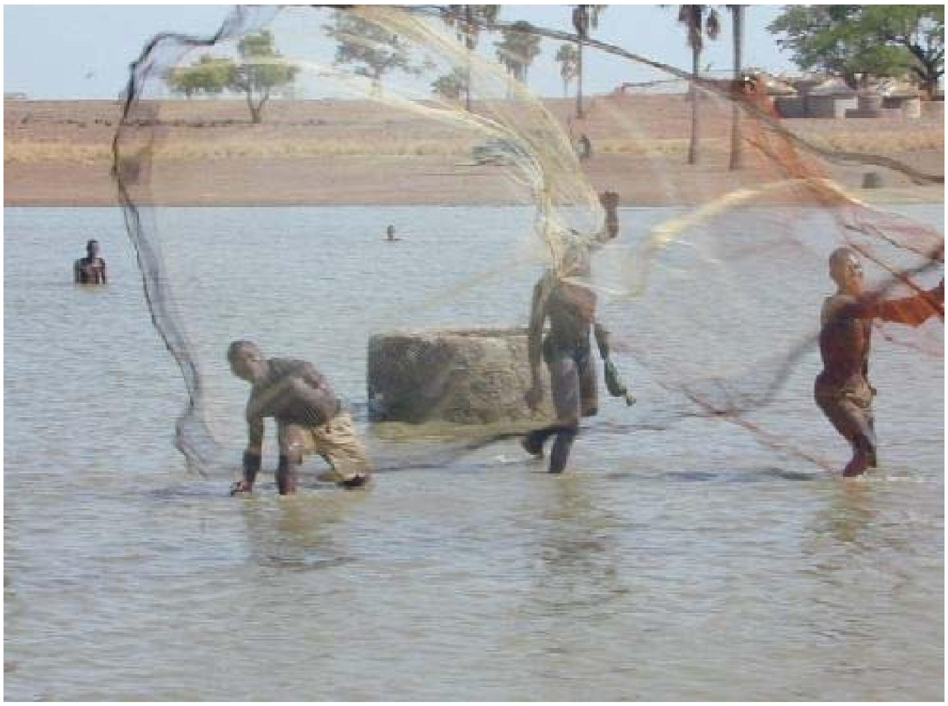
Examensarbete
TVVR 07/5008

MODELLING THE IMPACT OF SMALL RESERVOIRS IN THE UPPER EAST REGION OF GHANA



Master Thesis

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May 2007

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Avdelning för Teknisk Vattenresurslära
ISRN
ISSN

Modelling the Impact of Small Reservoirs in the Upper East Region of Ghana

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May 2007

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Picture on front page:

A Small Reservoirs in the Upper East Region of Ghana(SRP website, 2006).

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Report TVVR 07/5008

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ABSTRACT

Reservoirs are precious assets in semi arid and arid regions of the world. The Upper East Region of Ghana by virtue of its climatic condition is classified as a semi arid region. It has a total of 160 small reservoirs located on streams and rivers which are in the upstream of the Ghana portion of the Volta Basin. There have been significant reductions in the flow of water from all the three main tributaries to the Volta Lake which is further downstream and contains the Akosombo Hydro- power dam the main source of the countries electricity supply.

The effect of many small reservoirs in the Upper East Region of Ghana was investigated using the WEAP model. A total of 61 small reservoirs were identified on streams and rivers in the region. This number was achieved by adding very small reservoirs together. They were classified as Small Reservoir 1, 2 and 3 (SR1, SR2 and SR3) corresponding with their sizes.

The model was first adapted to the region and calibrated using measured discharge values. Then three different scenarios were created to access the impact of the small reservoirs on the White Volta River.

The results obtained indicate that the reservoirs have low impact on the flow of the White Volta River. However the creation of bigger reservoirs on the river could have significant effect on the flow of the WVR and reduces its contribution to the Akosombo Lake which is further downstream in the Volta Basin.

ACKNOWLEDGEMENTS

Sincere thanks go to the Almighty God for making this thesis a success. This project work would not have been possible without the help of Prof.dr.ir. Nick van de Giesen of Delft for his directions and support. I will also like to thank Mr. Ampomah of the Ghana Water Resources Commission who assisted me with the data.

Sincere thanks also go to my supervisor Dr. Rolf Larsson. Great thanks also go to my sponsors, my family and all my friends for their immense contributions.

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

UN	United Nation
UER	Upper East Region
WEAP	Water Evaluation and Planning Model
SRP	Small Reservoir Project
WVB	White Volta Basin
WVR	White Volta River
PMP	Probable Maximum Precipitation
PMF	Probable Maximum Flood
WMO	World Metrological Organisation
DA	District Assembly
IFAD	International Fund for Agricultural Development
FAO	Food and Agricultural Organisation
GWP	Global Water Partnership

TABLE OF CONTENTS

1 INTRODUCTION

1.1 Background

"Water is an essential life sustaining element. It pervades our lives and is deeply embedded in our cultural backgrounds" (UN World Water Development Report, 2006).

Water is required by all living creatures for survival. It is also required for economic growth and development. The achievement of the millennium development goals depend largely on improved water supply and sanitation in the developing countries. Issues of drought, flood, and extreme climate change have dominated the news in recent times and have caused the death of thousands of people. This has caused governments of certain countries such as Ghana to take more stringent action on water resources management. The management of water resources is the concern of all stakeholders involved. Most of the rivers in the world have been dammed to serve as water storage facilities for hydropower generation, drinking water supply and irrigation purposes. Reservoirs are indispensable storage facilities in arid and semi-arid regions of the world where there is irregular rainfall. Extreme drought and floods characterize these areas resulting in insecure livelihood.

Small multi purpose reservoirs are used widely for the provision of drinking water and irrigation purposes. In the rural areas of Ghana where surface water is scarce, reservoirs are used for daily activities to improve the livelihood of the people. The Upper East Region of Ghana and other Northern Regions of Ghana where there is irregular rainfall patterns, small dams have been constructed on small rivers and streams to ensure a year round growing season and also water supply for livestock and domestic purposes as well.

Small dam development in the Northern regions of Ghana have been considered as one of the solutions for curtailing the higher incidence of poverty by improving the standard of living of the people through improved smallholder irrigation techniques and livestock production. They are seen as important tool in achieving some of the goals of vision 2020 of Ghana and also the United Nations Millennium Development goals of poverty reduction.

1.2 Research Problem

There have been major developments of a large number of small reservoirs in all the six riparian countries of the Volta Basin. These are mainly situated on the upstream portion of the basin depending on the country. Burkina Faso and Ghana are the countries with a greater portion of the basin in terms of areas and major development of small dams are peculiar in these countries.

They are used mainly for water supply and for irrigation purposes. The developments of small reservoirs have significant effect on the flow of the rivers on which they are situated. For the case of the Volta basin where the reservoirs are located upstream there is the possibility of inadequate flows in the downstream portion of the basin and other hydrological problems such as increased evaporation leading to rapid dry up of some of the streams generating serious repercussions. There is also the problem of location of small reservoirs to ensure adequate water throughout the year to meet irrigation and livestock demands.

There is the need to ascertain the impact of this large number of small reservoirs on the Volta basin with regards to the downstream communities and the general flow condition of the rivers. This can assist in the construction and planning of these small reservoirs in order to minimize the effect on the downstream users.

There is also the need to find out how these small reservoirs in the upstream portion of the basin affect the hydro-power dam located in Akosombo which is downstream of the Volta River.

1.3 Objective

The main objective of this thesis work is to find out the extents to which the large numbers of small reservoirs affect the downstream users. The other objective will be to find a way of evaluating and planning the construction of many of these small reservoirs to ensure efficient use of the water resources in the Upper East Region of Ghana.

These objectives will be achieved using the Water Evaluation and Planning Model (WEAP Model).

1.4 Scope of Work

The thesis work will cover the Upper East Region of Ghana which has a large number of small reservoirs, 160 in number (J. Leibe et al, 2005) with the Tano and Vea being the biggest. The study will cover reservoirs which are located on the various streams in the region. That means that small reservoirs which are not located on any river or stream will not be considered in this study. The Tano and Vea reservoirs will not be included in this study because according to their areas they are not classified as small reservoirs. This may produce some discrepancies in the results.

The thesis will involve the following

- Identification of the various reservoirs and their locations in the region
- Quantification of water for farming and livestock production purposes
- Calibration of the WEAP model
- Creation of scenarios and evaluation.

1.5 Review of Previous Work

There are a lot of research activities going on in the whole Volta Basin. The Small Reservoir Project (SRP) is currently undertaking research works on planning and evaluating ensembles of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security: tools and procedures (SRP website, 2006).

The SRP is part of the Challenge Programme for water and food. Research works already conducted in the UER of Ghana includes estimation of reservoirs storage capacities and evaporation losses from small reservoirs in which various categories of small reservoirs were identified according to their storage capacities and their surface areas. Evaporation losses from these reservoirs were also identified (J. Leibe et al, 2005). There have been studies into the water use, productivity, and profitability of small scale irrigation schemes in UER. The study involved two irrigation farming sites with two different technologies. It also involved the measurement of water released per area of farmland (Faulkner, 2006)

1.6 Limitations

The data obtained were from previous field studies conducted by individuals and organisations working on the various projects on the main Volta Basin and specifically in the Upper East region of Ghana. These differences in data may generate some differences in the data set. The total number of reservoirs in the Upper East region was not considered since most of them are located on the small streams which have no or inadequate flow data. This will affect the result obtained from the simulation. Moreover the exclusion of the two big reservoirs Tano and Vea will affect the results significantly because they store a large volume of water for a large scale irrigation purposes. This thesis work was also limited to 61 reservoirs out of a total of 160 reservoirs in the Region.

1.7 Structure of report

This report is made up of eight chapters. The first chapter is introduction which describes the objectives of the study. The second chapter is the literature review and talks about integrated water resources in the White Volta Basin and general reservoir properties construction and its importance. The third chapter is a description of the study area and talks about the general living conditions in the study area, the rainfall characteristics, land use, uses of water and the White Volta basin.

The fourth chapter describes the WEAP model, it characteristics and applications. Its also describes how the model works and some application of the model. The next chapter is the method of the thesis and describes the steps taken to achieve the objectives of the thesis. The chapter that follows this present the results and discussion of the thesis which is also followed by conclusion and recommendation chapters, reference chapter and the appendix.

2 LITERATURE REVIEW

2.1 Importance of Reservoirs and Dams.

A reservoir is a man-made lake which is created when a dam is built on a river or a stream. The river or stream water back up behind the dam creating a reservoir which is used for various purposes. The reservoir is equipped with an outlet structure which is constructed with concrete or pipe. They are mostly constructed for the following purposes

- To hold water for domestic use, agricultural purposes (irrigation) and for industrial use. When water is retained in reservoirs they are made to go through a period of self purification since sedimentation is allowed to take place. The water is then clear to some extent to be used for domestic purposes.
- To hold water to prevent flooding when there is intense rainfall that can cause flooding to a community. Reservoirs commonly used for this purposes are called attenuation reservoirs and are used to prevent flooding of low lying areas. They store water during periods with abnormally high rainfall and gradually release the water during periods of low rainfall.
- To hold water for the purposes of electricity generation and for powering wind mills. The reservoirs for this purpose are equipped with turbines which generate the electricity.

Reservoirs can be constructed for secondary purposes as recreation such as sailing, fishing and water skiing.

2.2 Technical aspects of Small Reservoirs

Small reservoirs (size approximately 0.01 km^3) (SRP Website, 2006) are a result of small dams constructed on streams or rivers to impound water and are mostly constructed with earth materials such as clay, gravels, rocks or sometimes boulders. Most reservoirs normally use clay which has been well compacted as the water proofing element which prevent loss of water through seepage. The banks of the reservoirs can be of gravel or boulders depending on the condition of the existing soil type and the purpose of the reservoir. A simple small reservoir is shown in the figure 2.1. The use of good earth material is a prerequisite for long lasting reservoirs and also for efficient utilization. That is to say that the efficiency of the reservoir is dependent on the materials used in the construction.

Proper surveying and field studies should be conducted before the construction begins. Field studies involves the selection of site and the determination of slope of the reservoir which is another important steps since this is required to ensure constant flow into and out of the reservoir.

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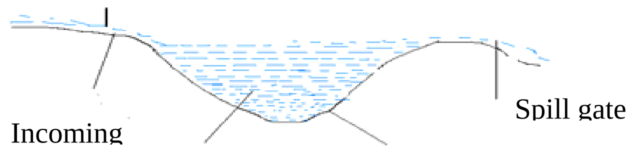

Figure 2.1 A sketch of a small reservoir showing the various part

The spillway is the part that is used to empty the reservoirs when too much water has been stored in the reservoir. It normally consists of an outlet pipe made of either caste concrete or PVC pipes. The lining of the reservoir could be of well compacted clay or a water proofing material such as polyethene. The riverbed could be gravels bed with a good slope to ensure adequate flow into the reservoir.

Small reservoirs in the UER of Ghana are mostly constructed with compacted earth mostly clay material with the people in the communities providing the labour during construction. The embankment is also made of clay. The spillways are designed based on the Probable Maximum Flood (PMF) which is estimated from the PMP (Probable Maximum Precipitation). The PMP is defined according to WMO in 1986 as “the greatest depth of precipitation for a given duration that is meteorologically possible for a given size storm area at a given particular location at a particular time of year” (WMO, 1986).

The size of the small reservoir in a community is normally driven by the budget allocation of the institutions providing the funds and not necessarily on the intending uses of the reservoir.

2.3 Environmental Aspects of Small Reservoirs

The proper functioning of an ecosystem depends to a large extent on water. Water is therefore indispensable in an ecosystem and it flora and fauna (A. B. Avakyan et al 2001). It is an important aspect of the ecosystem providing a breeding place for birds and sustenance of other wildlife.

Small reservoirs which are not properly managed can serve as breeding grounds for mosquitoes and thereby increasing the prevalence of malaria in that community. There is the need to understand the interaction between the reservoirs and the ecosystem in order to conserve and also improve it thereby eliminating the negative effect of small reservoirs.

During periods of floods, erosion of the banks of the reservoirs can cause significant damage to the reservoirs and the nearby farmland can be inundated. Another environmental problem associated with small reservoirs is their inability to flush out pollutants from the communities as a result of nutrients generated from the use of chemicals for farming. This makes the community susceptible to water borne diseases.

2.4 Institutional Framework of Small Reservoirs

The reservoirs in the UER and the most of the other northern part of Ghana were constructed through project funded by various Non - governmental organisations which are undertaken various developmental projects. There is therefore little or no coordination among these organisations in the management of these reservoirs (SRP website, 2006). The management of these reservoirs is a duty of the communities which are benefiting from the projects. The districts assemblies (DA's) play an important role when it comes to the management of these reservoirs by training personal in the communities in the management of the reservoirs. The agricultural department of the district assemblies are normally responsible for the training. The Vea and Tano reservoirs in the UER have a good management body which undertake their own maintenance and management aspect.

2.5 Economic Analysis of Small Reservoirs.

Reservoirs in the region are used for smallholder irrigation and livestock production. The farmers do not have to pay for the use of these small reservoirs and do not have to spend some of their profit on the maintenance of the reservoirs. The little profit generated from the sale of their produce goes a long way to improve the standard of living of the people.

A lot of benefits are derived from the construction of small reservoirs as already mentioned. They can be a good avenue for the eradication of poverty in the communities if they are properly managed and maintained.

Net returns of USD 109 and USD 53 for plots of 0.05 ha of tomato and onion, respectively pertains in the UER which is very substantial if one considers the poverty situation in the region. (IFAD, 2006)

2.6 Integrated Water Resources Management of the White Volta Basin

Integrated water resources management encompasses water resources as an integral part of the ecosystem and also as natural resources. According to the Global Water Partners (GWP) IWRM is defined as (GWP website, 2006) "the process which promotes the co-coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems." There are various other definitions of IWRM.

The water resource users in a watershed or basin form part of the management of the entire basin. There are various guidelines or principles under the concept of IWRM. The Dublin Principles are generally used as a set of guidelines for IWRM. These principles have been carefully formulated and have been internationally accepted as guidelines for IWRM. The Dublin guidelines are outlined below. (GWP, 2006)

- Water is a finite and vulnerable resource essential to sustain life, environment and development. The principle requires a holistic approach to water resources management. All the elements of the hydrologic cycle and their interaction with the ecosystem should be taken into account in addressing issues of IWRM.
- Water development and management should be based on a participatory approach, involving users, planners and policymakers at all levels. The principle recognizes water as a resources in which all stakeholders should be involved in it management. A stakeholder in the water sector includes everyone since everyone uses water. In this regards various communities forming part of a river basin should be involved in the decision making of the management of the river basin.
- Women play a central part in the provision, management and safeguarding of water. It has been widely accepted that women play a very important role when it comes to collection, use and safeguarding of water resources for domestic and agricultural use. Women should therefore be involved in the decision making processes of water resources management.
- Water has an economic value in all its competing uses and should be recognized as an economic good. If water is recognized as an economic good more value would be placed on water resources. This could ensure efficient use of water resources since people would be made to recognized how expensive it is in the provision of water for domestic, agricultural and industrial purposes

There are a lot of organizations which are responsible for Integrated Water Resources Management of the White Volta basin. Table 2.1 shows the various organizations and their roles in the White Volta Basin.

Table 2.1 Organisations and their roles in the White Volta Basin (UNESCO, 2006).

Organization	Role
The Ghana Water Resources Commission	Implementation and dissemination of IWRM
District Assemblies	Provision of Socio-economic infrastructures.
Non Governmental organization e.g. TRAX, Rural Aid, World vision international	Provides financial as well as technical works.
International Water Management Institute IWMI	Undertaking small dams projects in the Basin
ECOWAS	Responsible for the eradication of Onchocerciasis
CGIAR: Challenge Program International	Research on food and water
WVBB White Volta Basin Board, Ghana	
IUCN/EU	Volta Governance, International
ZEF: GLOWA-Volta Project	Decision Support System

These organizations are working in collaboration to solve a lot of pressing issues in the Basin. Hydrological and water management issues such as small scale irrigation, Climate change for water management, Sporadic drought spells, Small hand-dug wells, Inclusion of Women and other marginalized groups in decision making process, Coordination of Water Management activities at the Basin Level and other environmental and livelihood issues are been addressed as well. Under the WVB pilot project the following activities have been undertaken: (UNESCO, 2006)

- Public Awareness creation of IWRM issues
- Identification, registration, permitting and billing of water users
- Building of a Decision Support System (DSS) as planning and decision tool
- Strengthening of stakeholders capacities for IWRM and planning
- Stakeholder process involving government agencies, district authorities, water institutions, traditional authorities, NGOs and actual water users

Some of these activities have already been carried out

2.7 Irrigation and crop water requirements in the basin

Agriculture is the backbone of most developing countries in the world and Ghana is not an exception. Irrigation technologies allow more crops to be cultivated all year round with less dependent on rainfall. According to the FAO Ghana has a renewable water resource of 53.2km^3 (FAO, 2006) Water used for crop production is 0.25 km^3.This shows a very low rate of irrigation in the country. Irrigation in Ghana is practiced on the small scale basis and is informal. The cultivable area in Ghana is about 42% of the total area of the country out of which 4.25% of the area is under cultivation (FAO, 2006).

Table 2.2 Existing Irrigation sites and their water requirements in Ghana (Kwabena Wiafe, 1997)

Project	Region	Water Source	Irrigable area (ha)	Crops	Irrigation water requirements (Mm^3)
Asutsuare	G/Accra	Main Volta	660	Rice	17.16
Dawhenya	A		404	Rice	10.5
Tano	U/East		2,207	Rice/ Vegetables	39.78
Afife	Volta	Agali	880	Rice/okra	22.88
Vea	U/East	Yagaratanga	850	Rice/ Vegetables	7.14
Bontanga	Northern		450	Rice /okro	11.7
Afram plains	Eastern	Volta	101	Groundnuts/vegetables	0.85
Ashaiman	G/Accra		117	Rice/okra	3.04
Aveyime	Volta	Volta	63	Rice	1.64
Kpando-Torkor	Volta	Main Volta	40	Okra	0.34
Small schemes	Northern		16	Rice/	0.13
Libga Golinga	Northern		26	Vegetables	0.68

Ghana has the potential of developing 384,000 ha of irrigation based on water and soil availability. (World Bank Report, 2005). There is the possibility of developing approximately 300,000 ha of irrigable land in the White Volta Basin and this is going to require close to 3600 million cubic meters of water. (Kwabena Wiafe, 1997)

The Irrigation Company of the Upper East Region of Ghana manages the biggest irrigation scheme in Ghana which is the Tano and Vea Irrigation schemes (Kwabena Wiafe, 1997). The two dams on the Vea and the Tano Rivers were constructed in the 1980's and have since then become the largest managed irrigation schemes in the country. Agriculture contributes approximately 60% of the Gross National Product (G.N.P) of the country and the livelihood of 80% of the people depends largely on agriculture (Kwabena Wiafe 1997). This has necessitated the development of irrigation in major areas of the country where rainfall is erratic can only support one planting season.

3 STUDY AREA

3.1 General Overview.

The Upper East Region of Ghana is one of the most deprived or poorest regions (Ghana Statistical Department). It is situated in the centre of the Volta Basin in the north-eastern corner of Ghana and is bordered by Burkina Faso to the north and Togo to the eastern part. It has a population of 920,089 people according to the 2000 national census and has a population density of 96.6 inhabitants/km^2 and a growth rate of 3 %.(Asenso-Okyere et al, 2002). The region is the second lowest ranked in terms of mean annual income of approximately USD157. This is a little higher than the adjacent region which is Upper West Region. According to the Statistical Department of Ghana report in 1998 the Upper East Region has a poverty incidence of 88%. This means the region has the highest number of poor people in the country.

The regional capital is Bolgatanga with other important towns such as Bawku, Navrongo and Paga. It is made up of 8 districts and has a land size of 8842 km^2 which is approximately 3.4% of the total land mass of Ghana and is predominantly rural (87%). The map showing the UER is shown in figure 3.1. The UER has the highest elevation of 455m in the northern part and the lowest of 122m in the southern part of the region. (Leibe 2002)

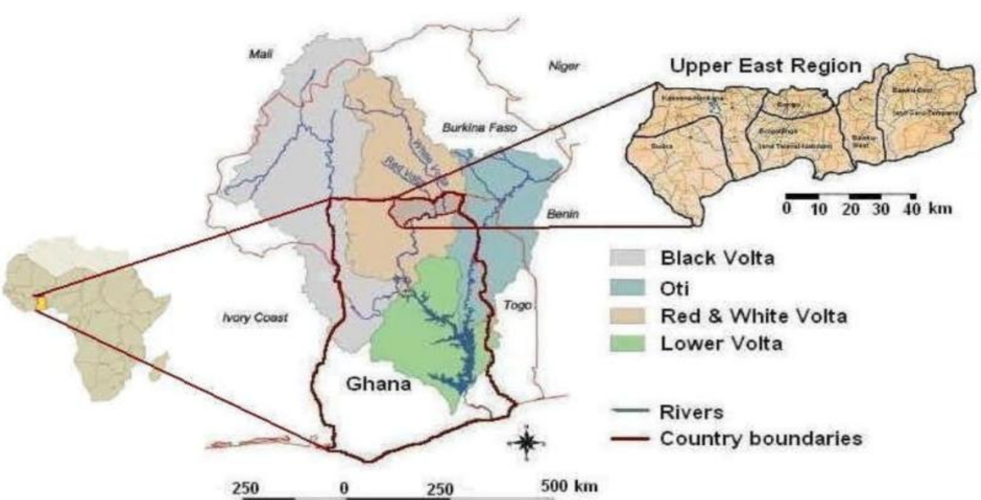

Figure 3.1 Map showing the Upper East Region in relation to Ghana (adapted from Leibe, 2002)

3.2 Climate and Rainfall Patterns

The region just like the other Northern regions of Ghana have variable rainfall pattern with extreme cases of drought and sporadic flood and has an annual average rainfall of 1044mm which is suitable for a single wet season crops. Rainfall is usually between the months of July and September unlike the southern part of the country which has a relatively longer period of rainfall. The temperature is between 27°C and 36°C in the northern part and 24°C and 34°C in the southern part. The region is therefore characterised as a semi-arid.

Most of the rains in the region fall as thunderstorm originating from squall lines (Eldridge, 1957; Hayward and Oguntoyinbo, 1987; Friesen, 2002). The region has a rainfall intensity which normally exceeds the infiltration capacity of the soil. This means that runoff occurs even without the soil been moist implying that groundwater is not replenished (J. Leibe et al, 2005) The UER has an average annual potential evaporation of 2025mm.

3.3 White Volta Basin

The UER falls within the White Volta basin which is a sub basin of the Volta Basin and has been classified as an Operational HELP Basin.(Hydrology for Environment Life and Policy) HELP is a joint initiative between United Nation Educational Scientific Organisation (UNESCO) and the World Metrological Organisation(WMO) and is led by the International Hydrological Programme. The objective of the HELP programme is to create new approaches to water basin managements through the creation of framework for water law and expert, water resources managers and water scientists to work together in solving water related problems. (UNESCO website, 2006). A basin is considered as an Operational HELP if it fulfils the following criteria; (UNESCO, website 2006)

- "It has implemented the HELP philosophy
- Has involved the HELP stakeholders in the management of the basin
- is substantially functioning across several HELP key issues in an integrated manner;
- demonstrates an active interface between science and water managers, and society;
- has established mechanisms for unrestricted information and data access and exchange;
- Follows the WMO Resolution 25 on international exchange of hydrological and related data."

It is one of the main tributaries of the Volta River and has a total area of 104,749 km^2.The area in Ghana is 45804 km^2 and that in Burkina Faso is 58945 km^2. It is located upstream of the lake Volta in Northern Ghana and southern part of Burkina Faso (UNESCO, website 2006). The area of the various tributaries of the White Volta basin and their length is shown in table 3.1. The network of the rivers and streams in the UER is also shown in figure 3.2

Table 3.1 Various tributaries of the White Volta Basin and their areas and length (UNESCO, 2006)

Name	Area(Km^2)	Length(km)
White Volta	49,230 (106,740)*	1,140
Tamne	880	50
Morago	620 (1,610)*	80
Mole	5970	200
Kulpawn	10,600 (10,640)*	320
Sisili	5,180 (8,950)*	310
Red Volta	590 (11,370)*	310
Asibilika	1,520 (1,820)*	100
Agrumatue	1,410 (1,790)*	90
Nasia	5240	180
Nabogo	2960	70

* Total area including catchment outside Ghana

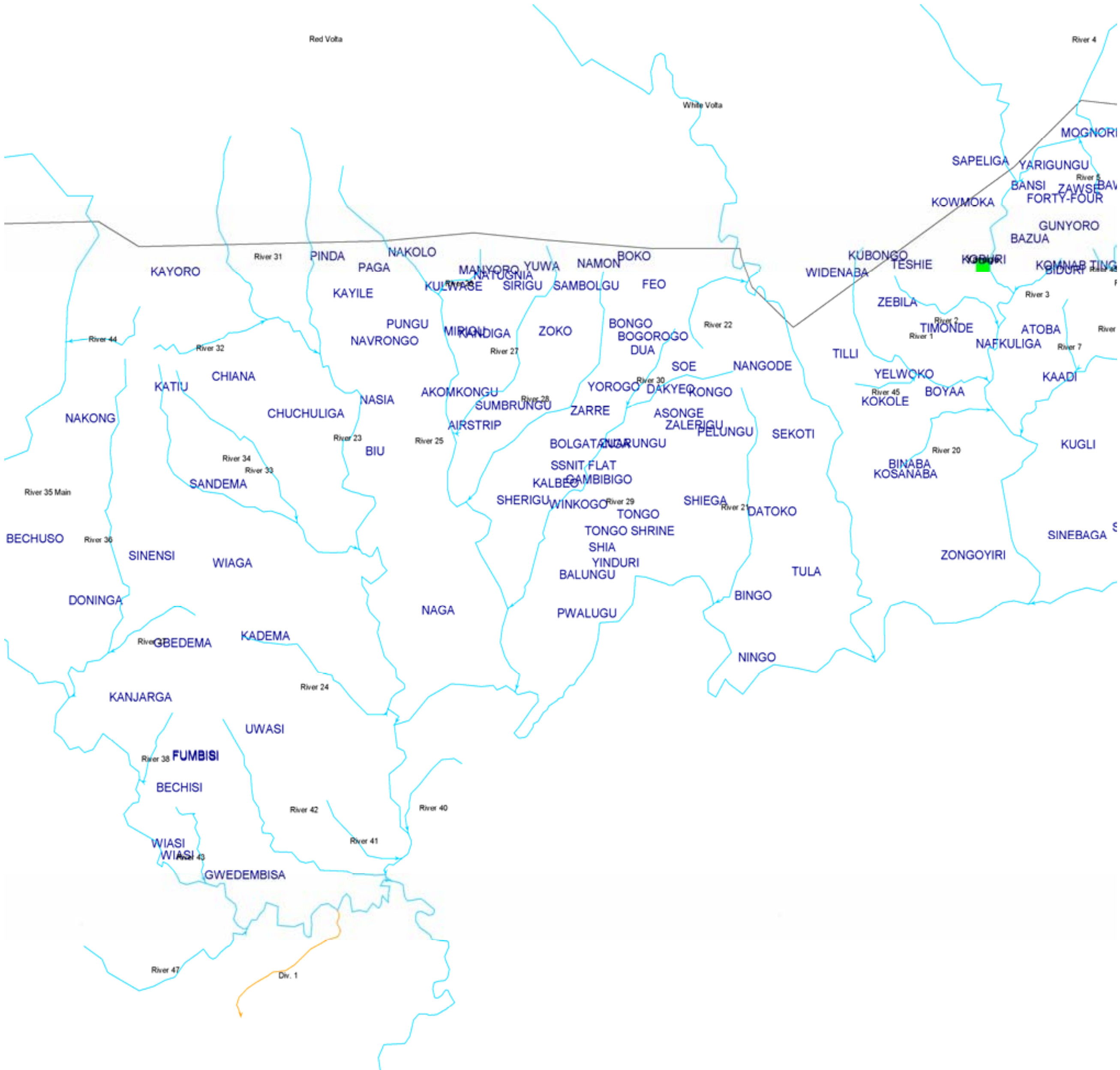

Figure 3.2 Network of Rivers and streams in the UER.

The total annual discharge leaving Burkina Faso through the Red and White Volta Rivers is estimated at 3.7 km³/year (FAO Corporate Document Repository website, 2006). The land is predominantly flat, particularly in the southern part which is 0.1% (S.Wagner et al, 2002)

There are a lot of projects going on in the White Volta basin. Among these is the Small Reservoir Project (SRP), the GLOWA Volta project, the Ghana Water Resource Commission and the CGIAR Challenge Program on Food and Water which are all aimed at improving the livelihood of the growing population in the region through intensive Research work. The White Volta falls within the interior savannah ecological zone. The geologic formation of the basin is Voltain and granite and there is generally low groundwater yield from dug wells and boreholes in the basin between 5.23 $x10^{-4}$ to 1.05 x 10^{-3} m^3/sec and an average depth of 38m (Kwabena Wiafe, 1997).

According to Andah Runoff coefficients are generally low; meaning that direct recharge of aquifers from precipitation is less than 20% across the Basin. This figure means that less runoff end up as recharge for groundwater. (Andah et al, 2005)

The White Volta River is one of the main tributaries of the Volta River which forms part of the Volta Lake. The Akosombo and Kpong dams use water from the Volta Lake for hydro-power production. Downstream of these dams, there are substantial farming activities which use water from these dams for irrigation practices.

The Volta Lake is by far the largest man-made lake ever to be constructed in the world and is also the largest regulated Lake in the world. (Dams under Debate, 2006)

The Akosombo Hydro power plant produces 912MW of electricity at it full capacity whiles the Kpong dam produces 160MW.(VRA website, 2006)

In recent years there has been a significant reduction in the contribution of runoff from the white Volta river and the other rivers in the basin to the main Volta river (P. Gyau-Boakye, 2000) due to a lot of factors which include exploitation of water resources in the upstream of the white Volta river. Table 3.2 shows the mean annual runoff of the main rivers of the Volta Basin. The mean annual flow of the WVR is 9.57 billion m^3

Table 3.2 Rainfall and annual runoff for selected stations (Andah et al, 2005).

Sub-basins	Total area (km^2)	Mean Annual Rainfall (mm)	Mean annual runoff ($x10^6m^3$)	Runoff coefficient (%)	Length (km)
Black Volta	149,015	10.23.3-1,348.0	767	8.3	1,363.3
White Volta	104,749	929.7-1,054.2	9,565	10.8	1,136.7
Oti	72,778	1,150.0-1,350.0	11,215	14.8	936.7
Lower Volta	62,651	1,050.0-1,500.0	9,842	17.0	
Total	400,710	876.3-1,565.0			

Runoff Coefficient is related to different land covers and hydrological soil types

3.4 General Reservoir Properties and Distribution.

In northern Ghana and other semi-arid regions of the world reservoirs are most precious assets. There are lots of reservoirs used for various purposes in the UER of Ghana. This is an important and most easy way to overcome rampant drought and floods in the area and also give hope to the growing population. There are a total of 160 small reservoirs in the UER which have different storage surface areas ranging from 1 to 35 ha (J. Leibe et al).Many of these reservoirs were constructed by different organisations, mostly NGO'S undertaking various developmental projects in the UER. There is little or no coordination among the organisations undertaking the construction of these reservoirs (SRP website, 2006). This often makes the maintenance of the reservoirs a problem. Some are left to dry up and a lot of investment are left to go waste. The distribution of small reservoirs in the region is represented in figure 3.3.

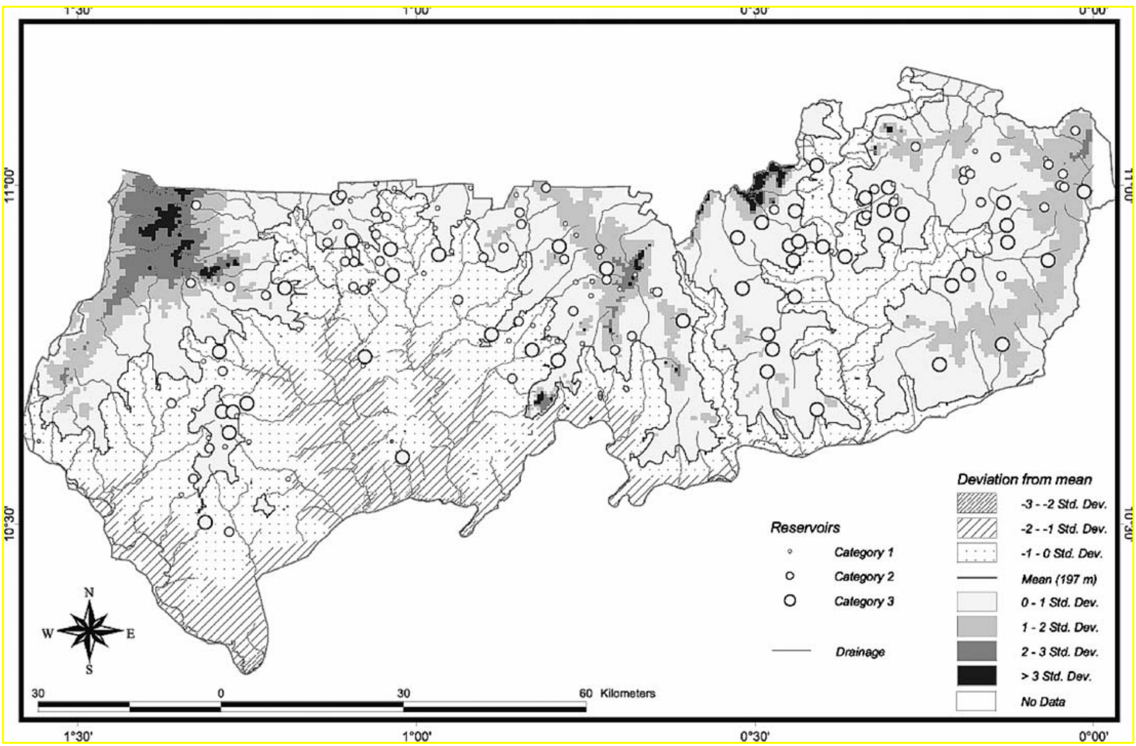

Figure 3.3 Map showing the distribution of Reservoirs in the UER (J. Leibe et al.)

The number of reservoirs in the region varies from district to district. Table 3.3 shows the reservoir distribution according to districts and their surface areas. The Bawku East district has the highest number of small reservoirs with a total area of 323 ha. The reservoirs are categorized into three with category 1 having an area between 1 and 2.79 ha. Categories 2 and 3 have area between 2.88 and 6.93 ha and 7.02 and 35 ha respectively.

Table 3.3 Distribution of small reservoirs by districts. (Leibe, 2002)

	No. of Reservoirs			Total	Surface Area (ha)			
District	cat1	cat 2	cat3		Cat 1	Cat 2	Cat 3	Total
Bawku East	6	17	17	40	11.34	72.36	239.40	323.10
Bawku West	1	1	13	15	2.79	5.67	177.93	186.39
Bolgatanga	10	8	4	22	19.35	37.71	44.46	101.52
Bongo	10	7	2	19	17.91	35.91	34.38	88.20
Builsa	10	6	7	23	14.94	30.51	93.06	138.51
Kassena-Nankani	14	14	7	35	28.17	67.77	65.88	161.82
TOTAL	51	53	50	159	94.5	249.93	655.11	999.54

3.4.1 Potential Evaporation of reservoirs in the UER

The monthly potential evaporation and the volume depth relationship according to Leibe, 2002 of the UER of Ghana are shown in figure 3.4. The net monthly potential evaporation was recorded over a period of ten years. The minimum and maximum evaporation was compared with the Meteorological station data of Navrongo.

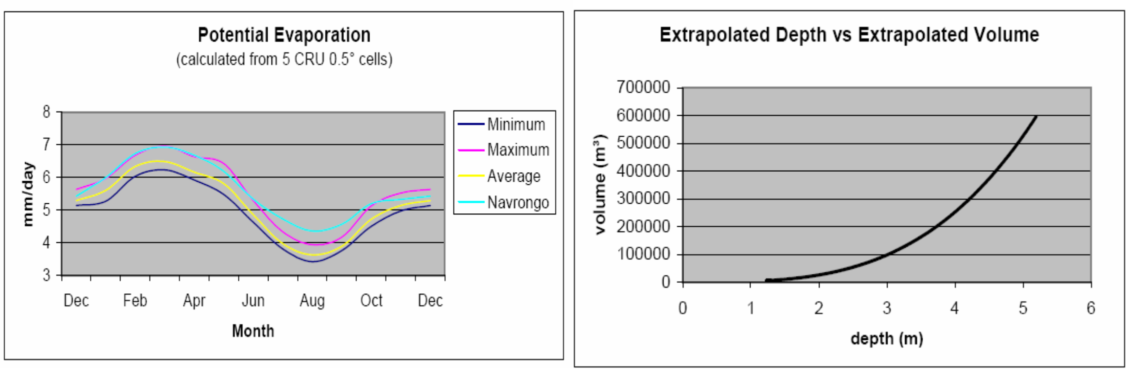

Figure 3.4 Monthly net potential evaporation and volume depth relationship of reservoirs in the UER (Leibe 2002).

3.5 Land Cover and Use

Land cover in a detailed sense refers to the attributes of a part of the earth's surface and immediate subsurface, including biota, soil, topography, surface and ground water, and human structures((IGBP/IHDP, 1993).

Land plays an important part of the development of agriculture for the sustenance of livelihood. The region falls within the Guinea Savannah ecological zone and is one of the erosion prone areas in Ghana. The soil is relatively dry due to less percolation from rainfall. The economic activities in the region is mostly agriculture. Majors crops cultivated are watermelons, cashew nuts; vegetables: tomatoes, onions. Livestock production is also predominant in the region with the rearing of animals such as cattle, sheep, goat, poultry and pigs.

The land use in the UER and the whole of the White Volta basin is predominantly extensive land rotation cultivation approximately 3.2 to 9.6 km away from the village and extensive grazing of livestock. (FAO, 1991). Grazing lands are generally poor due to bush fires. Land sizes are usually small, often in the range of 1.2 ha. (Andah et al, 2005). In the UER and the whole of Ghana land is mostly owned by chiefs and traditional elders in the various communities. This creates a lot of problems with regards to the management and release of land. There is generally inadequate information on land use in the UER and the whole of the White Volta basin.

3.6 Water Uses in the UER

The region has it main source of water from streams and rivers with little contribution from groundwater. Agriculture production uses most of the water for mainly irrigation and livestock production. Boreholes are the major sources of water supply for domestic purposes for the people of the UER although the yield of groundwater is generally low. The water use for agriculture and livestock production is mainly from reservoirs which are used to store water during the wet season.

The water demand in the UER is expected to increase due to an anticipated increase in the population, urbanization and improved standard of living of the people. Irrigation accounts for approximately 80 percent of the water use in the UER of Ghana and the entire Volta basin (Shiklomanov, 1999). Crops mostly grown in the area are maize, millet, rice and vegetables. Urban and rural water use is less at the moment. The rate of water use for domestic purpose is approximately 0.11 m^3/s while that for irrigation purposes is $2m^3/s$. (Kwabena Wiafe, 1997).The type of irrigation mostly practiced in the UER is the gravity flow irrigation system with fewer technologies such as sprinkler and pump irrigation schemes.

3.7 Downstream of the White Volta

The downstream water use of the White Volta River is basically the hydro-power generation at the Akosombo dam. The White Volta basin is a major contributor to the hydropower generation. With a contribution of more than one third of the total flow into the lake Volta, the White Volta River is considered very important in the electricity generation. (Andah et al, 2004)

Other use of the White Volta River is for irrigation purposes and drinking water supply. These uses are most of the time dependent on the upstream flow conditions. More upstream flow means more downstream uses and more contribution to the hydropower generation. Irregular flow upstream means less water would be expected in the downstream portion of the river. This implies that activities upstream are a major contributing factor to the downstream activities.

In recent years there have been low water levels in the Akosombo dam. This prompted the Volta River Authorities to shut down some of their turbines and thereby introducing power shedding in some parts of the country. This has been primarily attributed to low flow from the major rivers into the Akosombo dam.

The White Volta River is also dammed in the Burkina Faso portion indicating that the flow to the downstream users is, to a large extent, regulated.

4. WEAP MODEL

4.1 Introduction and Development of WEAP

Water Evaluation and Planning System (WEAP) is a microcomputer tool for integrated water resources planning (WEAP User guide 2005). It is easy to use and offers a comprehensive approach to water resources management.

Various organizations have been responsible for the development of the WEAP model. The Stockholm Environmental Institute SEI provided primary support and the US Army Corps of Engineers provided funding for the development of the model.

A number of agencies were involved in the development of the Model. They include The World Bank, USAID, and the Global Infrastructure Fund of Japan (WEAP User guide 2005).

The model functions on the principle of water balancing. Since the first version of the model was developed in 1990 the model has been applied in a lot of research work. It has been applied primarily in a number of studies concerning;

- Agricultural systems
- Municipal systems
- Single catchments or complex Trans-boundary river systems

4.2 Model Structure

The structure of the model is such that, the water resource system is represented in terms of groundwater, reservoirs withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The analyst can choose the level of complexity to meet the requirements of a particular analysis. This customization can also be used to reflect the limits caused by restricted data (Sieber et al, 2005).

The model consists of five main views:

Schematic

The study area is defined in the schematic view. It is a GIS based tool which allows vector or raster layers to be imported and used as background layers. Its uses a drag and drop method in which objects such as demand nodes, reservoirs, groundwater supply, etc can be positioned. This allows for changes and modifications to be made in the area with ease. A sample of the schematic view is shown in figure 4.1.

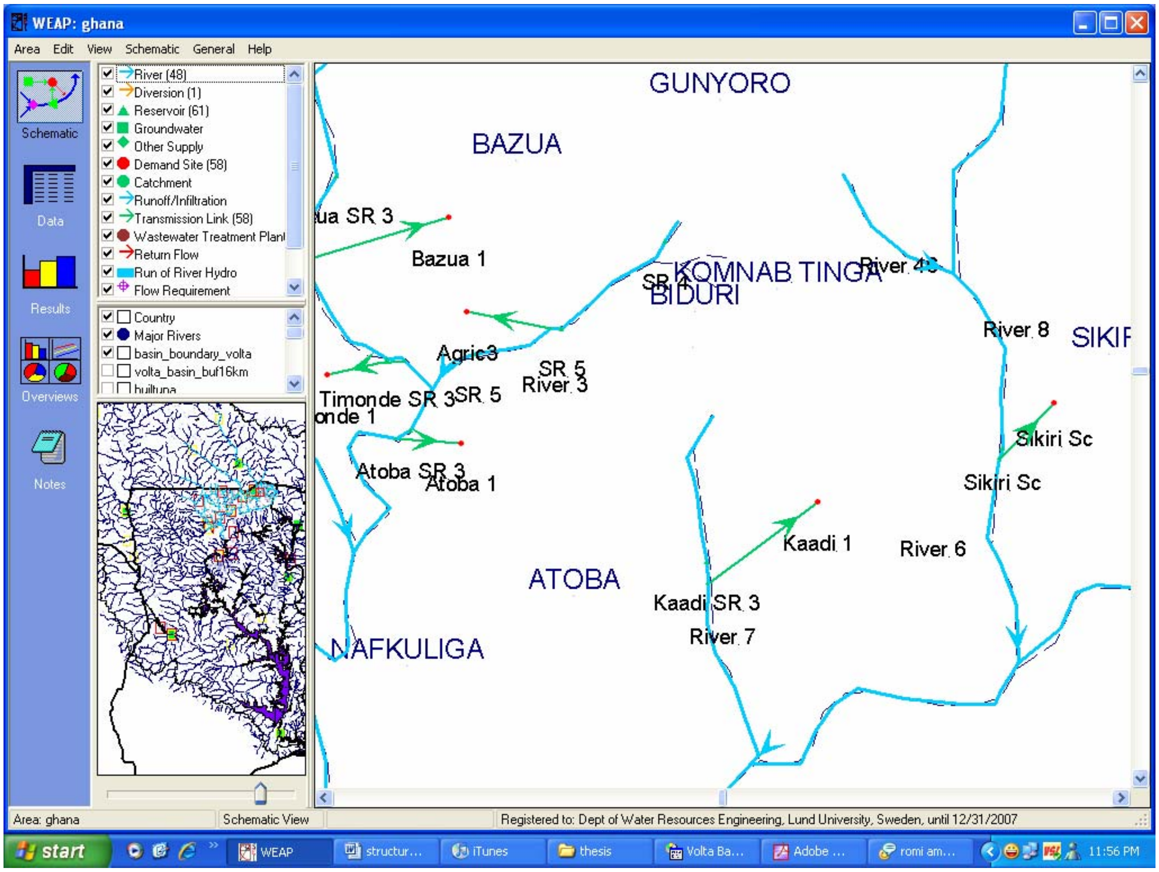

Figure 4.1 Schematic view of WEAP model showing the various nodes.

Data

The data view is where data is entered into the program. It allows variables and various assumptions to be created using mathematical relationships. Data can also be imported from Excel.

Result

Results are easily accessed. Every model output is displayed. This can also be exported to Excel for further modification.

Overview

This allows for easy accessibility of key indicators in the model.

Note.

Notes can be added to the model for documentation of the key assumptions.

4.3 Modelling Process of WEAP

The modelling of a watershed using the WEAP consists of the following steps (Levite, 2003).

- Definition of the study area and time frame. The setting up of the time frame includes the last year of scenario creation and the initial year of application.
- Creation of the Current Account which is more or less the existing water resources situation of the study area. Under the current account available water resources and various existing demand nodes are specified. This is very important since it forms the basis of the whole modelling process. This can be used for calibration of the model to adapt it to the existing situation of the study area.
- Creation of scenarios based on future assumptions and expected increases in the various indicators. This forms the core or the heart of the WEAP model since this allows for possible water resources management processes to be adopted from the results generated from running the model. The scenarios are used to address a lot of "what if situations", like what if reservoirs operating rules are altered, what if groundwater supplies are fully exploited, what if there is a population increase. Scenarios creation can take into consideration factors that change with time.
- Evaluation of the scenarios with regards to the availability of the water resources for the study area. Results generated from the creation of scenarios can help the water resources planner in decision making.

4.4 Applications of the WEAP model

The model has been applied to quite a number of basins in different countries of the world and still active in a lot of countries. It has been applied to Lake Naivasha in Kenya to develop an integrated water resource management model in order to attain both economical and ecological sustainability (Alfara 2004). The model was used to identify possible scenarios which can improve the current situation of the lake.

It has also been applied in the complex situation of the Aral Sea to evaluate water resources development policies. By using the features of the scenario creation the WEAP model was used to provide a structured approach to integrated water- demand analysis (P. Raskin, et al 1990)

Another application of the model is on the Volta Basin under the ADAPT project which is the Adaptation of Strategies for Changing Environment. Under the ADAPT project the model was used to investigate the effect of changing climate on the already stressed water resources, food security and the environment and the consequence on the socio- economic situation on the people living in the basin.(Andah et al, 2003)

The model has also been applied in the following other areas:

- In the United State of America the model has been used for a number of research projects and is still active in some States.
- South Africa on water demand management scenario in a water stressed basin.
- Limpopo and the Volta River Basins in Zimbabwe and West Africa for Planning and evaluating ensembles of small, multi-purpose reservoirs for the improvement of smallholder livelihoods and food security tools and procedures (SRP website, 2006).

5 METHOD

5.1 Input Data

A GIS based vector layers of the area of UER of Ghana and the whole of the Volta Basin was obtained from the Volta Basin Starter Kit July 2006. The kit was compiled by the International Water Management Institute (IWMI) and the Challenge Program on Water and Food. The Starter kit also provided information on the runoff data and a range of other useful information.

The year chosen for the current account was 2004. The runoff data for the year 2004 was obtained from the starter kit and other sources. Boundaries of the UER area were set using the raster layer of the whole Volta Basin which was also obtained from the Basin Starter Kit. Streams in the area were redrawn by using the drag and drop button of the river button on the WEAP model.

Data on the water use and areas of irrigation was obtained from the study conducted on water use and irrigation of some selected areas of the UER of Ghana. (Faulkner 2006)

5.2 Modelling Process

5.2.1 Calibration of the Model.

The current account year was used to calibrate the model. Reservoirs were categorized into three groups namely SR1, SR2 and SR3. Small Reservoir category three (SR3) has the biggest surface area in the range of 7.02 – 35 ha and SR2 have areas in the range of 2.88 to 6.93 ha while that of SR1 is in the range of 1–2.79 ha.(Leibe et al, 2005).

An average value was obtained from this and the calculation of the storage capacity was done using the relation;

Volume = 0.00857 x $\text{Area}^{1.4367}$ m^3. (J. Leibe et al, 2005).Where the area is in meter square.

All the reservoirs in the model were assigned a volume according to table 5.1.

Table 5.1 Categories of the reservoirs and their properties.

Reservoir Category	Area (Ha)	Average Area (m^2)	Average Volume (m^3)
SR1	1-2.79	1,8950	11,984
SR2	2.88-6.93	4,9050	46,991.8
SR3	7.02-35	210,100	374,935.9
SR4			SR 3+ SR 1
SR5			SR 3 + SR 2

Most of the reservoirs are located on the second and third order streams which have limited rainfall data. The streams and rivers were named River 1 to River 49 and include the major rivers which are White and Red Volta rivers. The reservoirs which are not located on any of the streams were not included in the study since they don't have any hydrological links to any of the streams and therefore have no impact on the streams. This will reduce significantly the total amount of storage capacity for all the reservoirs, which 186 billion m^3.

Demand sites were limited to agricultural use for small scale irrigation systems. This is because 80% of the water in the district is spent on growing crops and for livestock production. The demand sites in the model were denoted with the corresponding name of the town where the demand is located and with a number 1, 2 or 3 corresponding to the small reservoir close to the area.

The demand priority was set to 1 in the model. The model uses demand priorities which can be set between 1 and 99 depending on the priority of the demand sites. The highest demand priority is 1 with the minimum being 99. A demand priority of 1 means that as long as there is flow in the river or streams that demand must be satisfied.

Faulkner (2006) conducted a study into the water use and availability in the UER of Ghana. The results obtained in the study of two reservoirs and farming communities are presented in the table 5.2.

According to Faulkner the water release per area irrigated was found to be 11,365 m^3/ha for the Weega system of irrigation which was a well managed system. The value obtained for the Tanga system of irrigation was 32,901m^3/ha for the same crops as the Weega system. The Tanga system was described as a poorly managed system (Faulkner 2006).The average value of water released for the two systems was used in the model for all the reservoirs as their annual water use rate. The areas of land cultivated for the places where there are SR 3 type reservoirs were chosen to be approximately 9 ha. And that for SR2 and SR1 type reservoirs was set to be 2.6 ha and 1.6 respectively. These values were used in the model based on the assumption that all the areas with

SR3 type reservoirs have the same irrigated areas. The SR 4 type reservoir is a combination of SR3 and SR1 while the SR5 reservoirs is that of SR 3 and SR 2

Table 5.2 Water use and irrigated areas of two small scale irrigation sites in the UER (Faulkner, 2006)

	Area under Cultivation (ha)	Total Water Released for Season (m^3)	Water Released per Area Irrigated (m^3/ha)
Tanga Canal A	0.8629	34121	39542
Tanga Canal B	0.7591	19245	25352
Tanga Total	1.6220	53366	32901
Weega Canal A	2.8824	32373	11231
Weega Canal B	3.1245	35895	11488
Weega Total	6.0069	68268	11365

The figures 5.1 and 5.2 show an overview and a detail sample of the study area in the WEAP model. It shows the major rivers and streams in the UER. The detailed sample of the schematic view shows the demand sites as Red dots with the name of the town and the number 1, 2 or 3 depicting the kind or reservoir closed to that demand site. This also shows the names of the various towns in the UER.

The average monthly evaporation for the small reservoirs was obtained from figure 3.4 which was adapted from Leibe (2002). The value obtained was 152.5mm/month and this value was used to represent all the reservoirs in the district.

In all a total of 61 reservoirs were located on streams in the region. This value is far lower than 186 million m^3 of the total storage capacity of reservoirs (Leibe et al 2002). The difference may be attributed to the fact that not all the reservoirs in the region were considered. Only the reservoirs on streams and rivers were considered.

5.2.2 Assumptions Made

In the modelling of the reservoirs in the study area, some assumptions were made regarding some of the input data. The runoff data obtained was only on some selected stations from various towns in the whole basin. For streams with no gauge stations their runoff data were deduced from the neighbouring stations. This was done by taking into consideration the catchement area of the stream. Concerning water use in the region, it was assumed that the water use for domestic purposes was negligible and that water in the region is basically for irrigation and livestock production.

With regards to the areas of irrigated land in the various towns, it was assumed that the land sizes were the same as 9 ha for SR3 type and that for SR2 and SR1 type reservoirs was set to be 2.6 ha and 1.6 respectively. The rate of water use was also assumed to be the same as 22,133m^3/ha for all the reservoirs.

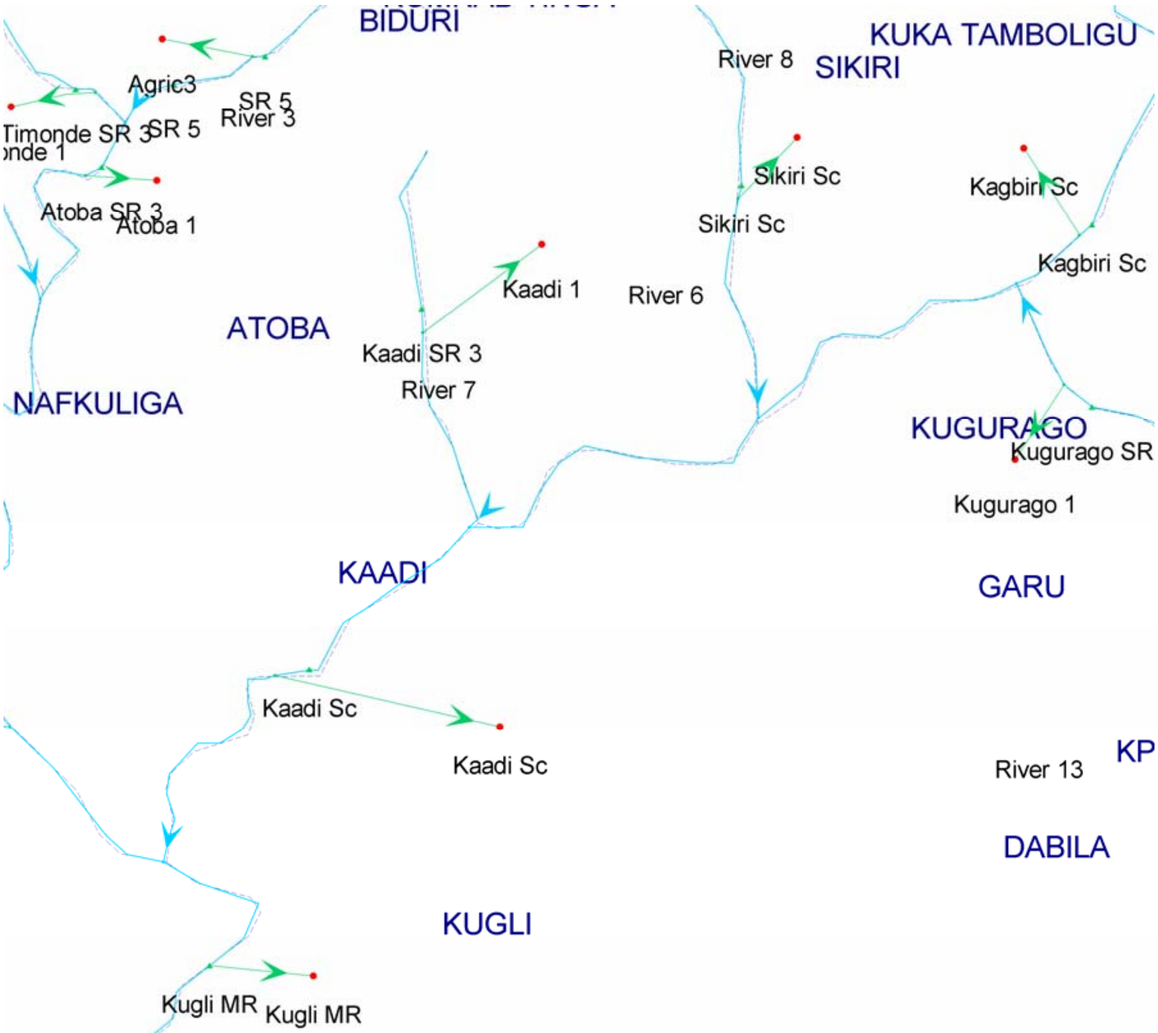

Figure 5.1 A detailed schematic view of the study area in the WEAP model

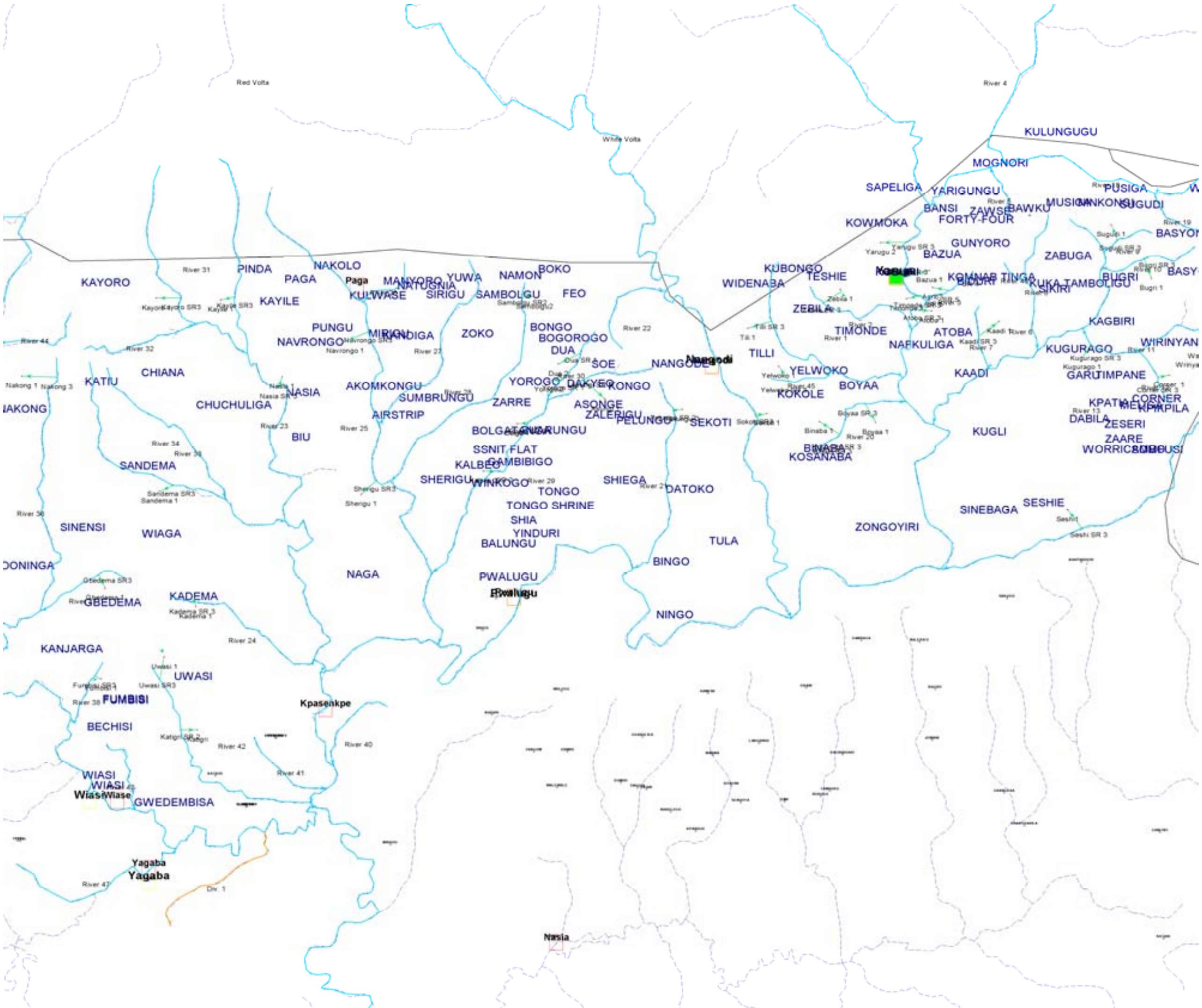

Figure 5.2 An overview of the UER in the WEAP model

5.3 Creation of Scenarios

The following scenarios were created in order to ascertain the impact of these small reservoirs on the flow of the streams in the study area. In creating these scenarios the water year method was used to specify different climate conditions in the given period of the scenario analysis. This is shown in table 5.3 and was used to represent all the three scenarios created. The values were chosen based on an assumption. The model gives the values for the water year as Normal = 1, Wet =1.3, Very wet = 1.45, Dry =0.8, Very Dry = 0.7. This means that the discharge values are multiplied by these factors.

Table 5.3 Water Year Method for various years under scenario

Year	Water Year Type
2005	Normal
2006	Normal
2007	Wet
2008	Wet
2009	Dry
2010	Very dry
2011	Dry
2012	Wet
2013	Very wet
2014	Dry
2015	Normal

5.3.1 Scenario 1; Increase in the Number of Small reservoirs

The increase in the number of small reservoirs could be considered a business as usual scenario where there are more reservoirs constructed and more irrigated lands exploited. The impact on the runoff would be achieved by increasing the number of reservoirs in accordance with expected population growth over a period of time. A total of 8 reservoirs were assumed to be added to the existing number. These additional reservoirs were assumed to be of higher storage capacities than the SR3 type category with a storage capacity as defined in table 5.4 and were located on the main White Volta River.

Table 5.4 New Reservoirs and their properties.

Name of Reservoir	Storage Capacity (Million m^3)	Irrigated land(ha)	Start up Year.
Naga MR	1	45	2008
Zarre MR	0.9	45	2008
Pwalugu MR	0.9	45	2008
Wiaga MR	0.9	45	2008
Balungu MR	0.9	30	2008
Kugli MR	0.9	30	2010
MR3	0.9	30	2010
Nangodi	0.9	43	2012

5.3.2 Scenario 2; Increase in irrigated Land/Increase in Demand

The effect of an increase in irrigated land and a corresponding increase in amount of water use would also be applied to find out how they impact on the runoff. According to the International Fund for Agricultural Development (IFAD) report, for there to be a significant growth in the Basic Need Income (BNI) smallholder irrigation, the existing areas of irrigated lands which are below 1.6 ha should be increased to 2.4 ha. (IFAD Report).

In the creation of this scenario, the irrigated areas were increased from 9 ha for every SR3 type reservoir to 13 ha. For SR1 and SR2 type reservoirs the increase was from 1.6 ha to 2.4 ha and 2.4 ha to 5 ha respectively.

5.3.3 Scenario 3; Increase in Demand during the wet months

This scenario looks at complimentary irrigation during the wet seasons of June, July and August. Under this scenario the demand rate for irrigation was increased during the specified months. It assumes that the reservoirs would be used for other irrigation purposes than the normal irrigation. The demand rate was increased from 22317 m^3/ha to 32000m^3/ha to access the possibility of using the reservoirs for more irrigation for better economic gains. This was achieved by using the monthly variation principle in the WEAP model. The months of June, July, and August were varied to allow for more irrigation by increasing the activity level.

6 RESULTS AND DISCUSSION

6.1 Introduction

This chapter describes the results obtained from the model. This includes both the results obtained from the calibration of the model and also when scenarios were created. The results are represented in tables and charts.

6.2 Calibration results

Calibration of the model was done to adapt the model to the UER taking into consideration all the necessary indicators such as the water use and annual activity level of the irrigated areas. This also included the storage capacity of the reservoirs.

6.2.1 Stream Flow

The total flow from the WVR observed at the point where river leaves the UER was 10.7 billion m^3 for the calibration of the model which is year 2004. The measured flow for the same river according to the gauge station reading is 9.565 billion m^3. This shows a difference of approximately 1 billion cubic meters. The difference between the two values may be due to the fact that the water uses for domestic purposes were not included in the study. Figure 6.1 shows the results obtained from the model for stream flow of the various rivers and streams. The White Volta River is shown as the thick blue line.

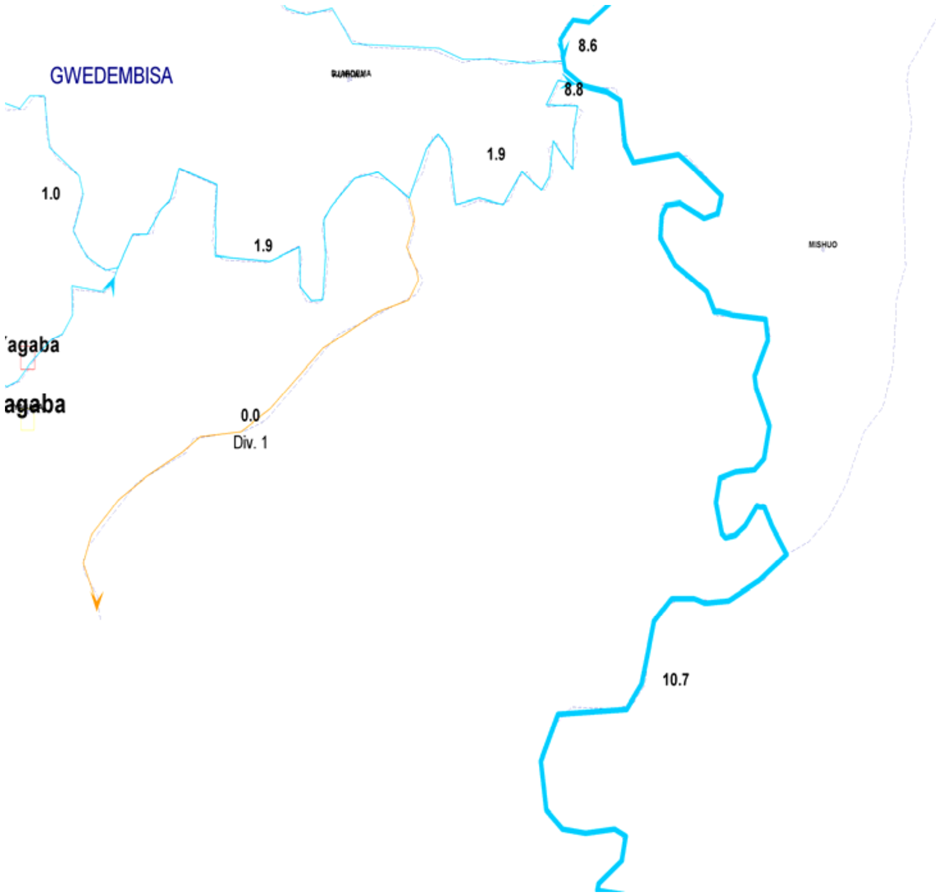

Figure 6.1 The flow of water from the various streams in billion m^3 in the UER for the current account year 2004.

The table in appendix 1 depicts the flow condition of the White Volta River and all its tributaries and shows the annual flow in billion cubic meters. The same result is represented in figure 6.2

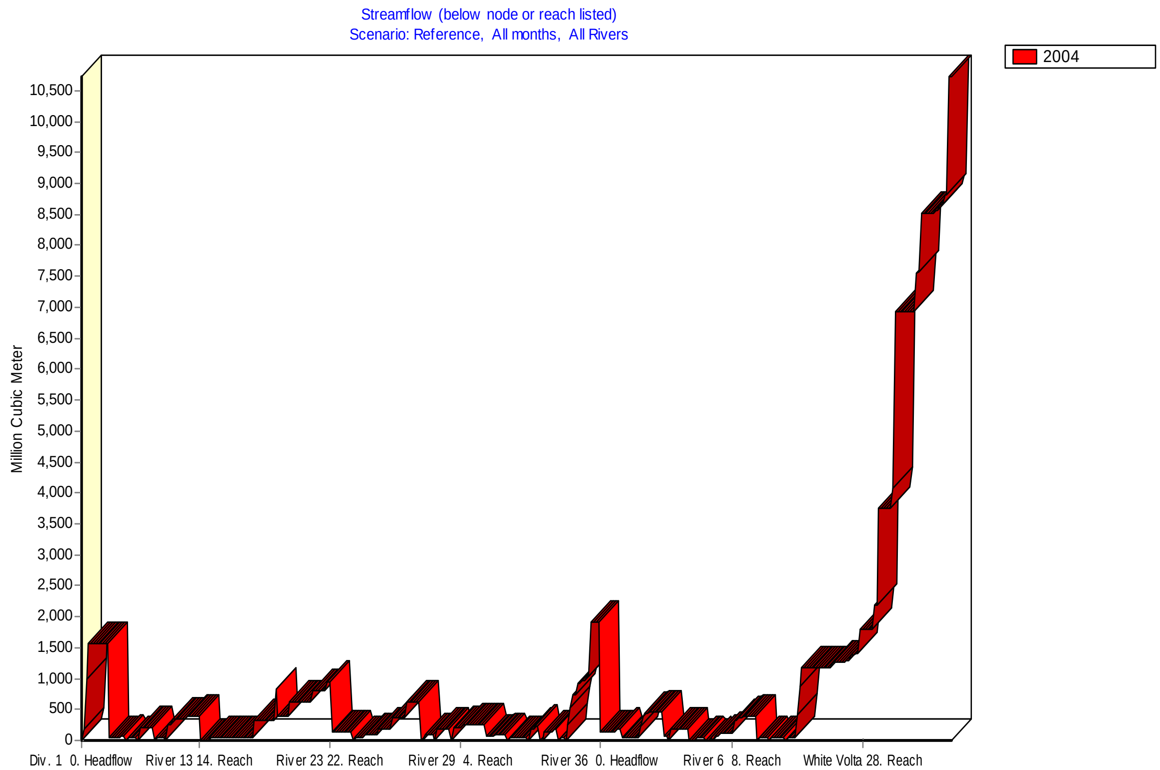

Figure 6.2 Chart of stream flow for streams in the UER in million m^3

6.2.3 Reservoir storage capacities

The results for the various small reservoir storage volumes showed that some of the reservoirs are 50 % full in the dry months of January, February, and March. During those months the demand for water is not totally reached. However, reservoirs with labels Kpasenkpe Sc, Naga Sc, Naga Sc3 showed 100% volume in all the months including the dry periods. The storages of the various reservoirs are presented in appendix 2. The demand priority given to all the reservoirs in the WEAP model was 1. In the wet seasons all the reservoirs were filled with water. Figure 6.3 shows the storages of reservoirs in the UER. This excludes all reservoirs with 100% storages throughout the year.

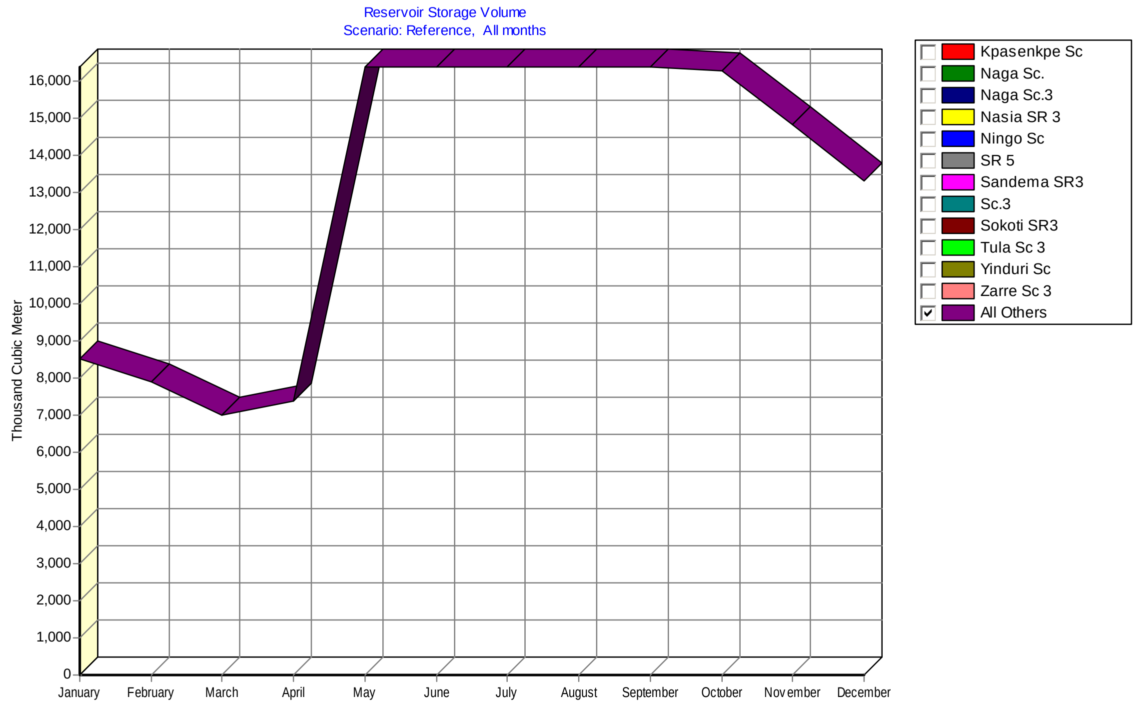

Figure 6.3 Reservoirs storage volumes for various months in million m^3

6.2.4 Demand site coverage

Appendix 3 shows the percentage of the demand sites covered by the streams for the twelve months in the current account year of 2004. The percentages vary from 0 to 100. The demand sites with total coverage are denoted with 100% and vary with the various months. Some of the demand sites showed low coverage in the months of January, February, and March. However the sites were all covered in the wet season periods. Reservoirs located on the upstream of small streams that finally joins the main White Volta River showed low demand coverage during the mean months unlike the reservoirs located on the main White Volta River which showed all year round coverage. This could be attributed to the fact that since the small streams have small catchement area the flow generated is less and thus less water is stored in the reservoirs. But the reservoirs downstream were located at places where all the flows from the small streams meet thus having more water in the whole year.

6.3 Simulation Results

6.3.1 Scenario 2 Increase Demand

This was the scenario in which the irrigated land sizes were increased as described in chapter 5.

6.3.1.1 Stream Flow

The results for the stream flow under this scenario showed very low reduction of runoff downstream of the White Volta River. However the reduction was slightly significant in the stream flow in the dry years which were 2009 and 2010.

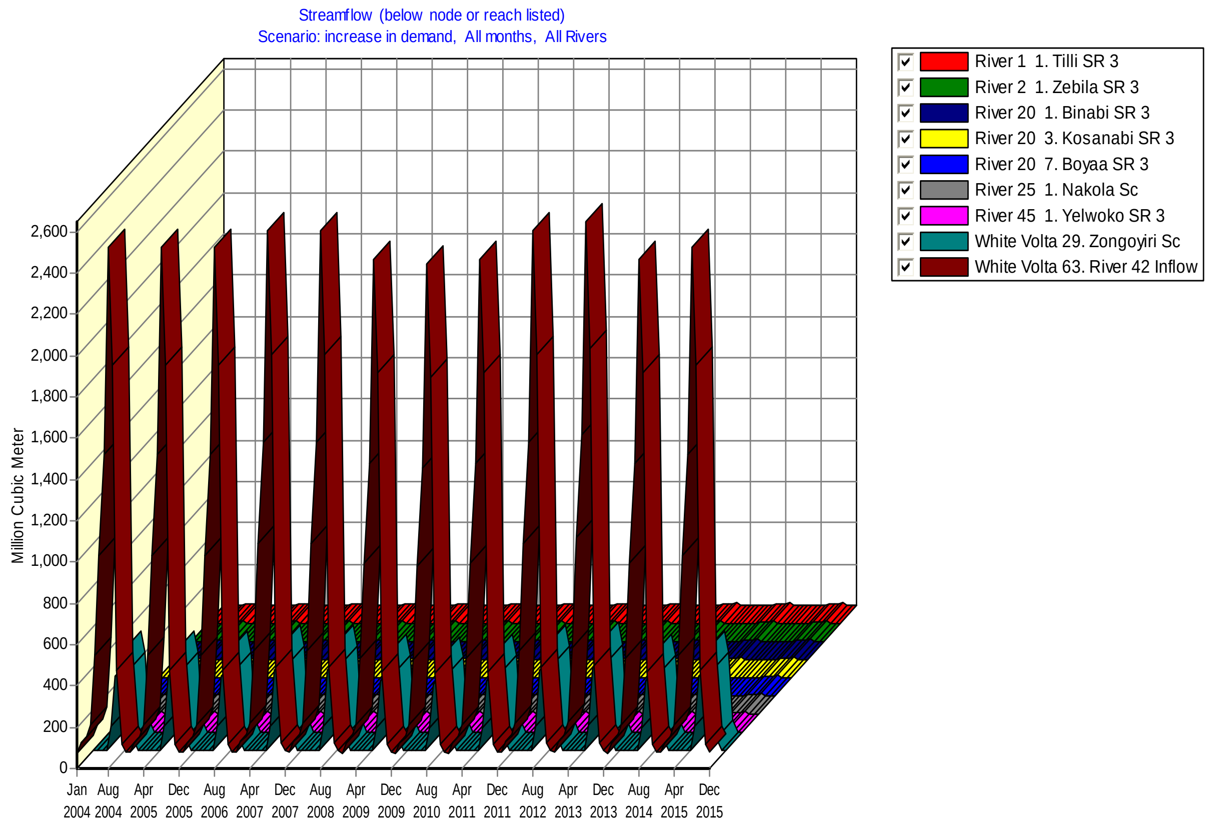

Figure 6.4 Stream Flow for Increase in Demand scenario.

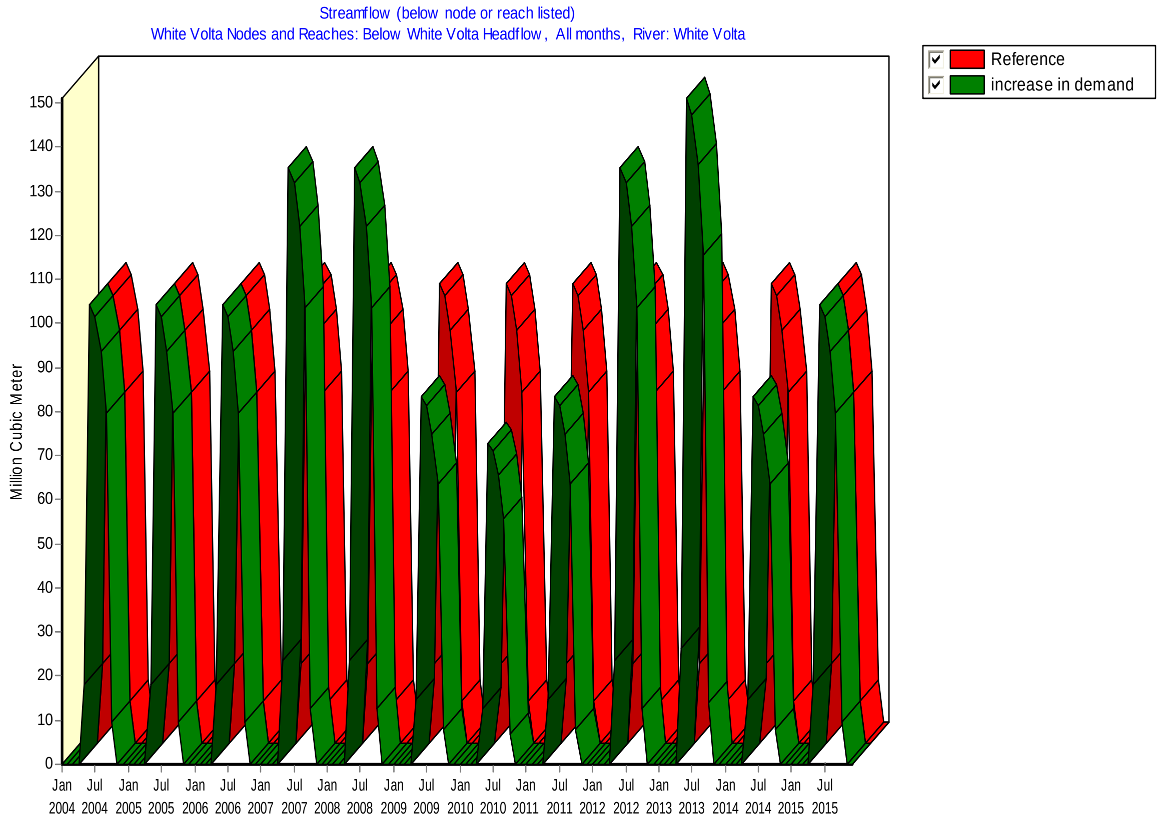

Figure 6.5 Stream flow for Increased Demand Scenario and the Reference Scenario

6.3.1.2 Demand Coverage

The analysis for three different years 2010, 2013 and 2015 was considered. The year 2010 was chosen to represent year with less rainfall as described in the table 5.3. The demand coverage for the months of January, February, March and April were extremely low. The percentage ranges between 69 % in Jan and 29% in April for reservoirs located on small streams (second order streams). The January coverage was higher although it is part of the dry months. This could be attributed to the fact that the reservoirs were able to store up some amount of water during the previous year's wet season thus making some amount of water available in the dry season. The reservoirs located on the main White Volta River showed 100% coverage for all demand sites. Year 2010 is considered to be a very dry year according to table 5.3. The results showed less demand coverage in the dry months as shown in figure 6.6. This is because less water was stored during the previous year's wet season but the end of the wet season and the dry months for the preceding year saw better demand coverage.

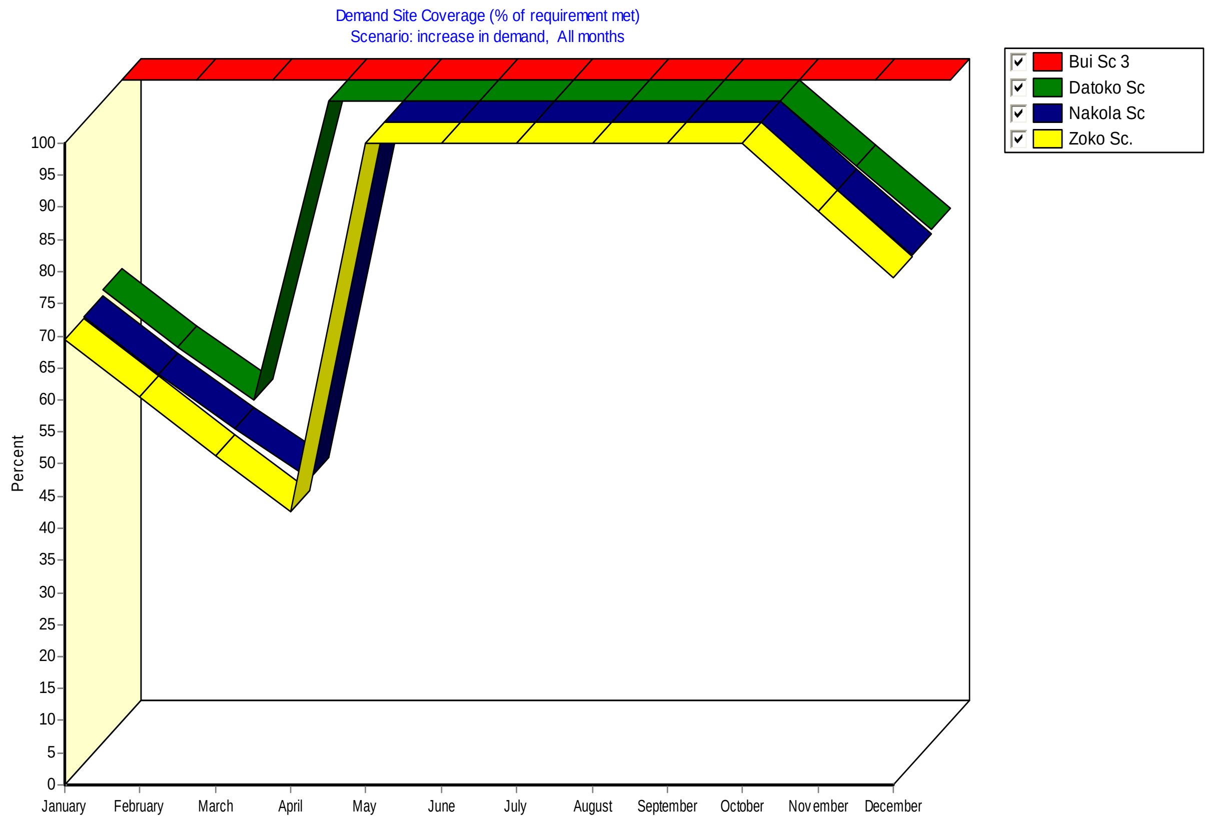

Figure 6.6 Demand site coverage for year 2010 for some selected reservoirs in the very dry year.

The year 2015 was chosen to be a normal year with normal runoff for the various streams in the Region .The results for unmet demand that is percentage of demand areas which are not met are also represented in figure 6.8. This shows an increase over the period of study in agreement with the demand increases. As the demand goes up the unmet demand also increases.

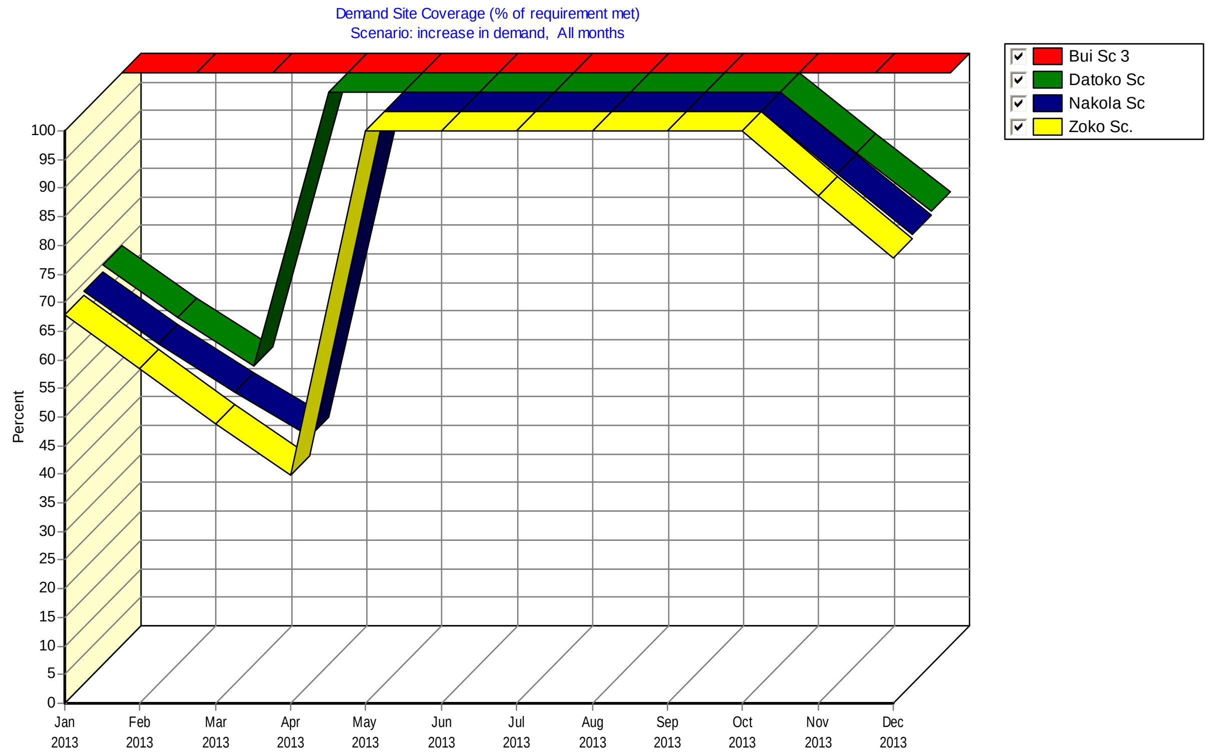

Figure 6.7 Demand Coverage 2013 for some selected reservoirs.

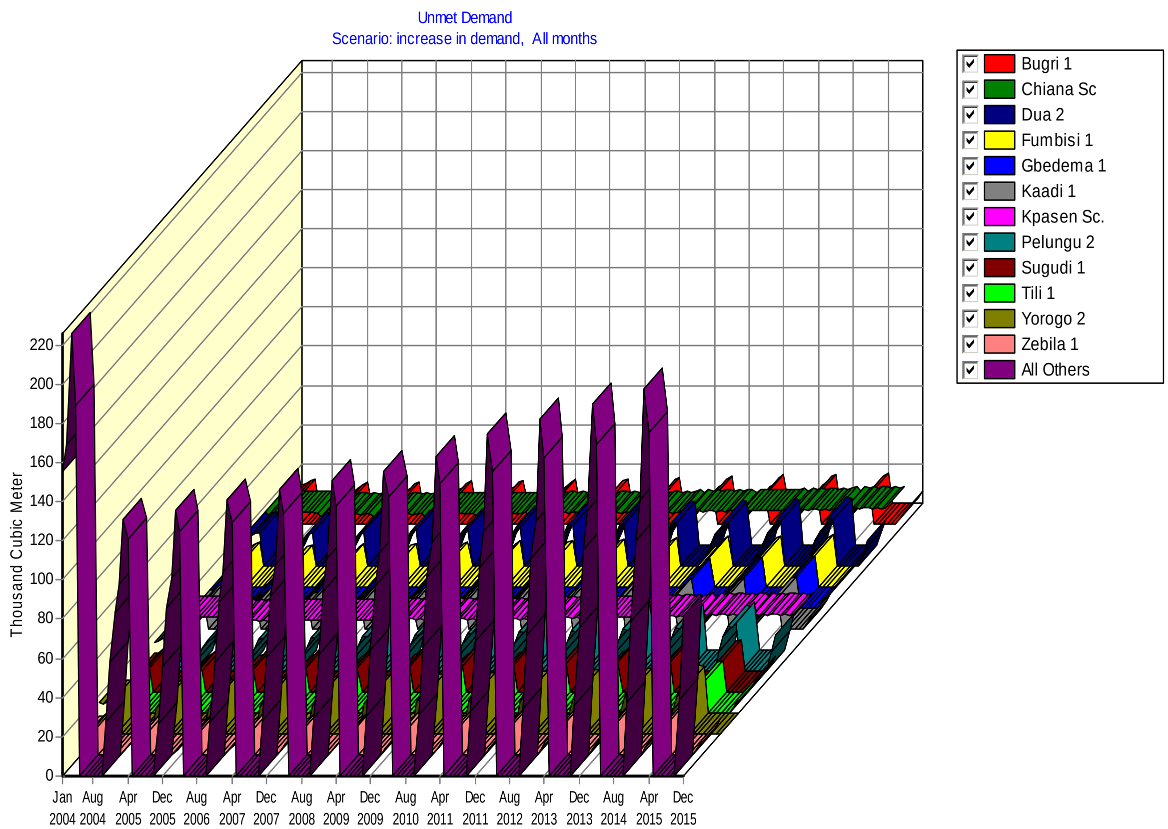

Figure 6.8 Unmet Demand

6.3.1.3 Reservoir Storage volume

The storages for the various reservoirs agree with the demand coverage of the same reservoirs. The dry months showed less storages and less demand coverage through out the years under study. This is represented in figure 6.9

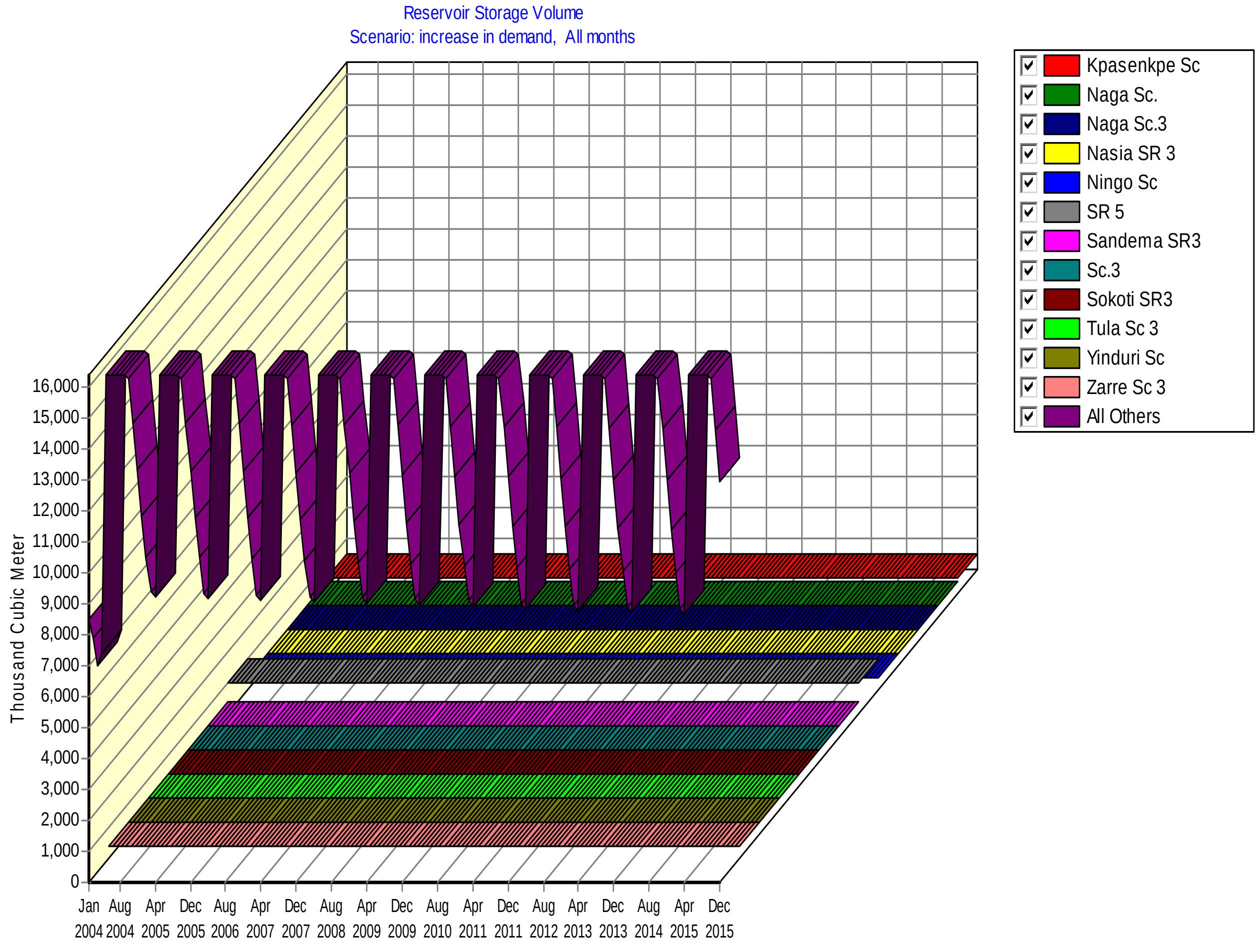

Figure 6.9 Reservoir Storage Volume Mm^3.

6.3.2 Scenario 3; Increase in Demand during the Wet Season.

This scenario as described in chapter 5 shows an increase in the demand during the wet seasons of June, July and August.

6.3.2.1 Demand Coverage

The results showed 100% coverage for the months of Jun, July and August though there were increases in demand. There was enough water to serve more irrigated lands during those months. The reservoirs that were located on the main river showed continuous coverage throughout the period. The unmet demand for these months was zero.

6.3.2.1 Reservoir Storage volume

The reservoirs were all full in wet months just like the demand coverage. However two reservoirs located at Yorogo SR1 and Dua SR1 showed zero volumes in the months of Feb, Mar, April. These reservoirs were however filled during the wet months. This is represented in appendix 5.

6.3.3 Scenario 2; Increase in reservoirs

This is described in chapter 5 and shows the case when the number of reservoirs are increased according to table 5.4

6.3.3.1 Stream flow

The results obtained for the stream flow showed a reduction in the main White Volta River in the monthly average values. The difference in the stream flow for the month of December between the current account year and the “more reservoirs added scenario was 0.5 Mm^3 while that of February was 1M m^3. The highest difference was seen in the month of March which was 5 Mm^3.

6.3.3.2 Reservoir Storage Volume

The additional reservoirs were filled through out the period in which they were in operation. They were filled to full capacity in all the months.

The demands for the additional reservoirs were also met during the period.

6.4 Evaluation

The results obtained from the model showed that not all the demand sites were covered during the dry months of the year. Most of the demand sites on the second order streams are clear examples of sites which were not covered throughout the year. However the reservoirs located on the main White Volta River showed a constant supply of water in all the years under study and under all the scenarios created. Some of the reservoirs located on the small streams were able to store some amount of water during the wet season which is utilized during the dry months however not all the demand requirement is met in the dry months. The later part of the dry season received very little coverage.

The volume of the reservoirs behaved in a similar manner as the demand coverage. The reservoirs were filled to higher volumes during the wet months however the dry months showed less volume. When the demand sites were increased in the wet months, the reservoirs were able to handle the increase. This indicates that the reservoirs, particularly those located on the main river, can support complimentary irrigation during the wet seasons.

The increase in demand scenario showed an increase in the unmet demand in the dry months. This was increasing with the years under study according to figure 6.8 because the demand was increased in accordance with the years. Approximately 180,000 m^3 of water would be required to satisfy irrigation during the dry months.

The total annual flow from the river was not affected in any significant way in all the three scenarios. However the flows from the second order streams showed a significant reduction during the dry months. Thus the flow in the main river showed a very small difference in the dry months when compared to the current account year.

The third scenario which is the Increase in Number of Reservoirs Scenario showed a reduction in the flow values for the White Volta River. The reduction is in the range of 0.5 Mm^3 to 0.5 Mm^3 depending on the month. Although this reduction is insignificant compared to the monthly flow, the value can increase and cause a major reduction in the flow downstream when more reservoirs and demand sites are created on the main rivers.

6.5 Planning

In the planning of these small reservoirs, their location is of much importance in order to ensure demand coverage. This is much hindered by proximity since all the farmers cannot be located on the reservoirs located on the main rivers. However various farming groups can be created near reservoirs with constant supply of water and the reservoirs in those areas can be expanded to store more water for irrigation in all the farming seasons.

7 CONCLUSIONS

Water is a priceless commodity in the arid and semi-arid regions of the world where irregular rainfall is predominant. Creation of reservoirs is however a tool for ensuring adequate supply of water throughout the year. In the UER of Ghana where there is a higher incidence of poverty as compared to the other regions, small reservoirs are a major component of the people's farming activities. Development of small reservoirs is an efficient way of developing agriculture in the arid region of the world.

The aim of this study was to determine the impact of the large number of these small reservoirs on the downstream flow condition. From the results obtained for all the scenarios created, small reservoirs in the UER have relatively low impact on the downstream flow of the White Volta River. However reduction of the flow can be significant in the advent of the creation of larger reservoirs and more demand sites which may be located on the WVR as presented in the creation of more reservoirs with higher storage capacities and bigger demand sites scenario.

The reservoirs can also be used for other purposes such as more irrigated lands and more livestock production in the months of June, July, and August. More flow is realised in the streams during those months and so there is a possibility of making use of more water for other purposes.

The WEAP Model was a very good tool for this thesis. It is easy to use and offers a wide range of possibilities to be analysed under the scenario creation.

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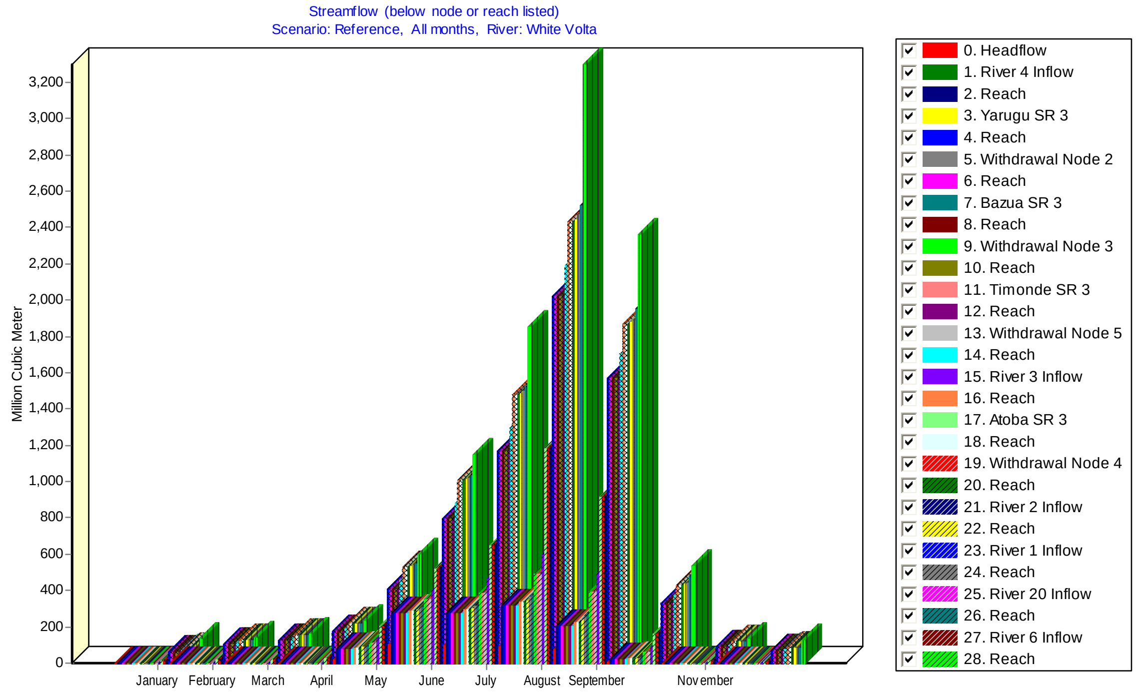
8 APPENDIX

Appendix 1 Results of Stream flow for the current account year.



Appendix 2 Results for Reservoirs storage volumes for the current account year in Mm^3

	Jan-04	Feb-04	Mar-04	Apr-04	May-04	Jun-04	Jul-04	Aug-04	Sep-04	Oct-04	Nov-04	Dec-04
Kpasenkpe Sc	500	500	500	500	500	500	500	500	500	500	500	500
Naga Sc.	380	380	380	380	380	380	380	380	380	380	380	380
Naga Sc.3	380	380	380	380	380	380	380	380	380	380	380	380
Nasia SR 3	380	380	380	380	380	380	380	380	380	380	380	380
Ningo Sc	380	380	380	380	380	380	380	380	380	380	380	380
SR 5	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000	1000
Sandema SR3	380	380	380	380	380	380	380	380	380	380	380	380
Sc.3	380	380	380	380	380	380	380	380	380	380	380	380
Sokoti SR3	380	380	380	380	380	380	380	380	380	380	380	380
Tula Sc 3	380	380	380	380	380	380	380	380	380	380	380	380
Yinduri Sc	380	380	380	380	380	380	380	380	380	380	380	380
Zarre Sc 3	380	380	380	380	380	380	380	380	380	380	380	380
All Others	8512	7904	6992	7376	16370	16370	16370	16370	16370	16267	14815	13297
Sum	13812	13204	12292	12676	21670	21670	21670	21670	21670	21567	20115	18597

Appendix 3 Results of demand site coverage in percentage for the current account year

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
Agric3	100	100	100	100	100	100	100	100	100	100	100	100
Asungi 1	100	100	100	100	100	100	100	100	100	100	100	100
Atoba 1	100	100	100	100	100	100	100	100	100	100	100	100
Bansi Sc	59.6	50.3	43.2	36.3	100	100	100	100	100	100	86.2	72.9
Bazua 1	100	100	100	100	100	100	100	100	100	100	100	100
Binaba 1	98.9	95.0	93.5	56.7	100	100	100	100	100	100	100	100
Bisigu Sc	100	100	100	100	100	100	100	100	100	100	100	100
Bolga 1	100	100	100	100	100	100	100	100	100	100	100	100
Boyaa 1	98.9	98.1	96.4	86.3	100	100	100	100	100	100	100	100
Bugri 1	63.6	53.4	45.4	38.2	100	100	100	100	100	100	88.0	76.4
Bui Sc 3	100	100	100	100	100	100	100	100	100	100	100	100
Chiana Sc	0	0	0	0	0	0	0	0	0	0	0	0
Corner 1	66.0	56.5	48.2	40.9	100	100	100	100	100	100	89.0	78.2
Datoko Sc	68.7	60.2	51.9	100.0	100	100	100	100	100	100	89.9	80.2
Dua 2	34.5	20.0	7.8	0.0	100	100	100	100	100	100	71.4	53.0
Fumbisi 1	60.0	51.9	44.4	37.3	100	100	100	100	100	89.7	79.9	70.4
Gbedema 1	60.0	51.9	44.4	37.3	100	100	100	100	100	89.7	79.9	70.4
Kaadi 1	58.8	48.5	41.7	35.3	100	100	100	100	100	100	86.0	72.5
Kaadi Sc	66.1	56.6	48.3	41.8	100	100	100	100	100	100	89.0	78.2
Kadema 1	68.3	59.6	51.3	43.9	100	100	100	100	100	100	89.8	79.9
Kadema Sc.3	100.0	100.0	100.0	100.0	100	100	100	100	100	100	100.0	100.0
Kagbiri Sc	63.6	53.5	45.6	39.2	100	100	100	100	100	100	88.0	76.4
Kalbeo 2	100.0	100.0	100.0	100.0	100	100	100	100	100	100	100	100
Katigri	100.0	98.8	97.0	96.1	100	100	100	100	100	100	100	100
Kayile 1	100.0	100.0	100.0	100.0	100	100	100	100	100	100	100	100
Kayoro 1	76.9	67.9	58.9	100.0	100	100	100	100	100	100	100	89.651
Kpasen Sc.	0	0	0	0	0	0	0	0	0	0	0	0
Kugurago 1	66.0	56.5	48.2	41.4	100.0	100.0	100.0	100.0	100.0	100.0	89.0	78.2
Naga Sc	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Naga Sc.	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

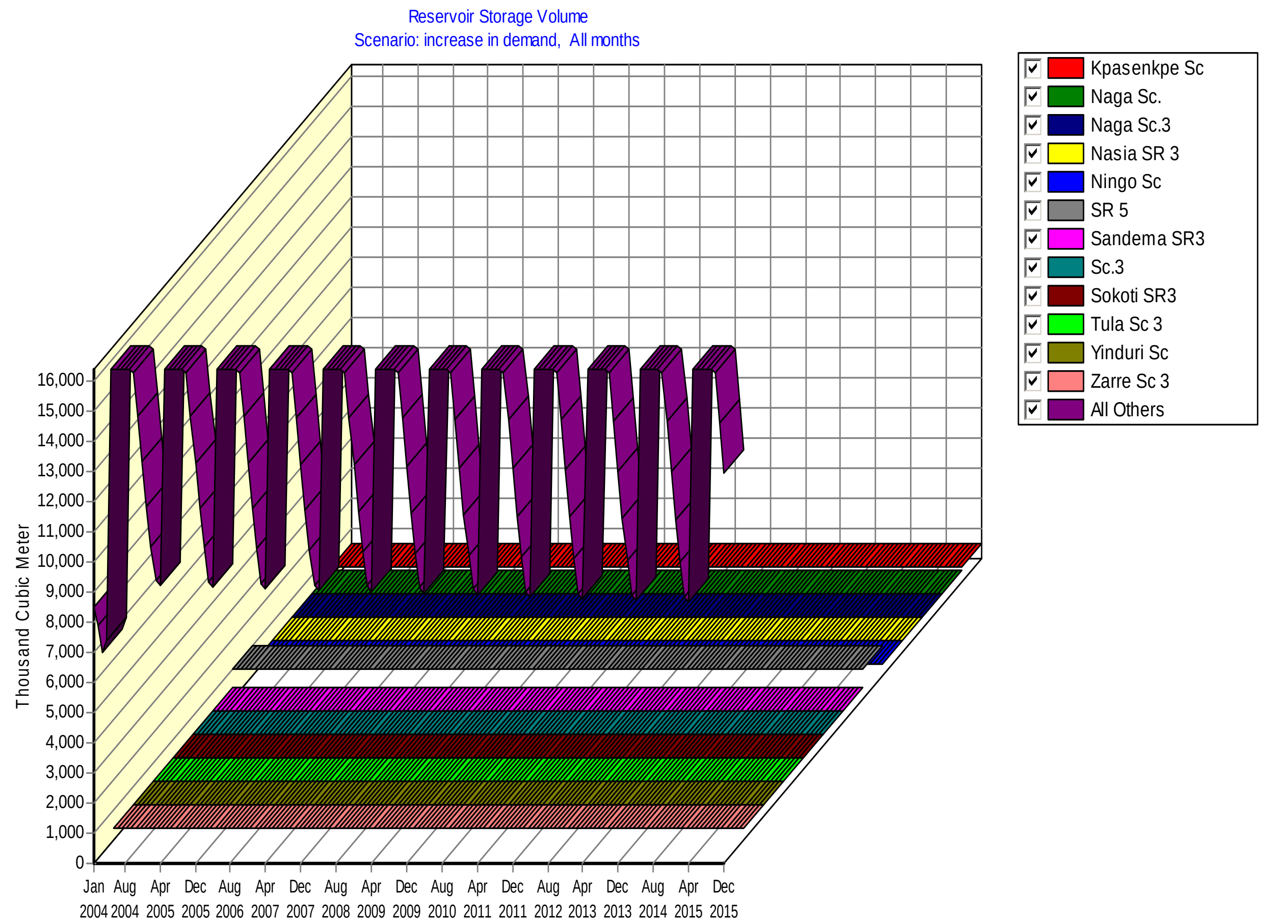
Nakola Sc	68.6	60.0	51.8	44.4	100.0	100.0	100.0	100.0	100.0	100.0	89.9	80.1
Nakong 1	68.3	59.6	51.3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	89.8	79.9
Nasia 1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Navrongo 1	68.6	60.0	51.8	44.4	100.0	100.0	100.0	100.0	100.0	100.0	89.9	80.1
Ningo Sc	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Pelungu 2	12.8	0.0	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	63.9	34.8
Sambolgu2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sandema 1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sc 3	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sekoti 1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Seshi1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sherigu 1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Sikiri Sc	58.8	47.3	40.9	34.9	100.0	100.0	100.0	100.0	100.0	100.0	86.2	72.8
Sinensi Sc	69.0	60.4	52.2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	90.0	80.4
Sugudi 1	58.9	48.7	41.8	35.2	100.0	100.0	100.0	100.0	100.0	100.0	86.0	72.5
Tili 1	58.2	47.8	41.1	34.9	100.0	100.0	100.0	100.0	100.0	100.0	86.0	72.5
Timonde 1	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Tula sc	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Uwasi 1	100.0	98.8	91.7	91.7	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Wrinyanga1	68.3	59.6	51.3	43.9	100.0	100.0	100.0	100.0	100.0	100.0	89.8	79.9
Yarugu 2	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Yelwoko 1	68.2	59.5	51.2	43.7	100.0	100.0	100.0	100.0	100.0	100.0	89.7	79.8
Yinduri Sc	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Yorogo 2	92.2	20.0	7.8	0.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Zarre Sc	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Zebila 1	58.7	47.9	41.2	34.9	100.0	100.0	100.0	100.0	100.0	100.0	86.0	72.5
Zoko Sc.	67.1	58.1	49.0	40.3	100.0	100.0	100.0	100.0	100.0	100.0	89.3	79.0
Zongoyiri Sc	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Appendix 4 Results of the demand site coverage in percentage for the year 2010

	Jan-10	Feb-10	Mar-10	Apr-10	May-10	Jun-10	Jul-10	Aug-10	Sep-10	Oct-10	Nov-10	Dec-10
Agric3	100	100	100	100	100	100	100	100	100	100	100	100
Asungi 1	100	100	100	100	100	100	100	100	100	100	100	100
Atoba 1	100	100	100	100	100	100	100	100	100	100	100	100
Bansi Sc	61	51	44	37	100	100	100	100	100	100	86	73
Bazua 1	100	100	100	100	100	100	100	100	100	100	100	100
Binaba 1	100	100	91	59	100	100	100	100	100	100	100	100
Bisigu Sc	100	100	100	100	100	100	100	100	100	100	100	100
Bolga 1	100	100	100	100	100	100	100	100	100	100	100	100
Boyaa 1	100	100	91	80	100	100	100	100	100	100	100	100
Bugri 1	64	54	46	38	100	100	100	100	100	100	88	76
Bui Sc 3	100	100	100	100	100	100	100	100	100	100	100	100
Chiana Sc	0	0	0	0	0	0	0	0	0	0	0	0
Corner 1	66	55	47	39	100	100	100	100	100	100	88	76
Datoko Sc	71	62	53	100	100	100	100	100	100	100	90	80
Dua 2	33	16	4	0	100	100	100	100	100	100	69	49
Fumbisi 1	59	51	43	35	100	100	100	100	100	89	78	68
Gbedema 1	59	51	43	36	100	100	100	100	100	89	78	68
Kaadi 1	59	48	41	34	100	100	100	100	100	100	85	71
Kaadi Sc	66	55	47	40	100	100	100	100	100	100	88	76
Kadema 1	68	59	51	43	100	100	100	100	100	100	89	78
Kadema Sc.3	100	100	100	100	100	100	100	100	100	100	100	100
Kagbiri Sc	64	54	46	39	100	100	100	100	100	100	88	76
Kalbeo 2	100	100	100	100	100	100	100	100	100	100	100	100
Katigri	100	100	100	100	100	100	100	100	100	100	100	100
Kayile 1	100	100	100	100	100	100	100	100	100	100	100	100
Kayoro 1	78	69	59	100	100	100	100	100	100	100	100	89
Kpasen Sc.	0	0	0	0	0	0	0	0	0	0	0	0
Kugurago 1	66	55	47	39	100	100	100	100	100	100	88	76
Naga Sc	100	100	100	100	100	100	100	100	100	100	100	100

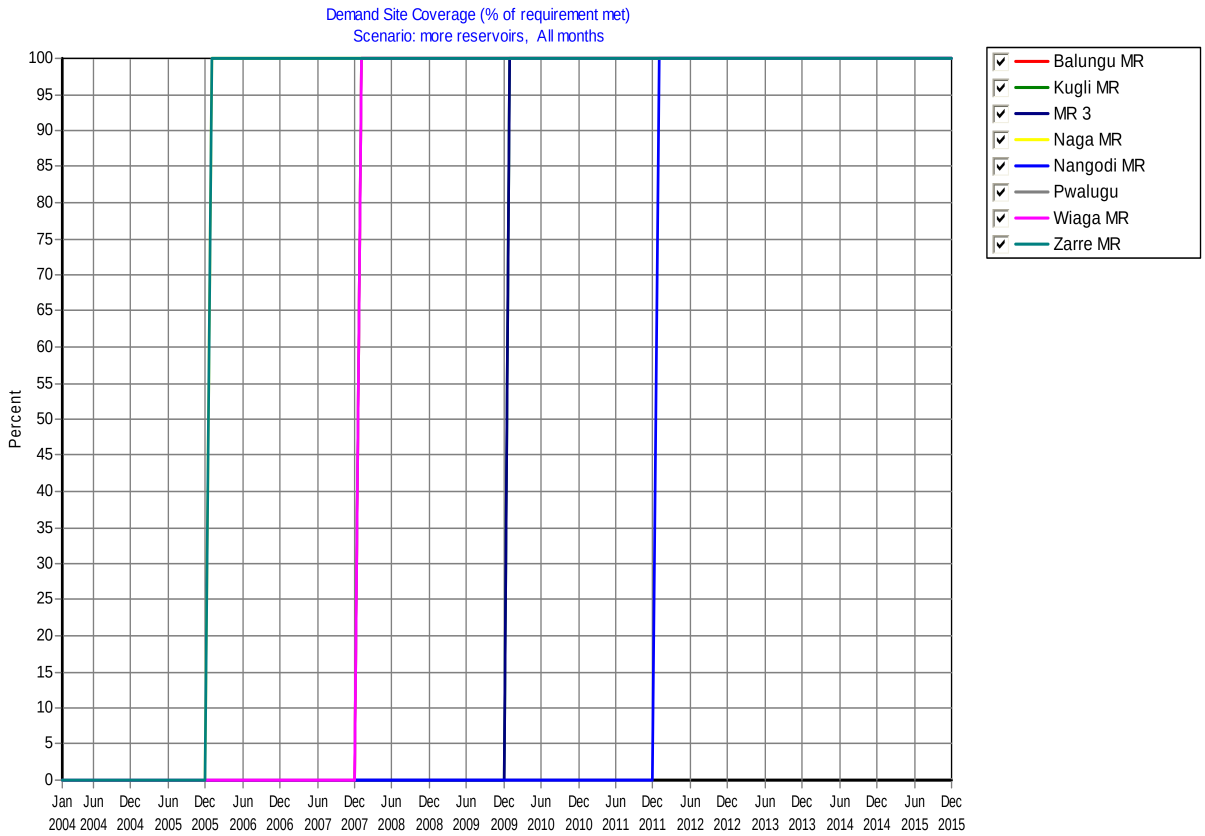
Naga Sc.	100	100	100	100	100	100	100	100	100	100	100	100
Nakola Sc	70	61	52	45	100	100	100	100	100	100	89	79
Nakong 1	68	59	51	100	100	100	100	100	100	100	89	78
Nasia 1	100	100	100	100	100	100	100	100	100	100	100	100
Navrongo 1	70	61	52	45	100	100	100	100	100	100	89	79
Ningo Sc	100	100	100	100	100	100	100	100	100	100	100	100
Pelungu 2	9	0	0	100	100	100	100	100	100	100	61	30
Sambolgu2	100	100	100	100	100	100	100	100	100	100	100	100
Sandema 1	100	100	100	100	100	100	100	100	100	100	100	100
Sc 3	100	100	100	100	100	100	100	100	100	100	100	100
Sekoti 1	100	100	100	100	100	100	100	100	100	100	100	100
Seshi1	100	100	100	100	100	100	100	100	100	100	100	100
Sherigu 1	100	100	100	100	100	100	100	100	100	100	100	100
Sikiri Sc	60	48	41	35	100	100	100	100	100	100	86	73
Sinensi Sc	71	62	54	100	100	100	100	100	100	100	90	80
Sugudi 1	59	48	41	34	100	100	100	100	100	100	85	71
Tili 1	57	47	40	34	100	100	100	100	100	100	85	71
Timonde 1	100	100	100	100	100	100	100	100	100	100	100	100
Tula sc	100	100	100	100	100	100	100	100	100	100	100	100
Uwasi 1	100	100	100	100	100	100	100	100	100	100	100	100
Wrinyanga1	68	59	51	43	100	100	100	100	100	100	89	78
Yarugu 2	100	100	100	100	100	100	100	100	100	100	100	100
Yelwoko 1	68	59	50	43	100	100	100	100	100	100	89	78
Yinduri Sc	100	100	100	100	100	100	100	100	100	100	100	100
Yorogo 2	94	16	4	0	100	100	100	100	100	100	100	100
Zarre Sc	100	100	100	100	100	100	100	100	100	100	100	100
Zebila 1	58	48	41	34	100	100	100	100	100	100	85	71
Zoko Sc.	69	60	51	43	100	100	100	100	100	100	89	79
ZongoyiriSc	100	100	100	100	100	100	100	100	100	100	100	100

Appendix 5 Results of the storage volume of reservoirs for scenario 3; Increase in demand during the wet months.



Appendix 6 Results of the demand in percentage of the additional reservoirs as described in scenario 2

Demand coverage of new reservoirs.



Appendix 7 Discharge values for some selected gauge stations.

White Volta headflow		Yakala	
Month	Flow m^3/s	Month	Flow m^3/s
Jan	0	Jan	0
Feb	0	Feb	0
March	0	March	0
April	0	April	0
May	6.8	May	14.76
June	40.2	June	22.81
July	37.9	July	12.85
August	27.5	August	47.266
Sept	34	Sept	3.5
Oct	3.64	Oct	0
Nov	0	Nov	0
Dec.	0	Dec	0

River 47 Gagaba		Gaba		
Month	Flow m^3/s		Month	m^3/s
Jan	0		Jan	20.84
Feb	0		Feb	1.68
March	0		March	1.15
April	0		April	1.27
May	0.67		May	2.47
June	5.57		June	10.75
July	12.6		July	48.42
August	102.57		August	137.19
Sept	87.485		Sept	75.87
Oct	5.445		Oct	10.68
Nov	0		Nov	3.5
Dec.	0		Dec.	14.35

White Volta below River 21 Pwalugu

Month	Flow m^3/s	Month	Flow m^3/s
Jan	18.25	Jan	0
Feb	32.86	Feb	0
March	39.03	March	0
April	53.27	April	0
May	66.55	May	0.85
June	87.06	June	1.89
July	168.05	July	0.579
August	271.17	August	3.5
Sept	241.49	Sept	4.97
Oct	53.56	Oct	0.51
Nov	28.95	Nov	0
Dec	23.67	Dec	0