samples were taken at a depth of 300 mm below the surface. Scooping below the water surface has an advantage of getting the best estimate of average sediment load as sediments are concentrated more beneath the water surface.

Also soil samples from both dam sites were weighed and oven dried in the laboratory to determine the bulk density for each site. The average concentration for the three months on which samples for both study areas was determined in order to find which category both subcatchments fell in as proposed by the then Zimbabwe MWRD and these are:

- 3000 mg/l: Well conserved catchment with moderate topography
- 5000 mg/l: The catchment is prone to erosion through poor conservation and steeper slopes
- 10000 mg/l: The catchment is highly susceptible to erosion.

The 500 ml water samples were analysed in the laboratory using the weighing and filtration method. The water samples were first sieved using a 63 micrometer sieve to remove sharp objects which might damage the filter paper. The sieved samples were then filtered and weighed after which they were then put in an oven at 100^{o}C for 30 minutes. From the oven, the samples were allowed to dry for 15 minutes and then weighed to get the weight in mg. The actual weight of the samples was then obtained by subtracting the oven dried weight from the weighed wet. Lastly the sediment load concentration was then calculated in mg/l since the sample volumes were known.

At Chesa Causeway dam a total of ten samples were collected (two in December, three in January, three in February and two in March) and these were averaged for each month. At Sebastopol dam a total of fourteen samples were collected after a storm (three in December, four in January, four in February and three in March). Water samples at both study sites were all taken after a storm so as to coincide with the time of concentration. The samples were then averaged to get the monthly sedimentation rates. The number of samples collected for each site was not the same due to the different rainfall patterns experienced at the respective study areas. A graph showing the average concentrations for each month is shown on figure 4.0.

The sediment yield (t yr^{-1}) and specific sediment yield (tkm^{-2} yr^{-1}) were calculated using Equations 3.3 and 3.4.

3.3.2 Hydrographic surveying

Control pegs were set up, traversed, levelled and tied up to a local grid reference using the spillway level as the reference. Spot shots were taken above the water edge 2 m above the full supply level. Points of plumbing were marked along the dam for distances of between 50 m to 150 m and less on bends or curvatures. The points were surveyed and levelled up to the main traverse. A graduated tag line was stretched on opposite points and 20 litre sealed plastic containers tied to it so that it remained floating. The motorised boat was used to navigate along the tag line. Depth sounding was then done at 10 m to 25 m intervals along the line. The sounding was done by dropping a weight attached to a string to the riverbed so as to measure the depth of water up to the surface of water. The depth was then subtracted from the water level reading. The spillway level was taken as the common datum to get the levels underneath the water, which were also related to land survey. Figure 4.0 shows depth sounding on a dam profile.

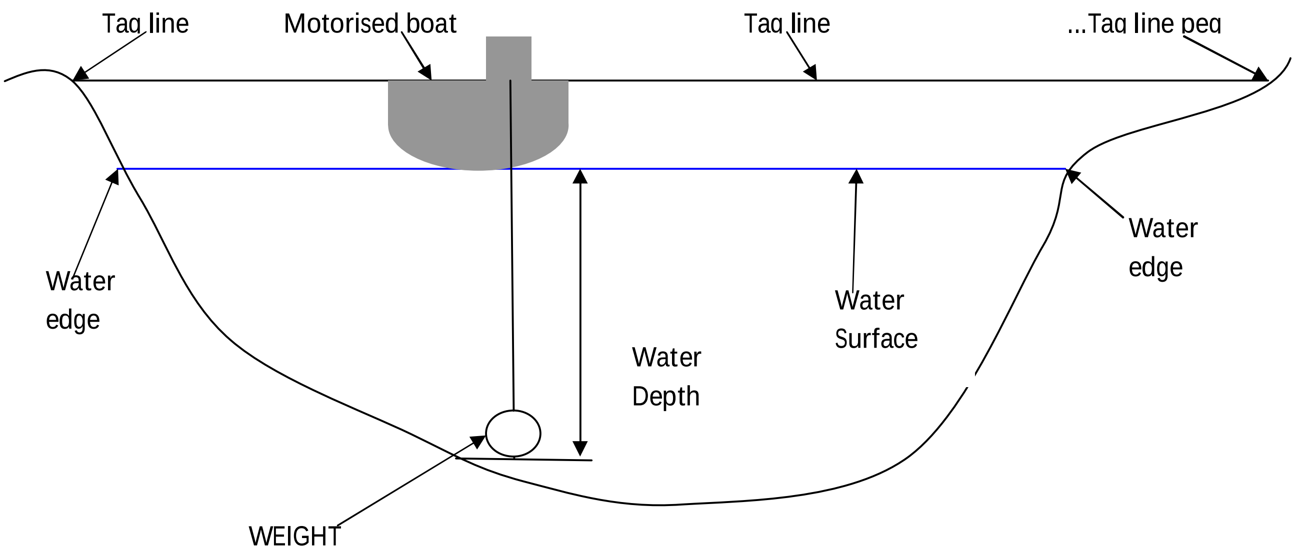

Figure 3.1: *Depth sounding*

When all the points had been taken, they were then reduced using the spillway as the datum and then plotted using a plotting set on a scale of scale of 1:2000. Contour lines were then drawn on the map at 1 m interval. The lines were drawn from the lowest points on the bed up to 2-3 metres above the spillway level. The points were reduced to get levels for both study areas, as shown in Appendices 1A and 1C. The contour maps for the dams are shown in Appendices 1B and 1D respectively.

Areas between contour lines were then digitised using a plannix. The formula below was used to calculate the volumes for each contour

$$V_{contour} = \frac{A_1 + (A_1 * A_1)^{1/2} + A_2}{3}$$

Where A1 = Area 1 (m^2), A2 = Area 2 (m^2), $V_{contour}$ = contour volume (m^3)

Equation 3.0

Volumes for each contour were then calculated using Equation 3.0 and accumulated to get the total capacity. Area/Capacity curves for both dams were plotted as shown in figures 4.1 and 4.3.

The trap efficiencies for both dams were calculated using Equation 2.5. The results for calculated key parameters for both study areas are summarised in Table 4.2.

3.3 Land use and land cover changes.

Landsat TM images for both sites in the years 1991, 2003, 2009 for the month of April were downloaded from the USGS website. The images were classified using the supervised classification into five land cover classes (cropped land, woodland, water, grassland and bareland) based on the maximum likelihood method. Training samples were then taken from the field using a GPS based on the five land cover classes. The classified images were then crossed with the catchments of the two dams to get the land cover specific to the areas. The statistic function in ILWIS GIS software was used to calculate the area of each land cover for the different years. The area of different land cover classes was then used for statistical analysis.

3.4 Predicting Impact of sedimentation on the available water use.

3.4.1 Derivation of a flow duration curve and gross yields

Estimating the average daily flow (ADF) for the catchment was calculated using Equation 2.11, then the 50 percentile flows (Q_{50}) for both reservoirs were then calculated using Equation 2.12 and the Base flow index Values were obtained from the table of Average Base Flow Index for FAO Soil Classes (Kamtukule, 2008) as shown in Appendix 3C.

Q_{90}, Q_{80}, Q_{70}, Q_{60} and Q_{40} percentile flows were obtained from the Standardised Regional Table of values derived from Standardised Regional Flow Duration Curves where the values of key exceedence percentiles are expressed as fraction of ADF as shown in Appendix 3B.

From Appendix 3B Curve E was selected for Sebastopol Dam since calculated Q_{50} as a fraction of ADF was found to be 0.29 m^3s^{-1} and it lies between 0.20 - 0.30. The subsequent estimated percentile flows were then converted to Gross Yields (m^3) by multiplying each of the percentile flows by the ADF which was found to be 0.05 m^3s^{-1} and the resultant product was multiplied by $31.6 * 10^6$. The same procedure was followed for calculating the Gross Yields of Chesa Causeway Dam.

3.4.2 Selecting a chosen acceptability of failure to a supply yield

In order to decide the appropriate return period for failure to supply a yield, reference was made to the regional standardised – yield relationships which are expressed as % of ADF. In consultation with experts from ZINWA Data Section, the return periods of 5 years and 2 years were chosen for Sebastopol and Chesa Causeway dam respectively. The return periods were chosen taking into consideration the water demands and the sizes of the area being serviced, as well considering the current capacities of both dams of $116*10^3$ m^3 and $392*10^3$ m^3 respectively.

The chosen return period values for each percentile flow given in the Appendix 3A represent the yield as a percentage of ADF and each of them converted to volume by multiplying by ADF. The resultant product was then multiplied by $31.6*10^6$, the required volumes for each of the gross yields are given in tables 4.4 and 4.5 for both dams.

3.4.3. Estimating evaporation losses and derivation of net yields

The relationship between storage and surface area was determined by plotting graphs of the two variables for both study areas using results obtained from the hydrographic survey. The relationship shown by figures 4.16 and 4.17 was used to estimate reservoir surface areas for each of the storages calculated in section 4.4.2. The following equations were adopted in estimating reservoir surface areas for reservoir volumes for the projected years:

- Sebastopol Dam

$A_R = 0.654V_r+3935$ ($R^2 = 0.992$)..*Equation 3.1*

- Chesa Causeway Dam

$A_R = 0.607V_r + 17586$ ($R^2 = 0.983$).. *Equation 3.2*

Where: A_R is the reservoir surface area (m^2)

V_r= Volume of Reservoir (m^3)

The evaporation for the different reservoir surface areas for the projected years was calculated using Equation 2.14.

The net yields were calculated by subtracting the evaporation and the dead storage from gross yields. Plots of the relationship of storage and net yield for both study areas are shown by Figures 4.18 and 4.19 they were used to estimate the net yields at different storages for the projected years.

3.4.4 Water demand projections for the study areas

Mt Darwin town population projections were calculated using Zimbabwe Central Statistical Office figures for Mashonaland Central Province taking 2002 as a base year. The projections were calculated using the formula:

$P_n= P_0 e^{rt}$ *Equation 3.3*

Where P_n = population being calculated

P_0 = base population (2002) in this case

r = rate (%) and t = time in years

According to Gleik (1996) the lifeline per capita consumption is assumed to be 50 l/c/d. The lifeline per capita consumption was adopted for each of the projected population and the demands were calculated for each year up to 2019. Population projections at a growth rate of 3% for the area from 2010 to 2019 are shown in Appendix 3G

The agricultural water demand for Sebastopol farm were made basing on the maximum amount of water to be abstracted from the dam (1 219 mm yr^{-1}) and multiplied by the area under irrigation (2.5 ha). The value of the maximum amount of water to be abstracted was obtained from the water permit issued by ZINWA. The agricultural water demand was assumed to be constant for each year up to 2021.

Results for both dams were converted to percentages of the cumulative totals of the calculated net yield, domestic water demand, sediment accumulation and storage for comparison and analysis of the two study areas. This was done to show the impact of projected sedimentation rates to the availability of water for the main uses of both dams as shown in figures 4.21 and 4.22.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Introduction

This section presents data and discusses the analysed data that was collected through physical measurements in the field for both study areas, interviews and literature review on findings of previous researches undertaken related to the research. The section follows the outline of specific objectives as stated in section 1.22.

4.2 Quantification of sedimentation rates

The results for both methods used are presented as follows:

4.2.1 Grab sampling method

Figure 4.0 is shows the trend in the monthly average sediment concentrations for the two dams for the 2009-2010 rainfall season.

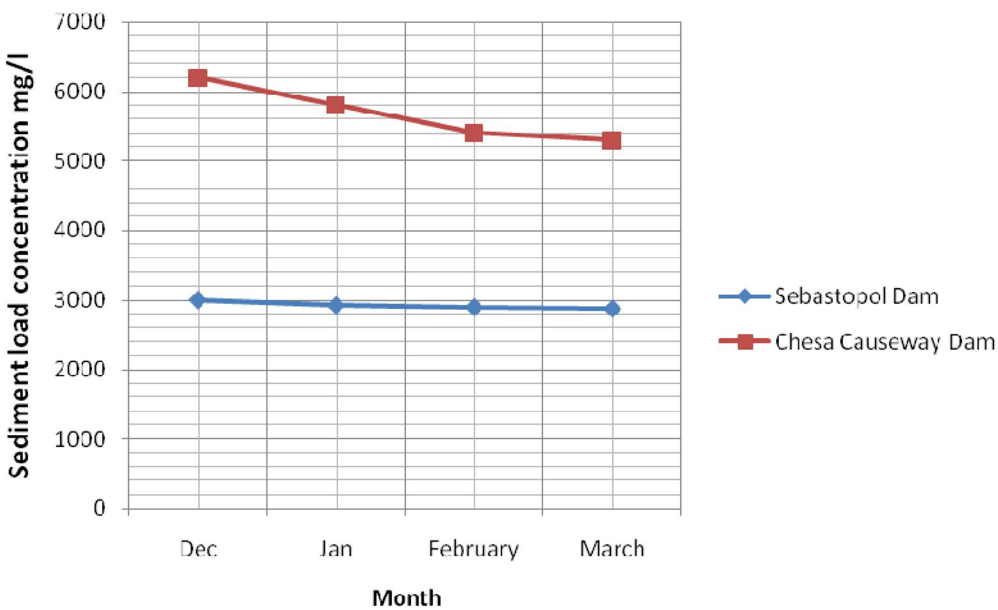

Figure 4.0: *Average monthly trends of sediment concentration for both study areas during the 2009/2010 rain season*

According to the classification described in section 3.3.1 Sebastopol dam had a seasonal average of 2930 mg/l which means that it is in a well conserved catchment with moderate topography. Chesa Causeway dam had a seasonal average of 5660 mg/l and it fell in the category of a catchment prone to erosion due to poor conservation practices following the Zimbabwean catchment classification.

The sediment concentrations were found to be decreasing as the rainfall season progressed for both study areas. This is due to the fact that on the onset of the rains the soil particles will be loosely attached to each other hence more erodible therefore high chances of detachment and transportation into the reservoirs, resulting in high sediment concentrations being recorded at the sampling points. As the rain season progressed the sediment concentration decreased as the soil particles became aggregated and less erodible therefore low values for the sediment concentration recorded at the sampling points.

The table below summarises the results of the calculated key parameters for both study areas:

Table 4.1: *Summary of the calculated parameters for both study areas*

	Sebastopol Dam	Chesa Causeway Dam
Bulk density (kg/m^3)	1650	1840
Gross mean annual inflow ($*10^6\ m^3\ yr^{-1}$)	1.5	29.5
Storage ratio (2010)	0.01	0.002
Estimated storage lost to sediment deposition during the 2009 – 2010 rain season (%)	2	9
Specific Sediment yield ($tkm^{-2}\ yr^{-1}$)	390	774

Table 4.1 shows that Chesa Causeway catchment has a smaller storage ratio than Sebastopol dam this is due to the reduction in capacity as a result of sediments being deposited. This implies that most of the run off being generated from the upstream of the catchment is not being collected into the reservoir. The estimated % storage lost to sediment deposition during the 2009 – 2010 rain season and specific sediment yield of Chesa Causeway dam are almost double that of Sebastopol dam. This confirms that Chesa Causeway dam is in a catchment prone to erosion due to poor conservation practices as compared to Sebastopol dam.

4.2.2 Hydrographic Survey

Using the hydrographic survey method the following results were found:

- **Chesa Causeway Dam**

Figure 4.1 shows a plot of the Surface Area/Capacity curve when the dam became operational in 1991 and Figure 4.2 shows Surface Area/Capacity curve for 2010.

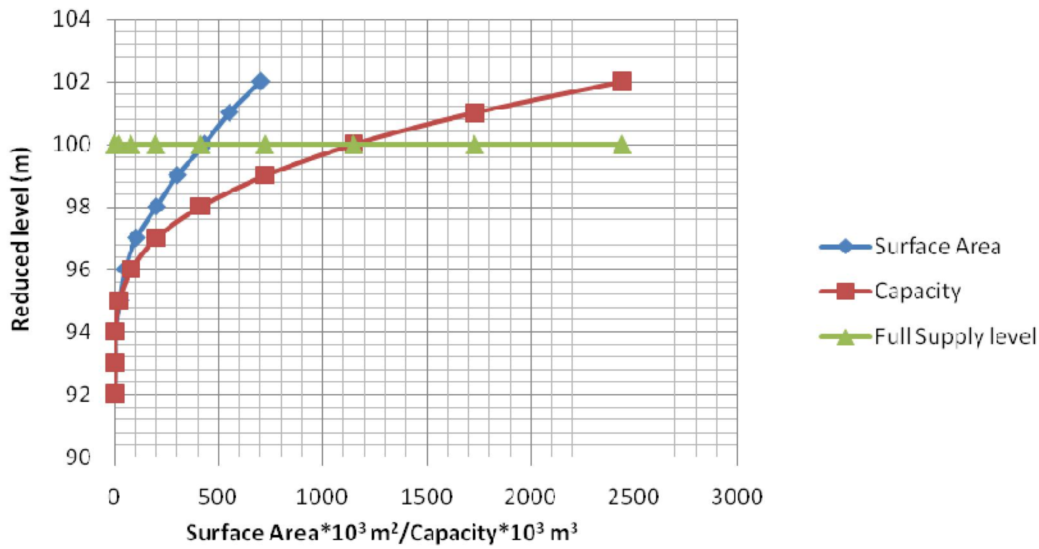

Figure 4.1: *Chesa Causeway Dam 1991 Surface Area/Capacity curve*

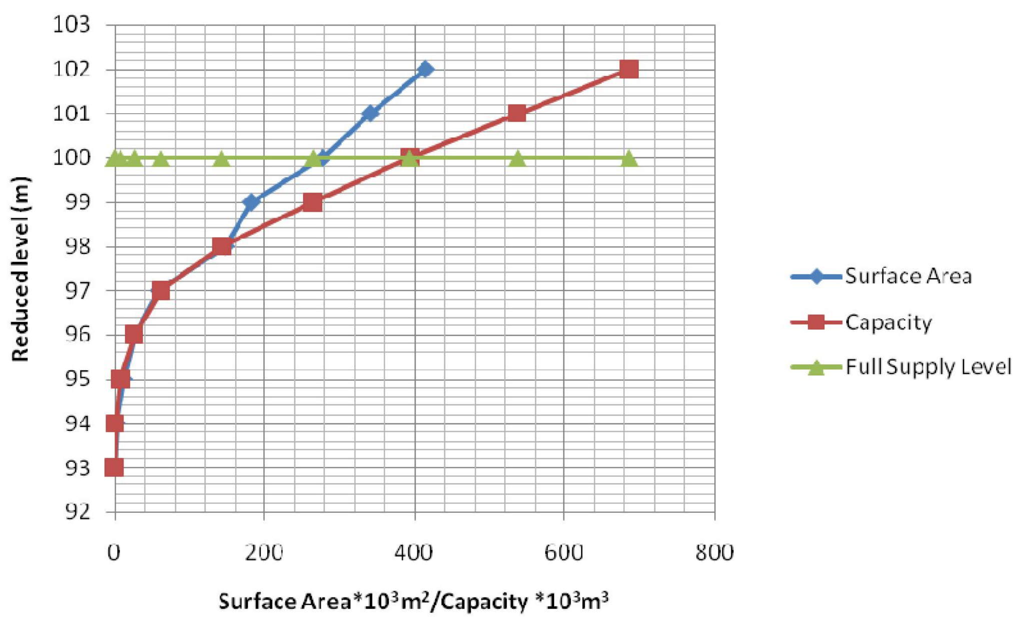

Figure 4.2: *Chesa Causeway Dam 2010 Surface Area/Capacity curve*

From figure 4.2, in 2010 at full supply level the dam has a storage capacity of $392*10^3$ m^3 as compared to 1 150 $*10^3$ m^3 when the dam became operational in 1991. This represents a 67 % loss of storage from the original storage capacity. The Surface area curve is not smooth for 2010 as compared to the design surface area curve of 1991, this can be attributed to the non-uniformity of sediment deposition across the dam surface area (from 98 m to 99 m reduced levels).

- Sebastopol dam

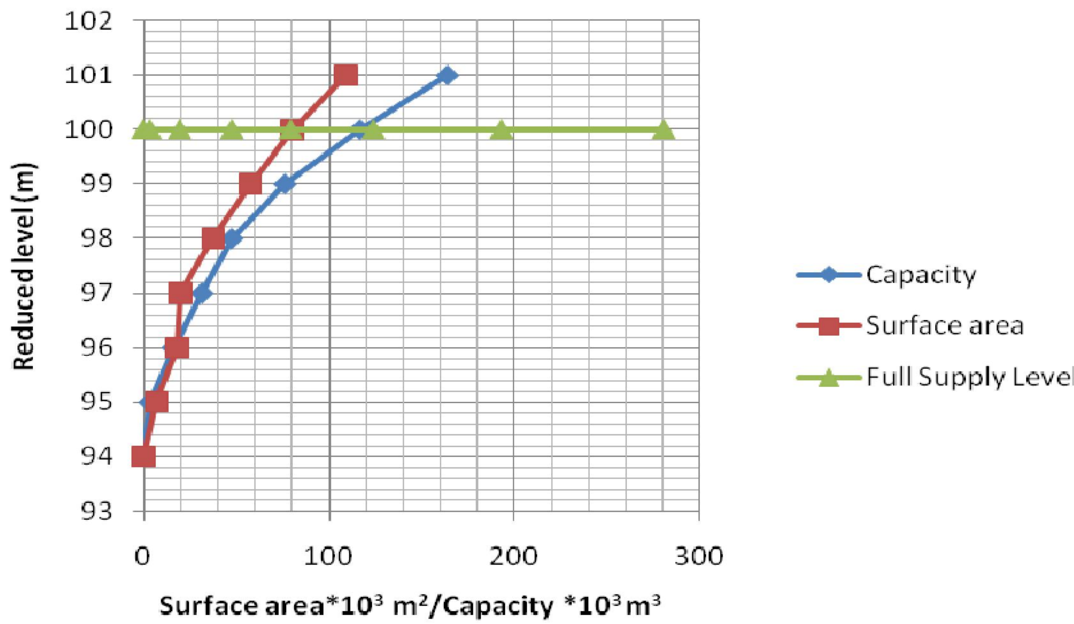

Figure 4.3: *Surface Area/Capacity Curve for Sebastopol Dam as at 2010*

The current dam capacity for Sebastopol dam at full supply level is $116*10^3$ m^3. This represents a loss of storage of 57 % from the original design capacity. The original area/capacity curve for the dam could not be found but following the trend shown by figures 5.1 and 5.2 the' kinks' on area curve on figure 4.3 can also be attributed to sediment deposition which is not uniform across the dam basin area.

4.2.3 Capacity changes of Chesa Causeway Dam over the years

A plot of volume changes over the years is shown in figure 4.4. The 1991 volume is the original and the volumes from subsequent years found through hydrographic surveys. The full supply was at a reduced level of 100 m for all the years.

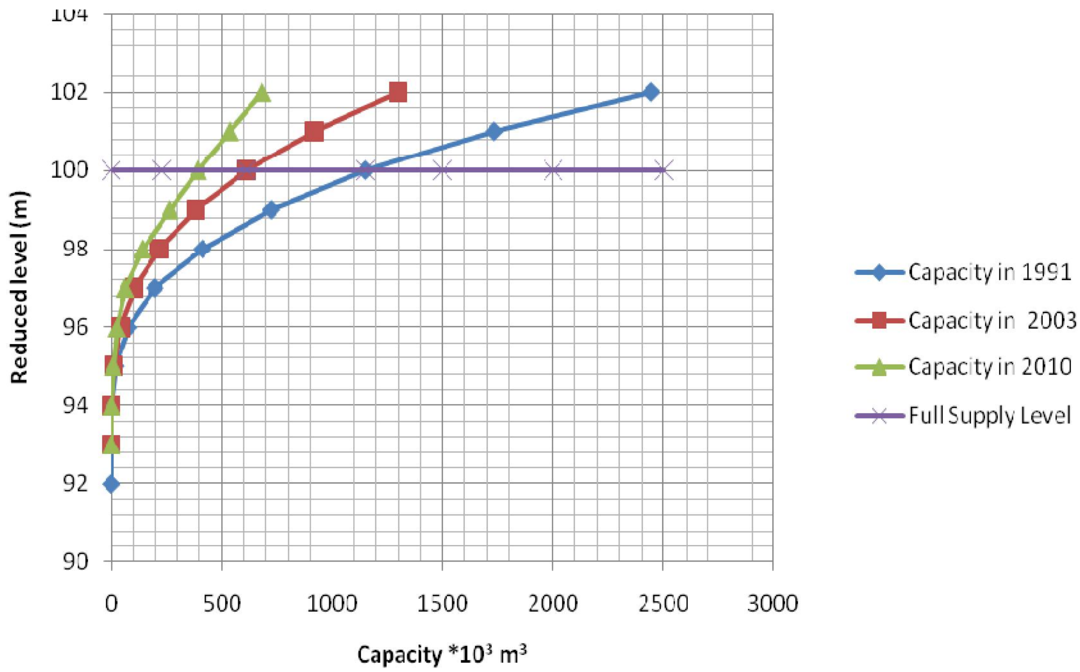

Figure 4.4: *Chesa Causeway Dam volume comparison over the years*

From figure 4.4 the reservoir basin has reduced in elevation by 1m from the original (where the original starting contour was 92 m) this can be attributed to the current high sediment specific sediment yields of 503 $tkm^{-2}yr^{-1}$ being deposited into the reservoir. This has resulted in the dam capacity decreasing by 46 % over a period of 12 years (1991-2003); from 2003-2010 there is a 33 % decrease and the overall decrease in storage volume over 19 years calculated as 66 %.

If no interventions are put in place to reduce the specific sediment yields assuming constant rate of deposition the reservoir would be completely silted up in the next 11 years which is 20 years less than the designed lifespan.

A summary of the results for the calculated key parameters for both study areas are shown in Table 4.2:

Table 4.2: *Summary of Hydrographic survey results for both study areas*

	Sebastopol	Chesa Causeway
Design Storage Capacity (*10^3 m^3)	272	1 150
Current Storage Capacity (*10^3 m^3)	116	392
Designed Lifespan (years)	50	50
Current Lifespan (years)	29	11
Design trap efficiency (%)	100	46
Calculated % Trap Efficiency for 2010	73	19
Design Storage ratio	0.17	0.04
Storage Ratio for 2010	0.07	0.01
Percentage storage lost to sediment deposition annually	1.4	3.5
Specific Sediment yield ($tkm^{-2}yr^{-1}$)	258	503

From Table 4.2 the calculated trap efficiencies for both dams have decreased by 27 % from the years they became operational (Sebastopol dam, 1968 and Chesa Causeway dam, 1991 respectively). A decrease in the trap efficiency results in an increase in sediment accumulation. The less conserved Chesa Causeway dam catchment area has a high specific sediment yield which is almost double that of Sebastopol dam catchment area, this is mainly due to alluvial gold panning activities taking place along Mufure river the main tributary of Chesa Causeway dam (see figure 4.9).

There is also a decreasing trend for the storage ratio for both dams during their years of operation, this has led to loss of storage due to sedimentation. For Sebastopol dam the storage ratio has decreased by 0.1 over a 42 year period of operation whilst that of Chesa Causeway dam has decreased by 0.03 over 19 years. The design storage ratio for Chesa Causeway dam was 0.04, this meant that the gross dam capacity (1 150* 10^3 m^3) was much smaller to capture much of the mean annual inflow of 29.54* 10^6 m^3 from the dam's catchment area of 229 km^2. The dam was wrongly sized during the design stage, from dam design principles storage ratio should have been > 0.1 for the dam not to be quickly silted up as well as being able to capture much of annual inflow from the dam catchment area. The wrong sizing of the dam in conjunction with the alluvial gold panning activities taking place along the main tributary have led to reduced lifespan of 25 years than the 50 years initially predicted.

Assuming a constant rate of specific sediment yield the results show that Chesa causeway dam is losing almost double percentage storage annually than Sebastopol dam. This translates to 67 % loss of storage in 19 years of operation for Chesa Causeway dam, whilst Sebastopol dam has lost only 57 % of its storage capacity in 42 years of its operation. These results confirm that the dam is in a less conserved catchment prone to erosion.

4.2.4 Comparison of results from sediment quantification methods used

A comparative table for the calculated key parameters from the sediment quantification methods used are shown in Table 4.3:

Table 4.3: *Summary of key parameters calculated from sediment quantification methods*

	Sebastopol Dam	**Chesa Causeway Dam**
Grab sampling		
Estimated storage lost to sediment deposition during the 2009 – 2010 rain season (%)	2	9
Specific Sediment yield ($tkm^{-2}\ yr^{-1}$)	390	774
Hydrographic Survey		
Estimated % storage lost to sediment deposition annually	1.4	3.5
Specific Sediment yield ($tkm^{-2}yr^{-1}$)	258	503

Both methods have confirmed that Chesa Causeway dam is a less conserved site than Sebastopol dam. This can be seen from the specific sediment yield values obtained from both methods as shown in Table 4.3, which are almost double than that of Sebastopol dam.

The estimated annual percentage storage lost due to sediment deposition and specific sediments yield values are high for both study areas using the grab sampling method as compared to the hydrographic survey method. This could be attributed to the nature of the method as it is a point method of measuring sediments in a dam, as opposed to the hydrographic survey method which involves surveying the whole dam basin to estimate the two parameters. The grab sampling method shows seasonal variability as opposed to the hydrographic survey which assumes a constant rate of deposition over a given period of time and therefore the rates do not take into account the seasonal variability hence the differences in magnitude of values for both parameters using both methods.

In conclusion both methods have confirmed that Chesa Causeway dam catchment has higher specific sediment yield and also a higher percentage of storage lost to sedimentation per year than Sebastopol dam. From the calculated storage ratios Chesa Causeway dam was wrongly sized during the design stage this also is contributing to the reduced lifespan.

4.3 Land use and land cover changes

In order to link the sedimentation rates to land use and land cover change**,** Landsat TM images for both study areas were processed and complemented with ground truth data.

4.3.1 Land cover Changes in the Chesa Causeway Dam Catchment

Figures 4.5 to 4.7 show the changes in land cover patterns for Chesa Causeway dam catchment from 1991 (when the dam was built), 2003 (when a hydrographic survey was conducted for the dam) and 2009. The Landsat images were taken for the month of April of each year.

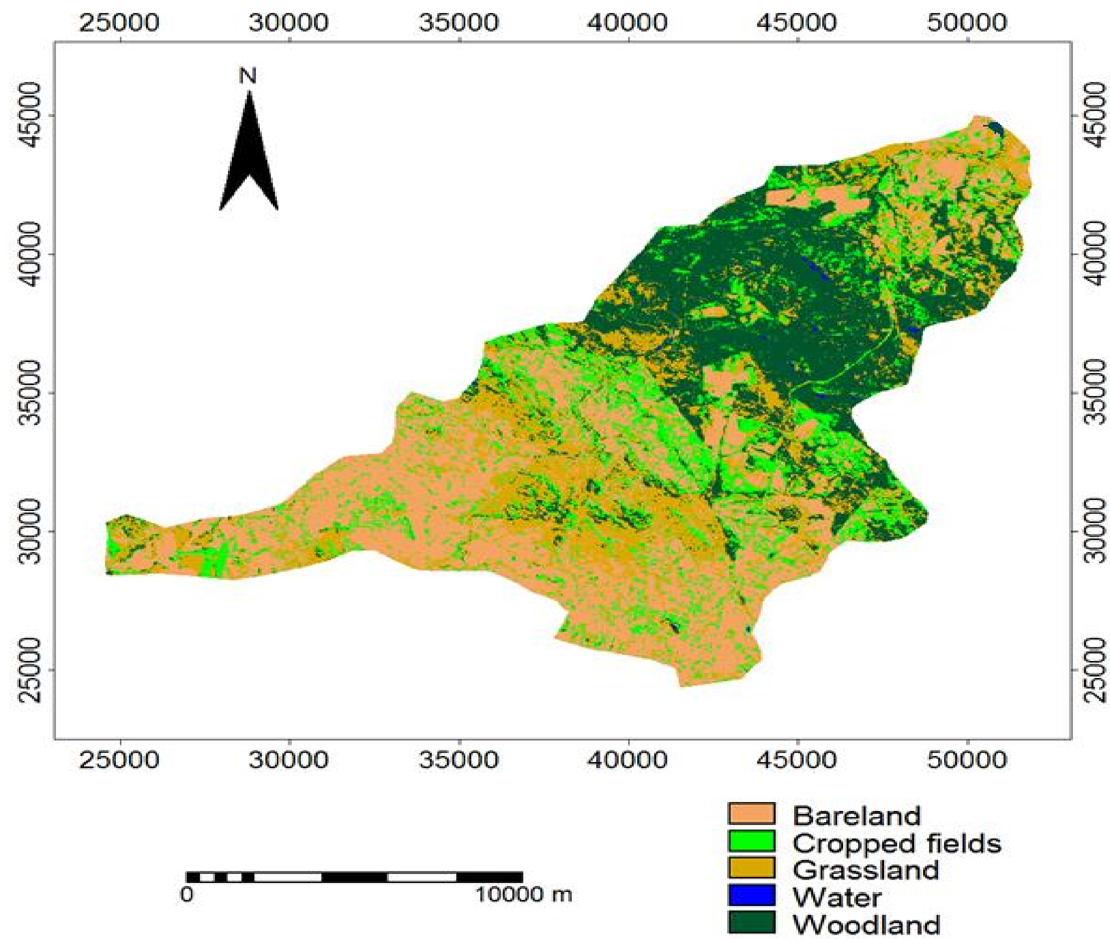

Figure 4.5: *Land cover pattern in 1991 for Chesa dam catchment area*

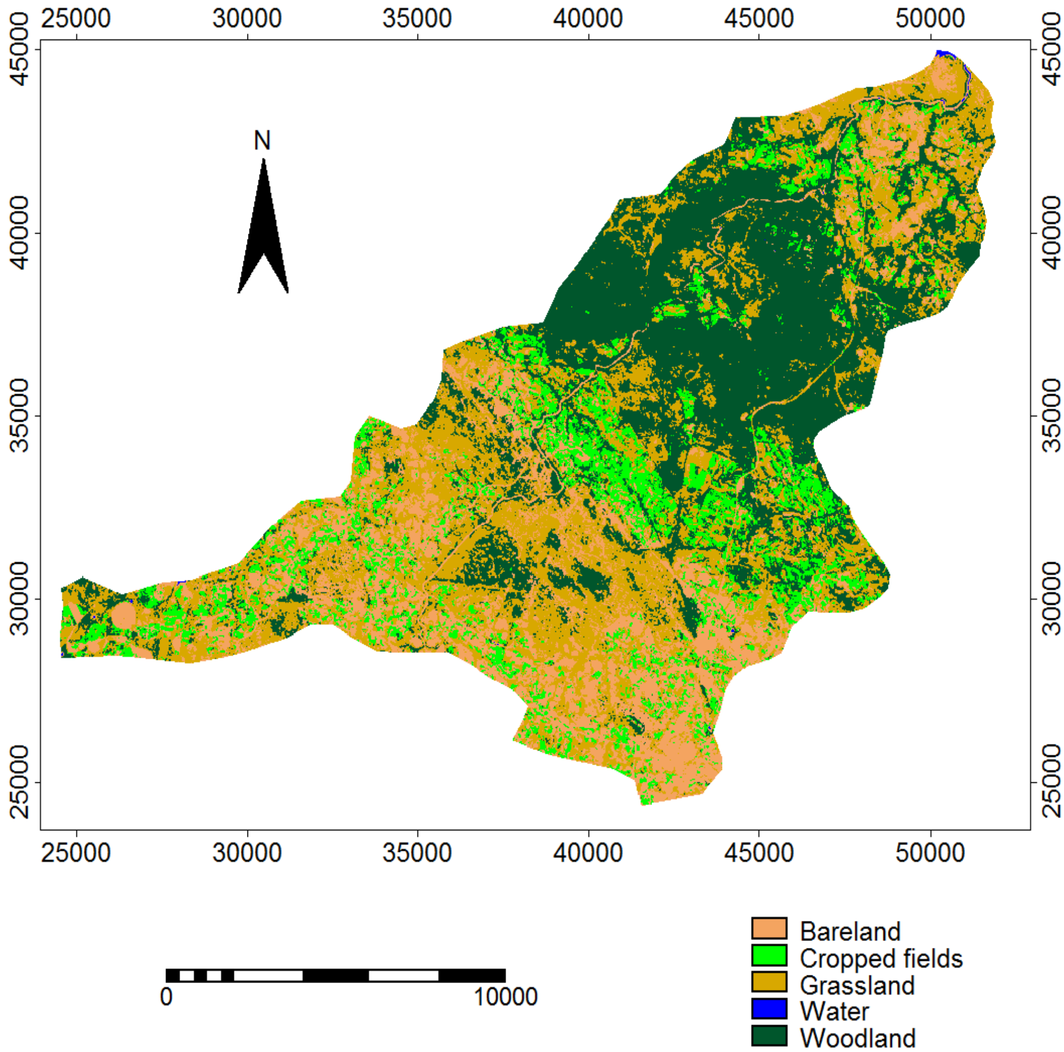

Figure 4.6: *Land cover pattern in 2003 for Chesa dam catchment area*

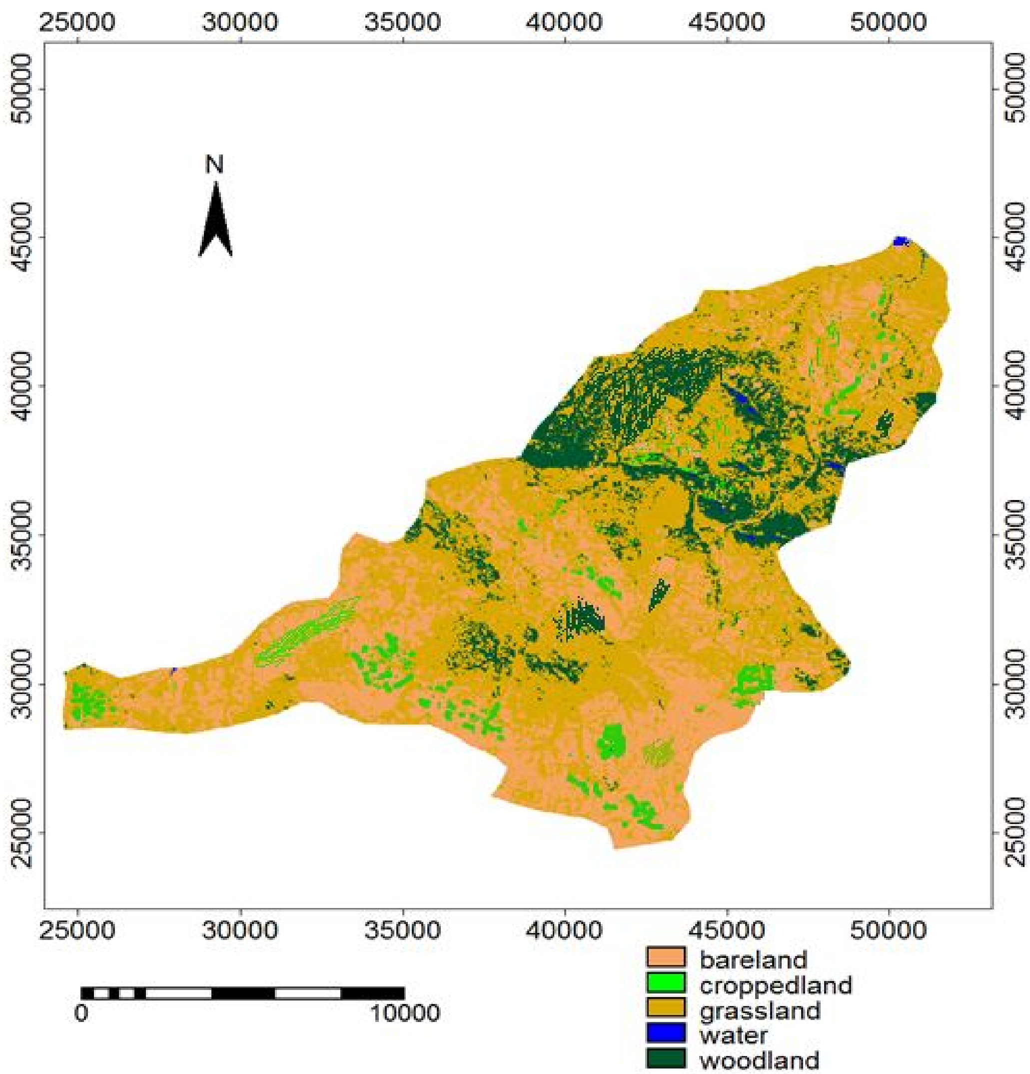

Figure 4.7: *Land cover pattern in 2009 for Chesa dam catchment area*

The land cover changes for different land classes over the years were then statistically analysed using ILWIS software in GIS and a histogram was produced as shown in figure 4.8 below**.**

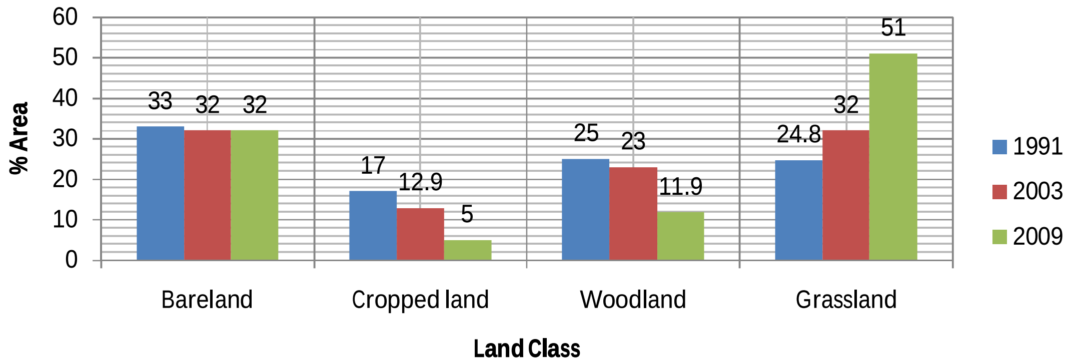

Figure 4.8: *Land cover changes for different classes for 1991, 2003 and 2009 for Chesa dam catchment area.*

From figure 4.8 above percentage areas for bareland have not changed much over the years with only a percentage decrease from 1991 to 2003. For cropped land and woodland there is a general trend where the percentage area is decreasing for both land classes over the years grassland cover is rising sharply from 25 % to 51 % over the years.

Up to 2000, the catchment area was predominantly a commercial farming area before the resettlement programme began. The commercial farming area within the catchment area was then subdivided into 20 hectare plots commonly known as A1, where indigenous farmers were allocated the plots. This has resulted in the decrease of cropped land from 17 % to the current 5 % as much of the land is not being utilised to its maximum potential due to a number of reasons which include financial constraints, rainfall variability and lack of proper education to the farming community on the choice of crops to grow which suit the climatic conditions experienced in the area. Much of the land which used to be cropped before 2000 is now being left fallow, this has led to an increase in grassland from 24.8 % in 1991 to 51 % in 2009. Lack of enforcement of environmental by-laws by the local rural district council regarding deforestation has led to uncontrolled cutting down of trees within the catchment and much of the woodland has now become grassland area. Of importance to note is the catchment area is located near Mt Darwin town where there are incessant power outages, this has led to people in the surrounding community relying on firewood as a source of fuel hence the reduction of woodland by more than half (25 % to 11.9 %).

From ground truth data, land cover changes are not the ones influencing the high sedimentation rates in this catchment but rather alluvial gold panning activities taking place within and along the main tributary of the dam which is Mufure river as shown in figure 4.9. The channel width and depth of the main river channel have been greatly reduced by sediment deposition and this results in high (calculated) specific sediment yields therefore reduced useful lifespan of the dam as shown in Tables 4.1 and 4.2.

Figure 4.9: *Pictures A and B Showing Alluvial gold panning activities taking place along Mufure river, the main tributary of Chesa Causeway dam (Date pictures taken: 28/01/2010)*

4.3.2 Land cover Changes in the Sebastopol dam catchment

Figures 4.10 to 4.12 show the changes in land cover patterns for Sebastopol dam catchment in 1991, 2003 and 2009. The Landsat images were taken for the month of April of each named year. The Landsat images showing the land cover patterns for Sebastopol dam catchment area are in the same years and months as that of the Chesa dam catchment area so as to have a comparative analysis of the results of both study areas.

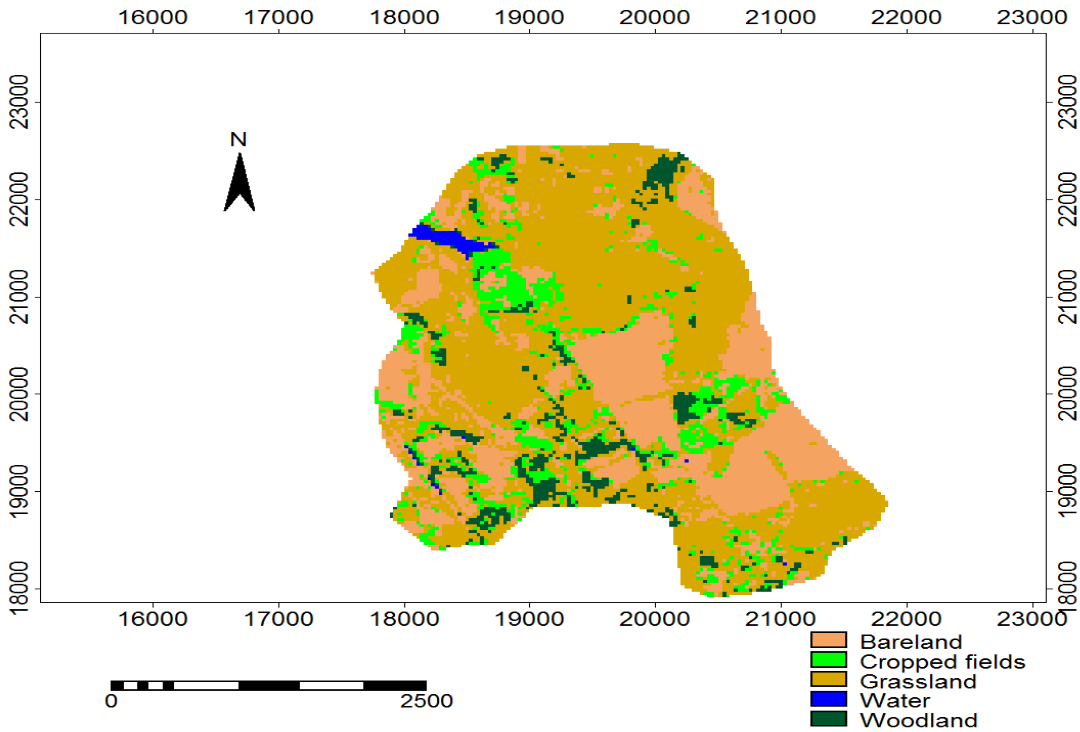

Figure 4.10: *Land cover pattern in 1991 for Sebastopol dam catchment area*

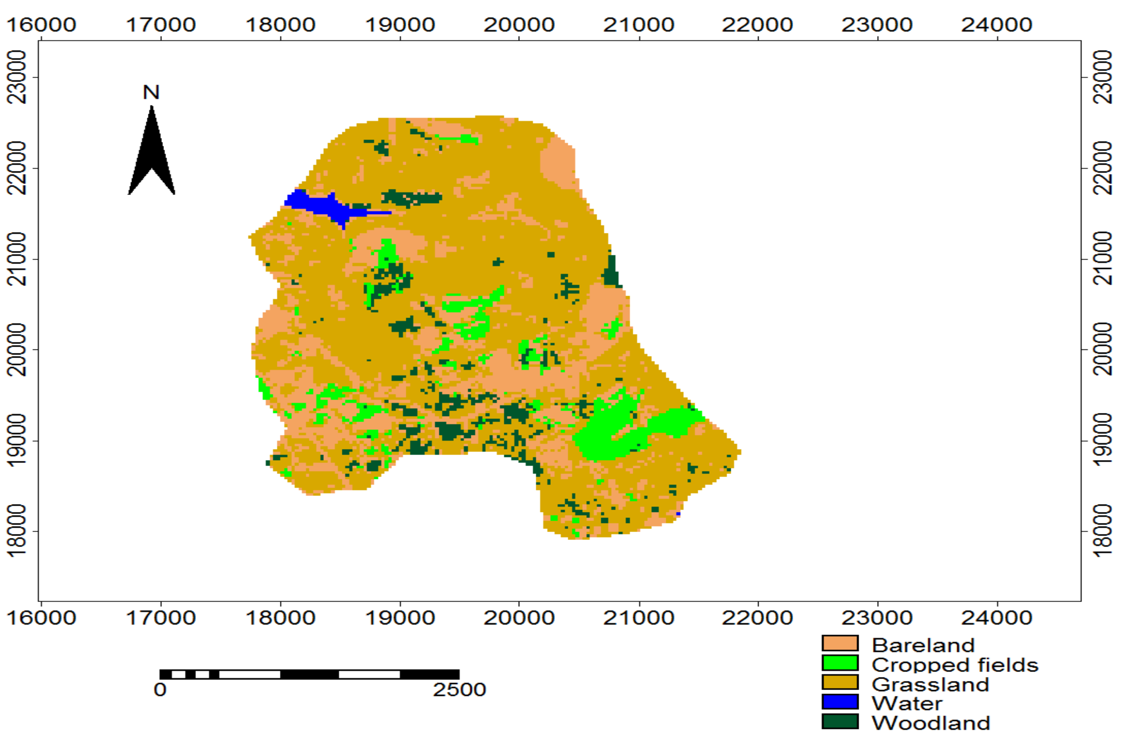

Figure 4.11: *Land cover pattern in 2003 for Sebastopol dam catchment area*

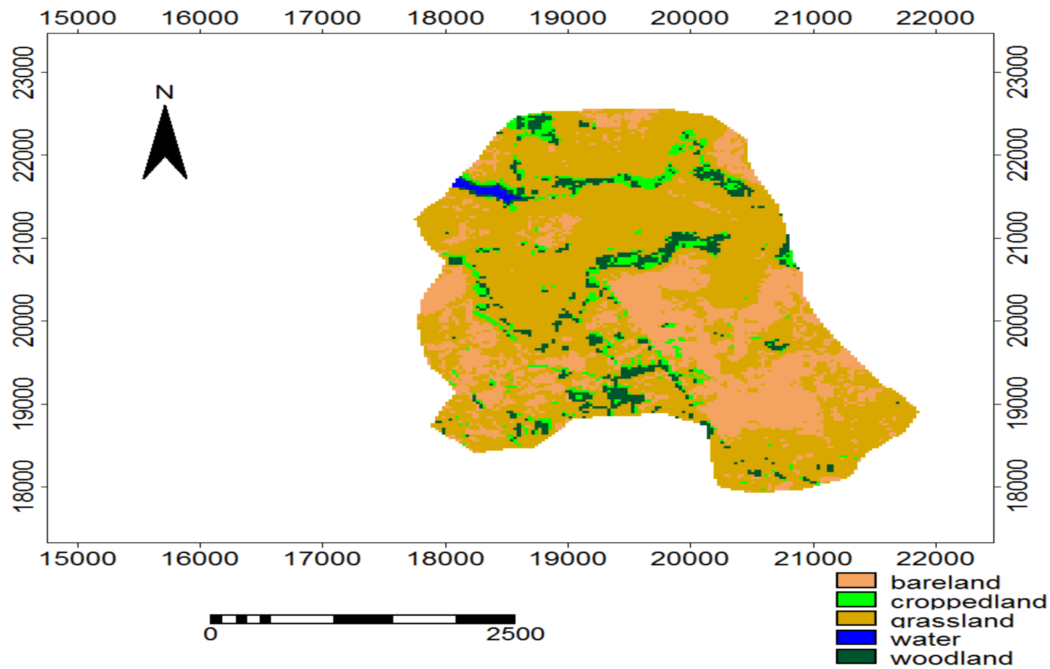

Figure 4.12: *Land cover pattern in 2009 for Sebastopol dam catchment area*

The land cover changes for different land classes for the study area over the years were then statistically analysed using ILWIS software in GIS and a histogram was produced as shown in figure 4.13 below**.**

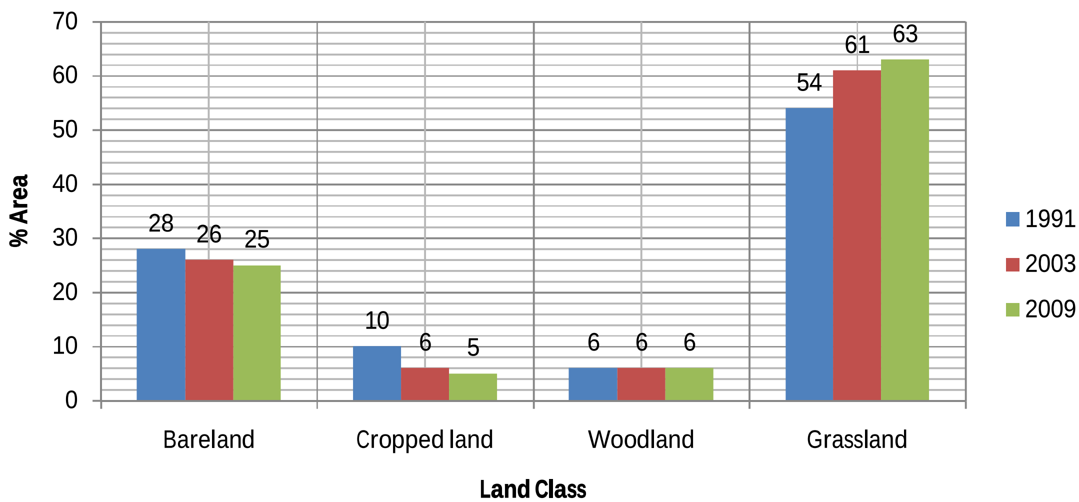

Figure 4.13: *Land cover changes from 1991, 2003 and 2009 for Sebastopol dam catchment area*

From figure 4.13 above there is no much change in percentage area for the land cover classes from 1991 to 2009. With only slight decreases of 3 % in bareland, 5 % for cropped land, whilst woodland has remained constant and a slight increase of 8 % of grassland for the same period under study. Furthermore figure 4.14 shows how well grassed the catchment is, the net effect of this will be more rainfall interception and reduction in velocity of flow during a rainfall event hence reduced erosion. This subsequently reduces sediment deposition into the reservoir.

Figure 4.14: *Sebastopol dam catchment area: pictures showing dominant grassland cover (11/01/10).*

From ground truthing, the main land use activity taking place is agriculture, with minimal effects of siltation of the dam hence the low sediment specific yields results found using both quantification methods discussed in section 4.2, as compared to those of Chesa Causeway dam hence a prolonged useful lifespan of the dam.

In conclusion land use activities influence the lifespan of reservoir and, in this case, the less conserved Chesa Causeway dam catchment which is characterised by alluvial gold panning activities will have a much less useful life than predicted.

4.4 Predicting the impact of sedimentation on available water for use.

4.4.1 Determination of reservoir yield

- **Sebastopol Dam**
    - **Estimation of percentile flows**

Using Equation 2.11 the ADF was found to be 0.05 $m^3 s^{-1}$ and daily average was found to 0.35 $m^3 s^{-1}$. Q_{50} (percentile flow) expressed as a multiple of ADF was found to be 0.29 $m^3 s^{-1}$. Q_{90}, Q_{80}, Q_{70}, Q_{60}, Q_{50} and Q_{40} percentile flows were calculated following the stages outlined in section 4.4.1. The percentile flows were then converted to gross yields as shown in Appendix 3D and a graph showing the relationship between percentile flows and gross yields was plotted (Flow duration curve) as shown in figure 4.15.

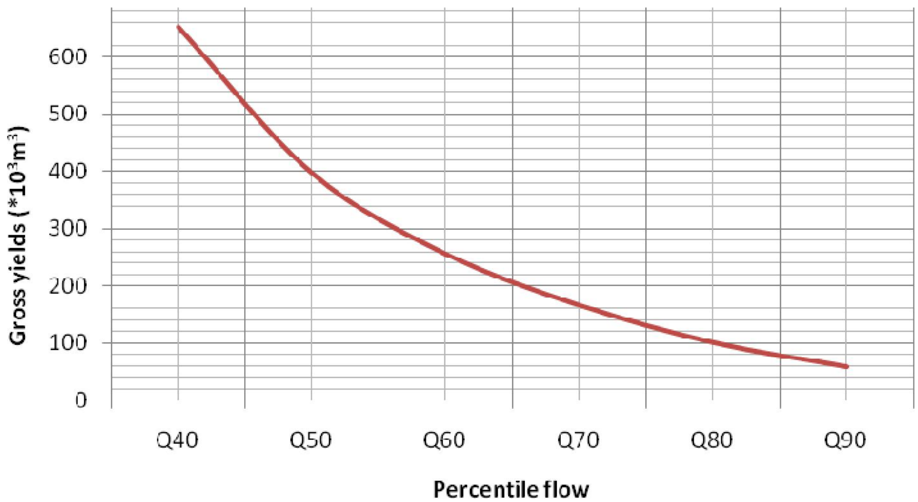

Figure 4.15: *Relationship between percentile flow and gross yield (m^3) for Sebastopol dam*

From the graph the gross yield from the catchment would be adequate to fill the Sebastopol dam whose current capacity is 116 $*10^3$ m^3 at 75% of the time during a normal rain season.

- **Chesa Causeway dam**

    - **Estimation of percentile flows**

Using Equation 2.11 the ADF was found to be 0.93 m^3 s^{-1}. Q_{50} (percentile flow) expressed as a multiple of ADF was found to be 0.22 m^3s^{-1}. Q_{90}, Q_{80}, Q_{70}, Q_{60}, Q_{50} and Q_{40} percentile flows were calculated as outlined in section 3.4.1. The percentile flows were then converted to gross yields as shown in Appendix 3E and a graph showing the relationship percentile flows and gross yields was plotted (Flow duration curve) as shown in figure 4.16.

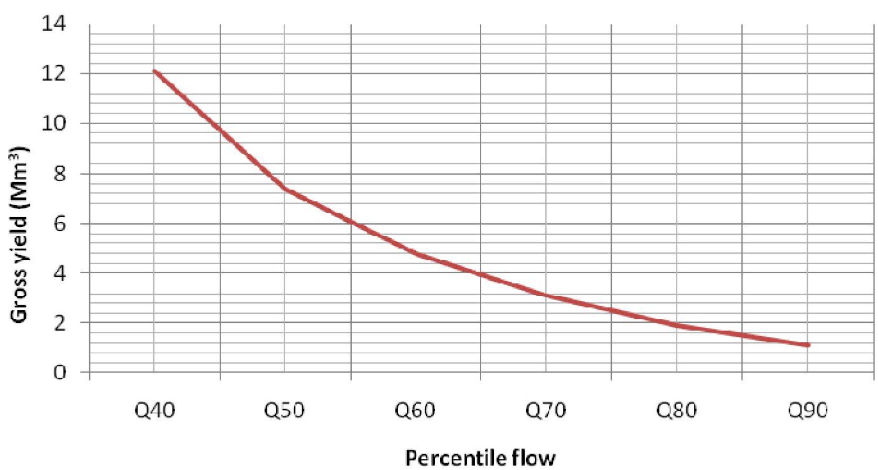

Figure 4.16: *Relationship between percentile flows and gross yield (m^3) for Chesa Causeway dam.*

From the graph the gross yield from the catchment would be adequate to fill the Chesa Causeway dam whose design capacity is 1 150* 10^3 m^3 at 87 % of the time during the rainfall season.

4.4.2 Estimating the Storage volumes for each gross yield

- **Sebastopol Dam**

Storage required for each gross yield is expressed as a percentage of the average daily flow (ADF) as shown on Table 4.4:

Table 4.4: *Estimated Storage volumes for the gross yields for Sebastopol dam***.**

Percentile flow	**Q_{90}**	**Q_{80}**	**Q_{70}**	**Q_{60}**	**Q_{50}**	**Q_{40}**
Storage as a % of ADF	0.48	1.60	3.00	5.0	10.00	18.00
Volume of Gross yield (m^3)	7584	25200	47250	91350	157500	283500

From the Table 4.4 the volume of gross yield decreases with an increase in percentile flow, therefore this shows that at higher levels of percentile flows the dam would be dry (from Q_{80}).

- **Chesa Causeway dam**
  Storage required for each gross yield is expressed as a percentage of the average daily flow (ADF) as shown in Table 4.5:

Table 4.5: *Estimated Storage volumes for the gross yields for Chesa Causeway dam***.**

Percentile flow	**Q_{90}**	**Q_{80}**	**Q_{70}**	**Q_{60}**	**Q_{50}**	**Q_{40}**
Storage as a % of ADF	0.2	0..70	1.50	2.80	5.00	8.50
Volume of Gross yield (Mm^3)	1.39	4.87	10.43	19.47	32.12	59.14

From the table above the volume of gross yield decreases with an increase in percentile flow, therefore this shows that at all percentiles of flow the dam would be full as the design capacity of the dam was 1 150* 10^3 m^3.

4.4.3 Surface area- Cumulative Volume relationship

Plots of the surface area-cumulative volume for the dams to establish the relationship of the two variables are shown in figures 4.17 and 4.18. The relationship needed to be established first so as to calculate the evaporation estimates from the dam.

- Sebastopol dam

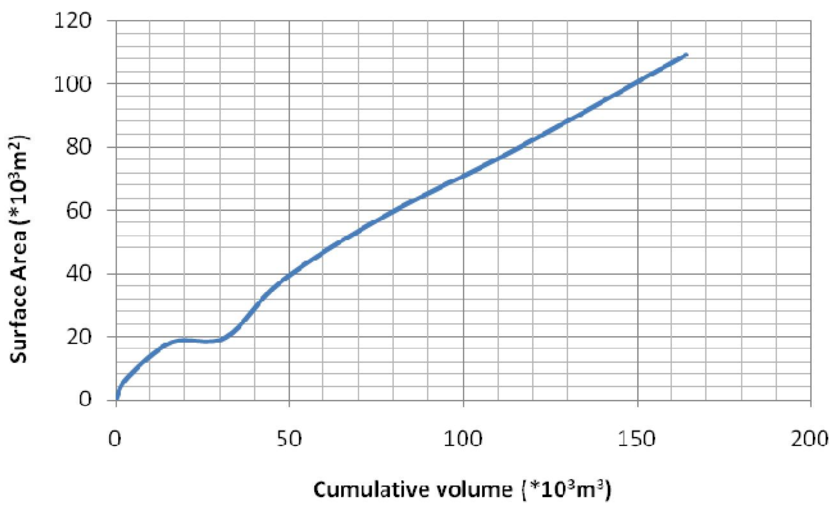

Figure 4.17: *Sebastopol Dam Surface area- cumulative volume relationship*

The plot of the two variables has a linear relationship with a strong co-relation co-efficient of 0.992. Reservoir surface areas for each of the six storage volumes determined in section 4.4.2 were then calculated using the above relationship. The evaporation estimates were then calculated using Equation 2.14.

- **Chesa Causeway Dam**

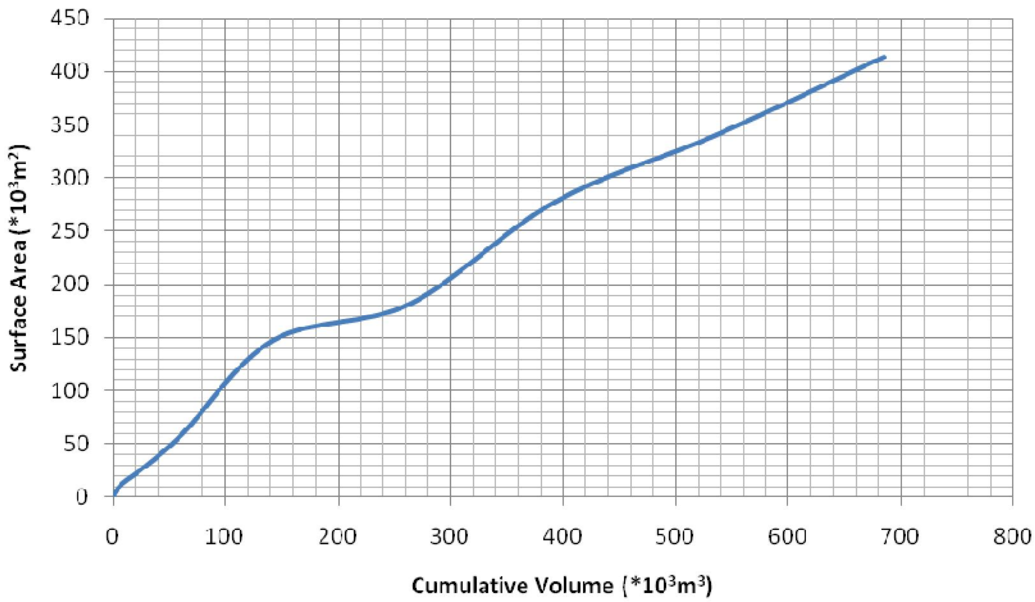

Figure 4.18: *Chesa Causeway Dam Surface area- cumulative volume relationship*

From figures 4.17 and 4.18 there are kinks this shows that deposition is not uniform across the surface areas of both the dams

The relationship is a linear relationship with a co-relation co-efficient of 0.983. Reservoir surface areas for each of the six storage volumes determined in section 4.4.2 were then calculated using the above relationship. The evaporation estimates were then calculated using Equation 2.14.

4.4.3 Derivation of net yields

- Sebastopol dam

The net yield was estimated by subtracting evaporation and dead storage from gross yields volumes. A plot showing the relationship between storage and yield is shown in Figure 4.19.

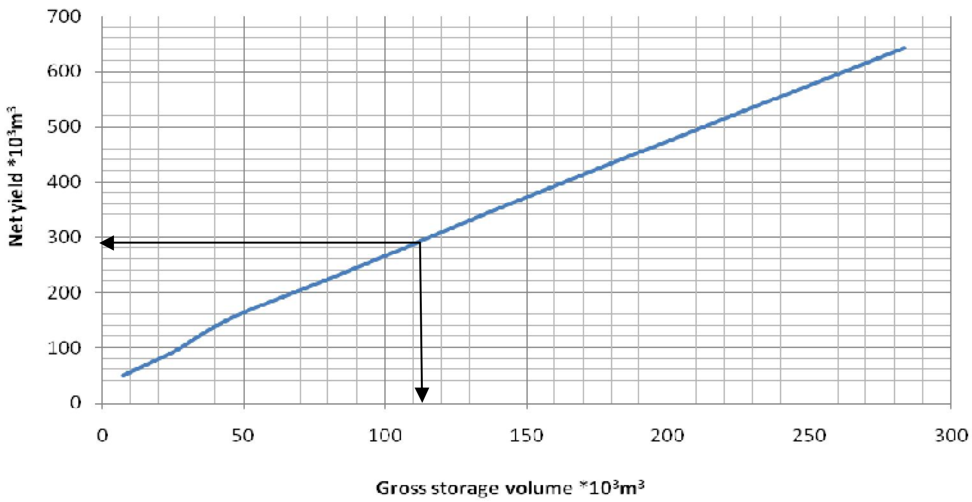

Figure 4.19: *Storage - Yield (m^3) relationship for Sebastopol dam*

Using the above relationship the current dam capacity is 116* 10^3 m^3 and the corresponding yield is 295* 10^3 m^3. The two variables have a power relationship with a co-relation co-efficient of 0.990 and it was adopted to calculate the yields at different storages for Sebastopol dam.

- **Chesa Causeway dam**

The net yields were estimated by subtracting evaporation and dead storage from gross yields volumes.

A storage yield relationship was then determined by having a plot of the two variables as shown in figure 4.20.

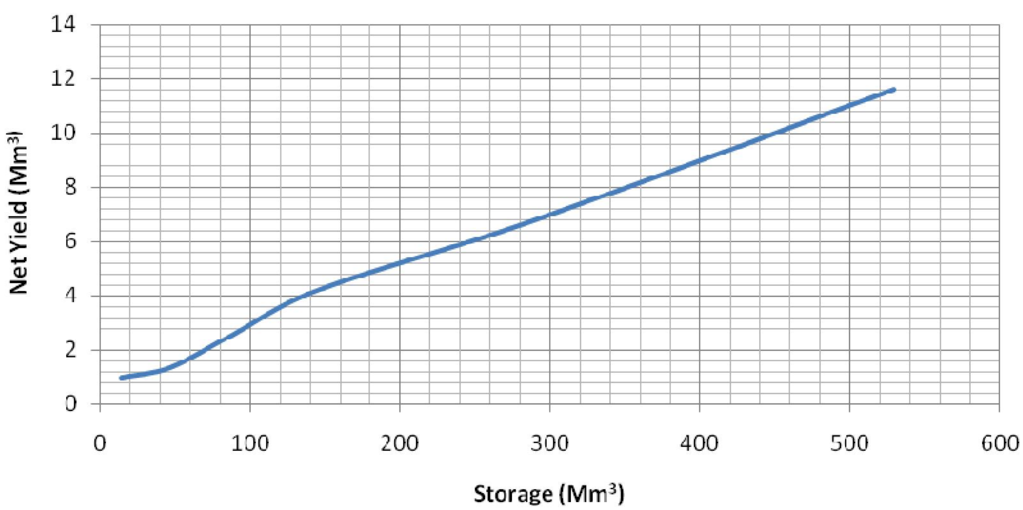

Figure 4.20: *Storage –Net Yield relationship for Chesa Causeway Dam*

The relationship of storage and yield is a power function with a strong correlation coefficient of 0.95. It was adopted and used to calculate the yield at different storage volumes for the dam.

4.4.4 Projected trends for the calculated key parameters

The calculated parameters were first expressed as percentages for the predicted years. Then the trends on the impact of sedimentation on the available water use are shown in figures 4.21 and 4.22 for both study areas.

- **Sebastopol Dam**

The predicted trends for Agricultural water use for Sebastopol farm are shown in figure 4.21.

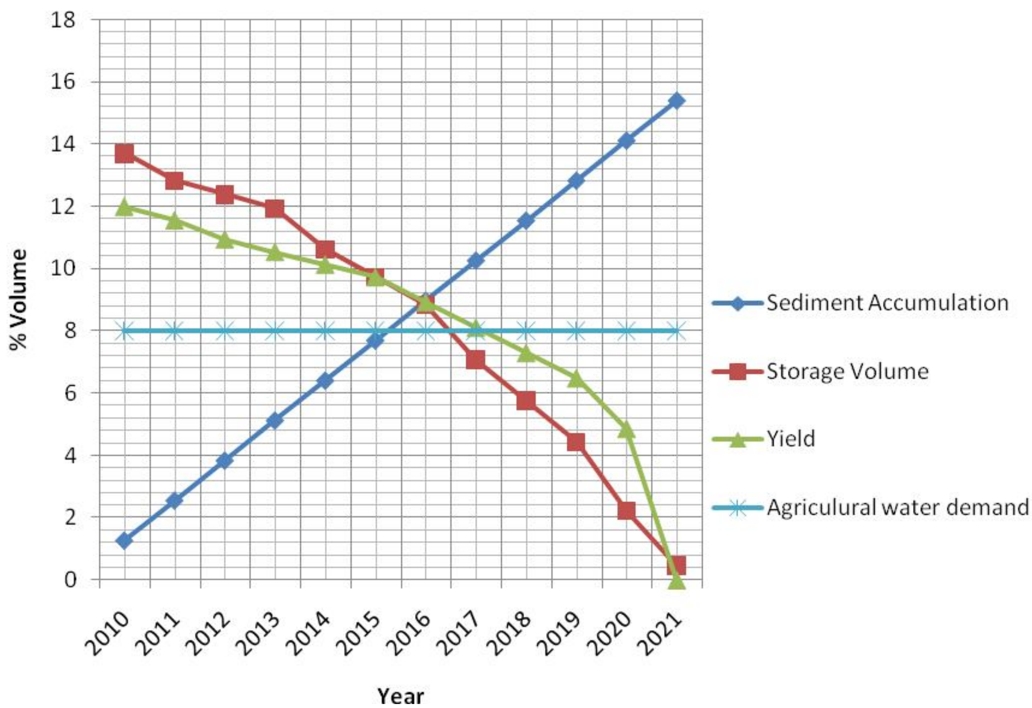

Figure 4.21: *Projected Impacts of Sedimentation on availability of Agricultural Water use for Sebastopol dam*

From Figure 4.21 there is a general trend where by the storage volume and the net yield are decreasing with time. The agricultural water demand was assumed to be constant (8 % per annum of the accumulative total demand of up to 2021). Both storage volume and net yield are dependent on the sediment accumulation. As sediment accumulates, storage volume and net yield are decreasing; in 2018 the demand is more than the storage volume and net yield.

This shows that the reservoir useful lifespan for supplying water for irrigation has been reached exactly 50 years as per the design of the dam.

- **Chesa Causeway Dam**

A linear graph was plotted in order to predict the impacts of sedimentation on availability of domestic water use (Chesa Causeway dam), as shown in figure 4.22.

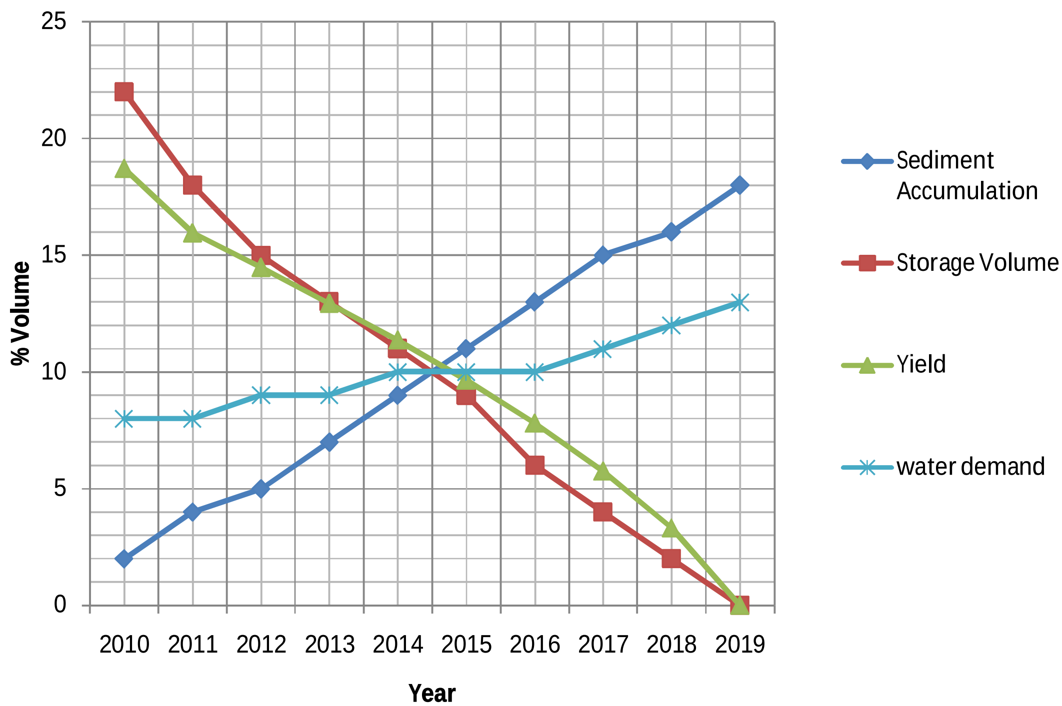

Figure 4.22: *Projected Impacts of sedimentation on availability of domestic water for Chesa Causeway dam.*

From Figure 4.22 the general trend is the same as that of Sebastopol dam, where by the storage volume and the net yield expressed as percentages are decreasing with time. The domestic water demand (%) is also increasing due to the increasing population for each projected year. Both storage volume and net yield are dependent on the sediment accumulation as sediment accumulates; storage volume and net yield are decreasing. By 2015 water demand would be more than the net yield meaning that the useful lifespan of the dam would have been reached. From the projections made the dam has a useful lifespan of 24 years, 16 years less than the projected design useful lifespan. The dam would no longer be useful for human benefit from 2016 to 2019 (where it would be eventually silted up) if the trend continue at the current rates.

Alternative water sources need to be looked into so as to continue sustaining the livelihoods of the communities dependent on the dam for survival. The short useful lifespan of the dam is due to high specific sediment yield from the catchment (confirmed by the sediment quantification methods used), as compared to Sebastopol dam.

The trends at both sites, whereby the net yield, and storage volume are decreasing with time whilst sediment is accumulating with time is the same as that was found at Chamakala dam on a study determining the impacts of sedimentation on the availability of water resources on Chamakala dam in Malawi (Kamtukule, 2008).

4.5 Discussion of major findings

Chesa Causeway dam was wrongly sized during the design stage. From dam design principles storage ratio should have been greater than 0.1 to allow for reasonable siltation while capturing much of the annual inflow from the dam catchment area. This low storage ratio has resulted in high specific sediment yields recorded using both sediment quantification methods as indicated by Table 4.3, hence reduced lifespan than the predicted. Unlike Sebastopol dam which had a storage ratio of 0.17 when it became operational, it was able to capture much of the mean annual flow from the catchment and as well as allowing most of the sediments to settle in the dead storage zone of the dam.

Land use activities influence the useful lifespan of a reservoir; in this case alluvial gold panning activities taking place along the main tributary of Chesa Causeway dam have also led to the reduced lifespan to only 25 years compared to the 50 years initially predicted. Whilst Sebastopol dam is in a catchment which is well conserved catchment following the Zimbabwean catchment classification as discussed in section 4.2.1.

From the projections made Chesa Causeway dam has a remaining useful lifespan of 24 years, 26 years less than the projected design useful lifespan. The dam would no longer be useful from 2016 (where it would be eventually silted up) if the trend continue at the current rates. Alternative water sources need to be explored immediately so as to continue to sustain the livelihoods of the communities dependent on the dam for life sustenance. Whilst Sebastopol dam has a useful lifespan of 50 years exactly as predicted during the design stage.

Practically, the following factors influence the useful lifespan of dam; sizing of the dam during the design stage and land use activities within the dam's catchment area.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

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

Conclusions

- Both methods have confirmed that Chesa Causeway dam has higher sedimentation rate (with S_{sy} values of 774 $tkm^{-2}yr^{-1}$: grab sampling and 503 $tkm^{-2}yr^{-1}$: hydrographic survey) than Sebastopol dam (with S_{sy} values of 390 $tkm^{-2}yr^{-1}$- grab sampling and 258 $tkm^{-2}yr^{-1}$- hydrographic survey). Chesa Causeway dam has lost more than half its storage capacity (66 %) in its 19 years of operation whilst Sebastopol dam has lost 57% of its storage over 42 years of operation. Also Chesa Causeway dam was wrongly sized during the design stage with a volume of $1.15*10^6$ m^3 to capture a mean annual inflow of $29.54*10^6$ m^3 from a catchment area of 229 km^2, with a gross storage ratio of 0.01. This also confirms the high rates of sedimentation hence a reduced useful lifespan of the dam.

- Land use activities influence the lifespan of reservoir and, in this case, the less conserved Chesa Causeway dam catchment which is characterised by alluvial gold panning activities will have a much less useful life than predicted. Sebastopol dam land cover classes (percentage areas) have remained almost constant in 1991, 2003 and 2009 whilst the main land use (agriculture) has caused minimal siltation of the dam hence prolonged lifespan of the dam

- Alternative water sources for Mt Darwin town need to be considered immediately for sustenance of livelihoods of communities' dependant on Chesa Causeway dam. From the projections made, if the trend continue at the current rate Sebastopol dam will have a useful lifespan of 50 years (from 1968 to 2018) as compared to Chesa Causeway dam with projected useful lifespan of 24 years (from 1991 to 2015), 16 years less than the projected.

Recommendations

- Hydrographic surveys and the grab sampling method should be both used for estimating sedimentation rates for a particular reservoir as they can be effective and useful tools for decision making in integrated catchment management. Feasibility studies should be conducted to find if it is possible to construct a sediment trap dam on the upstream of Chesa Causeway as well as considering raising of the dam embarkment,

- The study recommends all catchment councils adopt and enforce comprehensive catchment management plans as outlined in the 1998 Zimbabwe Water Act 20:24 subsection 12 (See a proposed Implementation plan attached in Appendix 2A). GIS and physical measurements should be used conjunctively as tools for decision making by scientist and policy makers in integrated catchment management,

- Water demand management techniques (for instance retrofitting), should be considered to reduce per capita consumption this may aid in prolonging the useful lifespan of the dam. There is need for the local council to borrow funds from the Central government so as to develop alternative water sources for Mt Darwin Town.

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APPENDICES

Appendix 1A: SEBASTOPOL DAM LEVELS

SEBASTOPOL DAM LAND SURVEY

	Wires					
Vertical Angle	Centre	Top/Btm	Slope Dist	Bearing	Reduced Level	Remarks
89.56.00	1.475	1.95/1.000	95	0	101.136	DW2-DW1
				180	101.004	
90.23.40	1.396	1.790/1.000	79	04.18.20	100.650	Spillway start A
90.23.00	1.402	1.810/1.000	81	06.05.40	100.650	Spillway start A
90.15.20	1.400	1.800/1.000	80	05.26.40	99.998	Spillway start A
90.48.20	1.000	1.800/1.000	80	02.44.00	100.070	
89.32.20	2.590	3.180/2.000	118	355.15.20	100.970	End Wall
89.27.20	2.245	2.490/2.000	49	44.30.00	100.810	Wall
88.24.40	3.235	3.470/2.000	47	40.24.20	100.660	
89.02.20	3.215	3.430/3.000	43	38.02.20	100.090	
90.59.20	1.360	1.715/1.000	71.5	08.54.00	99.999	Spillway
90.33.20	1.515	2.030/1.000	103	354.25.00	100.080	
90.18.00	2.290	2.580/2.000	58	17.14.00	99.990	
90.21.00	2.255	2.520/2.000	52	34.41.00	100.020	
90.38.20	1.185	1.260/1.100	16	186.18.00	101.140	
90.48.00	1.195	1.290/1.100	19	201.20.00	101.130	
90.04.00	1.650	2.310/1.000	31	345.58.00	100.910	
90.32.20	1.530	2.060/1.000	106	345.14.00	100.070	
91.12.20	2.100	2.205/2.000	20.5	209	100.060	
89.31.00	2.735	3.470/2.000	147	326.47.00	101.090	
89.35.20	2.650	3.300/2.000	130	186.47.20	100.876	DW3
				06.47.20		
89.28.20	3.585	4.170/3.000	117	319.19.00	100.090	
89.39.00	2.655	3.310/2.000	131	185.33.00	100.728	
89.50.00	1.880	2.760/1.000	176	310.51.00	101.230	
89.58.00	2.640	3.280/2.000	128	187.51.20	100.030	
				06.47.20	100.876	DW3-DW2
				186.47.20		HI=1.494
90.06.00	2.251	2.502/2.000	50.2	195.13.00	100.030	
89.16.00	2.275	2.550/2.000	55	184.05.00	100.790	Dam Wall
89.31.20	4.125	3.000	235	357.01.00	100.150	T.G RB1
89.36.20	2.770	2.000	154	12.11.00	100.670	TG LB1
89.45.00	3.130	2.000	226	338.04.00	100.230	TG RB2
89.15.00	2.275	2.550/2.000	55	181.22.00	100.830	Dam Wall
89.44.20	3.150	2.000	230	337.53.00	100.270	TG LB

89.21.20	2.430	2.860/2.000	86	206.44.20	100.910	
89.44.20	3.150	4.310/2.000	231	336.58	100.270	TG LB
89.43.00	2.365	2.730/2.000	73	02.31.20	100.370	TG LB
89.42.00	2.355	2.710/2.000	77	254.26.00	100.420	TG RB
89.57.00	2.370	2.000	74	315.16.20	100.060	TG
89.52.00	2.615	3.230/2.000	123	259.31.00	100.040	
89.50.20	2.450	1.000	290	318.02.00	100.740	
89.57.20	1.910	2.020/1.000	102	268	100.540	TG 4
89.48.20	2.000	3.000/1.000	200	260.06.20	101.050	
89.46.00	3.700	2.000	340	304.44.00	100.050	
89.48.00	3.220	4.440/2.000	244	271.07.00	100.000	TG
89.37.20	3.750	2.000	350	308.42.40	100.930	
89.51.00	2.950	4.900/1.000	390	299.28.00	100.441	TG CP 5
				119.28.20		
				119.28.20	100.441	TG-DW3
				299.28.20		HI=1.424
89.33.20	3.150	2.000	230	156.05.00	100.500	
88.26.00	1.385	1.570/1.000	57	359.00.00	102.040	
89.52.00	2.080	3.160/1.000	216	170.12.00	100.290	TG
89.32.00	2.315	2.630/2.000	63	255.18.40	100.060	
89.29.00	3.340	2.000	268	176.32.00	100.940	
88.23.00	2.375	2.750/2.000	75	301.26.00	101.610	
89.41.00	3.430	2.000	286	191.47.00	100.010	
89.47.20	1.530	2.060	106	271.48.00	100.730	TG
89.38.00	3.290	2.000	258	200.26.00	100.230	
89.28.00	1.555	2.110/1.000	111	289.04.00	101.340	
89.29.00	3.430	2.000	286	205.07.00	101.010	
89.54.00	2.270	3.540/1.00	254	218.25.00	99.860	
89.21.20	3.490	2.000	298	219.06.20	101.730	
89.33.20	3.350	4.700/2.000	270	224.24.00	100.610	TG
90	4.810	3.800	202	194.49.00	97.080	
90.04.00	4.150	3.000	230	191.47.00	97.440	
90.02.00	4.270	3.000	254	190.17.00	97.440	
89.59.20	3.390	2.000	278	188.31.20	98.520	
89.50.00	3.520	2.000	304	187.33.00	99.230	
89.41.00	3.710	2.000	342	187.29.00	100.040	
89.34.00	2.700	1.000	340	182.10.00	101.730	
89.20.00	3.760	2.000	352	193.05.00	102.230	
89.30.00	2.940	1.000	388	183.32.00	102.310	
89.35.20	3.930	2.000	386	186.18.00	100.700	
89.22.00	3.750	2.600	230	183.57.20	100.650	
89.19.00	4.000	2.000	400	190.40.00	102.640	

89.36.20	3.210	2.000	242	185.44.00	100.140	
89.15.00	4.230	2.000	446	188.57.00	103.470	
89.21.20	3.450	2.000	290	185.19.00	101.670	
91.56.00	2.375	1.000	275	213.08.04	102.433	CP1
				33.08.40		
				0	101.136	DW2-DW1
				180.00.00		HI=1.480
97.25.00	2.175	2.350/2.000	35	122.12.20	95.960	Outlet level
				33.08.40	102.433	CP1-TG CP
				213.08.40		
89.23.40	3.980	2.000	396	285.18.30	104.119	CP2
				105.18.30		
90.00.00	2.750	1.000	350	285.27.20	101.164	
90.01.20	3.420	2.000	284	294.27.00	100.458	
90.11.00	2.100	1.000	220	310.49.20	101.110	
90.12.20	2.000	3.010/1.000	201	322.28.00	101.190	
90.15.00	2.170	3.360/1.000	236	10.41.00	100.710	
90.04.20	2.990	3.980/2.000	198	322.21.00	100.673	
90.02.00	2.380	1.000	276	09.57.00	101.372	
90.08.40	3.280	2.000	256	357.02.20	99.988	
90.17.20	2.450	1.000	290	287.27.40	100.001	
90.10.00	2.380	1.000	276	358.03	100.730	
90.16.20	2.280	1.000	256	294.16.20	100.417	
90.07.20	2.530	1.000	306	348.07.40	1000.730	
89.43.00	3.550	2.000	310	350.49.20	101.896	
90.28.00	2.210	1.000	242	308.03.00	99.732	
90.07.20	2.610	1.000	322	345.10.00	100.616	TG
90.16.00	3.020	2.000	204	330.04.00	100.879	
89.59.00	2.750	1.000	350	345.29.00	101.265	
90.01.20	3.800	2.000	360	339.16.20	99.973	
90.11.00	3.220	2.000	244	332.35.00	99.912	
89.46.00	3.230	4.460/2.000	246	331.34.00	101.685	
90.37.00	3.190	2.000	238	336.43.00	98.162	
89.58.00	2.860	1.000	372	342.55.00	101.269	
90.25.00	3.680	2.100	316	338.42.00	97.935	
89.51.00	3.460	4.920/2.000	292	333.52.20	101.219	CP A – TG
				153.52.20		
				153.52.20	101.219	CP A- CP1
				333.52.20		HI= 1.440

90.00.20	2.630	2.000	126	354.00.00	100.017	
90.07.20	2.620	2.740/2.500	24	354.04.00	99.988	
89.22.00	2.660	2.000	132	00.25.20	101.458	
88.11.00	3.145	2.000	229	319.20.00	101.334	
90.13.20	1.915	1.000	183	347.38.00	100.034	
90.11.00	2.400	2.800/2.000	80	333.26.00	100.003	
91.31.00	2.960	2.700	52	352.09.00	98.323	
91.12.00	2.520	2.100	84	342.54.00	98.380	
90.06.20	1.445	1.000	89	328.32	101.050	
90.53.00	2.560	2.000	112	348.53.00	98.373	
89.18.40	2.940	2.000	188	352.40.00	101.979	
89.32.00	3.615	3.000	123	344.07	100.046	
90.27.00	2.755	2.000	151	348.55.00	98.718	
89.50.00	1.670	1.000	134	336.18.00	101.379	
89.51.00	3.140	2.000	228	346.16.00	100.116	
89.58.00	2.790	2.000	158	346.23.00	99.961	
89.36.00	1.840	1.000	168	338.59.00	101.992	
89.14.20	3.150	2.000	230	349.59.00	102.564	
90.13.00	2.900	2.000	180	346.33.00	99.078	
89.13.00	3.110	2.000	222	339.48.20	102.584	
89.48.00	3.200	2.000	240	344.45.00	100.297	
89.45.00	3.970	3.000	194	345.05.00	99.535	
89.30.20	2.500	1.000	300	344.09.00	102.748	
89.10.00	3.300	2.000	260	338.55.00	103.140	
				105.18.30	104.119	CP2-CP1
				285.18.30		HI=1.513
92.09.00	2.430	2.000	86	101.51.00	99.978	
90.18.00	2.770	2.000	154	109.10.00	102.056	
90.25.00	3.340	2.000	268	102.37.00	100.343	TG
90.48.00	3.375	3.000	75	87.14.00	101.210	
90.54.00	2.120	1.000	224	104.32.00	99.994	
90.10.00	3.200	2.000	240	110.47.00	101.734	
91.01.00	1.930	1.000	186	113.15.00	100.402	TG
90.22.00	2.030	1.000	206	118.03.40	102.284	
92.01.00	3.280	3.000	56	158.01.00	100.380	
91.36.00	1.700	1.000	140	123.29.00	100.025	
90.44.00	1.790	1.000	158	136.03.00	101.820	
92.43.00	3.118	3.000	23.6	167.50.00	101.397	
91.17.00	2.570	2.000	114	155.04.00	100.509	TG
90.52.00	1.730	1.000	146	156.24.00	101.694	
92.04.00	2.440	2.000	88	202.38.00	100.021	

92.15.40	3.515	3.000	103	192.17.00	98.056	
90.38.00	2.740	2.000	148	174.45.00	101.256	
91.18.00	2.670	2.000	134	190.17.00	99.923	
91.26.00	2.370	2.000	74	221.08.00	101.412	
90.35.20	2.840	2.000	168	193.59.00	101.065	
91.56.00	2.930	2.200	146	197.23.00	97.778	
91.09.20	2.720	2.000	144	216.43.00	100.009	
90.41.20	2.000	1.000	200	207.27.00	101.228	
90.37.20	2.650	2.000	130	230.10.00	101.570	
90.31.20	3.930	2.000	346	212.58.00	98.549	
91.17.00	4.770	4.000	154	216.09.00	97.414	
91.02.00	2.010	1.000	200	221.39.00	100.016	
90.39.00	2.140	1.000	228	215.45.00	100.906	
91.04.00	3.980	3.000	196	215.55.00	98.004	
90.33.00	2.980	2.000	196	225.53.20	100.771	
90.35.00	3.220	2.000	244	225.31.00	99.928	
90.30.00	3.240	2.000	248	231.48.00	100.228	
90.26.00	2.370	1.000	274	224.26.00	101.190	
90.44.00	4.620	3.500	224	225.29.00	98.145	
90.18.00	3.220	2.000	244	234.36.00	101.134	
90.27.20	3.400	2.000	280	232.02.00	100.006	
90.21.00	3.780	2.300	296	235.12.00	100.044	
90.08.20.20	2.590	1.000	318	226.27.00	102.271	
90.31.00	5.000	3.600	280	233.33.00	98.107	
90.15.00	4.670	3.000	334	231.06.00	99.505	
90.13.00	3.500	2.000	300	236.39.00	100.998	
90.03.00	4.020	2.000	404	234.40.00	101.259	
90.19.00	3.740	2.000	348	232.28.20	99.969	

HYDROGRAPHIC SURVEY

DAM NAME: SEBASTOPOL Date: 11-13/01/10 Water level: 100.040

TG RB 1	POINT	DISTANCE	DEPTH	REDUCED LEVEL
	0	1.525	0.000	100.040
	1	4.000	0.885	99.155
	2	14.000	2.120	97.828
	3	24.000	1.920	98.120
	4	34.000	1.780	98.280
	5	44.000	1.400	98.640
	6	54.000	1.500	98.540
	7	64.000	0.960	99.080
	8	74.000	0.710	99.330

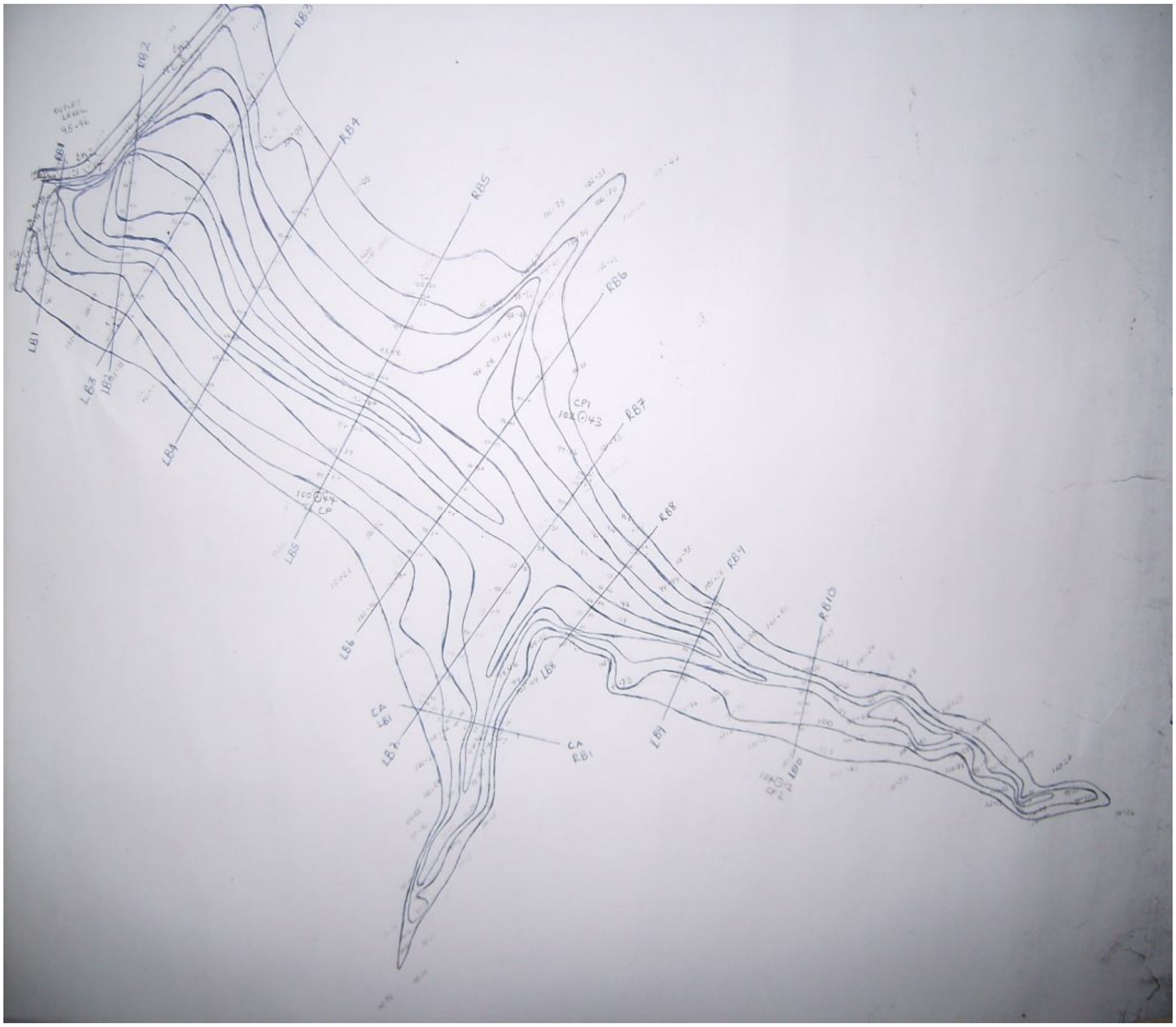
	9	84.000	0.190	99.850
	10	91.330	*	100.040
TG LB 1	11	94.000	*	*
TG RB 2	0	1.470	0.000	100.040
	1	4.000	0.490	99.550
	2	24.000	5.120	94.920
	3	44.000	5.130	94.910
	4	64.000	5.100	94.940
	5	84.000	4.110	95.930
	6	104.000	2.150	97.940
	7	124.000	0.760	99.280
	8	144.000	0.280	99.780
	9	158.900	*	100.040
TG LB2	10	163.000	*	*
TG RB 3	0	0.520	0.000	100.040
	1	4.000	0.640	99.400
	2	29.000	2.200	97.840
	3	54.000	4.000	96.040
	4	79.000	3.820	96.220
	5	104.000	5.370	94.670
	6	129.000	4.120	95.920
	7	154.000	4.000	96.040
	8	179.000	1.930	98.110
	9	204.000	1.280	98.780
	10	224.000	*	100.040
TG LB 3	11	230.000	*	*
TG RB4	0	1.300	0.000	100.040
	1	4.000	0.310	99.730
	2	29.000	1.230	98.810
	3	54.000	2.100	97.940
	4	79.000	3.380	96.660
	5	104.000	5.730	94.310
	6	129.000	3.190	96.850
	7	154.000	1.320	98.720
	8	179.000	1.150	98.890
	9	199.400	*	1000.040
TG LB 4	10	201.000	*	*
TG RB5	0	9.000	0.000	100.040
	1	15.000	0.220	99.820

	2	40.000	1.040	99.000
	3	65.000	1.860	98.180
	4	90.000	2.600	97.440
	5	115.000	5.400	94.640
	6	140.000	2.780	97.260
	7	165.000	2.270	97.770
	8	190.000	0.620	99.420
	9	208.500	*	100.040
TG LB 5	10	211.000	*	*
RB6-LB6	0	3.000	0.000	100.040
	1	4.000	0.220	99.820
	2	29.000	0.900	9.140
	3	54.000	1.430	98.660
	4	79.000	2.170	97.870
	5	104.000	3.500	96.540
	6	129.000	4.430	95.610
	7	154.000	2.600	97.440
	8	179.000	1.670	98.370
	9	204.000	0.870	99.170
	10	229.000	*	100.040
	11	235.750	*	*
TG RB7	0	2.000	0.000	100.040
	1	7.000	0.300	99.740
	2	32.000	1.360	98.680
	3 4	57.000 82.000	2.530 3.700	97.510 96.340
	5	107.000	2.860	97.180
	6	132.000	2.830	97.210
	7	157.000	2.440	97.600
	8	182.000	2.840	97.640
	9	207.000	1.430	98.610
	10	232.000	0.510	99.530
	11	257.000	0.100	99.640
	12	263.850	*	100.040
TG LB7	13	278.000	*	*
TG RB8	0	2.500	0.000	100.040
	1	5.000	0.230	99.810
	2	20.000	1.040	99.000
	3	35.000	2.240	97.800
	4	50.000	2.790	97.250

	5	65.000	3.300	96.740
	6	80.000	2.290	97.840
	7	95.000	2.260	97.780
	8	107.000	*	100.040
TG LB8		109.200	*	*
TG RB9	0	3.000	0.000	100.040
	1	6.000	0.330	99.710
	2	16.000	1.670	98.370
	3	26.000	2.330	97.710
	4	36.000	3.110	96.930
	5	46.000	1.520	98.520
	6	56.000	1.400	98.640
	7	66.000	1.040	99.000
	8	76.000	0.380	99.660
	9	77.500	*	100.040
TG LB9	10	78.050	*	*
TG RB10	0	2.000	0.000	100.040
	1	4.000	0.680	99.360
	2	14.000	2.360	97.680
	3	24.000	1.300	98.740
	4	34.000	0.910	99.130
	5	44.000	0.410	99.630
	6	54.000	0.160	99.880
	7	57.120	*	100.040
TG LB10	8	58.520	*	*
TG CA RB1	0	4.500	0.000	100.040
	1	7.000	0.940	99.640
	2	17.000	1.930	98.110
	3	27.000	2.420	97.620
	4	37.000	0.800	99.240
	5	47.000	0.390	99.740
	6	57.000	0.210	99.830
	7	64.300	*	100.040
TG CA LB1	8	76.000	*	*

Appendix 1B: Contour Map for Sebastopol Dam

(Scale 1:2000)



Appendix 1C: CHESA CAUSEWAY LEVELS

CHESA CAUSEWAY DAM HYDROGRAPHIC SURVEY

	Wires					
Vertical Angle	Centre	Top/Btm	Slope Dist	Bearing	Reduced Level	Remarks
				00.00.00	104.939	DW1-DW2
				180.00.00		HI= 1.513
89.57.00	1.800	2.600/1.000	160	00.00.00	105.853	DW2
94.15.00	4.663	4.830/4.500	33	03.327.00	99.350	SPILLWAY END
93.00.20	3.355	3.712/3.000	71.2	02.22.00	99.369	CENTRE OF SPILLWAY
91.46.20	3.570	4.140/3.000	114	01.55.20	99.358	SPILLWAY END
93.41.20	2.630	3.260/2.000	126	10.22.00	95.732	
94.42.00	3.320	3.740/3.000	74	54.50.00	97.089	W/E
94.47.00	4.490	4.000	98	12.49.00	93.818	
93.57.20	3.430	3.870/3.000	87	110.59.00	97.035	
95.49.00	3.380	3.760/3.000	76	24.22.00	95.402	
92.58.00	2.650	3.300/2.000	130	101.05.00	97.083	W/E
94.26.00	3.530	4.060/3.000	106	32.52.00	94.753	
92.32.00	3.650	4.300/3.000	130	93.26.00	97.062	W/E
92.57.00	3.710	4.420/3.000	142	46.21.00	95.443	
92.24.20	1.850	2.800/1.000	180	97.10.00	97.053	W/E
92.14.20	3.830	3.000	166	53.20.20	96.142	
91.28.00	3.190	2.000	238	101.26.00	97.172	
92.07.40	2.960	3.940/1.000	294	59.04.00	92.584	
91.33.20.00	4.100	3.000	220	62.58.00	96.382	
91.51.20	2.110	1.000	222	99.16.00	97.157	W/E
93.38.00	4.490	4.980/1.000	98	51.54.00	95.764	
92.27.00	1.880	1.000	176	90.30.00	97.055	W/E
95.07.20	2.540	2.100	88	68.41.00	96.087	
92.33.00	2.750	2.000	150	86.05.40	97.035	W/E
95.10.40	2.440	2.000	88	85.11.00	96.103	
93.10.00	3.530	4.060/3.000	106	86.37.00	97.075	W/E
93.29.00	3.540	3.000	108	94.41.00	96.362	
92.39.00	2.730	3.450/2.000	145	09.20.20	97.025	W/E
93.13.00	2.660	2.000	132	90.08.00	96.397	
93.12.20	2.660	3.200/2.000	120	49.41.00	97.152	W/E
92.38.20	2.790	2.000	158	92.18.20	96.395	
92.27.00	2.780	2.000	156	62.14.00	97.009	W/E
91.59.40	2.060	1.000	212	09.22.00	97.018	
91.45.00	2.190	1.000	238	68.38.00	96.997	W/E
91.14.20	3.400	3.000	80	07.51.00	101.323	

91.31.00	3.190	2.000	238	63.55.00	96.965	
91.50.00	3.100	2.000	220	52.09.20	96.317	W/E
91.02.00	2.850	1.000	370	06.56.00	96.930	W/E
91.28.00	3.150	2.000	230	39.08.20	97.395	W/E
91.32.20	3.160	2.000	232	34.15.00	97.064	
91.26.00	2.400	1.000	280	23.54.00	97.050	W/E
90.45.00	3.100	1.000	420	07.49.30	97.855	CP1
				187.49.30		
92.00.00	2.960	2.000	192	36.38.00	96.795	
92.44.00	3.640	4.680/3.000	168	30.02.00	94.810	
92.53.20	2.800	3.600/2.000	160	21.38.00	95.598	
92.48.00	2.750	3.500/2.000	150	15.43.20	96.383	
91.58.00	3.100	4.200/2.000	220	14.09.20	95.806	
92.02.00	4.110	3.000	222	21.28.20	94.470	
91.48.00	4.200	3.000	240	25.39.00	94.717	
91.29.00	2.450	1.000	290	20.57.00	96.498	
91.35.00	2.450	4.440/2.000	244	15.30.00	97.263	
91.28.00	4.610	3.000	322	10.31.00	93.603	
91.26.20	4.420	3.000	284	10.33.00	94.902	
91.09.00	1.609	1.500	21.8	04.32.00	104.404	
				187.49.30	97.855	CP1-DW1
				07.49.30		HI=1.494
89.17.20	3.460	3.920/3.00	192	153.45.00	98.272	
90.01.20	2.300	2.600/2.000	60	95.27.00	97.026	
90.22.20	1.575	2.150/1.000	115	24.35.00	97.027	
90.27.00	3.470	3.000	94	187.34.20	95.141	
90.17.20	4.440	4.000	88	168.32.20	94.465	
90.00.00	2.330	2.660/2.000	66	00.09.20	97.025	
89.53.00	2.530	3.040/2.000	104	356.29.20	97.021	W/E
93.35.00	3.100	3.200/3.000	20	147.37.20	95.001	
93.22.00	3.280	3.100	36	130.141.20	93.596	
90.59.40	3.300	3.600/3.000	60	59.41.00	95.008	
89.51.00	2.675	2.000	135	28.48.20	97.027	W/E
90.52.40	4.750	4.500	50	37.21.00	93.833	W/E
90.19.20	1.620	2.240/1.000	248	19.33.00	96.334	W/E
91.00.20	4.300	4.000	60	13.36.00	93.996	
90.20.00	3.650	3.100	110	20.42.20	95.059	
89.48.20	3.000	4.000/2.000	200	356.23.00	97.028	
90.56.00	3.540	3.000	108	09.48.00	94.050	
92.16.00	2.290	2.000	58	284.48.00	95.339	
93.55.20	2.170	2.000	34	282.56.20	95.431	
90.46.20	1.525	2.000/1.000	105	357.25.00	96.981	
90.22.00	3.420	3.200	44	335.09.00	96.219	

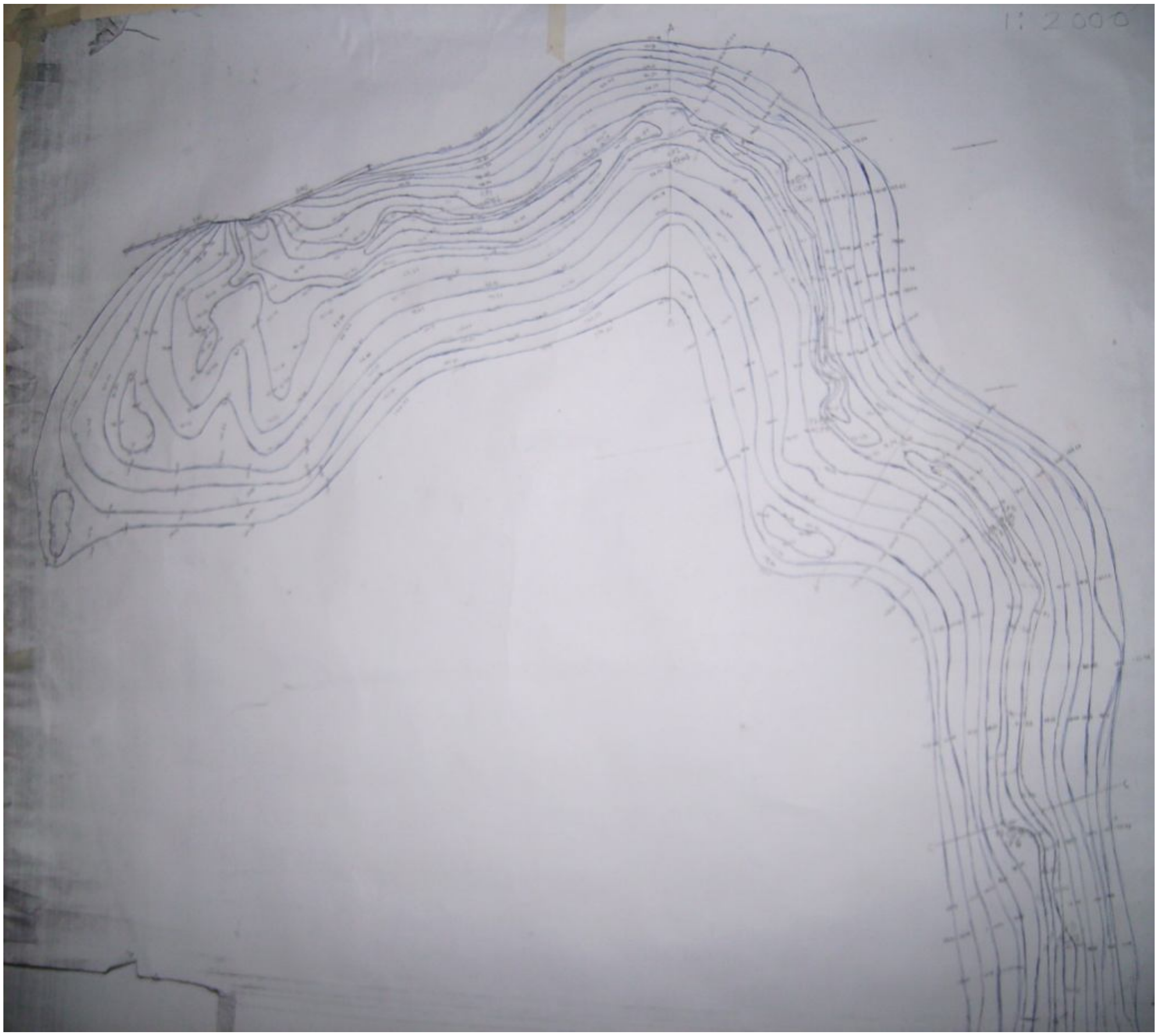
90.28.00	1.720	2.450/1.000	145	12.33.00	97.020	
90.53.20	4.320	4.000	64	343.03.00	94.608	
90.37.20	4.410	4.000	82	05.22.40	94.621	
90.27.00	3.670	3.000	134	14.35.00	95.199	
90.00.00	1.800	2.600/1.000	160	17.13.40	98.143	CP3
				197.13.40		
				197.13.40	98.143	CP3-CP2
				17.13.40		HI=1.455
91.53.00	3.190	3.000	38	161.12.00	95.160	
88.46.00	3.134	3.268/3.000	26.8	81.19.20	97.049	
92.46.00	3.175	3.000	35	117.16.40	94.736	
90.07.40	2.375	2.750/2.000	75	191.20.00	97.056	
90.14.20	2.300	2.600/2.000	60.2	128.48.00	97.047	
88.56.20	4.530	4.000	106	80.26.00	97.031	
91.40.00	3.330	3.000	66	87.20.00	94.349	
90.44.20	3.560	3.000	112	89.19.20	94.594	
90.00.00	2.560	2.000	112	100.22.00	97.063	
89.53.00	2.870	2.000	174	84.10.20	97.082	
90.15.20	4.940	4.000	188	91.03.00	93.819	
90.12.00	1.900	1.000	180	95.32.00	97.070	
90.09.00	2.330	3.660/1.000	266	92.09.00	96.571	
				92.56.00	97.818	CP4
				272.56.00		
				272.56.00		CP4-CP3
				92.56.00		HI=1.400
90.21.40	2.360	2.720/2.000	72	293.47.00	96.404	
91.45.00	3.260	3.000	52	290.24.00	94.371	
90.45.20	2.230	2.000	46	328.02.00	96.381	
94.03.20	3.600	3.500	20	335.38.00	94.207	
90.25.20	2.330	2.660/2.000	66	03.43.20	96.402	
91.57.20	2.250	2.000	50	32.53.20	95.263	
90.21.00	2.370	2.740/2.000	74	40.46.00	96.396	
90.09.20	2.515	3.030/2.000	108	21.03.20	96.410	
91.01.00	2.450	2.000	90	27.31.00	96.742	
90.01.00	2.770	3.540/2.000	154	24.10.00	96.403	
90.00.00	2.820	2.000	164	35.27.00	96.399	
90.34.20	2.800	2.000	160	27.54.00	94.820	
89.57.20	3.000	4.000/2.000	200	25.58.00	96.373	
90.09.00	2.190	1.000	238	31.30.00	96.382	
89.34.00	2.290	1.000	258	32.20.40	98.879	CP5
				212.20.40		

				212.20.40	98.879	CP5-CP4
				32.20.40		HI=1.395
91.37.20	1.215	1.430/1.000	43	151.54.20	97.842	CP5(LB)
				331.54.20		
99.14.00	2.735	2.770/2.700	7	151.54.20	96.430	
94.31.00	1.160	1.345/1.000	34.5	151.54.20	96.403	
98.32.20	3.270	3.200	14	151.54.20	94.948	
98.50.20	2.500	2.400	20	151.54.20	94.737	
95.57.20	2.140	2.285/2.000	28.5	151.54.20	92.149	
92.34.20	1.290	1.580/1.000	58	73.31.20	96.384	
91.03.00	3.390	3.780/3.000	78	82.10.00	95.455	
90.14.20	3.480	3.000	96	96.02.40	96.394	
90.41.00	2.550	3.100/2.000	110	78.37.00	96.412	
90.55.00	2.600	3.200/2.000	120	93.06.00	95.754	
90.17.00	2.950	2.000	190	94.40.00	96.384	
90.34.00	3.060	4.110/2.000	211	97.27.00	95.127	
90.07.00	3.300	2.000	220	94.36.20	95.526	
90.05.00	3.480	2.000	296	94.11.00	96.363	
89.54.00	3.680	2.000	336	97.57.00	97.180	CP6
				277.57.00		
				277.57.00	97.180	CP6-CP5
				97.57.00		HI=1.355
89.48.00	2.430	2.000	86	268.33.00	96.405	
89.56.00	2.160	2.320/2.000	32	09.20.00	96.412	
90.24.00	2.057	2.114/2.000	11.4	266.55.00	96.398	
90.28.20	1.430	1.860/1.000	86	53.22.00	96.404	
90.53.20	2.330	2.000	66	278.09.00	95.181	
91.08.20	3.250	3.000	50	26.38.00	94.291	
89.21.20	3.710	3.000	142	64.57.00	96.422	
88.25.40	4.420	4.800/4.000	80	66.45.00	96.309	
89.31.20	4.310	4.000	62	49.46.00	94.742	
89.06.20	2.630	3.265/2.000	126.5	60.19.20	97.879	CP7
				240.19.20		
89.59.00	1.805	2.610/1.000	61	00.00.00	98.143	CP3-CP4
				180.00.00		HI=1.433
				240.19.20	97.879	CP7-CP6
				60.19.20		HI=1.498

93.09.00	1.155	1.310/1.000	31	153.19.00	96.521	
94.19.00	3.170	3.100	14	154.02.20	95.156	
90.26.00	2.340	2.680/2.000	68	92.30.00	96.522	
91.04.00	2.490	2.980/2.000	98	101.41.00	95.063	
90.03.00	2.730	2.000	146	103.14.00	96.520	
89.40.00	3.850	4.700/3.000	170	95.39.00	96.516	
89.58.00	3.950	3.000	190	101.03.00	95.538	
89.49.20	2.260	3.520/1.000	252	103.47.00	97.899	CP8
				283.47.00		
				283.47.00	97.899	CP8-CP7
				103.47.00		HI=1.372
91.01.20	2.150	2.300/2.000	30	253.09.00	96.586	
90.31.00	2.250	2.500/2.000	50	128.20.00	96.570	
90.37.00	2.260	2.000	52	132.24.20	96.450	Island
93.44.00	2.145	2.190/2.100	19	285.23.20	95.891	W/E Island
91.35.20	1.260	1.520/1.000	52	137.45.00	96.570	
91.40.00	3.110	3.000	22	250.19.00	95.521	
90.14.00	2.280	2.560/2.000	56	143.07.00	96.763	Middle of Island
90.24.00	2.295	2.590/2.000	59	148.16.00	96.564	W/E Island
90.27.00	2.285	2.560/2.000	56	161.13.00	96.546	W/E
90.12.00	2.470	2.840/2.000	84	126.30.00	96.508	Island End
89.54.00	3.320	3.660/3.000	66	151.39.00	96.066	
90.02.00	2.560	3.120/2.000	112	124.28.00	96.646	
90.42.20	1.570	1.000	114	127.56.00	96.297	
90.10.00	2.560	3.140/2.000	114	130.47.40	96.379	
90.05.00	2.505	3.010/2.000	101	140.10.00	96.619	
89.56.00	2.830	3.660/2.000	166	131.20.00	96.634	
89.55.20	3.880	3.000	176	127.20.00	95.630	
89.26.20	4.930	3.800	226	124.06.00	96.554	
89.51.00	3.370	4.740/2.000	274	128.28.00	96.618	
90.07.00	3.440	2.000	144	125.53.40	95.538	
89.31.00	4.970	3.600	274	124.08.00	96.612	
89.55.00	4.780	3.000	356	126.15.00	95.009	
89.49.00	3.890	2.000	378	125.25.00	96.590	
89.19.00	2.990	1.000	398	125.10.00	101.037	CP9
				305.10.00		
				305.10.00	101.027	CP9-CP8
				125.10.00		HI=1.444
92.24.00	4.200	4.400/4.000	40	272.51.00	96.600	
102.48.00	4.295	4.200	19	190.24.00	94.071	

92.41.20	2.375	2.750/2.000	75	157.49.00	96.581	
91.34.20	2.610	3.240/2.000	124	160.36.00	96.460	
91.36.00	4.295	4.600/4.000	60	140.06.00	96.501	
91.21.20	4.400	4.800/4.000	80	150.04.00	96.179	
91.44.00	2.560	3.120/2.000	112	154.38.00	96.524	
91.15.20	2.800	3.600/2.000	160	161.24.00	96.181	
90.26.00	3.210	4.420/2.000	242	162.57.40	97.431	CP10
				342.57.40		
				342.57.40	97.431	CP9-CP10
				162.57.40		HI=1.305
91.43.00	3.070	3.000	14	217.23.40	95.247	
90.29.00	2.085	2.170/2.000	17	241.45.00	96.508	
90.01.00	2.160	2.320/2.000	32	196.11.40	95.567	
90.19.00	2.317	2.634/2.000	63.4	209.47.00	96.069	
90.03.00	2.385	2.770/2.000	77	210.33.20	96.284	

Appendix 1D: Contour Map for Chesa Causeway
(Scale 1:2000)



APPENDIX 2A: Proposed Implementation Plan for Chesa Causeway dam Catchment.

Chesa Water Resource system

Mufure river (7km long) and Chesa dam with a capacity of 1 150 000 m^3 are in a catchment area of 229km^2. In the same catchment area there are 5 boreholes and approximately 150 shallow wells. The subcatchment is spread over Kandeya and Madziwa communal areas, a small part of Mt Darwin town and newly resettled A1 farmers. The subcatchment council collects fees and allocates water to the Mt Darwin Rural District council.

Socio-economic system

The agricultural activities are rainfed except for small gardens along the Mufure River. The water in the dam is used to supply Mt Darwin town and there are small scale fishing activities along the river and on the dam. There are alluvial gold panning activities along the river.

Administrative and Institutional System

The subcatchment falls under Mt Darwin rural district council who are the main waters. The water resources are managed by Mazowe Subcatchment council.

Status Quo

Challenges being faced in the Sub-catchment

Water quantity

There is physical water scarcity during the dry season period and rainfall of 786mm/yr.

Institutional, Administrative and legal issues

There is a lack of enforcement of existing laws and regulations by the current rural district council. The council has a weak financial base resulting in it carrying out its mandate not in a reasonable and efficient manner.

Environmental Issues

There is a massive sedimentation of Chesa Dam at an annual rate of 39 000m^3/year this is due to lack of enforcement of the current environmental laws and regulations. As a result there are rampant alluvial gold panning activities which have led to massive land degradation.

Strategies: Goals and objectives

Goal: To ensure environmental sustainability.

Main Objectives

(1) To prolong the useful lifespan of Chesa Causeway dam by another 10 years by 2015.
(2) To reduce the rate of land degradation and deforestation in the subcathment by 90% in 2015.
(3) To promote an establishment of an effective and efficient institutional arrangement by 2012.

List of interventions

Water Quantity

Desilting of dam, new dam construction, Borehole sinking and construction, rehabilitation of boreholes and Water demand management.

Environmental Issues

Tree planting, Environmental monitoring, pit filling, Conservation farming and Incentives.

Institutional issues

Enforcement of laws and regulations, Improving financial base, permit system in gold mining, Awareness campaigns, consultative fora, Private sector participation and workshops

Impact of intervention on each strategy

STRATEGIES: Water Quantity			
Objective	Strategic Intervention	Criteria/Indicators	Impact of Intervention
To prolong the useful lifespan of Chesa Causeway dam by another 10years by 2015	Construct a trap dam upstream Periodic desilting of the dam Rehabilitation of boreholes and or Construction of new boreholes	Trap efficiency of the upstream dam (%) Amount of sediments removed in m^3	Zero water shortages Increase in reliability of the dam More alternative water sources
Strategies: Ecological health			
Objective To reduce the current land degradation rate of the dam's catchment area by 50% by 2013	Environmental monitoring Planting of Indigenous tree species Filling up of pits dug by panners Conservation farming	No. of Environmental officer employed No. of trees planted per year No. of pits filled Yield/hectare	Reduced siltation of the dam Reduced incidences' of livestock deaths Increased food security
Strategies: Institutions			
Objective To have an effective and efficient institutional arrangement by 2011	Enforcement of current laws and Legislations Issuing of mining permits Promote stakeholder participation	Amount of fines and penalties collected in $US No. of permits issued per year Consultative for a (No. held) Seminars held (No.) Workshops held (No.)	Increased financial base of the Rural district council Compliance , gender balance and high adoption rate of innovations

Strategy Analysis

The Multi criteria analysis was used to analyze the strategies against some criteria to determine which strategy would score higher than the others which would need to be prioritized during implementation. The score indicates the performance of the strategy towards achieving the respective objective using the criteria to measure the performance.

The original scores for performance of each strategy

STRATEGIES: Water Quantity		**Strategy Score Card**				
Objective	**Criteria**	**Indicators**	**Tech**	**Econs**	**Socio-econs**	**Best**
						High
To prolong the useful lifespan of Chesa	Trap efficiency of the upstream dam	%	80	75	40	High
Causeway dam by another 10years by 2015	Amount of sediments removed	m^3	85	86	50	High
Strategies: Ecological health						
Objective						
To reduce the current land degradation rate	Environmental officers employed	No.	60	70	45	High
of the dam's catchment area by 50% by 2013	Indigenous trees planted	No./Year	30	60	70	High
	Pits filled	No./Year	35	70	75	High
	Conservation farming	Yield/ha	75	65	70	High
Strategies: Institutions						
Objective						
To have an effective and efficient institutional	Fines and penalties collected	$US	20	80	75	High
arrangement by 2011	Permits issued	No./year	35	85	70	High
	Consultative for a	No./year	15	75	80	High
	Seminars held	No./year	20	65	72	High
	Workshops held	No./year	15	60	70	High

The standardized scores for performance of each strategy (Using the formula: Original Score /Best)

STRATEGIES: Water Quantity		**Strategy Score Card**			
Objective	**Criteria**	**Indicators**	**Tech**	**Econs**	**Socio-econs**
To prolong the useful lifespan of Chesa	Trap efficiency of the upstream dam	%	1	0.94	0.5
Causeway dam by another 10 years by 2015	Amount of sediments removed	m^3	0.99	1	0.58
Strategies:Ecological health					
Objective					
To reduce the current land degradation rate	Environmental officers employed	No.	0.86	1	0.64
of the dam's catchment area by 50% by 2013	Indigenous trees planted	No./Year	0.42	0.86	1
	Pits filled	No./Year	0.47	0.93	1
	Conservation farming	Yield/ha	1	0.87	0.93
Strategies: Institutions					
Objective					
To have an effective and efficient institutional	Fines and penalties collected	$US	0.25	1	0.94
arrangement by 2011	Permits issued	No./year	0.44	1	0.82
	Consultative for a	No./year	0.19	0.94	1
	Seminars held	No./year	0.28	0.9	1
	Workshops held	No./year	0.21	0.86	1
TOTAL			**6.11**	**10.3**	**9.41**

The economic strategies scored the highest after the analysis hence, therefore it is suggested that economic measures should be prioritized in the implementation of the various strategies. However, it is almost impossible to implement the economic measures without technical backing or without first implementing the socio-economic measures such as awareness creation for some of the measures.

Implementation Plan

Strategic Intervention	Criteria/Indicators	Responsibility	Time frame			Cost USD
			S	M	L	
Water Quantity						
Construct a trap dam upstream	Trap efficiency of the upstream dam (%)	ZINWA & DDF				
Periodic desilting of the dam	Amount of sediments removed in m^3	ZINWA & DDF				20000
Rehabiltation of boreholes and or	No. of boreholes rehabilitated	ZINWA & DDF				6000
Construction of new boreholes	No. of boreholes constructed	ZINWA & DDF				15000
Ecological Health						
Environmental monitoring	No. of Environmental officer employed	RDC				15000
Police Raids on " Illegal panners"	No. of arrests and convictions	Police				1500
Planting of Indegenous tree species	No. of trees planted per year	RDC				2000
Filling up of pits dug by panners	No. of pits filled	RDC				3500
Conservation farming	Yield/hectare	Agritex				5000
Institutions						
Enforcement of current laws and	Amount of fines and penalties collected	RDC				20000
Legislations	in $US					
Issuing of mining permits	No. of permits issued per year	RDC				3000
Promote stakeholder participation	Consultative for a (No. held)	ZINWA, RDC, Police, Agritex & NGO's				10000
	Seminars held (No.)	ZINWA, RDC, Police, Agritex & NGO's				5000
	Workshops held (No.)	ZINWA, RDC, Police, Agritex & NGO's				5000
Review of Implementation plan	No. of amendments	ZINWA, RDC, Police, Agritex & NGO's				5000
Recommend for Nationalisation	Applicability of pilot Implentation plan	ZINWA, RDC, Police, Agritex & NGO's				

S – short term (5yrs)

M- Medium term (10yrs) N

L- Long term (15years)

Risk	**Rating**	**Mitigation**
Natural disasters	Moderate	Disaster preparedness plans put in place
Inflation may rise	Moderate	Bulk buying of required equipment and fiscal policy reviews
Funding may not be easily available	High	Borrow from central government
Population decrease below productive capacity in the near future	Low	Invite foreign labour

Appendix 3A: Regional standardised- yield relationship for return periods of failure to supply yield.

Percentile flow Q%	Q_{90}	Q_{80}	Q_{70}	Q_{60}	Q_{50}	Q_{40}
Return period (2years)	0.20	0.70	1.50	2.80	5.00	8.50
Return period (5years)	0.48	1.60	3.00	5.80	10.00	18.00
Return period (10years)	0.75	2.00	3.90	7.30	13.00	23.00

(Adopted from Kamtukule, 2008).

Appendix 3B: Values of exceedence percentiles expressed as fractions of ADF

Q_{50} as fraction of ADF	Curve	Q_{95}	Q_{90}	Q_{80}	Q_{75}	Q_{70}	Q_{60}	Q_{50}	Q_{40}	Q_{25}	Q_{10}	Q_5
0.00-0.05	A	0	0	0	0	0.002	0.005	0.015	0.04	0.179	1.42	3.778
0.05-0.10	B	0	0.001	0.004	0.01	0.012	0.029	0.068	0.141	0.423	1.84	4.367
0.10-0.15	C	0	0.007	0.016	0.03	0.034	0.064	0.12	0.222	0.56	2.34	4.753
0.15-0.20	D	0.01	0.024	0.045	0.06	0.075	0.116	0.177	0.311	0.727	2.39	4.373
0.20-0.30	E	0.02	0.037	0.064	0.08	0.105	0.162	0.251	0.412	0.865	2.63	4.192
0.30-0.40	F	0.03	0.047	0.087	0.12	0.147	0.225	0.345	0.517	0.947	2.43	3.981
0.40-0.50	G	0.1	0.134	0.191	0.23	0.262	0.345	0.455	0.632	1.035	2.42	3.688
0.50-0.60	H	0.18	0.217	0.279	0.32	0.35	0.428	0.523	0.7	1.082	1.19	2.955
0.60-0.70	I	0.2	0.247	0.326	0.38	0.421	0.531	0.669	0.838	1.176	1.06	2.884
0.70-0.80	J	0.22	0.279	0.369	0.42	0.474	0.594	0.743	0.95	1.373	2.14	2.515
0.80-0.90	K	0.29	0.356	0.466	0.53	0.585	0.703	0.846	0.995	1.269	1.84	2.239

(Adopted from Kamtukule, 2008).

Appendix 3C: Average baseflow Index for FAO Soil Classes

Soil Class	Soil Name	Lithology	BFI	Std. dev	Range
Fo75	Orthic ferrasols	Polymorphic sandstone consolidated & unconsolidated sand & conglomerate	0.59	-	0.37-0.86
Fo94	Orthic ferrasols	As of Fo75	0.85	-	0.85
I-Bc	Lithic cambisols	Precambrian: schist, quartzite,syenite, dolerite, graphitic schist, gnesis, amphobolite charnockkite, crystalline limestone, granitic Batholiths	0.51	0.07	0.37-0.58
Lc49	Chromic luvisols	Precambrian: gnesis, schist, phyllite, Greenstone	0.35	0.13	0.16-0.48
Lf10	Ferric Luvisols	Basement complex: granite, gnesis, migmatite, basic intrusive rocks: dolorite Gabbro	0.39	0.17	0.18-0.61
Lf81	Ferric Luvisols	As of Lf 10	0.42	0.13	0.22-0.61
Lf 82	Ferric Luvisols	As of Lf 10	0.21	0.06	0.14-0.3
Lf90	Ferric Luvisols	Precambrian: schist, quartzite, syenite, Dolerite	0.6	-	-
Lf91	Ferric Luvisols	Same as I-Bc	0.41	-	0.35-0.46
Nd8	Dystric nitosols	Same as Lf90	0.83	-	0.80-.86
Ne 1	Eutric nitosols	Same as I-Bc	0.83	-	-
Ne41	Eutric nitosols	Same as Lc 49	0.33	0.41	0.3-0.58
Ne54	Eutric nitosols	Same as I-Bc	0.4	-	0.30-0.58
Q12		Basement complex: mignatite,basic intursive rocks: dolerite, gabbro	0.14	0.41	0.00-0.30

(Adopted from Kamtukule, 2008)

Appendix 3D: Percentile flows converted to Gross yields for Sebastopol Dam

Percentile flow	Q_{90}	Q_{80}	Q_{70}	Q_{60}	Q_{50}	Q_{40}
Fraction of ADF	0.037	0.064	0.105	0.162	0.251	0.412
Gross Yield in thousands (m^3)	58	101	166	256	397	651

Appendix 3E: Percentile flows converted to Gross yields for Chesa Causeway dam

Percentile flow	Q_{90}	Q_{80}	Q_{70}	Q_{60}	Q_{50}	Q_{40}
Fraction of ADF	0.037	0.064	0.105	0.162	0.251	0.412
Gross Yield (Mm^3)	1	1. 88	3.09	4.76	7 .38	12. 11

Appendix 3F: Estimation of the net yields for Chesa Causeway dam

Gross Yield (Mm^3 yr^{-1}	1.39	4.87	10.43	19.47	32.12	59.14
Net yield (Mm^3 yr^{-1}	1.0	1.37	2.57	4.25	6.86	11.59

Appendix 3G: Population Projection for Mt Darwin Town

(2010-2019)

Year	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Population	15100	15560	16034	16522	17025	17544	18078	19196	19780	20200