ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES,
DEPARTMENT OF ENVIRONMENTAL SCIENCE

WATER RESOURCE UTILIZATION AND ITS RELATED EFFECTS : LAKE ABIYATA AND THE SURROUNDING

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DEDICATION

The success of this thesis is dedicated to My husband Habtamu Alebachew and our two beloved daughters Liya and Naomi for their love and the exitment they have given to my life.

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LIST OF ACRONYMS

CRL	Central Rift Valley Lakes
EU	European Union
GDP	Gross Domestic Product
ha	hectare
JICA	Japan International Cooperation Agency
kms	kilometers
m	meter
m.a.s.l	meters above sea level
Mm^3	Million meter cube
m^3/s	meter cube per second
MoWR	Ministry of Water Resources
NMSA	National Meteorological Services Agency
OIDA	Oromiya Irrigation Development Authority
OWRB	Oromiya Water Resources Bureau
RVLB	Rift Valley Lakes Basin
SEI	Stockholm Environment Institute
SN	Scenario
SNNPRS	Southern Nations Nationalities and People Regional State
TOC	Top of Conservation
UNESCO	United Nations Educational, Scientific and Cultural Organization
WWDSE	Water Work Design and Supervision Enterprise
WEAP	Water Evaluation And Planning system

ABSTRACT

The Study was conducted in Ziway-Abiyata Catchment in the Central Rift Valley of Ethiopia, to assess the effects of current and future water use practices on the hydrology mainly lake level change of the Lake Abiyata and its surroundings using a WEAP model. Records of hydrology, meteorology, irrigation, domestic water supply and industrial water supply for the study area have been statistically tested and arranged as an input data source to fit the model. Hydrologic and climatic data were correlated with lake levels. The demand and the supply of water resource, base line data and the future development activities of the area were compared using mainly three different scenarios SN1, SN2 and SN3. While by altering the priority settled for the Bulbula River's flow to a least priority level, additional three scenarios $SN1^{1}$, $SN2^{2}$ *and* $SN3^{3}$ *were generated. The results revealed that unless the minimum historical flow requirements are maintained, all scenarios indicated the future effects on Lake Abiyata. For the SN1, the lake level declined by 0.79 m and 0.34 m for Ziway and Abiyata lakes respectively. While compared with the baseline scenario, in the* $SN1^{1}$ *the lake level drops were 2.61 m and 0.59 m for Abiyata and Ziway lakes respectively. The SN2 scenario revealed a decline by 0.89 m and 0.42 m for the Lake Ziway and Lake Abiyata compared with the baseline scenario respectively. But in the* $SN2^{2}$ *scenario, a maximum level drop over the simulation period of 3.5 m and 0.7 m below the mean value of the existing condition for Lake Abiyata and Lake Ziway respectively was predicted. The SN3 option had less level drop effect compared with the SN2 scenario for both lakes despite the additional level drop by this development. The lake level drop below the natural sill in Lake Ziway may result in the total dry up of the Bulbula River, which consequently threatens Lake Abiyata's existence as a permanent lake. Similarly, compared with the lake baseline mean lake level, the Abiyata Soda Ash Enterprise expansion will drop the Abiyata Lake level by about 0.09 m, which was less than the effect due to upstream irrigation development proposition in a general sense. It is necessary that more detailed resource assessment of water should be done, including sustainable abstractions (safe yields) and the spatial variability of water quantity. In addition to this, the new projects on the study area demand Integrated Water Resources Management and Environmental Impact Assessment before the realization of the projects.*

Key words: Central Rift Valley Lakes, WEAP model, Lake Abiyata, lake level change.

Descriptions of scenarios:

SN1: Ziway pressurized irrigation (15500 ha) on Lake Ziway and other plus the existing demand (1980-2004).

SN2: Proposed dam on Meki River to irrigate 3500 ha plus SN1

SN3: Proposed diversion weir on Meki River to irrigate 2300 ha plus SN1

INTRODUCTION

1.1 Background

Over the past few decades, a drastic increase in human population accompanied by an unwise utilization of resources has exacerbated vulnerability of the land and water resources in almost every corner of the globe (UNESCO**,** 2008). In Sub Saharan Africa, where poverty, sever degradation of natural resources and climate variability are intertwined, the problem becomes even more complex and overwhelming (Mark and Nicostrato, 1997).
In Ethiopia, the uneven spatial and temporal occurrence and distribution of the water resources among others have been considered as the major factors affecting the development and management of water sector of the country (MoWR, 1999). Among the different water regimes of the country, the Central Ethiopian Rift Valley with Lakes Ziway, Langano, Abiyata and Shalla is one of those rain fall deficit areas where the surrounding agro climatic and geological factors are believed to have significant impact on the hydrological system.

Moreover, it is well documented fact that the Rift Valley Lakes are sensitive to changes in the water use regime and most lakes particularly those located in a terminal position have undergone significant lake level changes since the 1970s due to excessive abstraction of water, sever land degradation, deforestation and over irrigation (Tenalem Ayenew, 1998; Dagnachew Legesse and Tenalem Ayenew, 2006 and Lijalem Zeray, 2006).

The Ziway-Abiyata catchment in the Central Rift Valley Lakes (CRL) has the greatest potential for effective development owing to its favorable agro climatology and socio-economic conditions that attract investments mainly in the agricultural sector. More importantly, Lake Ziway catchment has been one of the extensively utilized parts of the CRL area. Besides, the recently expanding floricultures can add a stress over the available water resource in the catchment. Owing to these interlinked factors, the level of the lakes in the catchment fluctuated and water surface area contraction increased year after year (Dagnachew Legesse and Tenalem Ayenew, 2006). In addition to the water scarcity in this watershed, according to Lijalem Zeray (2006), the volume of water reaching Lake Abiyata is seriously decreasing on the past few decades owing to unplanned and unbalanced utilization (Tenalem Ayenew 2002b; Lijalem Zeray, 2006). Obviously, being a closed basin, any change in land and/or water resources can have amplified ecological and socioeconomic consequences undermining the sustainability of resources in general in the area. In this catchment for example, the decrease in the flow of River Bulbula, the major feeder river of Lake Abiyata, will impose a direct impact on the Lake Abiyata and its surrounding ecosystem (Tenalem Ayenew, 2002a). Similarly, other related unregulated utilization of the water resource in the catchment consequently will impose unprecedented effect on the hydrology of the water resources as evidenced mainly by a fluctuation in lake level.

Due to the vulnerability of the water resource in this fragile hydrological setting, development activities in the area in general and agriculture production in particular are being threatened. Moreover, the efficient, equitable, and optimum utilisation of the available water resources in this catchment for significant and sustainable socio-economic development will remain a challenge which also demands urgent response.

Thus, undertaking an assessment to understand and find scientific evidences on the effect of the current water resource utilization on the hydrology mainly lake level change of the area is a timely necessity. Such undertakings are helpful to clarify interrelated problems, identify options for improved water resource use, and develop knowledge base to strengthen local authorities in the field of environmental management enabling a sustainable development of the CRL. Therefore, this research aimed to generate clear and relevant evidence on the current effect of water resource utilization and its significance in the Ziway-Abiyata catchment mainly on lake level of Abiyata.

By linking the demand and the supply of water resource of the study area through developing scenarios, the research tried to compare the future development scenarios of the area with possible consequential effects so that appropriate remedial measures can be realized.

Records of hydrology, meteorology, irrigation, domestic water supply and industrial water supply have been used as an input source for WEAP modeling (SEI, 2007). Hydrologic and climatic data were correlated with lake levels to develop scenarios based on the input data (Vallet *et al.*, 2001; Tenalem Ayenew 2002c; Dagnachew Legesse and Tenalem Ayenew, 2006). However, the research did not address both water quality aspect and groundwater features and only surface water abstraction and its direct effect to the lake level of both lakes are addressed.

Furthermore, following the introduction part, the thesis has been organized as follows: Chapter 2 covers the review of literature that explores the theoretical and practical background of the problems and approaches implemented to mitigate them. Chapter 3 focuses on methodological approach with description of the study area and data analysis procedures. Chapter 4 presents the empirical findings of the study followed by discussion. Finally, Chapter 5 deals with conclusions and recommendations based on the findings.

1.2 Statement of the problem

Water resources management in Lake Abiyata and its surroundings has become an issue of very high significance because of great socio-cultural, ecological and economic values it is associated with. The catchment comprises a national park with a variety of wildlife, a significant livestock activity, and a growing tourism industry. On top of this, the current increasing demand on resources potentially imposed hydrological problems in the catchment (JICA and OIDA, 2001; Dagnachew Legesse and Tenalem Ayenew, 2006). Previous studies have indicated that the prevailing system of uncoordinated water resources management in the basin cannot sustain the ever-increasing water needs of the various expanding sectors. To this end, in this catchment, the vulnerability of Lake Abiyata has been gaining a significant attention that led to concern over the sustainability of water uses in this catchment and the subsequent effects on hydrology, socioeconom and the environment of the study area in general. It is therefore timely and crucial that assessment be done to investigate the effects of the current water use practices on the lake level change of Lake Abiyata in order to gain an understanding that helps to design a strategy which integrates the various sectored needs against the available water resources so that both socioeconomic and ecological objectives are sustainably attained.

1.3 Objectives of the study

1.3.1 Main objective

The main objective of the study is to assess the effects of water use practices in the Ziway -Abiyata catchment on the lake level change of Lake Abiyata.

1.3.2 Specific objectives

- To quantify water abstraction for different activities in the upstream area of Lake Abiyata especially around Lake Ziway.
- To evaluate the extent of water abstraction for soda ash production at the Abiyata lake.
- To determine the extent of the proposed development activities and their related effects on the lake level of Abiyata.
- To evaluate which activity is more significant for the lake level control.
- To evaluate different scenarios with regard to the availability of water resource.

2. LITERATURE REVIEW

2.1 Overview of the Central Rift Valley Lakes (CRL)

The Ethiopian Rift Valley, as part of the Great East African Rift Valley, splits the Ethiopian highlands into northern and southern halves, forming a floor in between occupied with the chain of lakes characterized by varied size, hydrological and hydrogeological settings. With the total area of 1.3 million ha, it encompasses three major water basins from NE to SW. The Awash basin with Lakes, Koka, Beseka, Gemari and Abe, the Central Ethiopian Rift Valley with Lake Ziway, Langano, Abiyata and Shalla and the Southern basin with Awassa, Abaya, Chamo and Chew-Bahir as the most important lakes (Halcrow, 1992; Tamiru Alemayehu *et al*., 2006).

Many of the lakes are located within a closed basin fed by perennial rivers. The major rivers in the region are Awash, Meki-Katar, Dijo and Bilate feeding lakes Abe, Ziway, Shalla and Abaya respectively. Lakes Abaya and Chamo are seasonally connected by overflow channel, Ziway and Abiyata by the Bulbula River, Langano and Abiyata by the HoraKelo River. The two major lakes in the CRL are Lake Ziway and Lake Abiyata. Lake Ziway being the centre of agricultural development, while Lake Abiyata is an important nature reserves and also belongs to the Abiyata- Shalla Lakes National Park.

The geological and geomorphologic features of the basin in general are thought to have been associated with extensive volcanism and Cenozoic volcano-tectonic and sedimentation processes. The large part of the rift valley areas being characterized by lacustrine sediments and volcano-sedimentary rocks. Lacustrine sediments being the most common and form the second largest next to ignimbrites (Tesfaye Chernet, 1982). Owing to the geological formation in the upper soil profile, i.e. porosity and permeability, there is continuous recharge to the groundwater. The highlands in both sides of the rift valley provide several perennial streams that enter the lakes occupying the low-lying middle areas of the rift.

Beside their provision of ecological services and function, some of the lakes and feeder rivers have been used for irrigation, soda abstraction, commercial fish farming, recreation and more importantly harbor a wide variety of endemic birds and wild animals (Hengsdijk *et al.,* 2007). However, the basin has become environmentally very vulnerable over the last few decades owing to the anthropogenic and natural consequences.

The ever increasing population coupled with an increasing demand on the natural resources in the catchment has profoundly exacerbated environmental degradation. For instance, it has been reported that the chemistry of some of the lakes specially the terminal lakes, such as Abiyata and Shalla has been affected (Elizabeth Kebede *et al.,* 1992; Tenalem Ayenew, 2002b). Few lakes shrunk due to excessive abstraction of water; others expanded due to increase in surface runoff and groundwater flux from percolated irrigation water (Makin *et al.,* 1976; Elizabeth Kebede *et al.,* 1992). Excessive land degradation, deforestation and over-irrigation changed the hydro meteorological setting of the region as well.

2.2. Major Water use practices in the CRL

It is well understood that any development requires water. But, how much and what types of developments are feasible with respect to the sustainability of the water resource in the area become important issues. Some of the major activities that use the water resource in CRLs include irrigation, domestic and livestock water supply, soda ash extraction, commercial fish farming, recreation and tourism as well as for harboring variety of endemic and wild lives.

Irrigation: To minimize drought risk and sustain agricultural production, supplemental irrigation has been used as a means in the region. Irrigation is the source of income for many of the farmers living near the rivers and around the lake. Surface water extraction for irrigation occurs in the catchment of Meki River (from the Gurage highlands), upstream of Lake Ziway; the Ketar River (from the Arsi highlands), also upstream of Lake Ziway; directly from Lake Ziway; and along Bulbula River, downstream of Lake Ziway.

Fig 1 Section view of Sher -Ethiopia Flower farming in the study area.

Domestic and livestock water supply: Ethiopia has been considered by many to be a water rich country. The relative water 'richness' of a country or a region is expressed in terms of the annual per capita water resources availability in the area. This is a simple indicator of whether an area is in a state of water scarcity or water surplus, based on the total runoff of the area in question. Generally, annual per capita water availability above 2,000 m^3 is considered relatively safe. Once it drops below 1,700 m^3 a state of water stress exists, with a high level of risk in dry or drought years. As it drops towards 1,000 m^3 and below, it becomes a state of water scarcity, in which the consequences are more severe and the risk much greater. Problems with access to safe domestic water supplies and water for food production become chronic in Ethiopia as a whole and in particular in the study area (Halcrow, 2007).

The major sources of water are ponds which are close to villages, rivers and lakes. In most places in the catchment, the main source for drinking water is underground water, supplementary to surface water of Lake Ziway (Dagnachew Legesse *et al.*, 2004). The water supply scheme in Meki town for example, depended on four deep wells. Hence, access to potable water in the rural areas is expected to be one of the lowest in the country.

Industrial water use: The availability of the water resource and the associated minerals coupled with the welcoming policy of the government invited the agro industrial sector in the region to establish development activities that mainly depend on water abstraction. For example, the basin contains soda ash, diatomite and bentonite in sufficient quantities and high quality for economic exploitation (Halcrow, 2007). Currently the only industry available in the area is Abijata Soda Ash Enterprise. Soda ash, an important mineral resource, has been mined at a government owned mine on Lake Abiyata using solar evaporation of brines from the lake. The plant on Lake Abiyata produced close to 15,000 tons of sodium carbonate per year and expanded a few years ago to 20,000 tons per year, to satisfy local needs, it could be developed to a greater extent in the future.

Commercial fish farming: Since the 1980's, there has been an introduction of improved fishing technologies in Lake Ziway and Lake Abiyata supported by an EU funds. Since Lake Abiyata is enclosed totally within the Abiyata-Shalla National Park and Wildlife Reserve, it is officially closed for fishing activities, even if some fishing activity is evident in Lake Abiyata (Ebrahim Esa, 2008). However, over fishing have been reducing the production (Zinabu Geberemariam, 1989). Currently, according to Tenalem Ayenew (2004), commercial fisheries covers most of the country's freshwater resources, including lake Ziway which is one of the most intensively fished lakes in Ethiopia (Tenalem Ayenew, 2004).

Biodiversity Values: Generally, the central rift valley is well known for its fauna and flora biodiversity (Halcrow, 1992). The vegetation in the CRL is characterized by Acacia open woodland. Nevertheless, since the 1970's, it has been heavily deforested and exotic species such as Pinus patual and Eucalyptus regnans have been introduced and this has resulted in open vegetation which is floristically poor and uniform (Hengsdijk and Herco, 2006a). Approximately 50% of the bird species in Ethiopia have been recorded in the Rift valley owing to the conducive and diverse aquatic and terrestrial habitats in the area. The Abiyata-

Shalla Lakes National Park was created primarily for its aquatic bird life, particularly those that feed and breed on lakes Abiyata and Shalla nest in large numbers.

2.3 Major environmental problems in the CRL

The environmental problems in the rift valley can be categorized into two major groups: Anthropogenic, linked with human activities for various reasons and the naturally induced problems that are caused by natural forces such as climatically related surface changes and tectonic forces. The anthropogenic problems mainly originate due to improper utilization of water resources and substantially changed the hydrological and hydrogeological setting of the rift lakes. Similarly, climate related factors such as a decrease in precipitation and a rise in surface temperature have influenced the general hydrology of the basin. Some of the major environmental problems in the basin, among others include, soil salinization, pollution, land degradation, deforestation, loses of biological diversity, and extreme lake level fluctuation. The overall significance of these environmental problems will have a cumulative effect on the aquatic and /or terrestrial ecosystems function and services that harbor a wide variety of endemic wild life, threatening the biodiversity of the area at large.

2.4 Hydrological system in the CRL

The CRL is a closed basin; hence there is no inflow and outflow of surface water to the catchment. In addition there is also no evidence of significant ground water inflow or out flow (Hengsdijk and Herco, 2006b). This eventually has made the water resource in the area originates mainly from rainfall. Moreover, on the surface, the rainfall being intercepted by the vegetation and surface structure on the land, the rain water temporarily accumulates in ponds and surface depressions or infiltrates in the soil, from where it directly evaporates or be utilized by crops. The spatial distribution of the evapotranspiration in the catchment changes as a result of the changes in land use. For example, the increase in irrigated agriculture, deforestation and other abstractions alters the evapotranspiration (Hengsdijk *et al.*, 2007). A portion of the rainfall can eventually recharge the groundwater if it exceeds the infiltration capacity of the soil. Consequently, the ground water in turn is gradually discharged into the lakes or the rivers as base flow, are temporarily stored, or are utilized. Similarly, above open water the evaporation rates exceed the rainfall. Thus, theoretically, the level of the lakes is maintained by a net flow of surface water and ground water. However, there is no significant evidence so far as to support the contribution of ground water for the fluctuation of lake levels in the CRL (Tenalem Ayenew, 2004).

2.4.1 Lake level changes in the CRL

Lake level change is described as height changes of a lake's water column that may be caused by geological, anthropogenic and climatic factors or a combination of these. According to Mercier *et al*., (2002) for example, changes in surface pressure, wind-driven events (e.g. Tides), an alternating temperature or composition, and modifications of the water circulation processes (i.e. recharge, outflow, evaporation), can result in lake level changes (Street, 1979; Tesfaye Chernet, 1982; Mercier *et al*., 2002; Tenalem Ayenew, 2004; Anna, 2006).

It has been documented that many of the rift lakes fluctuate in their level in response to the precipitation trends in the adjacent highlands (Tesfaye Chernet, 1982; Tenalem Ayenew, 2004).

Owing to the large-scale water use for irrigation and soda abstraction in the catchment, significant changes have been recorded in the last few decades. Lake Abiyata for instance, reduced in size by about 60% in 2006 of its size in the last few decades, after the implementation of the soda extraction and upstream irrigation in the Ziway catchment (Hengsdijk *et al*., 2007). The dominant factor affecting lake levels are climatic (rainfall and evaporation), followed by abstraction for irrigation

2.4.2 Methods of determination of lake level change

Water level is used to measure the changes in depth of a body of water over a period of time. Daily fluctuations in water level are common characteristics of many water bodies; including salt water and fresh water estuaries. Fluctuations of lake levels are important to document, whether they result from floods, droughts, excessive abstractions or just a normal water year. Measurements of lake surface areas are proved to be useful tools to observe changes in the water balance of a lake's catchment area, either due to climatic oscillation, modified land use practices or even neo tectonic effects (Anna, 2007).

Historical recorded lake level data are useful in developing computer simulations of lake fluctuations. One way of determining lake level change is by installing a permanent gauge on a structure such as a bridge pier or dam abutment, or a temporary gauge is fastened to a steel fence post and driven into the lake bed at a location convenient for observers. Amongst the modern ones, pressure sensors are commonly used to measure water levels, Ultrasonic Water Level Sensor uses the latest ultrasonic distance measuring technology for accurate non-contact water level monitoring.

2.5 Overview of Water Resource Management Policy of Ethiopia

Ethiopian Water Resources Management Policy emphasizes water for irrigated agriculture. The irrigation sub-policy is formulated to guide the development of the irrigable land resources of the country to improve food security and ensure a sustainable supply of industrial raw materials (MoWR, 1999). Comprehensive water management involves a number of functions that are closely related but which are carried out by different agencies and organizations. The functions include water law and policymaking, regulation, technical assistance and coordination, monitoring and evaluation, administration and financing, public education and involvement.

The general water resources policy among many others include: enhancing integrated and comprehensive management of water resources that avoids fragmented approach. Recognizing that water resources development, utilization, protection and conservation go hand in hand and ensure that water supply and sanitation, irrigation and drainage as well as hydraulic structures, watershed management and related activities are integrated and addressed in unison. Recognizing water as scarce and vital socio-economic resource, manage water resources as strategic planning basis with long-term visions and sustainable objectives. It ensures that water resources management is compatible and integrated with other natural resources as well as river basin development plans, with the goals of other sectoral developments in health, mines, energy and agriculture, etc.

As the fundamental planning unit and water resource management domain, the strategy recognizes and adopts the hydrologic boundary or basin. It also ensures that all planning, studies, programs and development objectives in the water sector include protection and conservation, operation and maintenance as well as replacement activities and budgets. It also promotes and encourages that conservation of existing water systems and efficient utilization of water is as feasible as development of new schemes.

Finally, the Water Allocation and Apportionment policy states that the basic minimum water requirement of Ethiopia should be recognized as the reserve (basic human and livestock needs, as well as an environmental reserve). This should have the highest priority in any water allocation plan (MoWR, 1999). This statement is significant when considering the environmental minimum requirement for terminal lakes like Lake Abiyata of the study area.

2.5.1 Strategies for water resource development and protection

Based on the water resource management policy (MoWR, 1999), the strategy for water resource development and protection aimed among others, to create primarily appropriate mechanisms to protect the water resources of the country from pollution and depletion so as to maintain sustainable development and utilization of water resources. Secondly, establish standards and classification for various uses of water in terms of quality and quantity for different scenarios including limit and ranges for desirable and permissible level. Thirdly, establish procedures and mechanisms for all action that are detrimental to water resources including waste discharge, source development and catchments management as well as conduct an integrated watershed conservation works together with the concerned bodies by identifying subsidiary watershed in which water system /scheme had been built or intended to be built and ensure environmental impact assessment for all water resource projects (MoWR, 2002).

2.6 Climate change

In the African tropics, the climate is characterized by large inter annual to centennial variability in rainfall, river flow regimes and lake level (Dagnachew Legesse, 2002), that have enormous socio-economic impact. East Africa is a region of extremely complex meteorological and climatological phenomena and coupling-mechanisms, possibly one of the most complicated of the continent. Since closed catchment basins are susceptible to local variations in evaporation and precipitation, the interpretation of past lake levels is a common method to assess prehistoric regional fluctuations in climate (Anna, 2006).

Being one of the very sensitive sectors, climate change can cause significant impacts on water resources by resulting changes in the hydrological cycle. The change on temperature and precipitation components of the cycle can have a direct consequence on the quantity of evapotranspiration component, and on both quality and quantity of the runoff component. Consequently, the spatial and temporal water resource availability, or in general the water balance, can be significantly affected, which clearly amplifies its impact on sectors like agriculture, industry and urban development (Kinfe Hailemariam, 1999).

3. MATERIALS AND METHODS

3.1 Description of the study area

3.1.1 Location and Topography

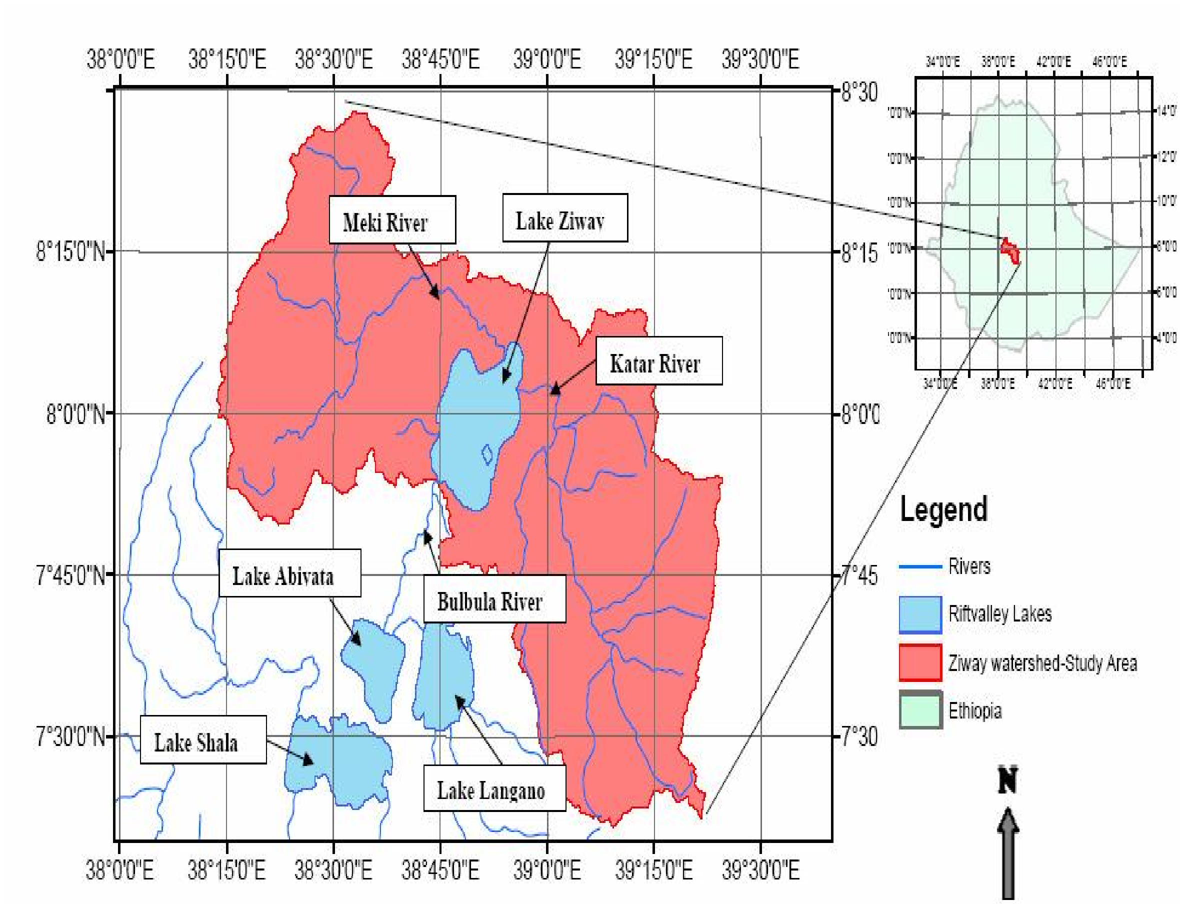


Fig 2 General Location Map of the Study area

The CRL in Ethiopia is situated between approximately, 38°15'E and 7°10'S to 8°30'S, at 100 kms south of Addis Ababa. In particular Lake Abiyata is located at approximately 30 kms south-south-west of Lake Ziway (Hengsdijk *et al*., 2007) and Lake Abiyata is situated at an altitude of approximately 1578 m a.s.l, the approximate coordinates are 7°35'N and 38°35'E.

3.1.3 Geology and Soil

Most of the CRL region is covered by volcanic rocks that mainly consist of ignimbrites, basalts and rhyolites (Tesfaye Chernet, 1982). On the rift floor, lacustrine sediments derived from the rift escarpments are found around the lakes.

The rift formation is associated with extensive volcanism where various volcanic products such as fissured basaltic lava flows alternating with volcano-clastic deposits are found in many places. With the exception of some patchy Precambrian outcrops to the south and north edge, the geological and morphological features of the CRL are the results of Cenozoic volcano-tectonic and sedimentation process (Tenalem Ayenew, 2002a).

Three main types of soils are observed in the study area: Sandy soils, lateritic clay soils and dark clay soils. Sandy and Sility Soils cover a large part of the area than clay soils. Sandy soils occur around the lakes. They are derived from ignimbrites, unwelded Pumiceous Pyroclastics and some coarse beds of lacustrine sediments (Halcrow, 2007).

3.1.4Climate

Lake Ziway and Lake Abiyata are both located in mid-altitude regions of the sub-tropical (monsoon) agro-climatic zone. The rainfall pattern is largely influenced by the annual oscillation of the inter-tropical convergence zone, which results in warm, wet summers (with most of the rainfall occurring from June to September) and dry, cold and windy winters.
Mean annual rainfall varies in the valley from approximately 500 mm (weather station at Lake Langano) and 650 mm (weather station Lake Ziway) to 1150 mm on the plateau. According to Tamiru Alemayehu *et al*., (2006), there is no clear trend (increase or decrease) in rainfall characteristics in the region during the last 40 years (Tamiru Alemayehu *et al*., 2006). The mean annual temperature in the highlands is approximately 15^0C and 25^0C close to the lakes. Actual evapotranspiration depends on the land use and availability of water and varies between 700 and 900 mm per year (Tenalem Ayenew, 2003).

3.1.5 Population

The Human population in the CRL is estimated to be 1.5 Million with an average family size of 5.3 persons and growth rate of ± 3% (Hengsdijk *et al*, 2007). Although there is uncertainty in the size of livestock density due to the seasonality of availability of fodder while the livestock population approaches 85 thousand Tropical Livestock Units (Scholten, 2007).

3.1.6 Agriculture

The Rift Valley Lakes Basin (RVLB) is primarily an agricultural basin and agriculture will continue to be an important part of the economy. Related sectors of livestock and industry based on processing of agricultural and livestock products will also be of importance. Most of the agriculture in the RVLB is subsistence and rain fed farming. There is a strong correlation between GDP and annual rainfall in Ethiopia and this will continue unless changes are made in the approach to agriculture. Water can be made to contribute to the national economy through the development of the country's water resources and expanding irrigation schemes so that agriculture production is improved by solving the problem of water shortage caused by the unpredictability of the rainfall (MoWR, 1999).

One of the factors that retard productivity is the small size of land holdings. This has been driven by population growth as land was divided and re divided among generation. There is some potential to increase the area under irrigation, but all new irrigations must be developed with caution as all water abstractions will impact the sensitive lakes of the RVLB and may not be sustainable.

3.1.7 Tourism

In Ethiopia, according to a World Bank study, tourism is the third next to coffee and oilseeds in terms of foreign earnings. RVLB encompasses natural, cultural, historical and religious tourist attractions that are currently in use. Lake Ziway provides various tourist attractions such as bird watching, fishing, boating, and churches on the island and horticulture.

The Abiyata - Shalla Lakes National Park was established in 1970 and covers a total area of 887 km^2 of which 405 km^2 land and 482 km^2 is water. There are now dozens of villages inside the park territory and there are other major threats, including environmental degradation most evident in vegetation and wildlife decline, increasing livestock numbers, the massive water level decline of Lake Abiyata, which has resulted in the loss of fish stocks, declining in water fowl numbers, plus sand extraction and a soda ash factory, all within the park. So it is at a critical stage as a national park as its watershed deteriorates and damage to its ecology worsens (Halcrow, 2007).

3.1.8 Hydrology

The Ziway-Abiyata catchment basin covering some 5610 km^2 (Dagnachew Legesse *et al*., 2004), is a closed basin that includes Lake Ziway which contains fresh water and Lake Abiyata saline and a terminal lake of the catchment. The major incoming rivers in this basin are the Ketar River and Meki River. The former discharges the water from the eastern and south-eastern plateaus while the later discharges the runoff from the plateau west of Lake Ziway. Both lakes are hydrologically connected, the major part of the water inflow of Lake Abiyata originated from Lake Ziway through the Bulbula River. However, considerably less water is discharged from Lake Langano to Lake Abiyata through the HoraKelo River (Dagnachew Legesse, 2002; Tamiru Alemayehu *et al.*, 2006).

This has made Lake Abiyata relatively shallow in depth which consequently made it susceptible to changes in climate and input from precipitation and discharge (Tenalem Ayenew, 2003). However, Lake Shalla and its catchment do not have a surface water connection with the other lakes in the CRL. As a closed lake, as Tenalem Ayenew, (1998) explained, the only significant water loss from Lake Abiyata is through evaporation (Tenalem Ayenew, 1998). Thus, a fluctuation in lake level and volume depicts the changes in inputs from rainfall and rivers discharges. The level of Lake Abiyata is influenced strongly by the input into Lake Ziway, which transfers water through Bulbula River. This explains why the level of Lake Abiyata falls consistently over a number of dry years and recovers during wet years. Hence, changes in Lake Abiyata should be perceived jointly with the abstraction of water for irrigation around Lake Ziway (Tenalem Ayenew, 2002a).

Table 1: Characteristics of sub catchments in the Ziway – Abiyata Catchment

Subcathment	Area (Km 2)	Gross area (including upstream catchments)
Meki	2225	2225
Ketar	3177	3117
Ziway	1848	7219
Langano	1890	1890
HoraKelo	174	2064
Bulbula	325	7574
Abiyata	693	10330
Total	10330	

Source: Hengsdijk et al, 2007

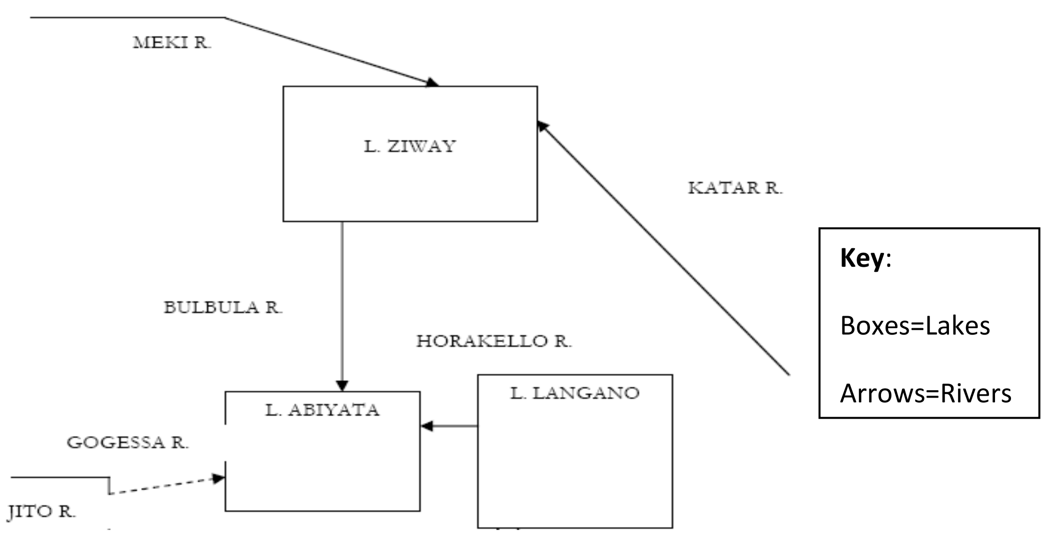


Fig 3 The schematic outline of the Ziway – Abiyata Catchment

3.1.8.1 Rivers

Meki River

Meki River originates in the highlands of Guraghe and travels a distance of about 100 km from the highlands at altitude of 3600 m to 1636 m before draining into the Lake Ziway. The total catchment area of the river near Meki town is 2433 km^2 . According to discharge data recorded near Meki town (1980-2004), average annual discharge of the river is 286.17 Mm^3 or 9.01 m^3/s. Monthly discharge of the river at Meki town station is summarized in table 2.

Table 2: Mean monthly discharge of Meki River (1980-2004) Near Meki Town

Average River Discharge (m^3/s)													Annual Volume Mm^3
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**	
0.78	1.55	4.52	6.52	5.90	7.01	18.48	32.14	19.59	8.39	2.35	0.89	9.01	286.17

Source: MoWR

The high discarge occurs during the months of August and september, while low discharge generally occurs during the dry season from December to February.

Ketar river

The catchment of the Katar River ascends to over 4000 m on the summits of Mounts Badda and Cacca. Because of the steep configuration of the Katar valley, areas suitable for irrigation are few in number and very limited in extent (Makin *et al*., 1976). The prime importance of the Katar River is the contirubution it makes to the Lake Ziway. The total catchment area of the river near Abura is 3350 km^2 . According to discharge data recorded at Abura (1980-2004), average annual discharge of the river is 389.04 Mm^3 or 12.26 m^3/s. Monthly discharge of the river at Abura station is summarized in table 3.

Table 3: Monthly discharge of Ketar River (1980-2004) at Abura

Average River Discharge (m^3/s)													Annual Volume Mm^3
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
1.91	2.62	3.28	6.24	5.35	6.59	17.17	50.30	32.90	14.47	3.85	2.40	12.26	389.08

Source: MoWR

Bulbulla River

Bulbula River descends some 58 m over a distance of 30 km between Lake Ziway and Abiyata. The level of this river for the first 6 km of its length is virtually the same as that of Lake Ziway due to a lava rock sill which effectively controls the level of the lake which is 1635.58 m a.s.l. Except periodically during the wet season the flow in Bulbula River usually derives entirely from Lake Ziway. Whenever the level of Lake Ziway falls below that of the controlling sill, the Bulbulla River dries up (WWDSE, 2008). According to discharge data recorded at Adamitulu (1980-2004), average annual discharge of the river is 168.07 Mm^3 or 5.32 m^3/s. Monthly discharge of the river at Adamitulu station is summarized in table 4.

Table 4: Mean monthly discharge of Bulbula River (1980-2004) at Adamitulu

Average River Discharge (m^3/s)													Annual Volume Mm^3
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
4.49	2.65	1.35	1.16	1.00	1.04	1.73	5.00	12.47	14.19	10.82	7.90	5.32	168.07

Source: MoWR

HoraKelo River

HoraKelo River is an outflow from Lake Langano and it connects the lake with the nearby terminal Lake Abiyata through its discharge. There is no development activity which is held depending on the River due to the quality of the water, which is unsuitable for agriculture. According to discharge data recorded near Langano (1980-2004), average annual discharge of the river is 23.73 Mm^3 or 0.75 m^3/s. Monthly discharge of the river at Langano station is summarized in table 5.

Table 5: Mean monthly discharge of HoraKelo River (1980-2004) at Langano

Average River Discharge (m^3/s)													Annual Volume Mm^3
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year	
0.55	0.33	0.18	0.13	0.11	0.14	0.26	0.79	1.61	2.22	1.70	1.00	0.75	23.73

Source: MoWR

3.1.8.2 Lakes

Lake Abiyata

The surface area of Lake Abiyata approximately is about 20500 ha. The maximum depth of the lake is 13 m, while the average depth is 7.6 m. The volume of the lake is approximately 750 Mm^3 (Hengsdijk and Herco, 2006b). It is drained by the Bulbula and HoraKelo Rivers which are the out flow of Ziway and Langano lakes respectively. The level of the lake has decreased after 1985, when water abstractions and land use changes increased dramatically (Tenalem Ayenew, 2004). Fig 4 also shows the hydrograph of the lake and the declining trend in the water level of the Lake for the year 1980-2004.

Lake Abiyata being a terminal lake with no outflow of water (and assuming that ground-water flow away from the lake is negligible), the inflow and the surface evaporation must in the long term balance (Makin *et al.*, 1976). Table 6 and Table 7 show the periodical size change of Lake Abiyata and the mean monthly lake level of the lake respectively.

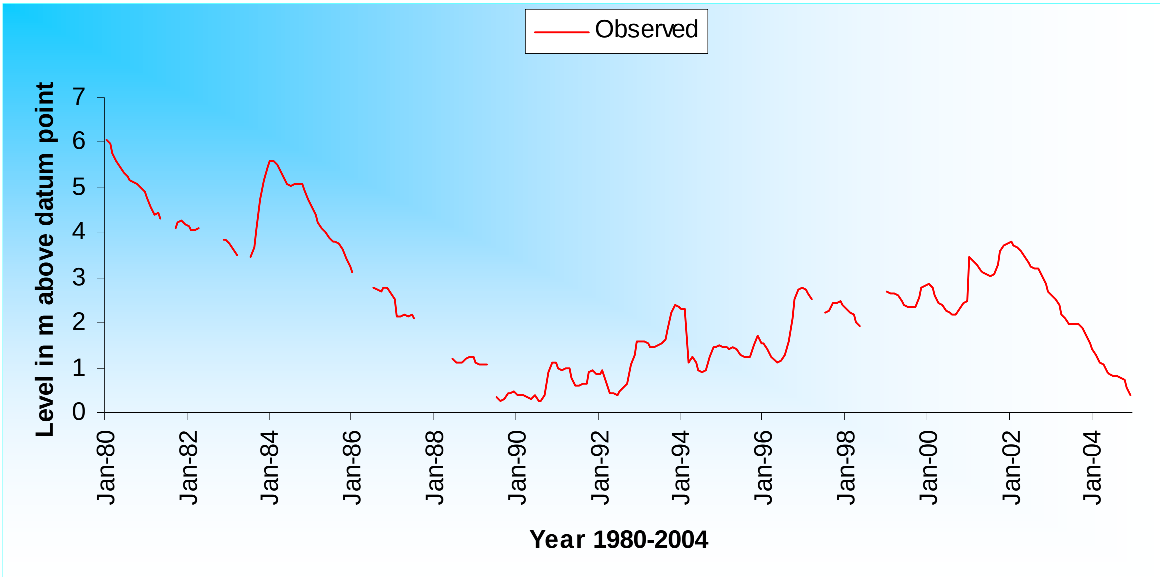


Fig 4 Abiyata lake level for the existing condition   Elevation of Zero on staff gauges: - 1576.4 m a.s.l Source: MoWR

Table 6: Change of the size of Lake Abiyata

Year	Size of Lake Abiyata(Km^2)
1973	194
1986	162
1999	163
2006	95

Source: (Hengsdijk et al., 2007)

Table 7: Mean monthly lake level of Abiyata (1980-2004) Nr Arore

Mean lake level of Abiyata in m												
Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
2.69	2.59	2.45	2.33	2.21	1.99	2.00	2.02	2.20	2.37	2.53	2.50	2.32

Source: MoWR

Fig 5 Lake Abiyata's shoreline showing the recessed area

Lake Ziway

Lake Ziway can be compared to a shallow saucer. It has an average surface level of 1636 m a.s.l. the lake covers an area of some 450 km^2 and has a maximum depth of 8 m and an average depth of 2.5 m. The main water source for the lake is the flows of Katar and Meki Rivers. The total catchment area of Ziway lake is about 7380 km^2 . Apart form the Meki and the Katar, Lake Ziway has its own catchment covering about 1700 $km^{2.}$ Although the lake catchment has no perennial rivers as such, there are several mineralised springs around the lakeshore and there may be a significnat groundwater flow towards the lake. The inflow plus the rain fall on the lake surface exceeds evaporation, thus giving rise to the Bulbula River outflow. The lake level record shows marked variations. These variations have had a striking impact on flows in Bulbula River; consequently, there is a close correlation between level of the lake and that of the Bulbula River. The mean monthly lake water level recorded and the hydrograph of the lake are shown in table 8 and Fig 7 respectively.

Fig 6 Boating activity for tourists at the Ziway Lake

Table 8: Mean monthly lake level of Ziway (1980-2004) Nr Bochesa

Average lake level of Ziway in m												
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Year**
1.08	0.96	0.86	0.81	0.76	0.73	0.82	1.17	1.47	1.53	1.39	1.25	1.07

Source: MoWR

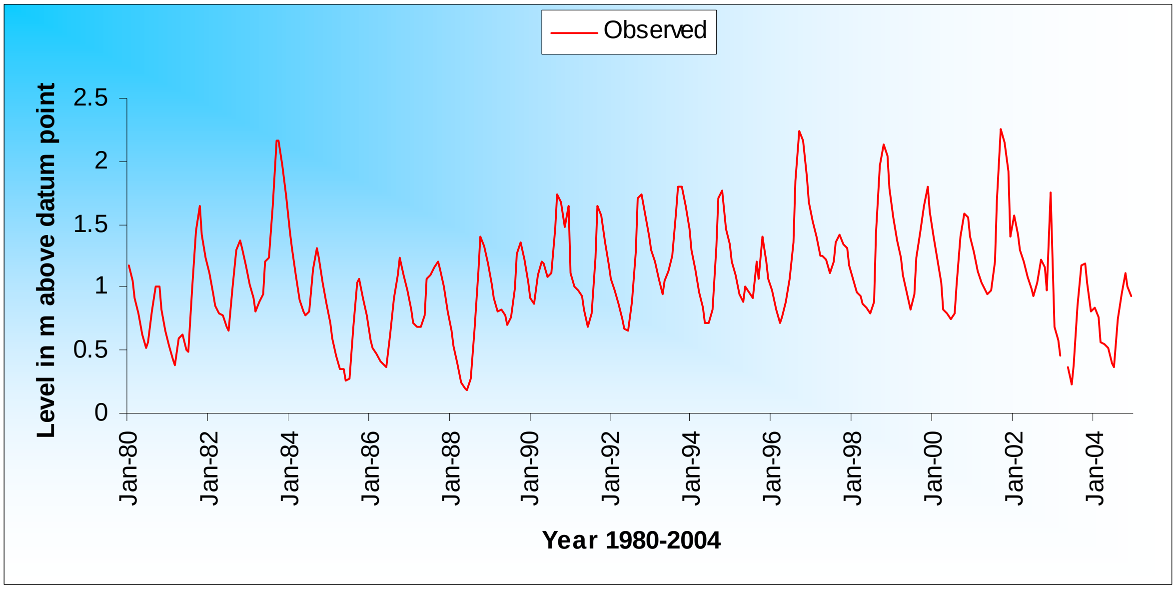


Fig 7 Hydrographs of Lake Ziway .Elevation of Zero on staff gauge: - 1635.1 m .a.s.l. Source MoWR

3.2 Future development Scenarios

The future water resource availability in the Ziway-Abiyata catchments is dependent on changes to the climate and hydrology in the basin, changes in environmental and human demands for water and changes in water resource management practices. Climatic and hydrological changes may occur due to climate change and land use change. Environmental and human demands may change due to specification of minimum flow requirements, water level requirements, irrigation development, increases in domestic water supply requirements (due to population increase) and increases in industrial demands (due to economic development).

These changes are evaluated through developing a set of 'future scenarios' over the presiding years. In the study area there are few development interventions which are planned for the future that include new irrigable areas around Lake Ziway and its upstream catchment area using Meki River as a source.

3.2.1 Planned irrigation schemes

According to the ongoing master plan some 56 potentially small, medium and large scale irrigation development areas have been identified in the RVLB as a whole most are based on either dam storage or river diversion. Further study is required on all of these; not all will prove viable, either on economic basis or due to other constraints such as water, or social and ethnic difficulties. However, this indicates that there is potential for irrigation development. One of the major irrigation plans in the study includes the Ziway Pressurized Irrigation Project to develop up to 15,500 ha of irrigation based on pumping directly from Lake Ziway (Halcrow, 2007; WWDSE, 2008).

3.2.2 Domestic water supply for Bulbula town

One of the basic needs of people on the study area is water supply. In the past thirty to forty years various water development activities have been underway by government, non-government organizations (NGOs) and communities to meet the need. Given the high investment cost of water scheme and the shortage to near water source, combined with the poor water quality of the available sources in some parts, it has impeded the full access of the public in the area for water supply schemes as in most part of the country and the region as a whole. The Bulbula town domestic water supply is intended to provide water for 5000 people, 90 lpcd (liters per day per capital) by abstracting water from Bulbula River (WWDSE, 2008).

3.2.3 Abijata Soda Ash Enterprise expansion

Abijata Soda Ash Enterprise stated its first phase of production operation by 1987 following the feasibility trails conducted during 1985/86. The production capacity of the Enterprise was also intended to eventually expand up to 200,000 and 1,000,000 tons of soda ash per year in the second and the final phase of production operation, respectively; where Lake Shalla will be used as a main source of raw water and Lake Abiyata as evaporation ponds.

In this thesis only a hypothetical expansion of 50000 tons per year is considered as the only water abstraction directly from the Lake Abiyata as it has been used in the Ziway Pressurized Irrigation Project (WWDSE, 2008). The consideration of Lake Shalla is out of the scope of this thesis which requires due attention and detailed environmental impact assessment.

Fig 8 Industrial activity on Lake Abiyata and pipes which uses for abstracting water

3.2.4 Dam construction on Meki River

There is also a plan for Lower Meki Irrigation Development Project: which is planned to develop a new surface irrigation area of up to 3,500 ha. This includes proposed dam site upstream from the Ziway Lake. The alternative to this development of constructing a dam is the option of using diversion weir to irrigated 2300 ha of land by abstracting water directly from the Meki River (JICA and OIDA, 2001; Halcrow, 2007).

3.3 METHODOLOGY

3.3.1 WEAP Modelling of the Ziway – Abiyata Catchment

3.3.1.1 General

Modeling has become an essential tool in modern world of water management. It is used extensively and plays an important auxiliary role in fulfilling the core tasks of water management, in policy preparation, operational water management and research, and in the collection of basic data (monitoring), among other things. Water Resources System Simulation modeling helps to understand the relationship between available water resources and the demand for those resources under existing conditions and under future development scenarios. In particular, the water resource modeling is used to identify areas of conflict caused by water scarcity.

WEAP is short for Water Evaluation And Planning System and is originally developed by the Stockholm Environment Institute at Boston, USA (SEI, 2007). It represents the system in terms of its various supply sources (e.g. rivers, creeks, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

WEAP applications generally include several steps. The study definition sets up the time frame, spatial boundary, system components and configuration of the problem. The Current Accounts, which can be viewed as a calibration step in the development of an application, provide a snapshot of the actual water demand, pollution loads, resources and supplies for the system. Scenarios built on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, costs and benefits, compatibility with environmental targets, and sensitivity to uncertainty in key variables (SEI, 2007).

3.3.2 Set up of WEAP model

WEAP consists of five main views: Schematic, Data, Results, Overviews and Notes. The schematic view indicates the configuration of the system including objects like nodes and reservoirs. The data view allows creating variables and relationships, entering assumptions and projections mathematical expressions. The result view allows detail and flexible display of all model outputs in charts and tables. On the other hand the overview highlights key indicators of the system for quick viewing. Finally the note view provides a means to document assumptions and other memorandam.

A typical stepwise approach will be followed to develop WEAP for a particular area:

(i) Create a geographic representation of the area,

(ii) Enter the data for the different supply and demand sites,

(iii) Compare results with observations and if required update data,

(iv) Define scenarios and

(v) Compare and present the results of different scenarios.

The Priority tab assigns each demand site a priority level ranging from 1 to 99. Level 1 is the highest demand priority for water in the system and is assigned to all municipal users. This means that WEAP will try to satisfy all the demands at this level before any other level of priority demand. The model uses these priority levels when allocating water for the demand sites. The model will deliver water to all the level one priority sites and, if there is any water remaining in the system, it will then deliver water to the remaining priority levels.

The operation of reservoirs is decided according to pre-defined operating rules for each reservoir. Such operation rules are approximation of reality and divide the reservoirs into water level-related Zones. Fig 10 shows Zoning of reservoir storage. The water lying above the full supply level is taken as the Flood Control Zone and cannot be stored. In the next zone, the Conservation Zone, water is used as required to meet demand. In the next zone down, the Buffer Zone, some restrictions are applied so that the water is not used too quickly. Below the “dead storage level” in the Inactive Zone it is not possible to use the water other than to satisfy evaporation and seepage losses from the reservoir.

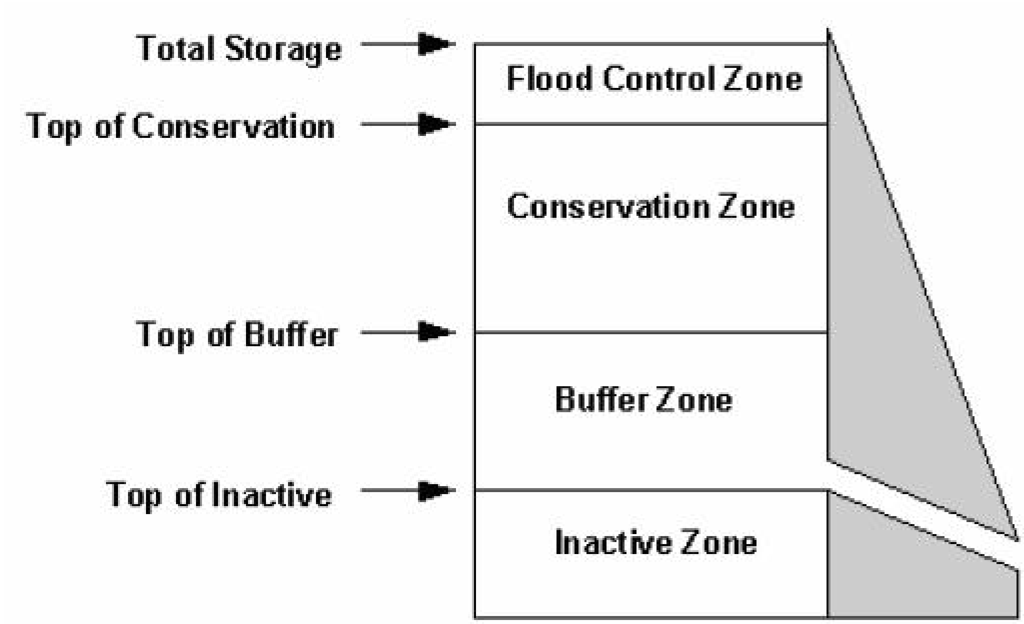


Fig 9 Zoning of reservoir Storage under WEAP

3.3.3 Configuration of WEAP model to Ziway – Abiyata Catchment

In the schematic part of WEAP the watershed is delineated, rivers, demand sites and reservoirs are specified. GIS maps of rivers and lake are used to determine the exact location of the streams in WEAP. Within the WEAP software, natural lakes are schematized as reservoirs. Importantly, these features act as storage within the model and also as local sites of evaporation losses. The two lakes in the model, Ziway and Abiyata were schematized in this approach. The total inflows to Lake Ziway which are Meki and Ketar rivers enter as head water. In addition to these the inflows from un gauged catchments to the lake is also configured as a river system with head water flow. Out flow of Ziway lake which is Bulbula River is configured as minimum flow requirement with highest priority in order to ensure its flow to Lake Abiyata. In the same way the total inflows to Lake Abiyata which are Bulbula and Horakelo Rivers were configured including un gauged catchment flows. It is also important to note that the model does not include spill flow from the river Gogessa into Lake Abiyata which flows to Lake Abiyata in years of excess rainfall for two reasons, one its contribution to the lake is very small which is about $10Mm^3$, (MoWR) and secondly the station for this river has been abandoned and have a few years of recorded discharge.

Demands from the surface water in the study area are amalgamated into seven groups for setting up of the model. The irrigation areas were lumped together based on the water abstraction sources, the demand sites which are included in the schematics are:

- **Meki irrigation** for all irrigations which abstract water from Meki River as the water source.
- **Ketar irrigation** for all irrigations which abstract water from Ketar River as the water source.
- **Bulbula irrigation** for all irrigation which abstract water from Bulbula River as the water source.
- **Ziway irrigation** for all irrigations which abstract water from Lake Ziway as the water source.
- **Sher Ethiopia irrigation.** Since water requirement for this site is different from others it is treated individually even if it abstracts water from Lake Ziway as its water source.
- **Ziway domestic water supply** which abstracts water from Ziway Lake.
- **Abijata Soda Ash Enterprise** which abstracts water from Lake Abiyata.

Return flows from irrigation sites were configured downstream of the sources. However return flow from domestic water supply was not included since the quantity is insignificant it is preferred to overlook. There is no water returned from Abijata Soda Ash Enterprise to the lake, due to this reason it is not included in the configuration.

There is no significant livestock demand on the surface water network of the study area which was identified in previous works. The livestock demand for water is met from groundwater and surface water springs owing to this reason it is not included in the modeling (Halcrow, 2007). Fig 10 shows the schematic of the WEAP model of the study area for the existing condition.

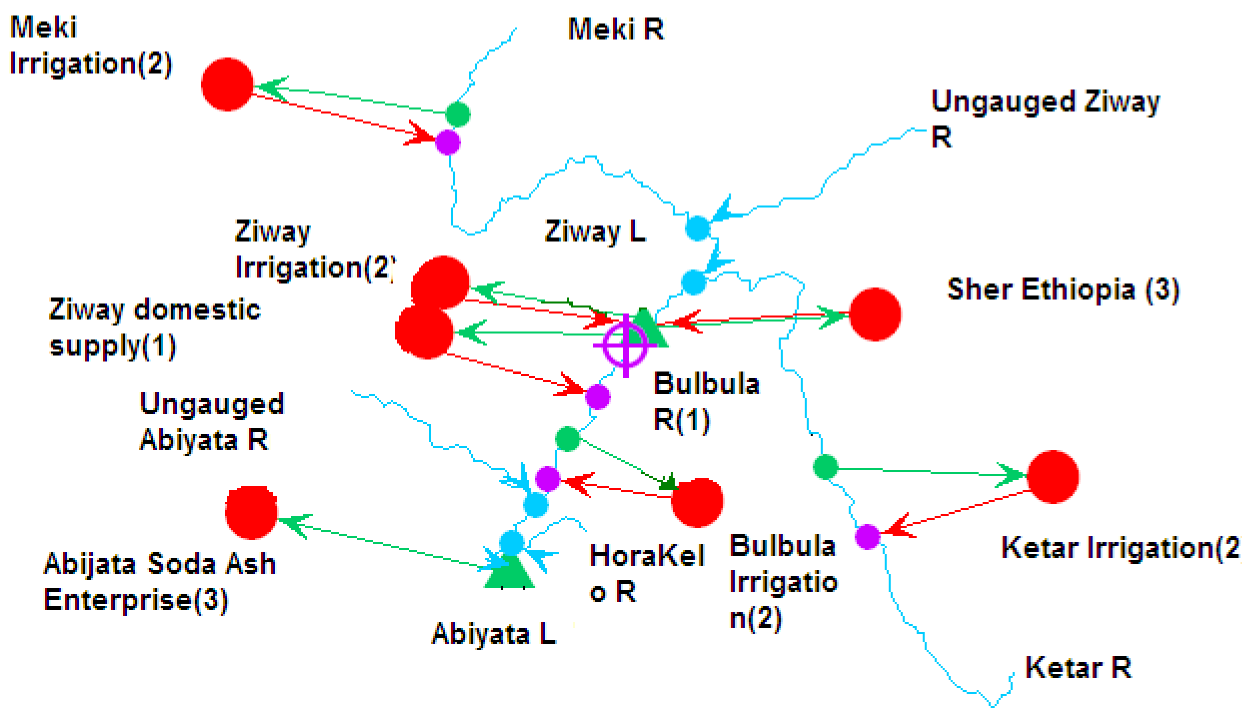


Fig 10 Schematic part of the WEAP model for Ziway-Abiyata Catchment for the baseline situation

3.3.4 Input Data to WEAP

The WEAP input data refers to the data that was integrated and used for the software "WEAP". The model was based on long term average conditions using monthly mean values of river flow, rainfall, open water evaporation and water demands for existing users (Irrigation schemes, water supply demands and industrial demand for the Abijata Soda Ash Enterprise on Lake Abiyata) from 1980 to 2004 for the 25 years period (see Annex I).

The water balance model was first run for the natural environment that is without water demands, and calibrated to achieve no net change in lake levels. The model was re-run to assess the long term water resource availability of the whole lakes system, by incorporating the estimates of existing water demand. Since it is very difficult to get ready made data for this research work the data were gathered from different sources. The major ones are:

1. Ministry of Water Resources (MoWR).
2. National Metrological Services Agency (NMSA).
3. Oromiya Irrigation Development Authority (OIDA)
4. Oromiya Water Resources Bureau (OWRB).
5. Water Work Design and Supervision Enterprise (WWDSE)
6. Abiyata Soda Ash Enterprise
7. The ongoing master plan study on the study area (Halcrow, 2007) and other relevant studies on the area like Meki Irrigation and Rural Development Project in Oromiya Region and Ethiopia (JICA and OIDA, 2001), the study on the capacity building programs for community based irrigation development in Central Oromiya region of Ethiopia (JICA and OIDA, 2004), Water Resources Utilization Study in Ziway Abiyata Lake System (OWRB, 2006) and Ziway Irrigation project Feasibility study (WWDSE, 2008) etc.

3.3.4.1 Hydrological and Climatic data

Monthly river flow data and lake level data were obtained from the Hydrology department of the MoWR for all stations within the Ziway-Abiyata Catchment. Since the data which were collected from the agency have some missing values (5% for Meki, 3.3% for Ketar, 8% For Bulbula and 5% for HoraKelo) this data gaps were in filled using the SPSS (Statistical Package for the Social Science, Version 15) software and the linear interpolation method was used to infill the gaps. Appropriate statistical procedures were implemented to check the quality of the data used and it’s found appropriate for the purpose.

The inflow data to the ungauged catchments for both lakes were taken directly from Ziway Irrigation Project Final Feasibility Report, (WWDSE, 2008) and quality checkup was made and it is also acceptable.

The lake level data of Abiyata (13% missing values) has poor quality because the stage datum point is not clearly confirmed by the MoWR Hydrology Department. As the water balance of the lake is under study, complete information was not available and, therefore, data from the feasibility study of the Ziway pressurized irrigation project (WWDSE, 2008) were used for the study. The capacity elevation curve for Lake Abiyata including the reference point is taken from the Feasibility study for Ziway Pressurized Irrigation Project (WWDSE, 2008). However, the data for the water balance of Lake Ziway is taken from the MoWR and it has full information needed for the model (see Annex I).

Meteorological data which were needed for the two lakes were collected from NMSA the rainfall data for Lake Abiyata and Lake Ziway while the areal rainfall data for Lake Ziway is used from the feasibility study with appropriate data checkup. The rainfall data for Lake Abiyata is incomplete and as recommended by the experts from the NMSA the gap was filled by using data from the rainfall station of Bulbula for the reason that the two areas are found in the same elevation and categorized in same climatic zones. The output of the software necessitates considering these gaps into concern when interpreting the results. Reservoir Evaporation is the monthly evaporation rate, and it accounts for the difference between evaporation and precipitation on the reservoir surface. Open water evaporation data were taken from the estimates of previous studies (see Annex I).

3.3.4.2 Water Demands

The assesement of the water abstractions refers to direct abstractions from surface water and it doesn't include abstractions from ground water resource and water use from rainfall. The irrigation demands were gathered from different studies on the area and relevant agencies. The identified sites were included in the model not as individual demands rather as lumped demands in order to facilitate easy configuration on the schematics, however it might lower the flexibility in modeling how each irrigation site may make demands on the surface water network according to its particular cropping pattern.

The only domestic water supply sites in which water abstracted from the surface water network is the Ziway city domestic supply for 40000 people. The only further additional industrial demand abstraction of surface water was identified as the Soda Ash factory on Lake Abiyata. The visit to Abijata Soda Ash Enterprise on January in order to gather abstraction data was not successful. However, according to the administrative officials of the factory, 15000 tons of Soda Ash is produced per year and for each tone 150 m^3 of water is abstracted (personal communication). This informal data were found to be supported by other pertinent study documents as well.

Since WEAP model requires priority set up for the demand sites included in the modeling the levels of priority were given based on the water resource policy and water sector strategies (MoWR, 1999 ; MoWR, 2002) and by referring to other studies which used the same model (Amani, 2004; Robert and Matthew, 2007). Table 9 shows how the priority to the study area was assigned to the demands.

Table 9: Assigned Priority Levels for the Ziway-Abiyata Catchment

Demand Type	Priority Level
Municipal	1
Abiyata Soda Ash Enterprise	3
Irrigation on the base line scenario	2
Flower farming	3

In this study the return flow from irrigation schemes were assumed to be 20 percent which re-enters the system where the rest 80 percent is assumed to be lost from the system. This value is used based on previous studies which estimated the return flows on this study area which is implicated to be semi arid and hence most of the water from the area lost due to evaporation before it re-enters the system (Halcrow, 2007; WWDSE, 2008).

Gross water requirement and estimated monthly water requirement were obtained from the Feasibility study for Ziway Pressurized Irrigation (WWDSE, 2008), which is given in Table 10. Irrigated area water requirement estimation for the 2004 condition is given in Table 11. It was very difficult to get the irrigation data even from the entitled agency due to lack of compiled data.

Table 10: Estimate of unit gross water abstraction

	Jan	Feb	Mar	Apr	May	Jun	Ju	Au	Sep	Oct	Nov	Dec	Annual rate(m^3/ha)
Meki VGT (Two cropping)	.112	.132	.146	.16	.104	.015	0	0	.002	.106	.112	.112	12087
Ketar	.112	.132	.146	.16	.104	.015	0	0	.002	.106	.112	.112	11483
Lake Ziway/ Bulbula	.112	.132	.146	.16	.104	.015	0	0	.002	.106	.112	.112	12691
Sher Flower	.083	.083	.083	.083	.083	.083	.083	.083	.083	.083	.083	.083	14600

Table 11: Existing irrigation schemes in the Ziway-Abiyata catchment water demand

Irrigation Scheme	Irrigation area in 2004 (ha)	Annual gross water requirement (Mm^3)	Net water requirement (Mm^3)
Meki Irrigation	397	4.8	3.84
Ketar Irrigation	580	6.66	5.36
Bulbula Irrigation	943	12	9.6
Ziway Irrigation	571	13.6	10.88
Sher Ethiopia flower farm	500	7.3	5.84
Total	**2991**	**44.36**	**35.5**

3.3.5 Model Calibration

Model calibration (parameter estimation) involves automatic and/or manual adjustment of model parameters to minimize the difference between observed and predicted values, which is called the objective function. Model validation involves testing the ability of a model to simulate the hydrologic response of a basin for conditions different from that used during the calibration period (Klemes, 1986; Dagnachew Legesse, 2002). Calibration was achieved by estimating the historic pattern of water demand and simulating the resultant flows. Calibration involved changing assumptions about the pattern of historic demand, altering demand priorities and lakes operating rules to improve the fit between simulated and observed flows. The WEAP model was calibrated using observed lake level data obtained from the MoWR for both lakes and out flow from Lake Ziway. All reservoirs were given priority 99 (i.e., the least), which meant that, at any given time, keeping the reservoirs full was of less importance than meeting demands.

3.3.5.1 Objective functions and Iterations by WEAP model

Model performance criteria where uncertain inputs, uncertain structures, uncertain initial conditions and randomness of natural systems are inherent ingredients in modeling hydrologic systems are important (Leavesley, 1994; Troutman, 1985). Similarly, data available for any specific system are incomplete and often uncertain. It is therefore a common practice to develop a model performance or validation criteria in order to test the integrity of the modeling exercise. In this study, model performance was evaluated using different techniques:

(1) Joint plots of the monthly simulated and observed hydrographs,

(2) Joint plots of the monthly simulated and observed lake levels

(3) The Nash– Sutcliffe coefficient of efficiency (R^2) based on the sequence of observed and simulated monthly over the calibration and validation periods.

The visual inspection of the joint plots helped to subjectively judge the ability of the model to simulate inter annual and seasonal variability. The regression coefficient (R^2) is the square of the Pearson product–moment correlation coefficient and describes the proportion of the total variance in the observed data that can be explained by the model.

The closer the value of R^2 to1, the higher is the agreement between the simulated and the measured flows. It is calculated using the following equation:

$$R^2 = \left[\frac{\sum_{i=1}^{N} (O_i - \bar{O})(P_i - \bar{P})}{\left[\sum_{i=1}^{N} (O_i - \bar{O})^2 \right]^{0.5} \left[\sum_{i=1}^{N} (P_i - \bar{P})^2 \right]^{0.5}} \right]^2$$

Where: N is Number of compared values, O_i is observed data, $\bar{O}$ is observed mean, P_i is simulated data, $\bar{P}$ is simulated mean.

Nash and Sutcliffe simulation efficiency, $E_{NS,}$ indicates the degree of fitness of the observed and simulated plots with the 1:1 line. It is calculated as follows with the same variables defined above:

$$E_{NS} = 1 - \frac{\sum_{i=1}^{N} (O_i - P_i)^2}{\sum_{i=1}^{N} (O_i - \bar{O})^2}$$

E_{NS} can have values ranging from $-\infty$ to 1. If the simulation is accurate, E_{NS} is equal to one. If the accuracy of the simulation results is smaller than the average value of the measured variables, then E_{NS} will have a negative value.

3.3.5.2 Calibration Approach

In this thesis many calibration approaches have been tried to fit the gap between the simulated and observed lake levels. Since the objective of calibration is tuning of model parameters based on checking results against observations to ensure the same response over time. This involves comparing the model results, generated with the use of historic meteorological data, to recorded stream flows.

According to Alamirew Dilnesaw, (2006) three types of calibration methods were distinguished: the manual trial-and-error method, automatic or numerical parameter optimization method; and a combination of both. The manual calibration is the most common and especially recommended in cases where a good graphical representation is strongly demanded for the application of more complicated models. However, it is very cumbersome, time consuming, and requires experience. For this study only the manual calibration approach was applied since the model doesn't have the other options mentioned.

The calibration approach is conducted by making use of the lakes operations rules. This is done by changing the values for Top of conservation (TOC) which is the maximum volume of water in the reservoir in each year for both Lake Ziway and Abiyata. In addition to this the ungauged flow for Lake Abiyata is neglected since the data which is estimated to the un gauged catchments of the Abiyata lake is about 40 Mm^3 /year (WWDSE, 2008) and where as in other studies the contribution of the Lake Abiyata's catchments to the lake's water is insignificant (Tenalem Ayenew, 1998; Dagnachew Legesse and Tenalem Ayenew, 2006). So it was preferred to neglect. When these changes were introduced to the model a better fit between the observed and simulated lake level is achieved. The TOC used in the modelling for both Lake Ziway and Abiyata is given on Table 12 and Table 13 respectively.

Table 12: TOC for Lake Ziway

	TOC	
Year	**Volume Mm^3**	**Level in m**
1980-1982	1624.23	1637.1
1985-1995	1624.23	1637.1
2003-2004	1624.23	1637.1
1983-1984	1777.2	1637.35
1996-2002	1777.2	1637.35

Table 13: TOC for Abiyata Lake

	TOC	
Year	**Volume Mm^3**	**Level in m**
1980-1985	1276.8	1582.4
1986-1987	1011.67	1581.4
2000-2002	1011.67	1581.4
1993-1999	887.21	1579.4
2003-2004	887.21	1579.4
1988-1992	768.17	1578.4

Fig 11 to Fig 15 gives before and after calibration results of the model out put for Lakes Abiyata, Ziway and the Bulbula flow respectively.

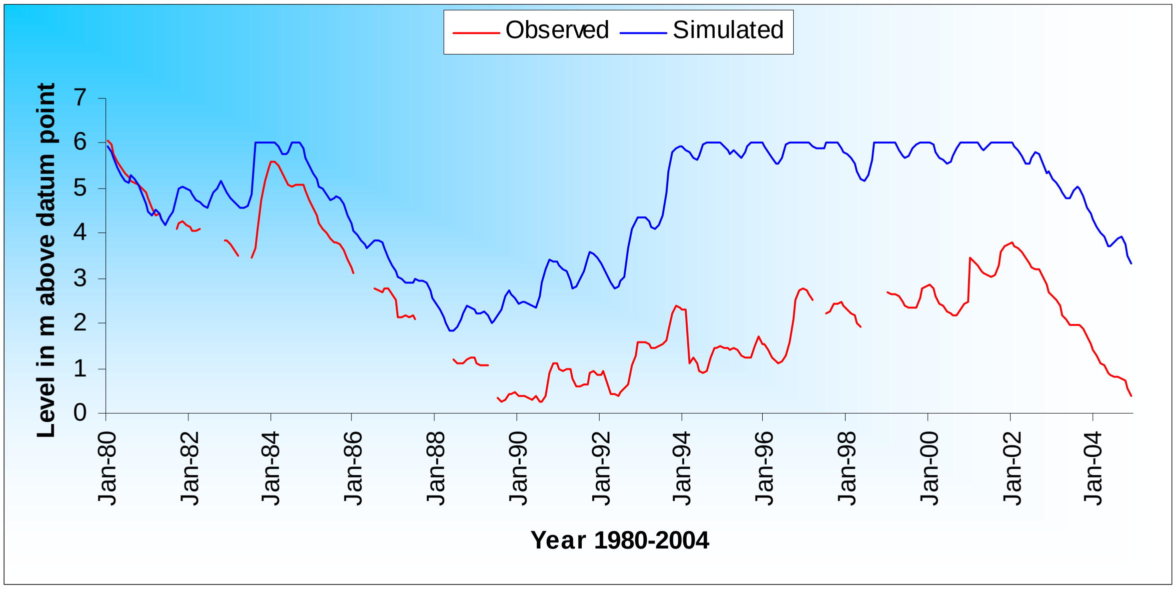


Fig 11 Simulated and Observed lake level of Lake Abiyata before calibration

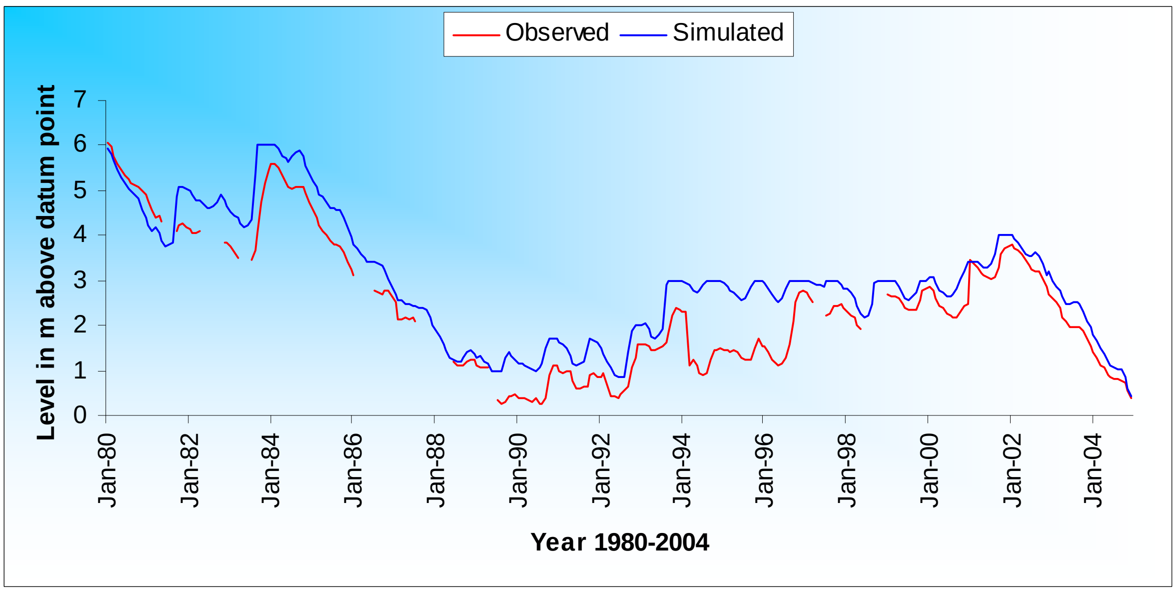


Fig 12 Observed and Simulated lake level of Abiyata Lake after calibration

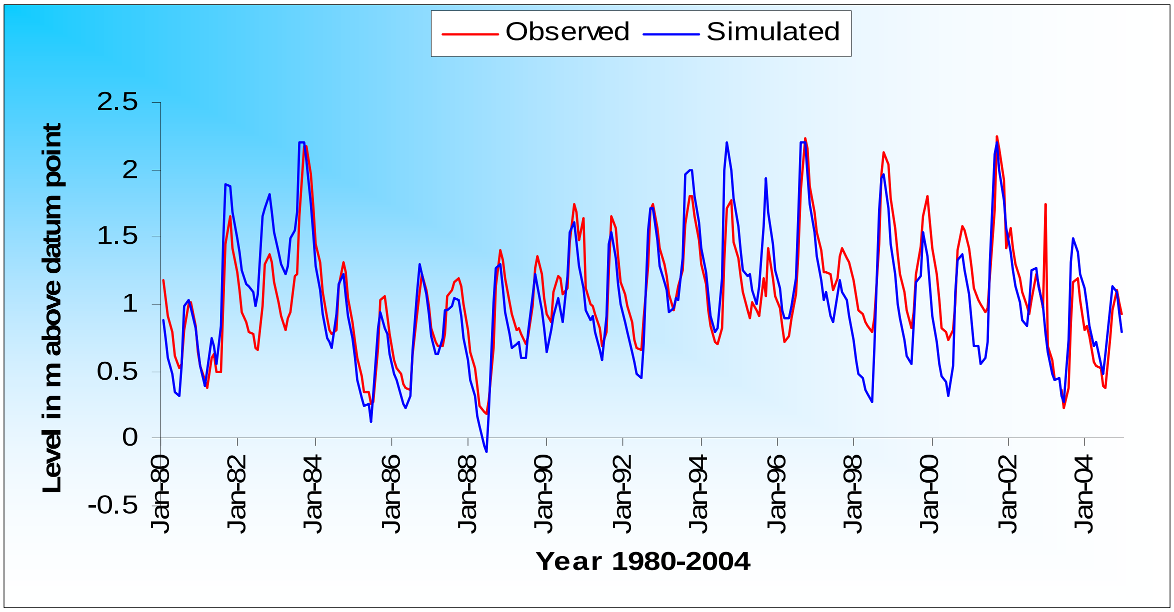


Fig 13 Observed and Simulated lake level of Ziway before calibration

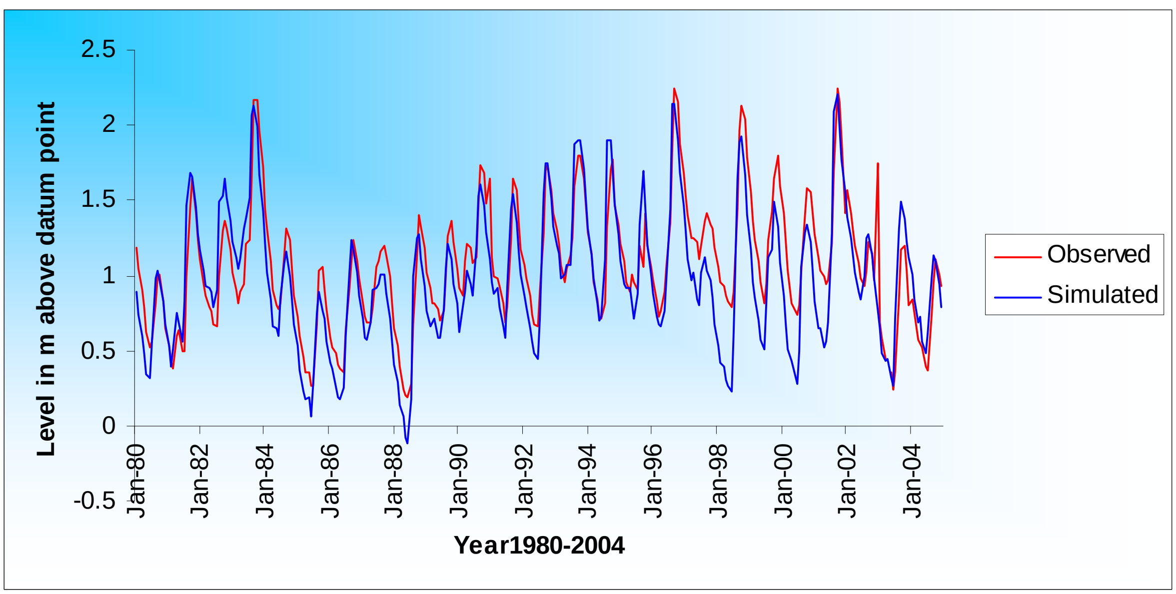


Fig 14 Observed and Simulated lake level of Ziway after calibration

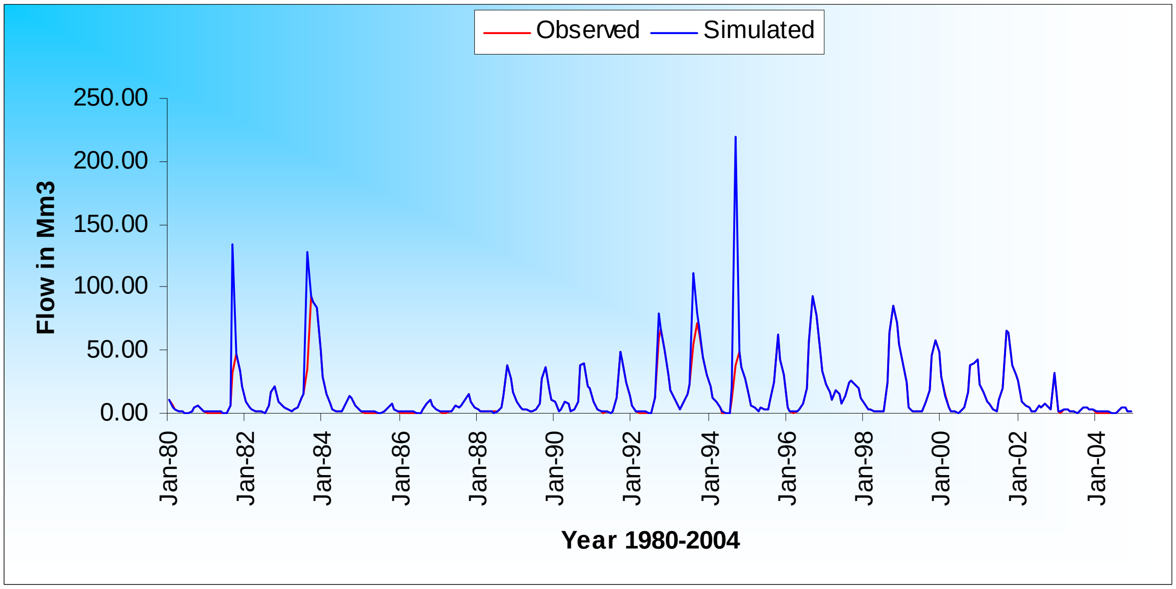


Fig 15 Observed and Simulated flow of Bulbula River (Observed Bulbulla and simulated out flow from Ziway Lake)

Besides the visual judgements undertaken the results were checked with the above mentioned objective functions equations and all the results of the model (R^2 is 0.79 and 0.65 for Ziway and Abiyata lakes respectively) are in an acceptable level.

Validation is comparison of the model outputs with an independent data set without making further adjustments. The process continues till simulation of validation-period for the lake level of both lakes confirms that the model performs satisfactorily. In the validation process, data for a period of four i.e. from 2001 to 2004 years was used in both Ziway and Abiyata lakes water levels to evaluate the model accuracy.

The statistical criteria used during the calibration procedure were also checked here to make sure that the simulated lake levels are still within the accuracy limits and it was in the acceptable level for both lakes.

3.4 DATA ANALYSIS

3.4.1 Description of water resources devlopment scenarios in Ziway – Abiyata catchment

Water sustainability assessment requires a scenario approach for taking a long wider view that considers future with fundamentally different development and environmental assumptions and policies. In WEAP the basic model was built using the real data to be used for scenario management and analysis. The reference or business as usual scenario is the base scenario that uses the actual data, to help in understanding the best estimates about the studied period. The objective of a reference scenario is to help people learn what likely could occur if current trend continue and to understand the real situation (SEI, 2007).

Reference scenarios can also be useful for identifying where knowledge is weak in analyzing likely trends and where more information needs to be collected.

In this study the basic model has been built using WEAP and it reflects the Reference scenario, which replicates the real situation. In the study area major development plans seem to concentrate on Lake Ziway and Meki River. This is due to the fact that Lake Ziway is the only major lake that has fresh water which is suitable for irrigation and with large scale irrigation potential. In addition to this fact the area is close to major market centers such as Addis Ababa and Nazret. This is underpinning the increasing private sector involvement in the environs of the lake.

Currently, a large scale pressurized irrigation scheme is planned for development around the northern rim of the lake near Meki (WWDSE, 2008). Since this lake is a multipurpose reservoir it is important to see the demands for irrigation purpose will likely change the lake regime and the catchment as a whole specially that of Lake Abiyata’s.

3.4.2 Baseline scenarios

For this scenario the existing data sets on the study area were used. These data input in WEAP is structured according to the schematic set-up of the catchment. The following classification is used:

1. Demand sites
2. Supply and resources
    a. linking demands and supply
    b. river
    c. local reservoirs
    d. return flows
    e. flow requirement

The year 1980 is chosen as the "Current Accounts" year, or base year, for this project and the entire project period is set to 1980 to 2004. The demand sites for the baseline scenarios are amalgamated into seven groups, which include:

Meki Irrigation, Ketar Irrigation, Bulbula Irrigation, Ziway Irrigation, Sher Ethiopia flower farming, Ziway domestic water supply and Abijata Soda Ash Enterprise. As it has been mentioned earlier the irrigation data for each is grouped based on their water source abstraction and lumped together as single demand site. The required data for the entire irrigation site have been gathered from the Feasibility studies, Interim reports and the ongoing master plan study.

Monthly variation and water use rate have been taken from the Ziway Irrigation Project Feasibility Report (WWDSE, 2008). The cropping pattern in this study has been taken as a diversified cropping patter due to lack of documents; the gross water abstraction is given in Table 10. The estimated monthly water abstraction for all sites is calculated based on 20% of the abstracted water is assumed to drain back to the system, through subsurface during irrigation. Table 14 gives the estimated water abstraction for the major demand sites for the year 2004.

Table 14: Estimated monthly water abstraction (2004 condition) for irrigation projects in the study area. (Mm³)

Abstraction Type	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Meki River Irrigation Diversion	0.54	0.63	0.70	0.77	0.50	0.07	0	0	0.01	0.51	0.54	0.54	4.80
Ketar River Irrigation Diversion	0.75	0.88	0.97	1.07	0.69	0.10	0	0	0.01	0.71	0.75	0.75	6.67
Ziway Lake Pumped Irrigation	1.52	1.80	2.00	2.20	1.41	0.20	0	0	0.03	1.44	1.52	1.52	13.60
Bulbula River Irrigation Diversion	1.34	1.58	1.75	1.92	1.24	0.18	0	0	0.02	1.27	1.34	1.34	11.98
Ziway Sher Flower pumped Irrigation	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	0.61	7.30
Ziway Lake pumped water supply	.11	.11	.11	.11	.11	.11	.1	.1	.11	.11	.11	.11	1.32
Lake Abiyata Soda Ash Diversion for producing 15000 tons/ year	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	0.19	2.25
Total	**5.18**	**5.92**	**6.44**	**6.95**	**4.88**	**1.59**	**1.03**	**1.03**	**1.10**	**4.95**	**5.18**	**5.18**	**48.00**

3.4.3 Ongoing and feasibility stage scenarios (SN1)

This section has included development plans which are at their feasibility and ongoing stages. The development scenarios which are incorporated in this section are: First the 15500 ha pressurized irrigation project which is at feasibility and detailed design study (WWDSE, 2008). However, in the study the whole proposed area is not planned to be implemented at once while it is intended to take all the area at once without considering the different phases in order to see the cumulative effect. Secondly, Sher Ethiopia Flower farm expansion plan to increase 500 ha of land which is already given to the farm is included (Halcrow, 2007). Thirdly the expansion plan of the Abiyata Soda Ash Enterprise to 50000 tons / year abstracting water directly from Lake Abiyata is considered and finally the domestic water supply from Bulbula River to supply for 5000 people was included in the modeling.

Hence, the schematic part of the first scenario (the Baseline) has been reconfigured in order to include the planned development schemes which are underpinned in the baseline condition. The data which are needed for this stage is obtained from different sources and most are the same as those used in the baseline scenarios. It is important to remind that, the outflow from Ziway Lake via Bulbula River is configured as minimum flow requirement which is same as the baseline scenario. This is maintained in order to assure the historical flow delivered to Lake Abiyata even in the development plans. This is also supported by the water resources policy which indicates that the environmental physical condition of the water body gets higher priority (MoWR, 1999). So in all scenarios this will be considered.

However, in order to answer what if this condition is not maintained as promised, the effects will be analyzed separately for the sake of completion. Moreover, the results will indicate important implications for the Lake Abiyata which is highly dependent on the inflow of this particular river. Assessing the problems imposed on surface water body, particularly that of lakes Ziway and Abiyata due to the planned development schemes is timely and the results may provide relevant information to concerned bodies about the future of these water bodies.

The planned Ziway pressurized irrigation project will be located in the Ziway, Dugda and Dugda Bora Weredas. The main objective of the Ziway pressurized irrigation is to ensure food security at local level and to produce industrial raw materials and export crops through development of sustainable pressurized irrigation system using water from Lake Ziway to be attained by reducing evaporation from the lake without affecting the natural flow to Lake Abiyata. The overall aim is to develop up to 15,500 ha of pressurized irrigation using drip and sprinkler techniques based on pumping directly from Lake Ziway.

Finally, the priorities which is specified in the baseline scenario is altered and for all it is assigned the baseline plus one level up which decrease the priority by one from the baseline. However the priority given to the Bulbula domestic water supply is the highest.

3.4.4 Pre- feasibility and identified stage scenario (SN2 & SN3)

Due to the location and topographic conditions of the area Lake Ziway has a potential for irrigation development technically both by pumping the lake water as of the previous scenario (SN1) and also by damming the Meki river at a distance about 20 to 25 kms upstream its confluence with the lake. Dams have long served Ethiopia, principally for irrigation and for hydropower. Many dams provide a multitude of benefits. However, careful planning is required to ensure that such developments are both appropriate and reasonably sustainable. The Water Resources Development Master Plan for Ethiopia study was carried out by Water and Power Consultancy Services (WAPCOS 1990) and the master plan identified six projects, all with storage dams, for the RVLB; one of the identified site is on Meki River. At that time the identified site for Meki is planned to irrigate 25000 ha of land. Currently the Meki Ziway Irrigation project by JICA and OIDA and the Ongoing Master Plan for the RVLB also identified a dam site on the gorges of the Meki River (JICA and OIDA, 2001; Halcrow, 2007).

The Meki River flows through a gorge north of the village of Dugda. A dam could be constructed within the gorge to provide irrigation water to land to the east which lies within Oromiya Regional State. The proposed dam site is located 48 kms upstream from Lake Ziway, which will have a Storage capacity of 170 Mm^3 and Dead storage of 25 Mm3. The height of the gorge appeared to be approximately 40 m. The reservoir formed by the dam would lie within SNNPRS. The catchment area at the dam site is approximately 1690 km^2 and the mean annual flow is estimated as $7.8 m^3/s$. The stage-storage curve is given in Annex I. The dam would provide head and seasonal storage to serve irrigation and possibly hydropower purposes.

There have been two alternatives which have been identified on the Meki River. These include dam construction as mentioned earlier or diversion weir. The two alternatives are proposed to irrigate a new agricultural land on Meki area using Meki River as a source. The two options were treated individually since either of the two is implemented and their results with respect to their effect on both lakes will be discussed. In this section the dam construction on the Meki River gorge is considered as SN2 scenario. The construction of dam is to irrigate 3500 ha of new area in Meki. For this a cropping intensity of 195% is considered. The alternative given for the diversion weir to irrigate 2300 ha of land by using Meki River will be considered as SN3 scenario. A cropping intensity of 105 % is considered for this option. Table 15 gives Diversion Water Requirement for the scenarios.

Table 15: Diversion Water Requirement (Mm^3/1000ha)

Cropping intensity	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
105%	0.15	0.12	0.19	0.17	0.12	0.67	0.93	1.28	2.22	1.13	0.08	0.05	7.11
195%	1.93	1.74	3.03	2.37	0.55	0.74	0.94	1.24	2.17	1.15	0.14	0.12	16.12

The scenario (SN3) includes the baseline scenario plus the SN1 and the planed 2300 ha irrigated by the Diversion Weir. The configurations in this scenario are rearranged to include the changes adapted. The priority assigned to these scenarios (SN2 and SN3) will be one level up of the SN1 which decrease the priority at this level by one and two level from the SN1 and Baseline scenarios respectively. The comparison of the two scenarios will be analyzed i.e. SN2 vs. SN3 which has less effect with regard to the lake level decrease of the two lakes. In addition to the scenarios mentioned earlier the magnitude of the effects by the Abijata Soda Ash Enterprise on the level of the lake will be undertaken as the only development on the lake without considering the new development scenarios. This will be done just to see the level of the effects which will be contributed only by the enterprise, and will help to see which activity is more significant for the lake level drop of Lake Abiyata.

4. RESULT AND DISCUSSIONS

4.1 Scenario analysis and results of WEAP model outputs

This chapter deals with the result of the scenarios. Scenario analysis aims to answer "What if…?" questions. The results were compared and linked with previous studies. In each section the output of the WEAP model will include results with priority altering for the Bulbula flow. It is important to consider the uncertainties and the assumptions which were used when interpreting the results.

4.1.1 Baseline scenarios

The baseline scenarios result will be structured and explained in terms of the following layout, and it will be followed in all the results of the scenarios in the preceding sections. The results will be explained with regard to:

- Lake level of Lake Ziway
- Out flow of Lake Ziway (Bulbula River flow)
- Lake level of Lake Abiyata

A/ The Lake level of Ziway in the Baseline Scenario.

The result for the baseline scenario revealed that the lake level of Ziway shows a variable trend. As it can be seen from Fig 16, the level in some years shows a rising while in some other a declining tendency. While since from the year 2001 to 2004 the level shows a constant decreasing trend. The maximum and minimum lake levels were recorded for the year 2001 and 1988 with a value of 1637.31 (2.21) m a.s.l and 1634 (-0.12) m a.s.l over the simulation period respectively. The mean lake level of the lake was 1636.07 (0.97 m above the datum point of 1635.1) m a.s.l.

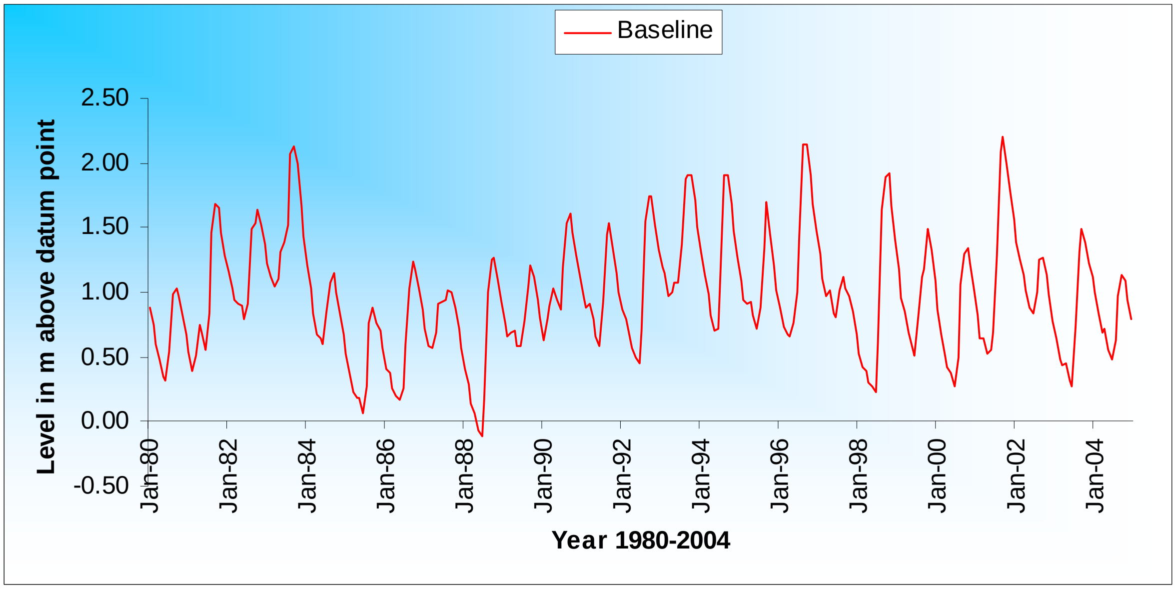


Fig 16 Simulated lake level of Ziway lake for the baseline scenario

B/ Bulbula River flow for the Baseline Scenario

The outflow of Ziway Lake through the Bulbula River is a major inflow for Abiyata Lake and at the same time the areas around the river are highly dependent on the river. Since it is the only fresh water source for its catchment surrounding the river including Abiyata lake areas, it becomes a multiuse purpose river.

Fig 17 shows the simulated flow trend of the Bulbula River which validate the fact that the flow of the river is showing a declining trend like Ziway Lake, which in turn confirms the great correlation between the two variables. Any change into Lake Ziway will directly be reflected in its outflow.

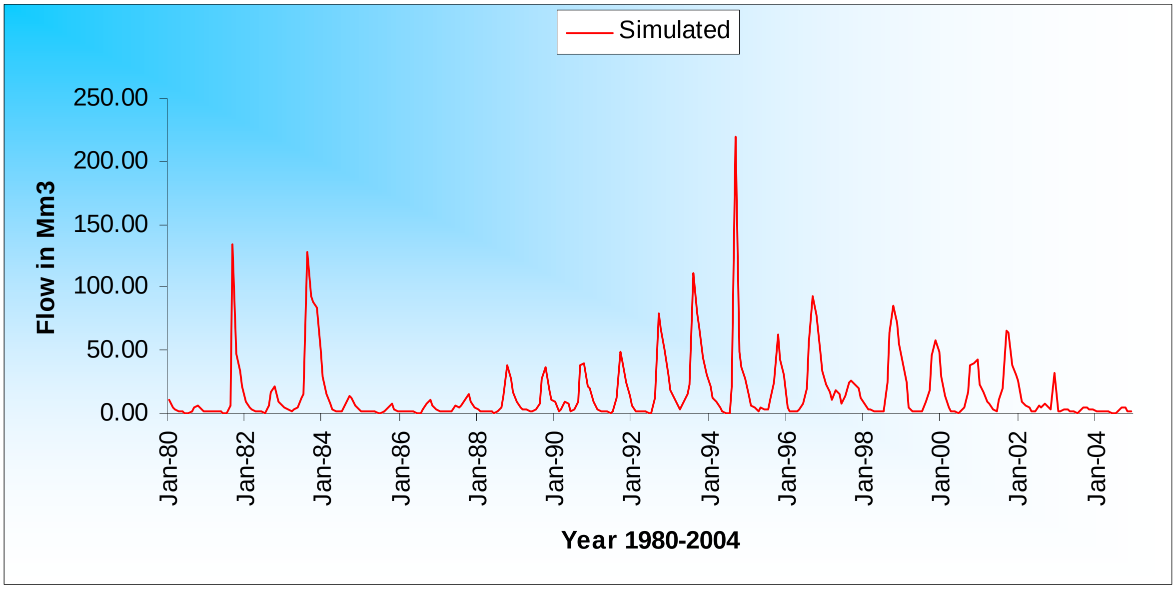


Fig 17 Simulated out flow of Ziway lake (Bulbula River flow) in baseline situation.

Additionally, the same up-and-down trend of change is observed in the flow of the River, while a decreasing trend is observed in this flow since the year 2001 like the level of Lake Ziway. It has a mean flow of 188 Mm^3 on the period of the simulation year. The maximum and minimum flows were recorded for the year 1994 and (1988, 2004) respectively. In the last two years of the simulation period the flow of the river showed a drastic decrease of about 160 Mm^3 of volume from the simulated historical mean flow. If this continues, it may result in an immense problem to Lake Abiyata.

C/ Results of Lake Abiyata for the Baseline Scenario

The lake level of Lake Abiyata as revealed from the result, showed a very extreme lake level drop with almost a constant declining trend. Fig 18 shows the baseline scenario for lake level of the Abiyata Lake.

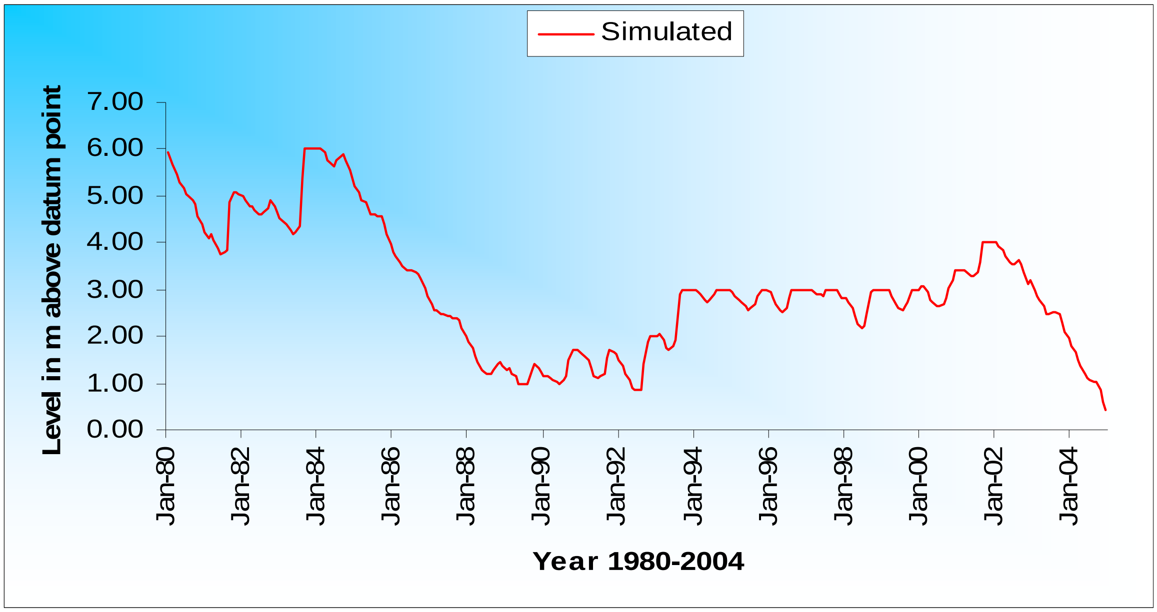


Fig 18 Simulated level of Abiyata lake for the baseline situation

The historical mean level of Abiyata Lake for the simulation period was about 3.01 m above the datum point (1576.4 m a.s.l). The maximum and minimum lake level data were simulated for the year (1983, 1984) and 2004 with values of 1982.4 (6.0) m a.s.l and 1576.82 (0.42) m a.s.l respectively. The result also revealed that there is a 4.2 m lake level drop compared with the early 80's and the last year of simulation. As it can be seen from Fig 18 a sharp lake level decrease occurred for the year 1985 to 1989 and 2001 to 2004.

4.1.2 Ongoing and feasibility stage scenarios (SN1)

For the planed and feasibility stage development scenario (SN1), the results of the model both for the highest priority (SN1) and least priority ($SN1^1$) with regard to the Bulbula River flow in the model will be presented one after the other. These two comparisons were made to identify the adverse effect of the two different conditions on the level of the lakes.

A/ The results for Lake Ziway for SN1 Scenario

The result of the model indicated a remarkable lake level drop between the existing and the SN1 condition as shown in Fig 19.

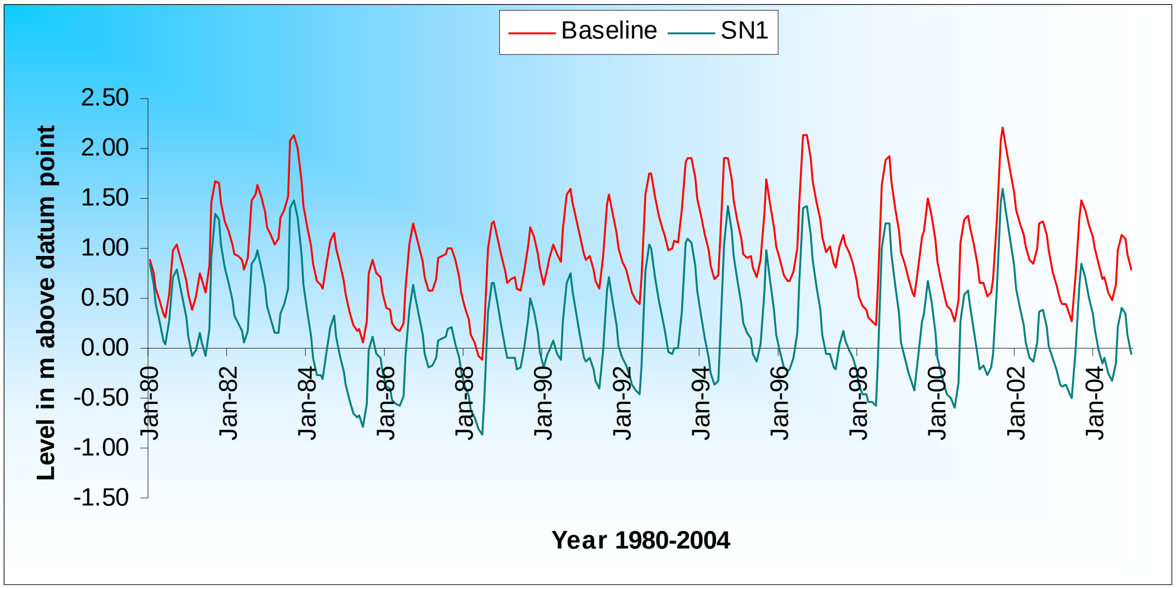


Fig 19 Simulated and SN1 lake level of Ziway lake.

The maximum lake level in the SN1 condition for the coming 25 year will be 1.59 m above datum point while in the case of the baseline it was about 2.21 m which shows a 0.62 m drop. The minimum lake level for the SN1 was 0.86 m below the datum point. When compared in terms of the mean values for the two scenarios i.e. the baseline and the SN1 the lake levels were 1636.07 (0.97) m a.s.l and 1635.28 (0.18) m a.s.l respectively above datum point (1635.1 m). It was showing a 0.79 m level drop between the two scenarios.

B/ Bulbula River flow for SN1 Scenario

The flow of Bulbula River for the SN1 condition revealed that there was also a decrease in the flow. The decrease in the flow of Bulbula River on average between the two scenarios was about 31 Mm^3, which is about 16% decrease from the mean baseline condition.

The difference between the mean maximum flows for the two scenarios was recorded to be 126 Mm^3. Fig 20 shows the hydrograph of the two scenarios.

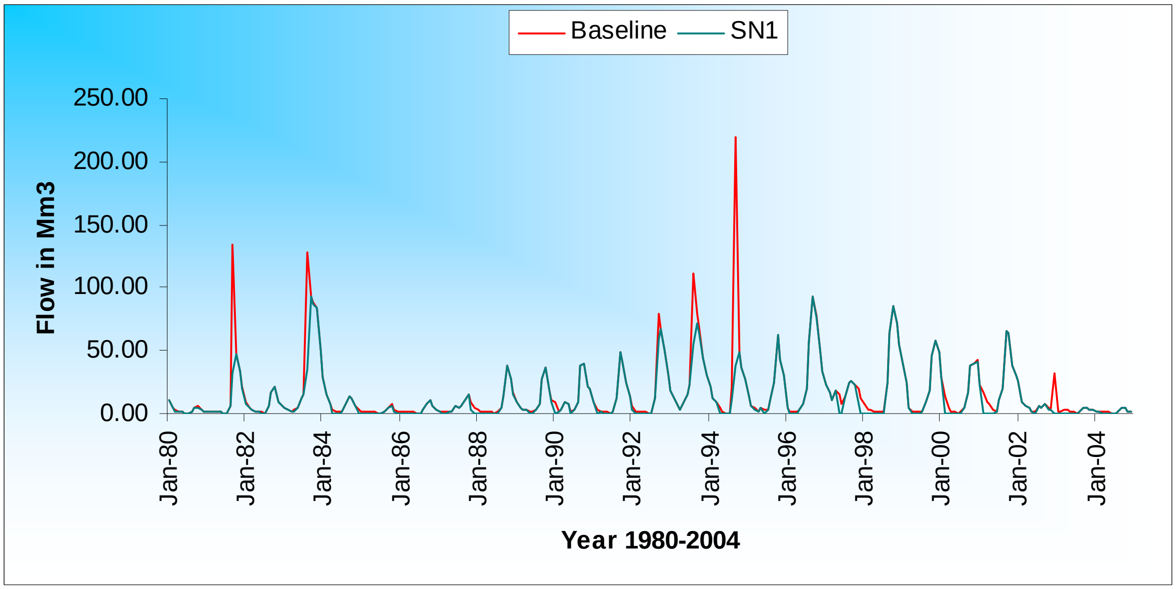


Fig 20 simulated and SN1 flow of Bulbula River

C/ Lake level of Lake Abiyata for the SN1 scenario

The result of the SN1 scenario confirmed that a decline in level for Lake Abiyata too. As it can been seen from Fig 21 the lake level difference between the two scenarios was 0.34 m lake level drop from the mean values even with the condition that its historical flow was maintained.

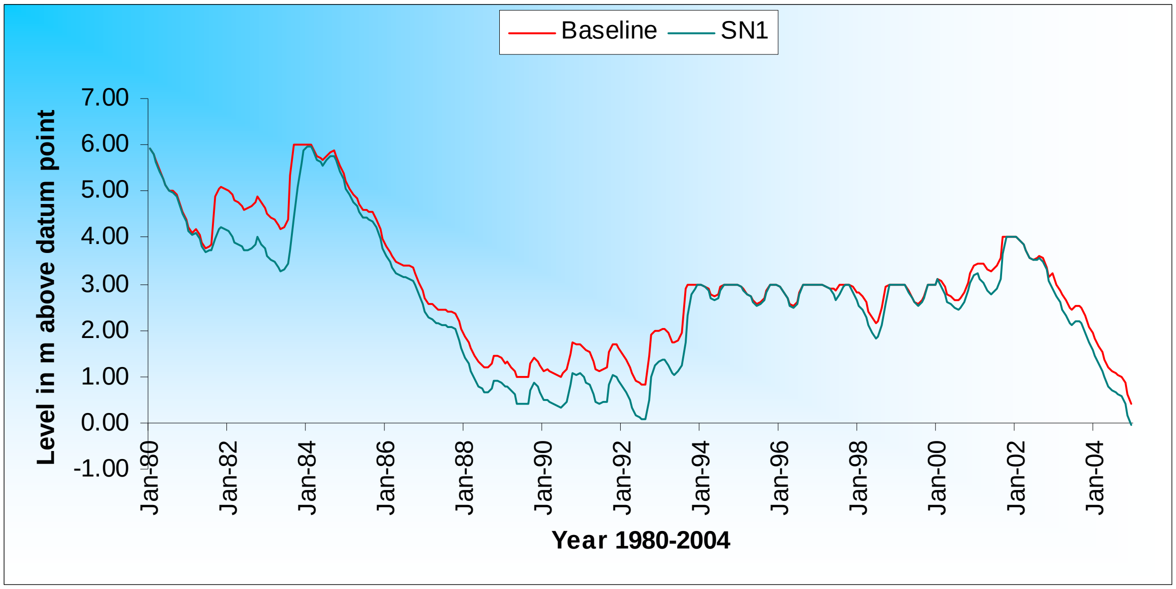


Fig 21 Baseline and SN1 lake level of Abiyata.

D/ Lake level of Lake Ziway for SN1[1]

In this part, the same condition for the SN1 scenario with the altering of the Bulbula river flow priority to the least level will be analyzed. It is assigned as SN1[1]; the results for Lake Ziway on this scenario will be presented as follows.

As it can be seen from Fig 22, the lake level for the three different conditions showed that the maximum level was at 1636.78 m .a.s.l or 1.68 m above datum point for the SN1[1]. The minimum level for this scenario was 1634.35 m .a.s.l or 0.75 m below datum point. The mean lake level for SN1[1] was 1635.48 (0.38) m above datum point.

Generally, there will be a lake level gain for the Ziway lake on this scenario by about 0.2 m on average compared with the SN1 condition. This indicates that there will be a minimized flow of Bulbula River in this particular scenario. This result has inwards due to the alteration of the priority for the Bulbula River settled as equal with the reservoir priority level. However, there will be still a lake level drop for the lake compared with the baseline scenario by about 0.59 m.

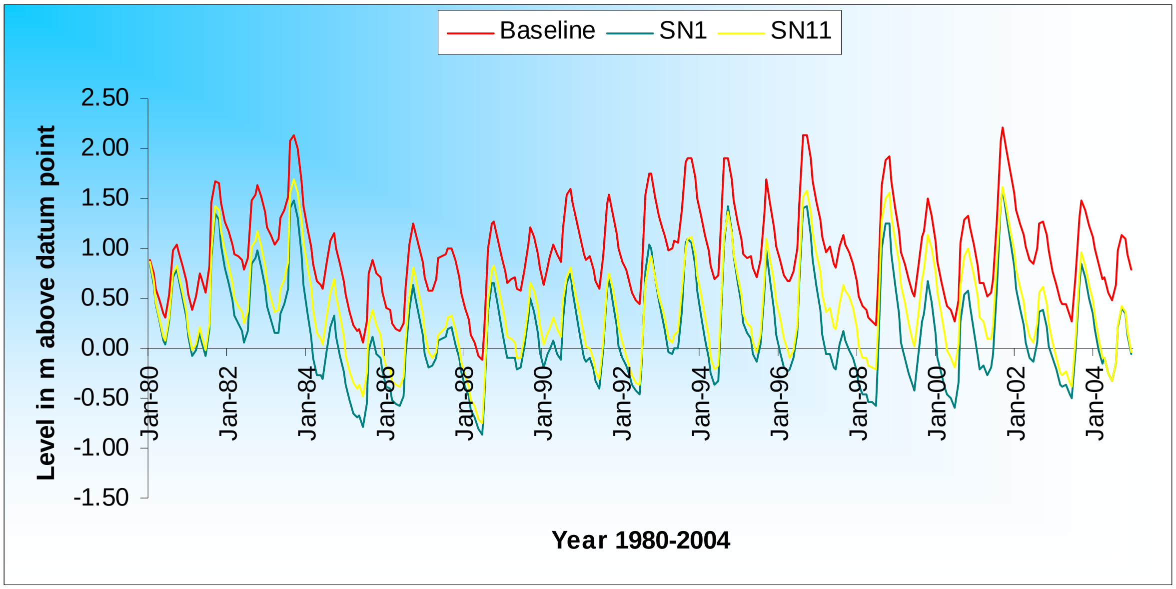


Fig 22 Baseline, SN1 and SN1[1] levels of Lake Ziway

E/ Bulbula River flow in SN1[1] scenario.

The results of the SN1[1] scenario revealed that a reduction in great amount of flow in the Bulbula River. The difference between the two scenarios for the SN1 and SN1[1] was about 52 Mm^3 flow decrease of the river which was an enormous amount of decline. It indicated that there was 33 % reduction of out flow just between the two scenarios. The difference between the baseline and the SN1[1] was about 83 Mm^3 which is about 44 % reduction of the river inflowing to Abiyata Lake. Fig 23 shows the flow of the River for the three scenarios.

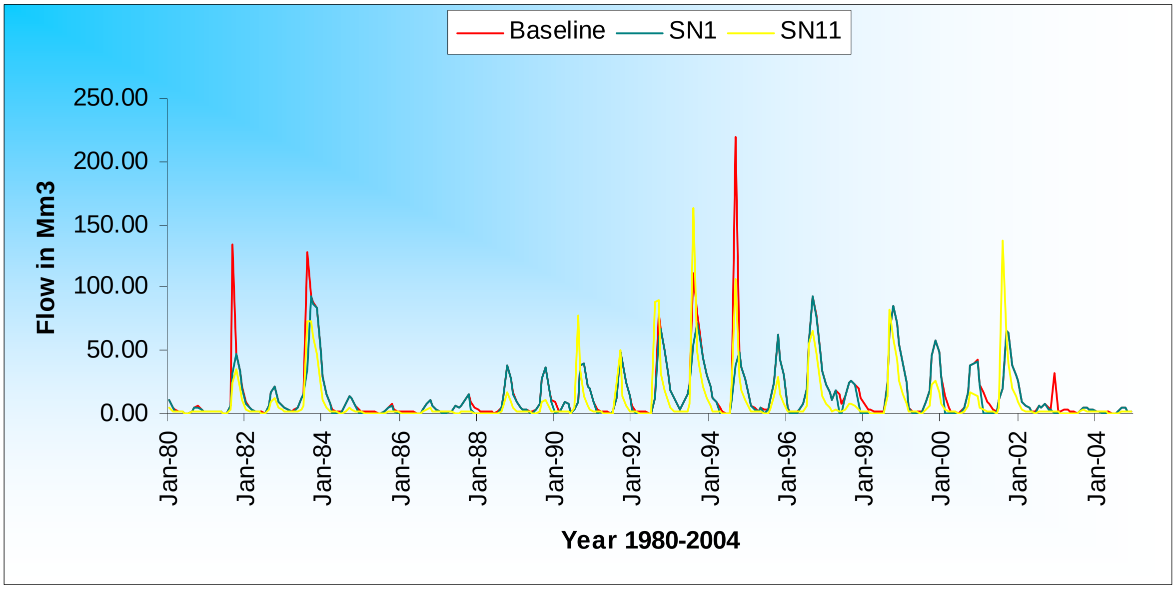


Fig 23 Baseline, SN1 and SN1[1] flow of Bulbula river

F/ Lake Level of Abiyata for SN1[1]

In this part, the lake level of Abiyata with regard to the SN1[1] condition with the change applied in the priority will be analyzed. As it is clearly indicated in Fig 24, there will be a considerable lake level drop for Lake Abiyata in this scenario. There was a 2.27 m level difference just between the SN1 and SN1[1] scenarios. While when the baseline and the SN1[1] lake level differences were compared, there was 2.6 m drop from the baseline mean level.

In addition to this, when it was compared with the early 80's where there was little (or no) development, there was 5.0 m level drop for the SN1[1]. However, for the SN1 and baseline it was about 2.4 m and 2.73 m lake level drop on average form the early 80's which had a mean lake level of about 5.4 m above the datum point.

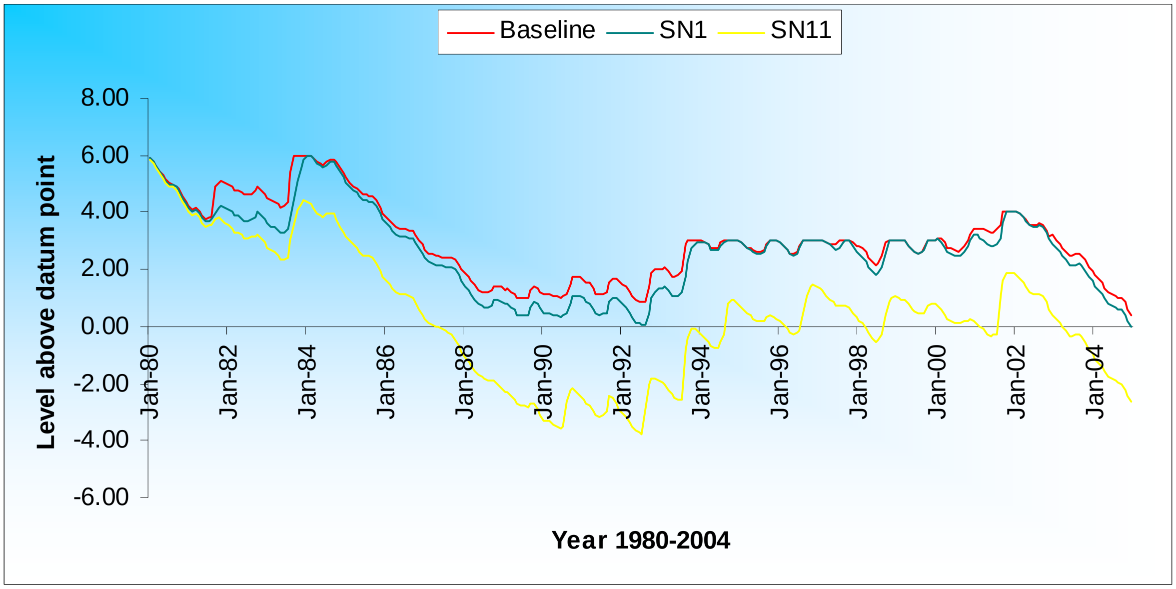


Fig 24 Baseline, SN1 and SN1[1] level of Abiyata lake

4.1.3 Pre-feasibility and Identifcation stage scenarios (SN2 and SN3)

In the pre-feasibility stage and identified stage development scenarios, the results considered the proposed dam construction on the Meki River gorge. In addition, the result also included the alternative advised. This is the plan to irrigate 2300 ha of land by using Meki River by a diversion weir. The scenarios results have been treated alternatively since either of the two will implement.

A/ Lake level of Lake Ziway in SN2

Lake level of Ziway with regard to SN2 i.e. the base line plus SN1 and the irrigation of 3500 ha by diverting water from the newly constructed dam, showed a lake level drop in general sense.

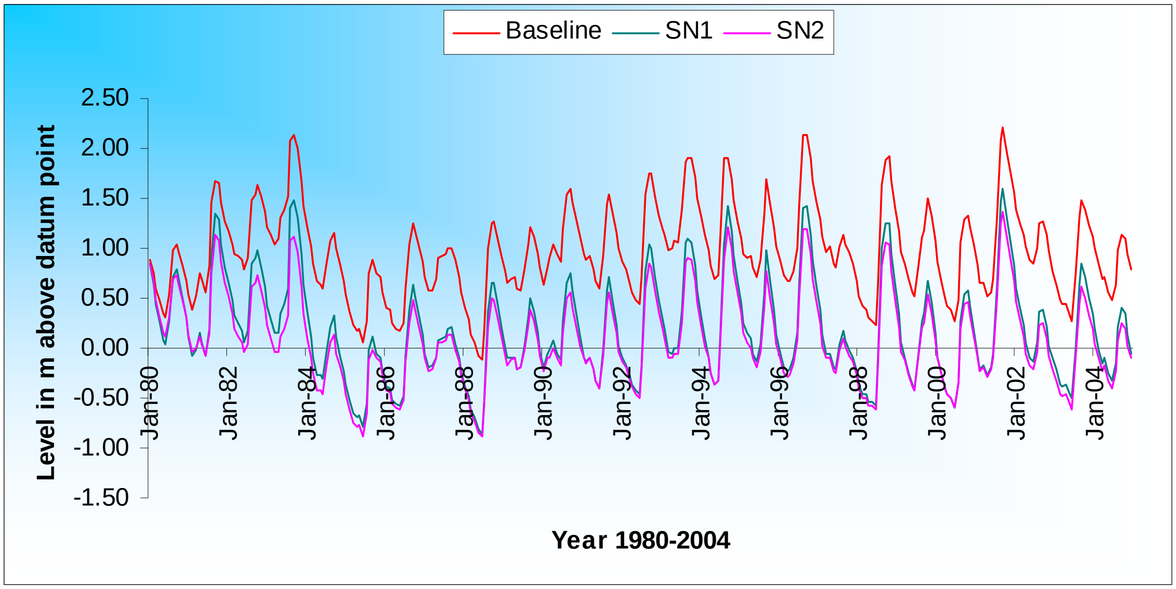


Fig 25 Baseline, SN1 and SN2 level of Ziway Lake

According to baseline,SN1 and SN2 level of Lake Ziway (Fig 25), the lake level of Ziway in addition to the SN1 development scheme, the addition of the 3500 ha irrigation on the Meki area using Meki river as a souce, will result a further lake level drop. There will be 0.89 m mean level drop just between the baseline and the SN2 scenario. There will be additional 0.1 m drop in addition to the previous drop exibited by the application of the SN1 on average. Since Meki River is one of the major inflow of Lake Ziway the two developments which are in different stage were inline with each other so it might affect the downstream project of the Ziway Pressurized Irrigation scheme.

The mean lake level for SN2 will be 1635.18 m.a.s.l (0.08 m above datum point) which is almost as same the current staff gauge datum point and even lower than the natural sill between the lake and the outflow to Bulbula River, which was about 1635.58 m.a.s.l. It was belived that unless the sill level is adjusted, Bulbula River will get dry. The importance of maintaing year round flow in the Bulbula, apart from any possible effect on the level of Abiyata, relates to the need of the river for different basic needs in the catchment.

B/ Bulbula River flow for SN2

This section will include the flow of the Bulbula River for SN2 scenario condition. Fig 26 showed that there was a flow change in between these scenarios. There was 3 % dcerease in flow compared with the previous scenario. However, there was 18 % flow decrease compared with the baseline situation.

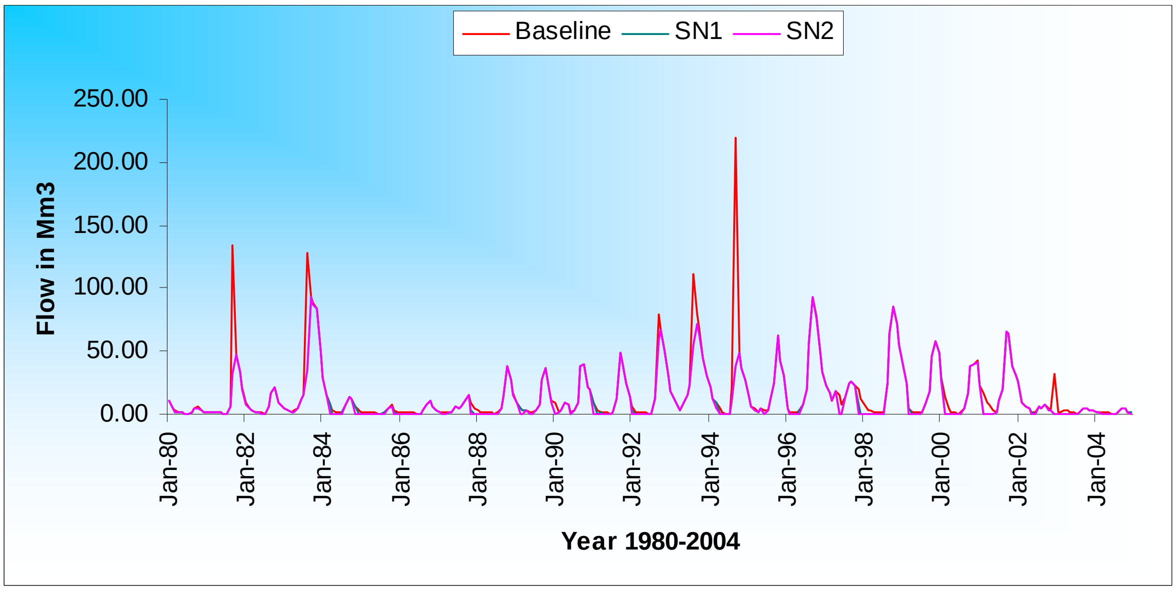


Fig 26 Baseline, SN1 and SN2 flow of Bulbula River

The reason for low flow decrease in the flow of Bulbula river was still related to the priority assigned to the river to the highest level. Due to this reason, in the model (WEAP), it was tried to satisfy the demand of Bulbula river with highest priority before any other less priority demand . This will at least assist Lake Abiyata to get the historical discharge from the river even if there was additional burden on the Ziway lake. This will put all the burden to Lake Ziway as it has been seen in the previous section resulting an additional level drop by about 0.1m.

C/ Lake level of Abiyata for the SN2 scenario

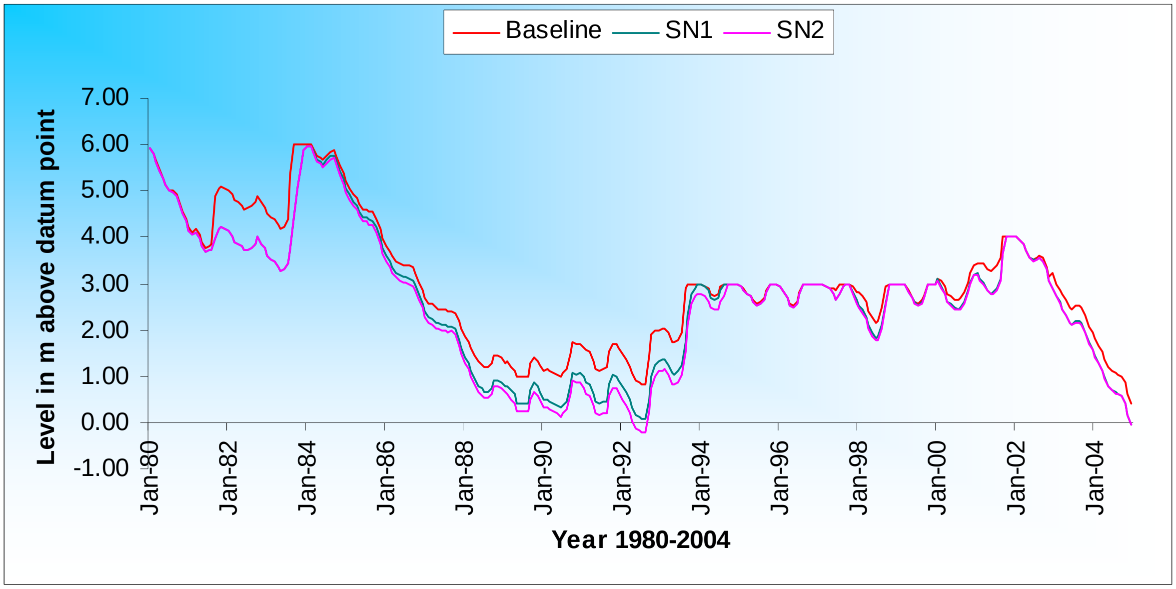


Fig 27 Baseline, SN1 and SN2 level of Abiyata lake

The lake level difference between the baseline and the SN2 scenario for Lake Abiyata was 0.42 m. The lake level gap between the SN1 and the SN2 scenarios showed, there will be an average lake level drop of about 0.08 m for the coming 25 years. Therefore, the additional development scheme to the previous scenario will add further stress on the water level of Abiyata lake even with the maintinace of the historical flow. Fig 27 shows the three scenario level of Abiyata lake.

D/ Lake level of Ziway for SN2^2

This section will deal with the SN2 condition with less priority settled for the Bulbula flow. Inaddition to the baseline plus the SN1 conditions, the result of the additional development shemes on Meki river in relation to Ziway lake level, Bulbula outflow and Abiyata lake level will be dealt here, designated as SN2^2.

The lake level of Ziway with regard to the SN2^2 has an average level of 0.27 m with a 0.2 m gain compared with the SN2 which gave least priority to its outflow. Also the differece between the SN1[1] and the SN2[2] was about 0.11 m drop. Besides, there was also a 0.7 m lake level decrease compared with the baseline scenario. Fig 28 shows the hydrograph of lake levels of Ziway in Baseline, SN1[1] and SN2[2] scenarios.

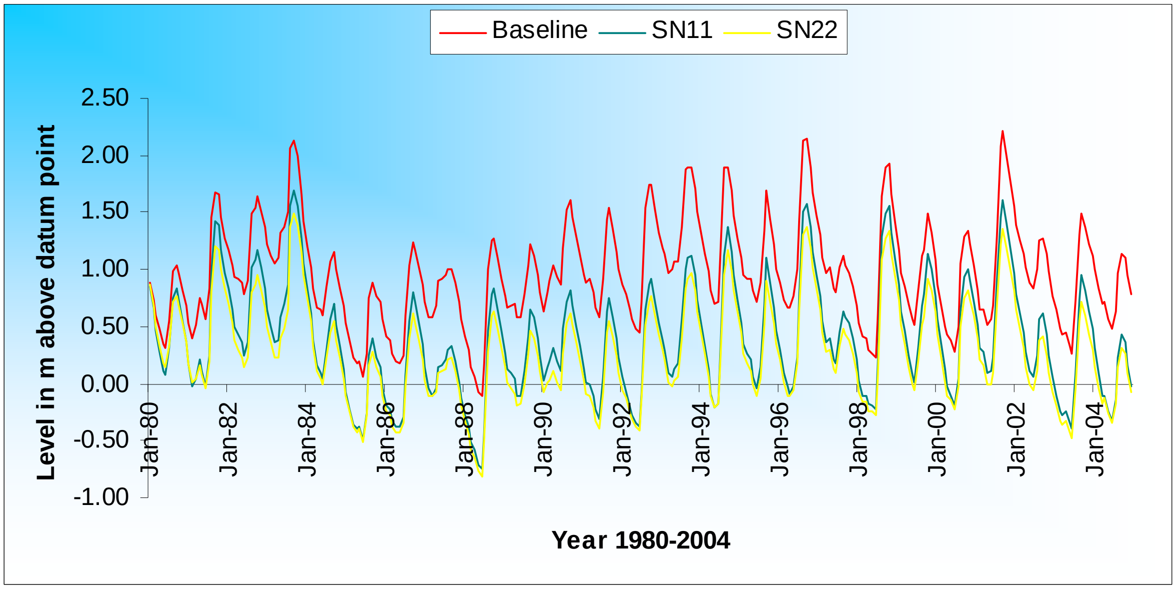


Fig 28 Baseline, SN1[1] and SN2[2] level of Ziway lake

E/ Bulbula River flow in SN2[2]

The Bulbula outflow to the SN2[2] scenario reaveled that there was a flow decline. Since it has got a least priority, the effect was refelected in both the river itself and downstream lake. The mean flow to this scenario was about 91.41 Mm^3. Which has about 51 % and 13 % flow decrease compared with the baseline and the SN1[1] scenarios, respectively. Fig 29 gives flow of the Bulbula river for the three scenarios.

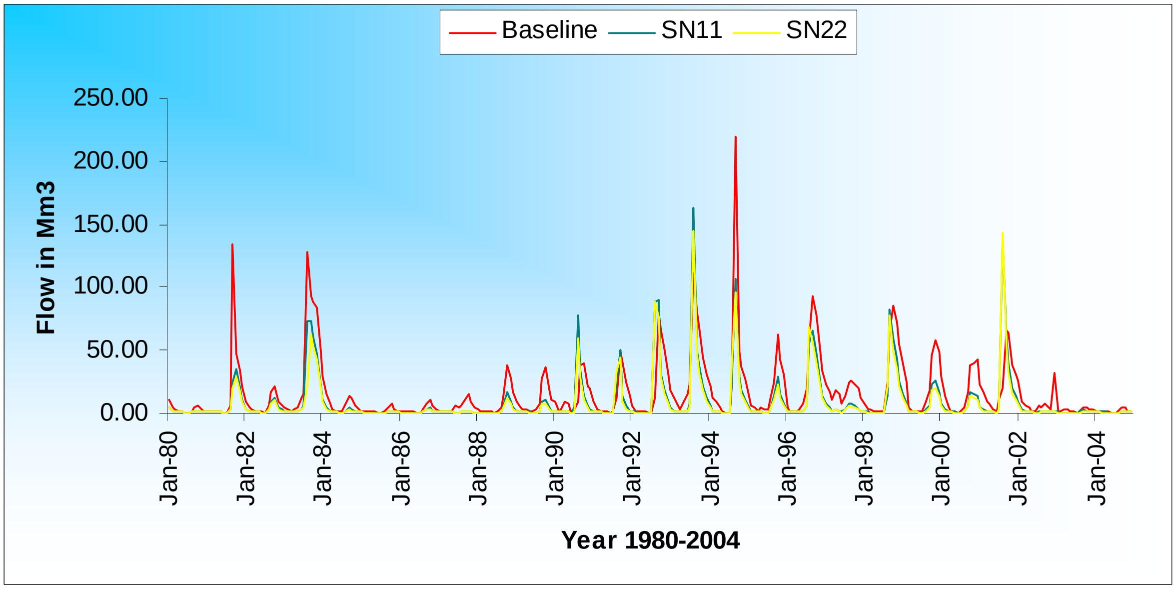


Fig 29 Baseline, SN1[1] and SN2[2] flow of Bulbula River

F/ Lake level of Abiyata for SN2[2]

Lake level of Abiyata with regard to the SN2[2] scenario reavealed, that the additional development in the upstream of Lake Ziway resulted in a lake level difference more significant compared with the lake level drop in the Ziway lake for the SN2[2] scenario.

The lake level differnce between SN1[1] and SN2[2] scenarios on average was about 0.9 m and there was a 3.5 m level drop between the mean level of the baseline and SN2[2] scenarios, which makes it the maximum lake level drop simulated in the model. Fig 30 shows the hydrograph for Lake Abiyata's level with regard to Baseline, SN1[1] and SN2[2] scenarios.

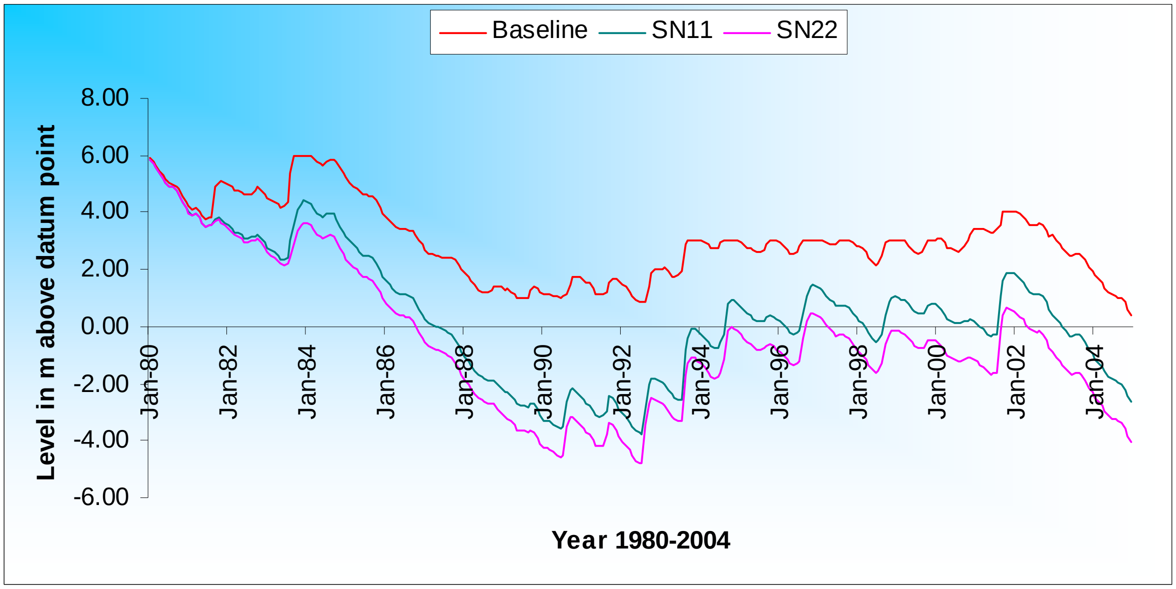


Fig 30 Baseline, SN1[1] and SN2[2] level of Abiyata lake

A/ Lake level of Ziway for SN3

This section will discuss the results of the alternatives to the SN2 and SN2[2] of the identification and prefeasibility stage scenarios of the model indicated as SN3 and SN3[3] respectively. Comparison between the two alternatives will be included regarding the three variables indicated above.

SN3 scenario treats the alternative for the Meki development, which was intended to irrigate 2300 ha of land by means of diversion weir. The lake level of Ziway with regard to this option showed a 0.07 m level rise compared with the SN2 scenario while the difference in lake level between the SN3 and the baseline being a drop by about 0.82 m.
This result indicates that the SN2 and SN3 development schemes with the diversion option will have less effect compared with the SN2 scenario.

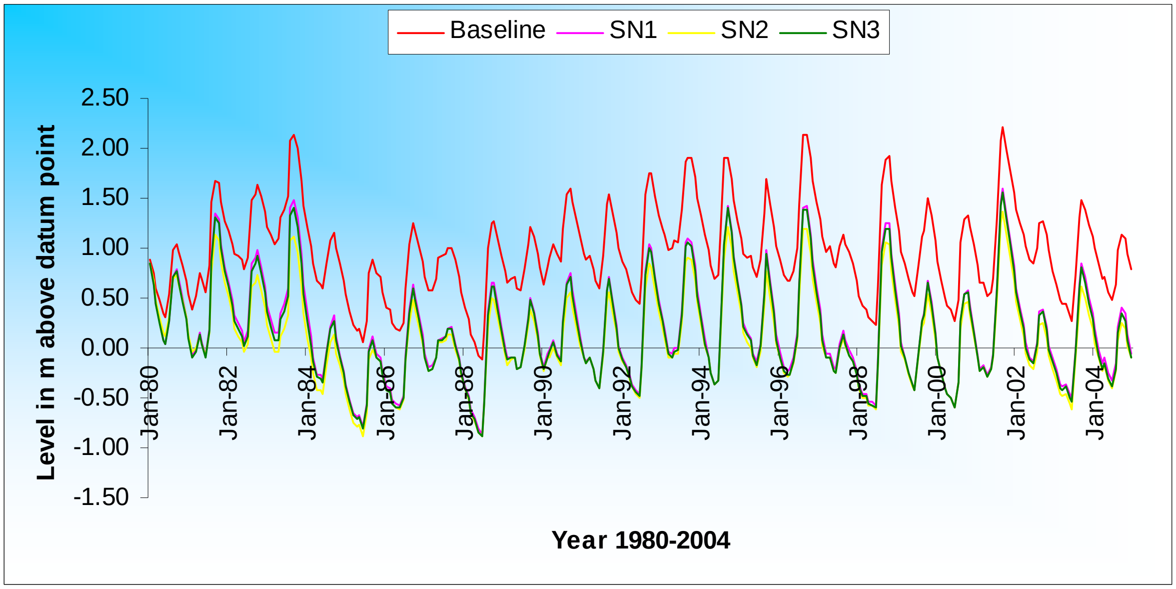


Fig 31 Baseline, SN1, SN2 and SN3 level of Ziway lake

Fig 31 revealed that there was a mean lake level of 0.15 m above datum point for the SN3 scenario over the simulation period.

B/ Bulbula River flow for SN3

Bulbula flow for the SN3 scenario confirmed that there was a gain in the flow of the river compared with the SN2 scenario even if the amount is small. Hence, there was still a remarkable difference between the baseline and the SN3 which is about 32.5 Mm^3 volume differnce. Fig 32 shows the flow of the river for these scenarios.

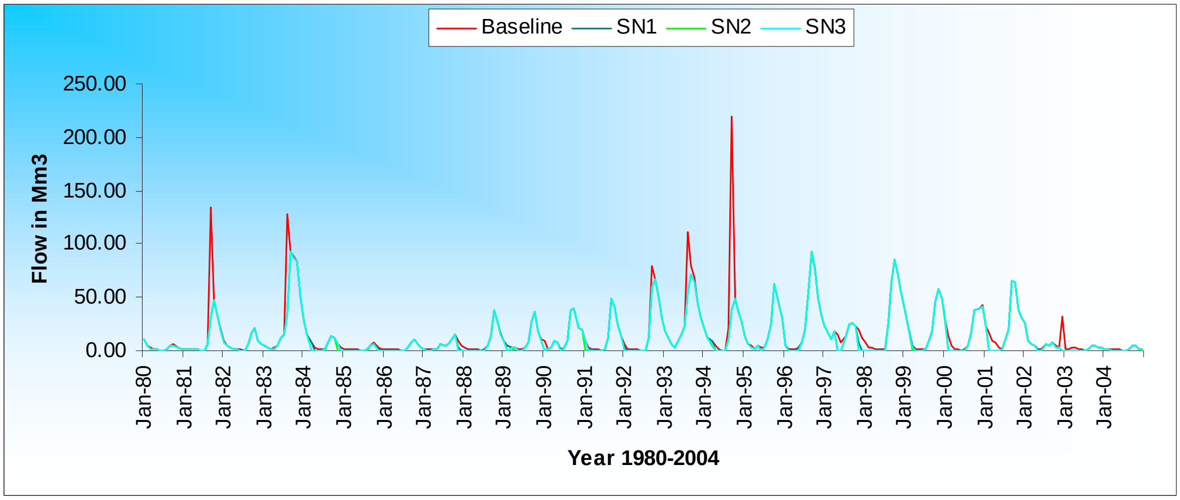


Fig 32 Baseline SN1, SN2 and SN3 flow of Bulbula river

C/ Lake level of Abiyata with regard to the SN3

The level of Abiyata with this scenario showed a gain by about 0.04 m compared with the SN2 scenario. There was still 0.38 m level drop between the baseline mean level of Lake Abiyata and the SN3 scenario.

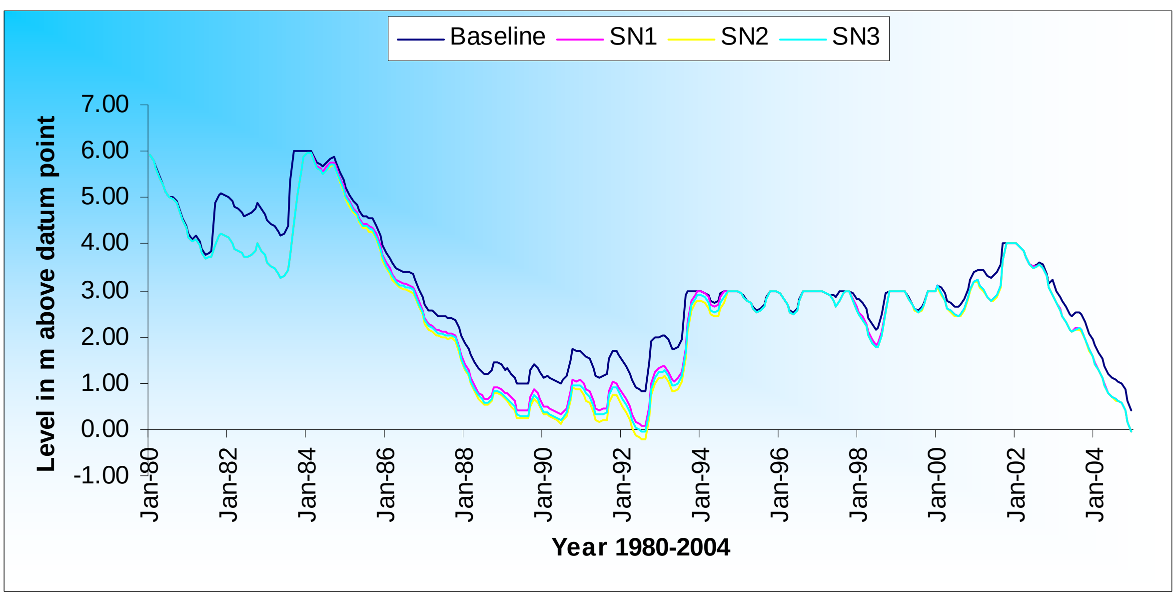


Fig 33 Baseline, SN1, SN2 and SN3 level of Abiyata lake

D/ Lake Ziway level for SN3[3]

This section presents the same SN3 condition with less priority for the flow of Bulbula river. It is desiginated as SN3[3.]

Lake Level of Ziway with regard to the SN3[3] situation reavealed that the lake level of Ziway showed a rise by 0.08 m comared to that of the SN2[2] condition. However, there was still a 0.62 m lake level drop compared with the baseline mean lake level. Fig 34 shows the graph of the Baseline, SN1[1], SN2[2] and SN3[3] level of Lake Ziway.

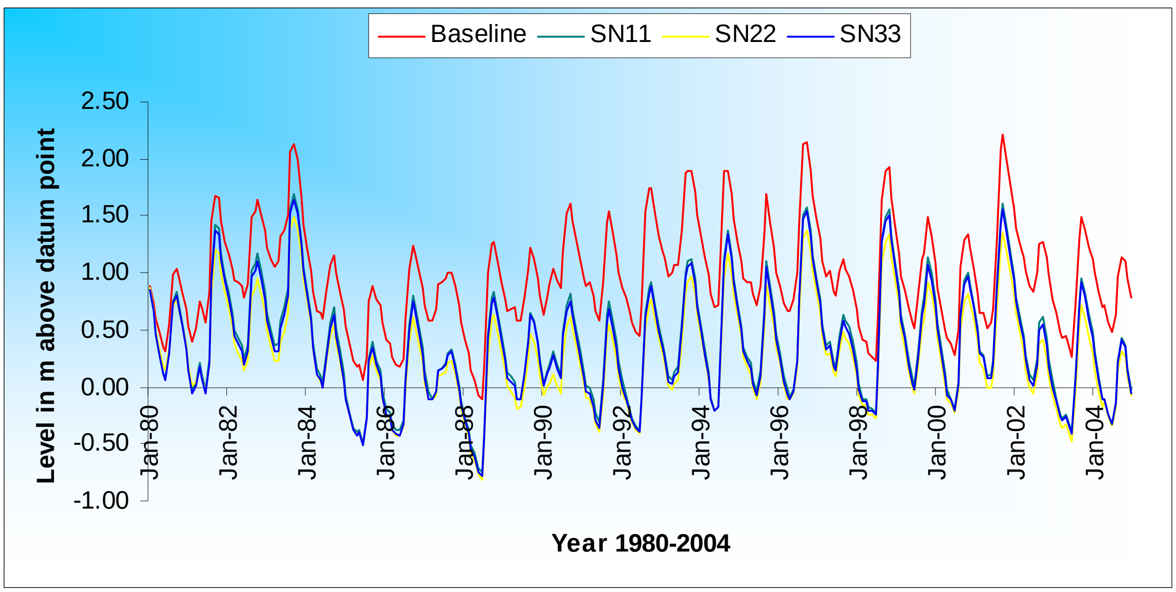


Fig 34 Baseline, SN1[1], SN2[2] and SN3[3] level of Ziway lake

E/ Out flow of Bulbula River with SN3[3] *scenario*

Fig 35 shows that there was a flow gain for the river compared with the dam alternative development i.e. SN2[2] condition with an amount of 11 Mm^3. There was still a flow decline compared with baseline of 86 Mm^3.

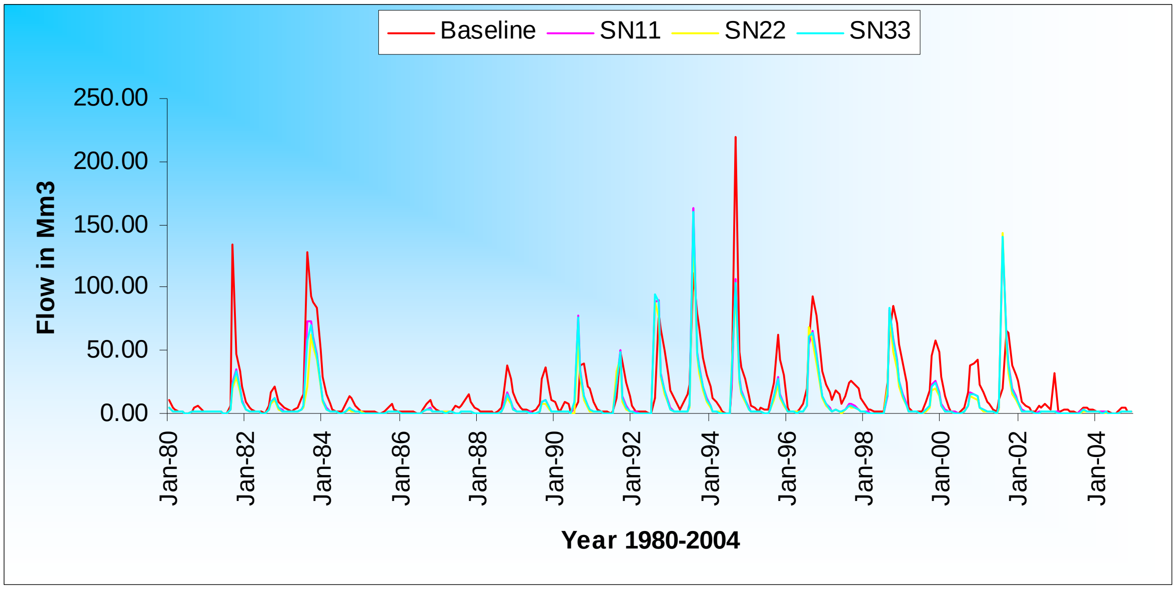


Fig 35 Baseline, SN1^{1}, SN2^{2} and SN3^{3} flow of Bulbula river

F/ Lake level of Abiyata Lake for the SN3^{3} scenario

The lake level of Abiyata in this scenario showed a gain of level with an amount of 0.7 m compared with the SN2^{2} scenario, while still there was a lake level drop of 2.8 m compared with the baseline condition. Fig 36 shows the level of Abiyata for the Baseline, SN1^{1}, SN2^{2} and SN3^{3} scenarios.

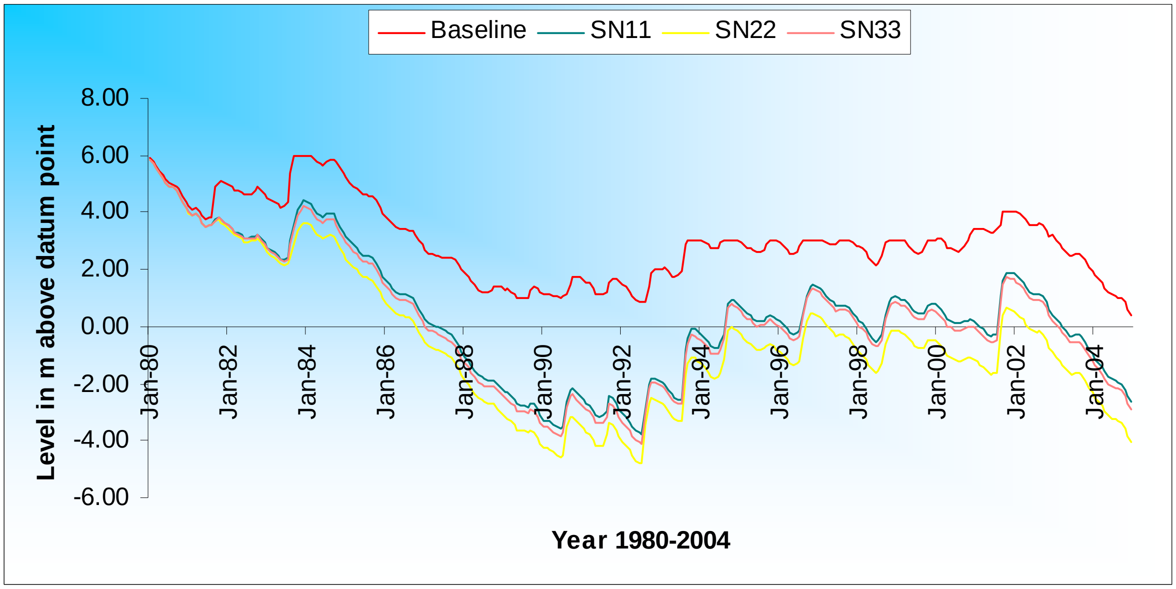


Fig 36 Baseline, SN1[1], SN2[2] and SN3[3] level of Abiyata lake

Table 16: Results of the Mean values of all the scenarios and the difference of each scenario with respect to the Mean.

Scenarios and their description	Ziway lake level in m above datum point of 1635.1m a.s.l		Abiyata lake level in m above datum point of 1576.4m a.s.l		Bulbula (Ziway out flow) in Mm^3	
	Mean lake level (in m)	Difference from the mean. Drop (-)/gain (+)	Mean lake level (in m)	Difference from the mean. Drop (-)/gain (+)	Mean flow In (Mm^3)	Difference from the mean. Drop (-)/gain (+)
Base line	0.97	0	3.01	0	188.04	0
SN1 (HP)	0.18	- 0.79	2.67	- 0.34	157.08	- 30.96
SN1[1] (SN1 + LP)	0.38	- 0.59	0.40	- 2.61	105.31	- 82.73
SN2 (HP)	0.08	- 0.89	2.59	- 0.42	154.40	- 33.64
SN2[2](SN2+ LP)	0.27	- 0.70	-0.48	- 3.49	91.41	- 96.63
SN3(HP)	0.15	- 0.82	2.63	- 0.38	155.50	- 32.54
SN3[3](SN3 + LP)	0.35	- 0.62	0.23	- 2.78	102.34	- 85.70

Descriptions of the scenarios:

1) Base line is the historical 1980-2004 existing condition for the study area simulated.
2) SN1 includes four variables which are:
   - 15500 ha pressurized irrigation using Lake Ziway as a source.
   - 500 ha expansion on the Sher Ethiopia Flower Farming using Lake Ziway as a source.
   - 50000 tons of soda ash expansion of Abijata Soda Ash Enterprise using Lake Abiyata as a source.
   - 5000 people domestic water supply to Bulbula town from Bulbula river

   This scenario (SN1) has underpinned in the baseline condition.

   LP stands for least priority given to the out flow of Lake Ziway through Bulbula River and HP stands for the high priority given respectively.
3) SN2 is for 3500 ha development on Meki area using Meki River as a source by constructing a dam on the river plus the SN1.
4) SN3 stands for the irrigation of 2300 ha land by the Diversion Weir option using Meki River as a source plus SN1.

Table 16 above gives the summary of WEAP model output for the 7 scenarios. The assumption used in the model regarding the input hydrological, meteorological and demand time series data which is from 1980-2004 (25 years) flow series will repeat in the future (Planning period).

The effect of irrigation expansion (the present water use + planned one) was assessed with reference to:

- The mean lake level observed over the Period 1980-2004 for Lake Ziway which is about 0.97 m above datum point of 1635.1m a.s.l.
- The mean flow observed over the period of 1980-2004 for Bulbula River which is about 188 Mm^3.

- The mean lake level observed over the simulation period for Lake Abiyata which is 3.01 m above datum point of 1576.4 m a.s.l.

For Lake Ziway the comparison between the baseline and the implementation of the major development scheme (SN1) has a lake level drop by about 0.79 m. This was with the condition that Bulbula river flow being assigned the highest priority. While with the same condition, only by altering the priority assigned to the river to the least, there will be a lake level gain by about 0.2 m. This was due to the reduction of the inflow to Lake Abiyata. It is clear that whenever there is a reduction in the flow of Bulbula River, the lake level of Lake Abiyata decreases and in contrary the level of Lake Ziway increases.

Moreover, the addition of the SN2 scenario on the previous scenarios (Baseline and SN1), has resulted the maximum lake level drop recorded in the model simulation for Lake Ziway which was about 0.89 m (1634.21m.a.s.l) drop from the datum point below the natural sill that controls the outflow from the lake to the river. In order to facilitate the minimum required flow to Lake Abiyata, the sill needs an adjustment. According to the WWDSE, (2008), feasibility study on the Ziway Pressurized Irrigation a 1 m and 1.5 m deeping of the sill has been suggested. This will have its own consequence on the ecosystem as a whole when a regulated flow is maintained to Lake Abiyata, putting the economic developments at the cost of Lake Ziway. Also for SN2 scenario, the same is true when altering the priority to least i.e. $SN2^2$ .There will be a lake level gain by about 0.19 m compared with the SN2 scenario for Lake Ziway.

The alternative suggested for the SN2 scenario was the SN3 scenario i.e. diversion weir option rather than the dam construction. Even if both have similar purpose of irrigating new agricultural area by abstracting water from the Meki River with different mechanisms, the diversion weir have a lesser effect on the level of Lake Ziway compared with the SN2 scenario. There was a 0.07 m level gain just only between the SN2 and SN3 scenarios for

Lake Ziway. When the comparison between the SN2^{2} and SN3^{3} is conducted there was a lake level gain of about 0.08 m.

The out flow of the lake through Bulbula River will be affected by the proposed development schemes. Whenever there is an increase in the lake level of Lake Ziway, the out flow to Bulbula River increases. For instance, for the SN1 there was 30% flow reduction compared with the baseline which is in line with the lake level decrease in Lake Ziway by 0.79 m. The pinpointing idea in this scenario for Bulbula River becomes clear when the priority assigned changes. Since Bulbula River doesn't have major tributaries, it only relies on the outflow of Lake Ziway. Hence, when the priority for the outflow gets least, the water coming to it decreases and affects the river itself and the next highly dependent Lake Abiyata at most.

Complement to the result, the maximum flow reduction for Bulbula River is recorded for the SN2^{2} scenario by which the flow decreases about 53% from the baseline. Still the SN3 option had less effect for the flow of the river compared with the SN2 scenario.

It is revealed from the results that the Abiyata lake level will be affected depending on the implementation of each scenario in different level. In general, it is confirmed from the result that whenever the Bulbula flow is set with the highest priority, the lake level drop compared with the least priority option is much better. The maximum lake level drop for the highest priority scenarios (SN1, SN2 and SN3) was about 0.42 m below the mean lake level value of the baseline scenario.

On the other side, for the least priority scenarios (SN1^{1}, SN2^{2} and SN3^{3}), the maximum lake level drop was about 3.5 m compared with the baseline mean lake level. This has an overwhelming effect on the existence of the lake which is already in danger. Since the major objective of this thesis was to see the effects of development activities on the level of Lake Abiyata, the outputs of the models employed showed that the new development schemes specially the ones with least priority, put Lake Abiyata in a huge threat to exist as a permanent lake.

It was inspiring to see only the magnitude of effect applied on the level of Lake Abiyata with regard of the factory available in its territory. The expansion of the 50,000 tons of soda ash on the lake is considered as the only activity in order to compare which activity plays more for the lake level drop between the upstream irrigation and the industrial activity on the lake itself. The result showed that there was a 0.09 m lake level drop for the expansion of the factory on the lake compared with the baseline scenario.

This revealed that the abstraction of the water for this particular scenario is about 7.5 Mm^3 of water will not have significant lake level drop, when compared with the other development scenarios for the simulated 25 year period. While the upstream abstraction of water for irrigation around Lake Ziway will have soaring effect on the water level of Lake Abiyata. Fig 37 shows the graph of the baseline and the expansion of the proposed soda ash on Lake Abiyata with no other development in line.

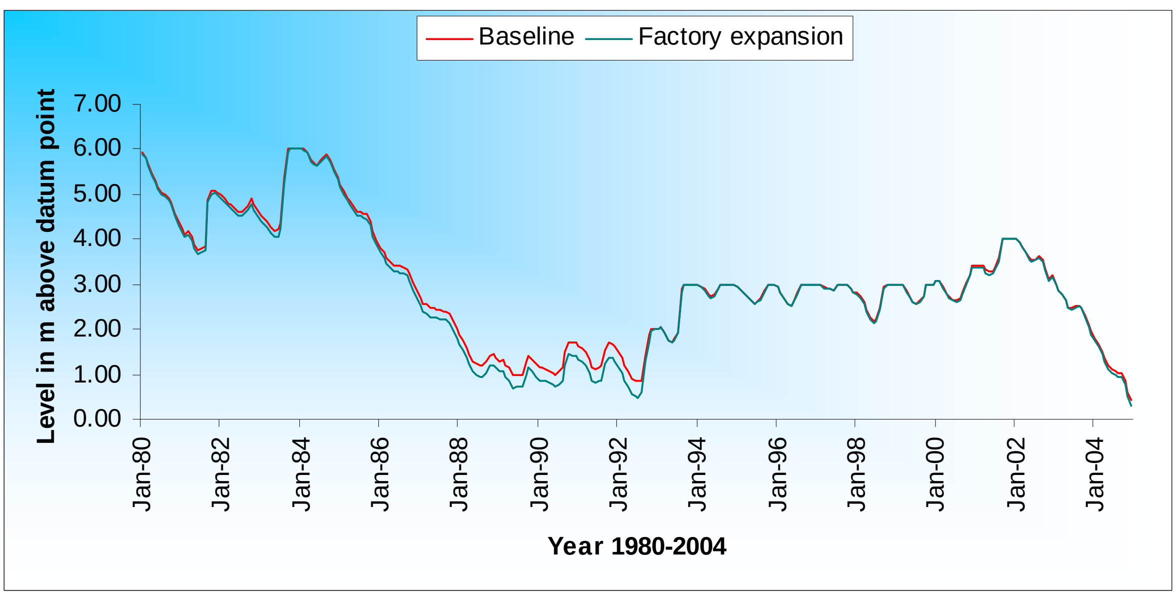


Fig 37 Baseline and expansion of 50000 tons of Soda Ash on Lake Abiyata with no other future developments

The results of the WEAP model have been compared with previous studies on the area. According to WWDSE, (2008) final feasibility study on Ziway pressurized irrigation, it was estimated that there will be a 0.50 m mean lake level drop for Lake Ziway, which in this study was about 0.59 m. The results were compared with only the least priority set-up since the study didn't address priority set-ups. The same study concluded that, if mitigation measures are not taken, further abstraction will cause Lake Ziway to drop significantly more than 0.70 m and Lake Abiyata may cease to exist as permanent lake. The mitigations which have been suggested in this study were to add regulated flow into Abiyata Lake from Langano and Shalla Lakes by pumping while addressing the quality and other related effects. According to the WEAP software results, this study indicated that there will be a 2.61m level drop for Lake Abiyata.

According to Tenalem Ayenew (2004), it was reported that the present annual abstraction for irrigation was estimated at only 28 Mm^3. If all the proposed irrigated areas are developed, the estimated annual water requirement will be 150 Mm^3 (Makin *et a*l., 1976; Tenalem Ayenew , 2004). This would result in a 3 m reduction in the level of Lake Ziway and ultimately lead to a drastic reduction in the level of Lake Abiyata and drying up of the feeder Bulbula River. Even if the 3 m reduction in lake level is different from what has been observed in this study, both studies indicate a remarkable drop in levels of both lakes.

A study by the JICA and OIDA on the Meki Irrigation and Rural Development project in Oromiya Region in 2001, compared the effects of the two alternatives which were proposed on Meki river while the study takes these developments as the only ones. In this study this option is taken along with the previous scenarios which include other major development plans in the study area. The results of this study explained the effects in terms of the storage change in the two lakes and the reduction in the flow of Bulbula River. The result of the study also revealed that there was lake level drop for Lake Ziway in both alternatives while the dam scheme will cause much more reduction in storage compared with the diversion scheme which has about 22 % more effect than the diversion scheme.

The effect of the reduction of the storage of Lake Ziway resulted in a much more less flow to Bulbula River which in turn brought a lake level decrease on Lake Abiyata (JICA and OIDA, 2001). This is also in line with this thesis results even if the results presented with respect to level, which reveal much effect projected due to implementation of the dam alternative to irrigate the land than the diversion weir option.

All the previous studies on the area confirmed that the additional development activities will have an adverse effect on the fragile ecosystem of the study area. The lake level drops of both lakes have effects which will be reflected on the ecosystem as a whole. The effects of improper utilization of water resources will be manifested in both environmental and socioeconomic activities in the region. These problems will have far-reaching devastating environmental consequences in the foreseeable future unless proper mitigation measures are taken. The most important environmental implications are outlined.

Lake Abiyata is a shallow highly productive alkaline lake whose muddy shore supports a wealth of bird life almost unequalled perhaps in the whole of Africa; as such it makes of great biological importance. Both the plant and animal life are very sensitive to lake area and size changes. These aesthetic values of the lake will be disrupted and the almost jeopardized tourism sector will be highly affected. In addition to this the lake level decrease will result in the close up of the only industrial activity which supports a number of people who depend on the factory.

Reduction in the volume of Lake Ziway could be expected to increase the ionic concentration of the water as in the case of Lake Abiyata, which will have grave consequences on the fragile aquatic ecosystem. Lake Ziway supports the heaviest fish stock in the region and is the principal source of commercial fishing in Ethiopia.
Therefore, the main economic consideration of altering the volume of Ziway for irrigation is the impact on its considerable potential as a freshwater fishery. The other more subtle effect of lake level reduction is on the vegetation around the lake edge, which plays an important role in providing food and shelter for numerous animals. Some species are apparently sensitive to short-term fluctuations and disruptions to their environment, including the marginal vegetation. Lowering of lake level may result in an increase of the transpiration

loss from the marginal vegetation and lowering of groundwater level and the grassland will be endangered. The lowering of groundwater level will also result in the drying up of springs used for community water supply purposes.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the result analysis, which includes different scenarios (Baseline, SN1, SN2, SN3, $SN1^{1}$, $SN2^{2}$, $SN3^{3}$ and expansion only on the lake), the following points are concluded. However, it is important to note that the study involved a certain level of uncertainty and hence, the results of this study should be taken with care and be considered only as indicative of the likely future as it gives a clue and increase awareness on the possible future risks of water use in the study area.

- In the baseline scenario, the water levels of Abiyata Lake indicate a declining trend. While the level of Ziway Lake showed a variable trend. However, a declining trend from 2001 to 2004 was exhibited for both lakes and the Bulbula River flow.
- The implementation of the SN1 resulted in a 0.79 m level drop on Lake Ziway while Lake Abiyata will drop by 0.34 m from the historical mean simulated value. The $SN1^{1}$ scenario showed a decline in the level of Abiyata by 2.6 m and 0.59 m drop for Ziway Lake.
- The SN2 scenario resulted in a maximum lake level drop for the Ziway Lake by dropping the level about 0.89 m compared with the baseline scenario. However this scenario has resulted a 0.42 m level drop for Lake Abiyata. The $SN2^{2}$ scenario will result the maximum level drop over the simulation period for Lake Abiyata which is about 3.5 m below the mean value. In the same condition the level drop for Lake Ziway was 0.7 m.
- The SN3 scenario resulted in a lake level drop of about 0.82 m and 0.38 m for Ziway and Abiyata lakes respectively. The $SN3^{3}$ scenario resulted in a lake level drop of 0.62 m and 2.78 m for Ziway and Abiyata lakes respectively.
- The lake level drop of Lake Abiyata with regard to the Abijata Soda Ash expansion plan alone was about 0.09 m from the mean baseline scenario. This is apparently not

significant but the concern is the possible cumulative effects of additions of even insignificant effects on the already endangered lake.

- The magnitude of effects applied of the diversion weir was less compared with the dam development scheme on the level of both lakes.
- Among the scenarios the high lake level drop compared with the mean minimum lake level value for Lake Abiyata was in the $SN2^2$ scenario which resulted in a 5.2 m level drop compared with the mean minimum level of the lake in the Baseline scenario. However, for Lake Ziway it was exhibited for the SN2 scenario which has 0.7 m drop compared with the Baseline scenario mean minimum level.
- The maximum level for both lakes was observed in the Baseline scenario with values of 6.00 m and 2.21 m above datum point for Abiyata and Ziway lakes respectively.
- The decrease in level of Lake Ziway resulted in total drying up of the Bulbula River flow and puts the existence of Lake Abiyata under question as well.
- The maintenance of the historical flow of Bulbula River will at least minimize the lake level drop by much more in relation to the least priority alternative. However this condition will put Lake Ziway in a great danger. In this condition, the new development schemes will be undertaken at the cost of Lake Ziway if the minimum flow requirements carry on.

Accordingly, as it has been affirmed in the water resource policy (MoWR, 1999), lake Abiyata's flow might be maintained. It seems that all development activities are undertaken at the expense of Lake Ziway. The Ziway pressurized irrigation scheme alone abstract a net water amounting to 157 Mm^3 per year in addition to the existing 48 Mm^3 per year water abstraction including all demands in the study area. This will disrupt the promised minimum flow requirement of Lake Abiyata in the long run.

In line with this, Lake Ziway also needs special consideration in the future. Since this lake is a multipurpose reservoir, effect will disrupt the whole ecosystem. The results direct that both lakes will be affected due to the planned development schemes while the magnitude of the effects depend on the interrelated priorities assigned to the Bulbula flow. From the results it can be concluded that level of Lake Abiyata is highly governed by the inflow of Bulbula River. As it has been explained by different researchers, the rainfall in the area has been very erratic and the magnitude did not change for the last few decades. Hence, the lake level drop might have been due to the land use change and other related factors.

This indicates that any future strategy or natural resources plan for the CRL will need to be based on the availability of water resource and their integrated management to ensure sustainable use of it and maintain the health of the ecosystem of the basin as a whole.

5.2 RECOMMENDATION

Based on the conclusions, the following recommendations are forwarded.

The plan for any kind of water abstraction in the watershed of the study area must be integrated and management should be based on a holistic approach for the whole basin.

- The Bulbula River flow need to be monitored in order to assure the minimum flow to Lake Abiyata based on its historical discharge.
- Other alternatives for water harvesting should be used in order to reduce the stresses from the surface water abstraction such as rain water harvesting, catchment management and etc.
- Detailed hydro geological studies around the lakes should be undertaken to obtain solid facts on the ground water potentials in order to shift some of the irrigation schemes to this resources.
- Adopting high efficiency irrigation method that minimizes water quantity required should be applied.
- A bathymetry survey of the Abiyata Lake and availability of all hydrological data in an organized manner is expected from the MoWR in the future. Especially, the datum point for Lake Abiyata which was believed to have been changed from time to time needs to be revised and available for users.
- More detailed resource assessment of water should be done, including sustainable abstractions (safe yields) and the spatial variability of water quantity.

Finally it is recommended to employ environmental impact assessment to all major development considered in the scenarios, as it has been declared in the Water Sector Strategy (MoWR, 2002), in order to establish procedures and mechanisms for all actions that are detrimental to water resources, environmental impact assessment is a necessity.

REFERENCES

Alamirew Dilnesaw (2006). Modelling of Hydrology and Soil Erosion of Upper Awash River Basin. PhD Thesis, University of Bonn: 233.

Amani A.(2004). Modeling Water Resource Management in Lake Navasha. MSc Thesis International Institute for Geo-Information Science and Earth Observation Enscheda, the Netherlands.

Anna G.(2006). Non-climatic Lake level change in Ethiopia. T.U Berg akademie Freiberg, Faculty of Geosciences, Geotechnology and mining.

Anna G.(2007). Non-climatic lake level changes in the Main Ethiopian Rift. Geophysical Research Abstracts, Vol. **9**, 06521 European Geosciences Union.

David Ingle Smith and Peter Stopp (1978). The river basin. An introduction to the study of hydrology. **275**

Dagnachew Legesse (2002). Analysis of the hydrological response of the Ziway-Shalla lake basin (Main Ethiopian Rift) to changes in climate and human activities. Ph.D. Thesis, Aix-en-Provence, France, Universite d'Aix-Marseille III.

Dagnachew Legesse., Vallet, C., and Gasse, F.(2003). Hydrological response of a catchment to climate and land use changes in tropical Africa: case study South Central Ethiopia. *Journal of Hydrology*, 67–85.

Dagnachew Legesse., Vallet, C., Gasse, F.(2004). Analysis of hydrological response of a tropical terminal lake, Lake Abiyata (Main Ethiopian Rift valley) to changes in climate and human activities. *Hydrological process*.**18**: 487-504.

Dagnachew Legesse and Tenalem Ayenew (2006). Effect of improper water and land resources utilization on the Central Main Ethiopian Rift Valley Lakes. *Quaternary International* **148:**8-18.

Ebrahim Esa (2008). Analysis of the impacts of Soda Ash mining on Abijata and Shalla Lakes Subwaershed: The Main Ethiopian Rift System. MSc Thesis Addis Ababa University.

Elizabeth Kebede., Zinabu GeberMariam., and Ahlgren, I.(1996). The Ethiopian rift valley lakes: Chemical characteristics along a salinity-alkalinity gradient..*Hydrobiologia,* **288:** 1-12

Halcrow.(1992). Reconnaissance Master Plan for the Development of the Natural Resources of the Rift Valley Lakes Basin. Ministry of water resources.

Halcrow.(2007). Rift Valley Lakes Basin Integrated Resources Development Master Plan Study Project. Ministry of Water Resource the Ongoing Master Plan (Volume 1 to Volume 8).

Hengsdijk ,H., Dagnachew Legesse., Herco, J., Tenalem Ayenew., Petra, S and Petra, H.(2007). Land and water resources assessment in the Ethiopian Central Rift Valley Project: ecosystems for water, food and economic development in the Ethiopian Rift Valley.

Hengsdijk, H and Herco, J.(2006). Agricultural development in the Central Ethiopian Rift valley: A desk-study on water-related issues and knowledge to support a policy dialogue.

Hengsdijk, H and Herco, J.(2006). Ecosystems for water, food and economic development in the Ethiopian central rift valley (BO-10-006-22) Report of inception mission to Ethiopia and Work plan 2006.

JICA and OIDA (Japan International Cooperation Agency and Oromiya Irrigation Development Authority) (2001). The study for Meki Irrigation and Rural Development Project in Oromiya Region, Ethiopia, Interim Report.

JICA and OIDA (Japan International Cooperation Agency and Oromiya Irrigation Development Authority) (2004). The study on the capacity building programs for community based irrigation development in Central Oromiya region of Ethiopia. Draft Final report. Volume **II**: Annex.

Kinfe HaileMariam (1999). Impact of Climate Change on the Awash River Basin, Ethiopia, Climate Research, International and Multidisciplinary, Volume, **212**: 91-96 pp

Klemes, V.(1986). Operational testing of hydrological Simulation Models. *Hydrological Science Journal* **31**, 13-24.

Leavesley, F. H.(1994).Modeling the effect of Climate Change on water resources-a review. Climate change **28**, 159-177.

Lijalem Zeray (2006). Climate change impact on Lake Ziway watershed water availability, Ethiopia. MSc Thesis University of Applied Science Cologne, Germany

Makin, M.J., T.J. Kingham., A.E.Waddams, C.J. Birchall and B.W. Eavis (1976).Prospects for irrigation development around lake Ziway, Ethiopia. Land Res. Study. Division Ministry of Overseas Development, 26. Tolworth, UK. 270 pp.

Mark W. Rosegrant and Nicostrato D. Perez (1997). Water Resources Development in Africa: A Review and Synthesis of Issues, Potentials, and Strategies for the future.

Mercier, F., Cazenave, A., Maheu, C.(2002).Inter annual lake level fluctuations (1993-1999) in Africa from Topex/Poseidon: connections with ocean-atmosphere interactions over the Indian Ocean. *Global and Planetary Changes* **32**,114-163.

Ministry of Water Resources (MoWR).(1999). Ethiopian Water Resources Management Policy.

Ministry of Water Resources (MoWR).(2002). Water Sector Development Programme 2002 – 2016.

OWRB (Oromiya Water Resources Bureau).(2006). Water Resource utilization study in Ziway Abiyata Lake System.

Robert Arranz and Matthew McCartney.(2007). Application of the Water Evaluation And Planning (WEAP) Model to Assess Future Water Demands and Resources in the Olifants Catchment, South Africa Working Paper 116.

Scholten, W.(2007). Agricultural development and water use in the Central Rift Valley of Ethiopia. A rapid appraisal. Internship Report. University of Twente.

SEI (Stockholm Environment Institute).(2007). WEAP: Water Evaluation and Planning System-User Guide. Stockholm Environment Institute, Boston, USA.

Street, F.A.(1979).Late Quaternary Lakes in the Ziway Shalla Basin,Southern Ethiopia, PhD thesis, University of Cambridge, UK,457.

Tamiru Alemayehu., Tenalem Ayenew., and Seifu Kebede (2006). Hydrochemical and Lake Changes in the Ethiopian Rift. *Journal of Hydrology* **316**: 290-300.

Tenalem Ayenew (1998). The hydrogeological system of the Lake District Basin, Central Main Ethiopian Rift. PhD Thesis, Free University of Amsterdam. The Netherlands.259.

Tenalem Ayenew (2002a). Recent changes in the level of Lake Abiyata, central main Ethiopian Rift. *Hydrological Sciences-Journal'des*, **47**(3) 493.

Tenalem Ayenew (2002b). Application of environmental isotopes for the study of the hydrogeological system of some Ethiopian Rift lakes. Proceedings of the International Conference on Isotopes. 10-14 March 2002. Cape Town,South Africa.

Tenalem Ayenew (2002c). Integrated groundwater flow system analysis in the Central Main Ethiopian Rift lake basin. Proceedings of the Australian National Chapter of the International Association of Hydrogeologists " Balancing the Groundwater Budget". 12-17 May, Darwin, Australia.

Tenalem Ayenew (2003). Evapotranspiration estimation using thematic Mapper Spectral Satellite data in the Ethiopia rift and adjacent highlands. *Journal of Hydrology* **279**: 83-93

Tenalem Ayenew (2004). Environmental implications of changes in the levels of lakes in the Ethiopian Rift Since 1970. *Regional Rural change* **4**: 192-204.

Tesfaye Chernet (1982). Hydrogeology of the lakes region, Ethiopia (Lakes Ziway, Langano, Abiyata, Shalla and Awassa). Ministry of Mines and Energy, Ethiopian Institute of Geological Surverys. Addis Ababa, Ethiopia.

Troutman, B. M.(1985). Errors and Parameter estimation in precipitation-runoff modeling.1, Theory. *Water Resources Research* **21** (8).

WWDSE.(2008). Ziway Irrigation Project. Final Feasibility Report. Annex-A Hydrology.

WAPCOS (Water and Power Consultancy Service).(1990). Preliminary water resources development master plan for Ethiopia: final report, vol., III, Ethiopian Valleys Development Studies Authority, Addis Ababa, 253 pp

UNESCO.(2008). The United Nations World Water Development Report, World water assessment program.

Vallet,C., Dagnachew Legesse., Gasse, F., Travi, Y., and Tesfaye Chernet (2001). Lake evaporation estimates in tropical Africa (Lake Ziway, Ethiopia). *Journal of Hydrology* **245**, 1–18.

Zinabu GeberMariam (1989). Water resources and fisheries management in the rift valley lakes. *SINET: Ethiopian J. Sci*. **12,** 95–109.

Appendices

Annex 1. Monthly Flow Time Series Used For Modeling

Annex 1.1 Ketar Flow (Mm^3) Area 3350 km^2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1980	**6.89**	**6.92**	**6.23**	**6.35**	**6.60**	**10.43**	**45.43**	**104.11**	**49.99**	**21.20**	**7.66**	**6.58**	278.39
1981	**5.99**	**5.89**	**11.01**	**58.72**	**21.65**	**7.57**	**34.05**	**172.05**	**152.98**	**90.84**	**9.64**	**6.58**	576.97
1982	**7.30**	**6.95**	**6.57**	**14.50**	**14.66**	**10.62**	**33.42**	**135.33**	**54.08**	**41.22**	**12.17**	**7.38**	344.20
1983	**1.29**	**1.29**	**1.29**	**25.90**	**44.28**	**63.63**	**31.90**	**267.79**	**111.71**	**63.25**	**1.86**	**11.86**	626.05
1984	**0.76**	**0.45**	**1.20**	**0.53**	**8.43**	**16.82**	**46.52**	**68.36**	**60.69**	**9.54**	**6.34**	**1.02**	220.66
1985	**5.35**	**4.75**	**4.59**	**8.74**	**21.30**	**8.64**	**44.90**	**91.19**	**50.52**	**10.57**	**5.20**	**6.10**	261.85
1986	**4.96**	**7.64**	**9.14**	**13.66**	**15.37**	**26.52**	**75.46**	**138.05**	**92.45**	**35.18**	**9.08**	**4.88**	432.39
1987	**4.93**	**4.85**	**13.05**	**48.52**	**26.23**	**39.58**	**26.85**	**51.81**	**45.69**	**19.75**	**6.35**	**6.72**	294.33
1988	**4.96**	**5.67**	**5.40**	**6.17**	**6.74**	**7.30**	**61.58**	**266.32**	**92.46**	**54.44**	**13.83**	**5.38**	530.25
1989	**6.44**	**6.30**	**6.24**	**17.11**	**15.53**	**10.52**	**34.39**	**67.11**	**78.09**	**32.41**	**9.18**	**7.20**	290.52
1990	**0.80**	**29.32**	**53.62**	**57.09**	**14.24**	**11.54**	**76.37**	**88.56**	**67.89**	**28.73**	**8.29**	**10.73**	447.18
1991	**5.77**	**5.99**	**10.06**	**14.43**	**7.42**	**9.21**	**37.64**	**122.62**	**96.60**	**16.45**	**6.85**	**6.39**	339.43
1992	**5.40**	**6.59**	**4.71**	**8.15**	**8.21**	**8.66**	**21.92**	**176.73**	**144.60**	**67.18**	**12.21**	**6.20**	470.56
1993	**7.27**	**17.55**	**5.88**	**13.67**	**30.82**	**30.98**	**43.96**	**141.50**	**95.63**	**53.90**	**19.20**	**7.58**	467.94
1994	**5.74**	**5.14**	**4.39**	**4.18**	**1.46**	**11.43**	**61.43**	**184.50**	**131.48**	**18.81**	**7.52**	**7.23**	443.31
1995	**4.18**	**4.24**	**21.27**	**19.35**	**14.58**	**6.79**	**33.75**	**129.67**	**158.89**	**12.30**	**6.29**	**5.48**	416.79
1996	**6.64**	**4.53**	**7.65**	**10.54**	**18.04**	**48.05**	**57.58**	**171.74**	**65.29**	**22.87**	**6.54**	**5.65**	425.13
1997	**7.80**	**4.47**	**4.19**	**16.07**	**6.97**	**7.33**	**36.35**	**56.20**	**29.61**	**14.94**	**18.65**	**5.79**	208.37
1998	**5.85**	**9.25**	**13.41**	**6.37**	**16.04**	**9.80**	**35.88**	**185.31**	**132.84**	**75.30**	**18.11**	**7.88**	516.06
1999	**5.34**	**1.16**	**4.58**	**4.41**	**4.52**	**8.54**	**45.54**	**90.68**	**56.81**	119.10	**19.96**	**6.33**	366.97
2000	**4.24**	**4.22**	**4.17**	**3.98**	**12.50**	**7.35**	**26.07**	**132.07**	**76.83**	**67.68**	**23.32**	**6.26**	368.70
2001	**4.71**	**4.15**	**5.82**	**6.88**	**20.28**	**37.01**	**91.92**	**214.42**	**101.40**	**27.98**	**6.55**	**6.71**	527.83
2002	**4.94**	**5.10**	**7.41**	**5.58**	**2.43**	**13.47**	**48.92**	**71.17**	**36.01**	**8.93**	**3.96**	**4.79**	212.71
2003	**6.53**	**3.72**	**4.16**	**10.53**	**10.17**	**6.53**	**44.51**	**139.12**	**77.66**	**20.07**	**4.93**	**5.15**	333.08
2004	**3.94**	**3.59**	**3.61**	**23.34**	**9.44**	**8.89**	**53.66**	**101.87**	**71.86**	**36.34**	**5.95**	**4.96**	327.44
Mean	5.12	6.39	8.79	16.19	14.32	17.09	46.00	134.73	85.28	38.76	9.99	6.43	389.08

Annex 1.2 Meki Flow (Mm^3) Area $2433km^2$

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1980	2.16	2.41	3.40	5.66	4.04	11.84	44.36	56.43	24.70	11.65	2.12	1.41	170.18
1981	1.07	1.18	36.66	51.92	14.87	7.39	28.51	80.71	58.75	13.68	1.60	3.05	299.39
1982	2.46	4.29	3.46	18.21	19.06	6.55	22.11	80.54	24.97	44.24	6.69	4.35	236.93
1983	1.42	6.67	12.36	30.77	48.11	36.19	26.56	89.43	55.42	20.16	4.48	2.38	333.95
1984	1.65	1.21	1.20	0.82	6.95	11.87	26.81	26.28	34.25	2.89	0.91	0.77	115.61
1985	0.59	0.44	0.45	4.38	17.30	3.27	24.40	72.72	40.24	7.22	0.87	0.45	172.32
1986	0.25	1.25	2.32	12.67	6.83	25.88	63.19	76.78	48.07	5.07	0.51	0.11	242.93
1987	0.02	0.68	20.60	47.30	46.23	37.90	20.12	16.80	18.87	6.73	1.01	0.11	216.37
1988	0.09	1.02	0.40	7.95	5.94	7.87	41.96	62.27	58.23	33.79	7.55	2.45	229.52
1989	0.37	5.88	8.83	25.00	7.91	10.13	40.63	41.13	47.25	26.04	4.26	2.37	219.80
1990	0.88	27.45	54.08	57.02	14.14	15.04	45.72	53.02	39.33	17.20	4.80	2.34	331.02
1991	1.33	6.28	19.20	7.41	2.44	9.80	65.51	93.50	52.18	9.31	2.25	1.79	271.00
1992	2.38	13.48	5.77	12.86	11.27	8.45	18.35	136.74	84.86	33.37	7.74	4.24	339.51
1993	2.48	2.38	2.65	34.86	46.98	31.95	67.48	144.14	51.61	57.06	11.59	2.41	455.57
1994	2.17	1.21	1.64	0.79	1.00	11.16	63.18	153.94	121.27	4.59	2.58	0.63	364.15
1995	1.76	2.00	22.36	12.65	10.02	6.63	28.26	72.11	82.63	6.36	3.37	1.91	250.06
1996	6.54	0.61	19.65	24.63	51.64	86.30	109.10	149.72	63.53	14.86	5.15	3.24	534.98
1997	0.84	0.65	2.65	25.78	7.75	11.31	44.45	44.45	13.99	14.40	16.03	2.47	184.77
1998	4.28	1.79	32.46	8.48	31.52	13.55	73.98	187.79	75.78	61.92	6.62	1.12	499.28
1999	0.24	0.18	7.61	0.30	1.36	7.35	55.29	60.05	26.32	85.06	32.31	4.69	280.76
2000	1.28	0.85	0.43	1.66	8.55	6.80	43.25	84.95	67.33	53.49	21.50	9.29	299.38
2001	0.37	1.04	16.22	9.50	23.55	59.97	112.28	129.68	73.22	8.55	2.98	2.34	439.70
2002	13.24	9.37	5.27	3.64	1.67	13.15	40.97	57.00	31.19	5.78	4.38	1.60	187.26
2003	2.31	1.24	21.03	16.16	5.24	11.96	112.78	125.75	54.14	9.82	0.84	3.80	365.07
2004	2.24	0.65	1.94	1.94	0.65	2.00	18.49	56.20	21.33	8.72	0.39	0.11	114.66
Mean	2.10	3.77	12.11	16.89	15.80	18.17	49.51	86.08	50.78	22.48	6.10	2.38	286.17

Annex 1. 3 Un gauged inflow into Lake Ziway (Mm³) Area 1055 km²

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	0.00	0.00	0.00	0.00	0.00	3.35	17.79	43.93	0.00	0.00	0.00	0.00	65.07
1981	0.00	0.00	6.91	12.52	0.00	0.00	27.12	30.45	11.84	0.00	0.00	0.00	88.84
1982	0.00	0.00	0.00	0.00	0.00	0.00	32.12	36.85	0.00	0.00	0.00	0.00	68.97
1983	0.00	0.00	0.00	10.22	9.87	0.00	26.22	33.44	0.00	0.00	0.00	0.00	79.75
1984	0.00	0.00	0.00	0.00	11.16	12.99	22.29	12.78	0.00	0.00	0.00	0.00	59.22
1985	0.00	0.00	0.00	0.00	0.00	0.00	9.46	15.59	0.00	0.00	0.00	0.00	25.05
1986	0.00	3.79	0.00	0.00	1.48	9.79	20.04	0.00	0.00	0.00	0.00	0.00	35.10
1987	0.00	0.00	0.00	0.00	0.66	0.00	19.28	0.00	0.00	0.00	0.00	0.00	19.94
1988	0.00	0.00	0.00	0.00	0.00	3.89	27.18	34.46	12.61	0.00	0.00	0.00	78.14
1989	0.00	0.00	14.80	0.53	0.00	5.51	21.17	31.99	6.16	0.00	0.00	0.00	80.16
1990	0.00	4.48	0.00	0.00	0.00	0.00	39.51	38.32	0.00	0.00	0.00	0.00	82.31
1991	0.00	0.00	0.06	0.00	0.00	7.38	29.55	28.29	0.00	0.00	0.00	0.00	65.28
1992	0.00	0.00	0.00	0.00	0.00	15.60	25.55	23.79	0.00	0.00	0.00	0.00	64.94
1993	0.00	0.00	0.00	12.19	0.00	4.67	12.38	20.74	0.00	0.00	0.00	0.00	49.98
1994	0.00	0.00	0.00	0.00	0.00	11.57	19.23	31.69	0.00	0.00	0.00	0.00	62.49
1995	0.00	0.00	0.00	19.25	0.00	0.00	25.47	12.47	0.00	0.00	0.00	0.00	57.19
1996	0.00	0.00	0.00	0.00	3.63	7.98	26.19	43.79	0.00	0.00	0.00	0.00	81.59
1997	0.00	0.00	0.00	1.18	0.00	8.64	19.88	0.00	0.00	0.00	0.00	0.00	29.70
1998	0.00	0.00	0.00	0.00	0.00	4.35	22.28	26.94	0.00	0.00	0.00	0.00	53.57
1999	0.00	0.00	0.00	0.00	0.00	6.59	22.97	31.60	0.00	0.00	0.00	0.00	61.16
2000	0.00	0.00	0.00	0.00	0.00	0.00	15.98	20.67	7.66	0.00	0.00	0.00	44.31
2001	0.00	0.00	7.79	0.00	2.56	7.88	35.72	29.10	0.00	0.00	0.00	0.00	83.05
2002	0.00	0.00	0.00	0.00	0.00	6.74	18.37	24.15	0.00	0.00	0.00	0.00	49.26
2003	0.00	0.00	0.00	8.20	0.00	5.76	19.66	22.13	0.00	0.00	0.00	0.00	55.75
2004	0.00	0.00	0.00	7.67	0.00	8.08	23.88	27.99	13.05	0.00	0.00	0.00	80.67
Mean	0.00	0.33	1.18	2.87	1.17	5.23	23.17	24.85	2.05	0.00	0.00	0.00	60.86

Annex 1 .4 HoraKelo nr Langano Outlet (Mm³) Area 2006 km²

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1980	1.15	0.42	0.10	0.08	0.04	0.04	0.07	0.61	1.63	1.75	1.00	0.26	7.15
1981	0.00	0.00	0.01	0.01	0.04	0.01	0.01	0.46	4.96	5.47	3.15	2.16	16.28
1982	1.00	0.57	0.32	0.08	0.17	0.06	0.09	2.73	4.72	19.29	5.30	4.01	38.34
1983	1.00	0.91	0.26	0.29	0.46	1.52	2.47	4.06	6.17	17.58	17.58	14.52	66.82
1984	9.03	5.47	2.93	1.05	0.23	0.17	0.38	2.04	3.14	3.28	1.30	0.42	29.44
1985	0.00	0.00	0.01	0.03	0.03	0.02	0.02	0.03	1.15	1.40	0.57	0.00	3.26
1986	0.00	0.00	0.01	0.02	0.02	0.00	0.63	0.71	1.39	1.49	0.93	0.21	5.41
1987	0.00	0.00	0.35	0.82	1.15	1.46	1.25	1.40	1.62	1.57	1.30	0.42	11.34
1988	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	2.22	3.43	3.22	1.62	10.59
1989	0.65	0.26	0.06	0.20	0.20	0.04	0.08	0.32	1.97	2.54	1.80	0.82	8.94
1990	0.84	0.49	0.90	1.30	1.37	1.21	2.57	6.24	10.45	11.32	6.50	3.53	46.72
1991	1.72	0.92	0.68	0.45	0.15	0.06	0.20	0.54	1.78	1.97	0.78	0.29	9.54
1992	0.07	0.03	0.03	0.14	0.11	0.01	0.01	0.13	1.33	5.16	7.84	5.37	20.23
1993	0.45	0.49	0.23	0.08	0.03	0.04	0.10	1.20	5.96	5.49	5.15	2.87	22.09
1994	1.15	0.80	0.54	0.49	0.54	0.06	1.05	5.66	10.59	10.80	5.66	3.01	40.35
1995	1.91	1.10	0.86	0.91	1.05	1.00	1.40	3.08	7.09	6.72	4.99	3.15	33.26
1996	1.68	1.30	0.91	0.32	0.61	2.03	3.36	10.06	10.70	10.38	9.54	3.58	54.47
1997	3.96	2.10	0.65	0.22	0.38	0.23	0.91	1.57	1.51	1.51	1.68	1.30	16.02
1998	1.00	0.65	0.38	0.12	0.08	0.04	0.00	0.73	1.63	3.08	3.08	2.09	12.88
1999	1.93	0.64	0.43	0.18	0.05	0.02	0.13	0.87	2.50	8.16	9.49	5.39	29.79
2000	2.70	1.03	0.32	0.08	0.11	0.04	0.07	0.48	2.29	7.19	7.69	5.23	27.23
2001	2.60	1.25	0.86	0.69	0.65	1.02	2.14	8.56	16.21	15.95	10.18	6.00	66.11
2002	3.52	1.56	0.88	0.44	0.22	0.12	0.06	0.69	1.71	1.54	0.45	0.10	11.29
2003	0.29	0.00	0.00	0.06	0.01	0.11	0.41	0.41	1.20	1.26	0.93	0.41	5.09
2004	0.03	0.00	0.00	0.21	0.00	0.01	0.06	0.01	0.11	0.25	0.00	0.00	0.68
Mean	1.47	0.80	0.47	0.33	0.31	0.37	0.70	2.11	4.16	5.94	4.40	2.67	23.73

Annex 1 .5 Bulbula River nr Adamitulu (Mm^3) Area 7488 Km^2

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
1980	10.47	5.49	2.41	1.60	1.50	0.46	0.50	2.25	5.24	5.40	3.10	1.01	39.43
1981	0.55	0.44	0.56	0.51	0.59	0.52	0.59	6.29	32.65	47.61	33.45	20.59	144.35
1982	8.48	4.25	2.67	1.60	1.43	0.78	0.69	5.55	17.52	21.10	9.00	6.00	79.07
1983	5.15	3.13	2.16	2.41	4.04	11.51	15.38	35.36	93.58	87.80	84.25	50.23	395.00
1984	29.09	15.33	8.38	3.66	1.81	1.44	1.78	7.77	14.29	11.74	5.59	2.47	103.35
1985	1.04	0.75	0.67	0.50	0.47	0.46	0.47	0.84	5.20	6.86	2.57	1.27	21.10
1986	0.67	0.57	0.57	0.55	0.58	0.49	0.61	3.38	7.93	10.84	5.54	3.23	34.96
1987	1.76	0.63	0.60	1.51	2.16	6.26	4.36	6.44	10.65	14.82	8.51	5.19	62.89
1988	3.19	2.16	1.74	1.75	1.69	1.71	1.76	3.92	13.21	37.55	27.52	16.15	112.35
1989	8.87	4.77	3.03	3.79	2.05	2.11	2.74	7.39	27.37	36.37	18.40	10.02	126.91
1990	9.08	1.12	3.73	8.63	7.35	2.12	3.25	9.83	38.15	39.09	21.73	19.86	163.94
1991	9.29	3.30	1.81	0.70	0.81	0.34	1.10	12.27	48.93	41.81	25.05	13.98	159.39
1992	5.95	2.02	0.66	0.29	0.04	0.01	0.11	12.23	58.94	67.18	50.12	30.88	228.43
1993	18.24	12.60	5.85	2.91	9.20	14.88	23.16	54.34	72.16	64.77	44.95	29.90	352.96
1994	21.28	12.12	8.88	4.79	0.13	0.10	0.08	10.55	38.85	48.58	36.30	27.42	209.08
1995	13.96	5.59	4.01	1.21	4.80	2.60	2.87	10.17	24.22	62.84	42.43	30.46	205.16
1996	4.93	1.48	0.76	0.84	2.31	7.00	19.26	55.86	92.77	77.10	48.55	33.49	344.35
1997	23.01	16.39	11.07	18.83	15.39	8.19	14.44	24.13	26.07	22.74	19.17	12.62	212.05
1998	7.22	3.58	3.18	0.92	1.63	1.47	2.03	24.48	63.33	85.41	72.03	55.54	320.82
1999	39.46	24.51	3.82	1.33	1.50	1.03	1.98	9.33	19.00	46.05	58.43	48.78	255.22
2000	28.78	14.52	4.45	1.73	1.37	0.60	1.68	4.57	16.07	37.58	39.13	42.01	192.49
2001	22.57	17.18	9.73	7.44	3.17	1.36	10.70	20.01	65.17	63.76	37.59	30.93	289.61
2002	25.80	8.93	6.49	4.96	2.11	1.12	5.71	4.98	7.00	3.84	2.85	32.59	106.38
2003	1.69	0.68	3.24	2.48	1.06	0.88	0.72	1.96	5.00	4.73	2.92	2.62	27.98
2004	0.36	0.01	0.00	0.00	0.00	0.00	0.00	0.82	5.08	4.82	1.83	1.59	14.51
Mean	12.04	6.46	3.62	3.00	2.69	2.70	4.64	13.39	32.34	38.02	28.04	21.15	168.07

Annex1. 6 Lake Abiyata Level (m) Lake Mean Stage-Level (m 0 Gauge height is at 1576.4 m a.s.l)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	6.04	5.96	5.76	5.58	5.46	5.34	5.26	5.17	5.12	5.08	5.00	4.92	5.39
1981	4.77	4.55	4.40	4.45	4.31				4.08	4.21	4.26	4.17	
1982	4.13	4.05	4.05	4.08							3.84	3.84	
1983	3.74	3.62	3.51				3.47	3.67	4.07	4.72	5.16	5.47	
1984	5.58	5.61	5.50	5.35	5.17	5.08	5.04	5.08	5.10	5.08	4.94	4.73	5.19
1985	4.57	4.41	4.23	4.10	4.02	3.88	3.80	3.80	3.74	3.62	3.43	3.26	3.91
1986	3.11						2.77	2.72	2.68	2.78	2.76	2.66	
1987	2.52	2.15	2.13	2.19	2.14	2.19	2.08						
1988						1.18	1.11	1.09	1.10	1.20	1.25	1.25	
1989	1.12	1.06	1.07	1.08			0.33	0.27	0.28	0.42	0.44	0.45	
1990	0.40	0.37	0.39	0.36	0.31	0.38	0.24	0.27	0.40	0.88	1.13	1.13	0.52
1991	0.97	0.95	0.99	0.98	0.76	0.61	0.59	0.64	0.65	0.89	0.96	0.87	0.82
1992	0.84	0.92	0.69	0.44	0.43	0.38	0.48	0.56	0.66	1.06	1.30	1.58	0.78
1993	1.60	1.60	1.54	1.44	1.43	1.50	1.52	1.62	1.82	2.20	2.38	2.36	1.75
1994	2.30	2.30	1.12	1.22	1.13	0.94	0.90	0.96	1.22	1.44	1.47	1.48	1.37
1995	1.44	1.45	1.40	1.44	1.42	1.30	1.22	1.22	1.25	1.51	1.69	1.53	1.41
1996	1.54	1.42	1.24	1.17	1.11	1.14	1.29	1.57	2.08	2.52	2.72	2.79	1.72
1997	2.72	2.65	2.52				2.22	2.27	2.42	2.42	2.47	2.39	
1998	2.30	2.22	2.16	2.01	1.90								
1999	2.70	2.65	2.65	2.62	2.48	2.39	2.36	2.34	2.33	2.55	2.76	2.83	2.56
2000	2.85	2.76	2.59	2.43	2.37	2.25	2.20	2.17	2.17	2.31	2.43	2.47	2.42
2001	2.45	2.36	2.28	2.17	2.10	2.06	2.03	2.06	2.30	2.60	2.72	2.77	2.33
2002	2.79	2.72	2.68	2.59	2.46	2.32	2.24	2.22	2.18	2.05	2.85	2.69	2.48
2003	2.61	2.50	2.37	2.17	2.10	1.98	1.97	1.97	1.96	1.88	1.69	1.54	2.06
2004	1.41	1.30	1.09	1.05	0.90	0.87	0.83	0.80	0.75	0.73	0.57	0.40	0.89
Mean	2.69	2.59	2.45	2.33	2.21	1.99	2.00	2.02	2.20	2.37	2.53	2.50	2.32

Annex 1. 7 Lake Ziway Level (m) Lake Mean Stage-Level (m 0 Gauge height is at 1635.1m a.s.l)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	1.18	1.05	0.91	0.79	0.62	0.52	0.56	0.81	1.00	1.01	0.83	0.65	0.83
1981	0.54	0.43	0.38	0.60	0.63	0.50	0.49	0.99	1.45	1.65	1.42	1.24	0.86
1982	1.11	0.94	0.86	0.79	0.77	0.68	0.66	0.99	1.30	1.37	1.31	1.17	1.00
1983	1.02	0.91	0.81	0.89	0.94	1.21	1.23	1.65	2.17	2.17	1.96	1.72	1.39
1984	1.44	1.31	1.09	0.90	0.80	0.78	0.81	1.14	1.31	1.24	1.04	0.87	1.06
1985	0.72	0.60	0.46	0.35	0.35	0.26	0.27	0.68	1.03	1.06	0.91	0.78	0.62
1986	0.58	0.52	0.48	0.41	0.38	0.36	0.63	0.92	1.09	1.23	1.10	0.98	0.72
1987	0.82	0.72	0.69	0.69	0.78	1.06	1.10	1.16	1.20	1.14	1.00	0.81	0.93
1988	0.65	0.53	0.39	0.24	0.20	0.19	0.28	0.67	1.13	1.40	1.33	1.19	0.68
1989	1.02	0.92	0.81	0.82	0.78	0.70	0.76	0.99	1.26	1.36	1.22	1.04	0.97
1990	0.92	0.87	1.09	1.21	1.19	1.08	1.12	1.46	1.74	1.68	1.48	1.64	1.29
1991	1.12	1.00	0.98	0.93	0.82	0.69	0.79	1.24	1.65	1.57	1.35	1.17	1.11
1992	1.07	0.98	0.87	0.74	0.67	0.66	0.89	1.28	1.70	1.74	1.57	1.41	1.13
1993	1.30	1.21	1.07	0.95	1.05	1.13	1.25	1.60	1.80	1.80	1.65	1.47	1.36
1994	1.29	1.15	0.96	0.84	0.72	0.71	0.82	1.33	1.71	1.77	1.46	1.34	1.18
1995	1.21	1.09	0.95	0.89	1.01	0.96	0.91	1.20	1.06	1.41	1.20	1.06	1.08
1996	0.97	0.83	0.72	0.76	0.89	1.07	1.35	1.84	2.24	2.16	1.88	1.68	1.37
1997	1.53	1.40	1.24	1.24	1.22	1.11	1.20	1.36	1.42	1.34	1.31	1.18	1.30
1998	1.06	0.96	0.93	0.87	0.83	0.79	0.89	1.44	1.97	2.13	2.04	1.78	1.31
1999	1.56	1.37	1.23	1.09	0.96	0.82	0.94	1.23	1.43	1.65	1.80	1.60	1.31
2000	1.41	1.22	1.03	0.82	0.79	0.74	0.80	1.02	1.40	1.58	1.55	1.41	1.15
2001	1.27	1.12	1.03	1.00	0.94	0.97	1.21	1.70	2.25	2.15	1.93	1.41	1.42
2002	1.57	1.41	1.30	1.20	1.08	0.99	0.93	1.03	1.22	1.15	0.97	1.75	1.22
2003	0.69	0.58	0.45		0.36	0.24	0.37	0.86	1.17	1.19	1.03	0.81	
2004	0.84	0.76	0.57	0.55	0.52	0.40	0.37	0.74	0.95	1.11	1.01	0.93	0.73
Mean	1.08	0.96	0.85	0.82	0.77	0.74	0.83	1.17	1.47	1.52	1.37	1.24	1.07

Annex 1.8 Lake Ziway Areal Rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	23.10	11.10	5.80	40.40	21.80	76.10	141.30	110.90	59.80	36.90	0.00	0.00	527.20
1981	0.00	9.40	159.30	110.50	36.90	7.50	220.70	196.80	186.70	19.80	4.60	0.20	952.40
1982	50.20	16.10	55.80	86.60	71.40	31.70	112.40	208.20	79.60	128.20	8.90	0.90	850.00
1983	18.10	62.00	65.50	118.60	198.90	49.20	171.40	144.30	80.60	28.90	0.00	0.00	937.50
1984	0.00	4.30	6.20	7.70	121.80	57.60	203.00	174.70	65.80	0.00	0.00	0.00	641.10
1985	0.10	0.00	19.50	96.90	93.50	21.10	165.70	158.50	81.90	6.10	101.20	0.00	744.50
1986	0.00	110.30	25.40	56.00	105.80	123.20	140.90	60.60	85.80	30.10	0.00	0.00	738.10
1987	0.00	21.90	86.40	56.90	225.40	14.50	59.80	73.90	38.20	9.70	0.00	0.00	586.70
1988	1.60	36.00	15.00	66.50	14.00	92.80	126.60	121.00	126.10	72.00	0.00	0.10	671.70
1989	7.80	42.70	168.30	101.80	6.30	121.70	121.80	146.30	125.00	11.90	0.00	24.80	878.40
1990	0.00	199.20	11.10	79.00	34.70	36.90	171.80	163.30	85.90	6.40	0.00	0.00	788.30
1991	3.10	75.10	140.30	5.00	28.90	52.30	133.80	151.60	41.90	6.10	0.00	18.40	656.50
1992	21.70	42.50	6.60	52.10	55.10	92.70	249.70	181.60	37.50	88.20	0.50	9.20	837.40
1993	50.40	97.20	0.60	102.50	98.20	69.90	186.70	134.10	40.60	67.90	0.10	0.00	848.20
1994	0.00	0.00	21.90	12.00	51.90	147.90	161.50	112.80	91.00	0.00	5.50	0.10	604.60
1995	0.00	14.30	43.50	115.50	21.60	44.20	78.20	98.30	52.70	4.00	0.00	3.90	476.20
1996	14.20	4.40	49.30	90.70	110.50	109.70	121.50	150.20	94.40	0.00	18.50	0.00	763.40
1997	20.00	0.00	39.10	182.50	2.40	111.30	161.00	59.10	30.80	83.70	0.20	0.00	690.10
1998	6.10	36.40	39.40	55.20	34.40	75.60	165.50	207.50	93.10	90.80	0.00	0.00	804.00
1999	5.50	0.00	44.40	11.20	41.10	81.90	125.60	90.80	73.50	143.60	0.00	0.00	617.60
2000	0.00	0.00	1.00	92.30	78.30	41.20	140.80	127.70	121.00	24.60	30.80	27.30	685.00
2001	0.00	21.10	146.70	29.10	123.40	62.50	145.10	149.80	65.90	0.00	0.00	0.60	744.20
2002	6.00	16.80	47.40	58.70	42.20	63.50	101.00	98.00	52.20	0.00	0.00	13.10	498.90
2003	20.30	3.10	73.80	121.90	24.30	74.70	225.70	137.90	73.30	0.00	1.10	37.30	793.40
2004	42.00	0.30	19.40	144.30	0.00	63.90	116.10	114.40	124.20	37.10	0.90	0.00	662.60
Mean	11.61	32.97	51.67	75.76	65.71	68.94	149.90	134.89	80.30	35.84	6.89	5.44	719.92

Annex 1. 9 Lake Abiyata Areal Rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	5.30	0.00	0.00	0.00	0.00	0.00	0.00	83.80	17.50	44.00	0.00	0.00	150.60
1981	5.30	25.40	236.30	65.10	16.50	12.10	167.30	101.00	103.60	6.30	0.00	0.00	738.90
1982	49.50	25.40	30.40	166.30	99.80	51.70	127.90	105.70	70.00	59.00	19.90	4.30	809.90
1983	1.80	27.50	103.20	75.08	69.80	74.15	134.10	109.92	72.51	79.90	0.00	0.00	747.96
1984	0.00	0.00	15.10	3.60	124.00	67.30	211.60	159.70	37.70	0.00	0.00	0.00	619.00
1985	0.00	0.00	18.80	125.30	65.80	0.00	131.50	73.60	80.30	8.00	9.60	5.80	518.70
1986	0.00	21.10	50.40	99.40	110.30	120.00	105.50	80.40	30.20	25.50	0.00	1.60	644.40
1987	1.30	18.50	129.10	114.30	154.70	56.60	64.30	44.70	54.30	36.30	0.00	0.00	674.10
1988	3.80	14.50	3.40	58.10	25.50	67.40	71.70	97.00	84.50	27.30	0.00	0.30	453.50
1989	13.60	114.20	48.30	108.60	7.20	135.20	98.80	66.00	165.70	35.20	1.80	5.22	799.82
1990	0.00	144.60	102.20	93.70	75.90	65.20	136.10	91.20	54.90	19.70	0.00	0.00	783.50
1991	6.70	48.10	95.70	6.10	18.00	108.90	153.30	42.90	57.70	0.00	19.60	5.22	562.22
1992	11.10	18.40	0.00	44.50	38.20	87.10	98.30	26.30	15.20	42.56	0.00	0.00	381.66
1993	45.20	61.30	0.00	21.50	79.10	70.10	68.90	144.70	52.40	104.80	0.00	0.00	648.00
1994	0.00	0.00	21.50	52.60	139.60	166.10	288.10	125.10	146.60	0.00	9.40	0.00	949.00
1995	0.00	24.60	30.30	154.20	60.20	36.20	127.50	101.90	63.00	1.80	0.00	32.70	632.40
1996	66.40	0.00	36.70	80.00	122.90	153.00	140.90	153.80	72.51	42.56	6.00	0.00	874.77
1997	15.71	23.40	0.00	37.30	69.10	11.50	134.10	70.00	53.70	118.80	11.80	0.00	545.41
1998	82.20	38.50	6.20	32.70	31.30	17.50	159.10	179.20	69.90	70.70	0.90	0.50	688.70
1999	1.20	26.26	150.10	45.40	46.70	39.60	60.40	106.20	88.70	217.10	0.00	0.00	781.66
2000	15.71	0.00	0.00	58.60	127.10	53.30	107.60	115.40	140.70	75.90	67.00	6.70	768.01
2001	0.00	17.00	84.70	51.40	105.70	151.80	112.00	85.90	68.50	8.00	1.20	0.00	686.20
2002	1.20	10.80	32.50	51.50	15.60	84.40	99.10	147.30	12.50	1.80	0.00	25.10	481.80
2003	12.20	14.60	35.10	81.30	17.40	105.80	177.80	125.40	61.40	0.00	3.60	36.10	670.70
2004	30.10	0.00	8.80	61.10	0.00	63.60	82.50	90.30	79.50	23.40	6.00	1.30	446.60
Mean	14.73	26.97	49.55	67.51	64.82	71.94	122.34	101.10	70.14	41.94	6.27	4.99	642.30

Annex 1. 10 Estimated Meki Dam Rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	26.7	54.2	92	99.8	92.5	106.7	179.3	168.7	107.9	142.5	139.2	8.5	1218

Annex1. 11: Estimated Meki Dam Open water evaporation (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
	119.8	119.5	135.5	123.3	124.8	106.2	93.5	96.2	103	122.4	120.5	122.5	1387.2

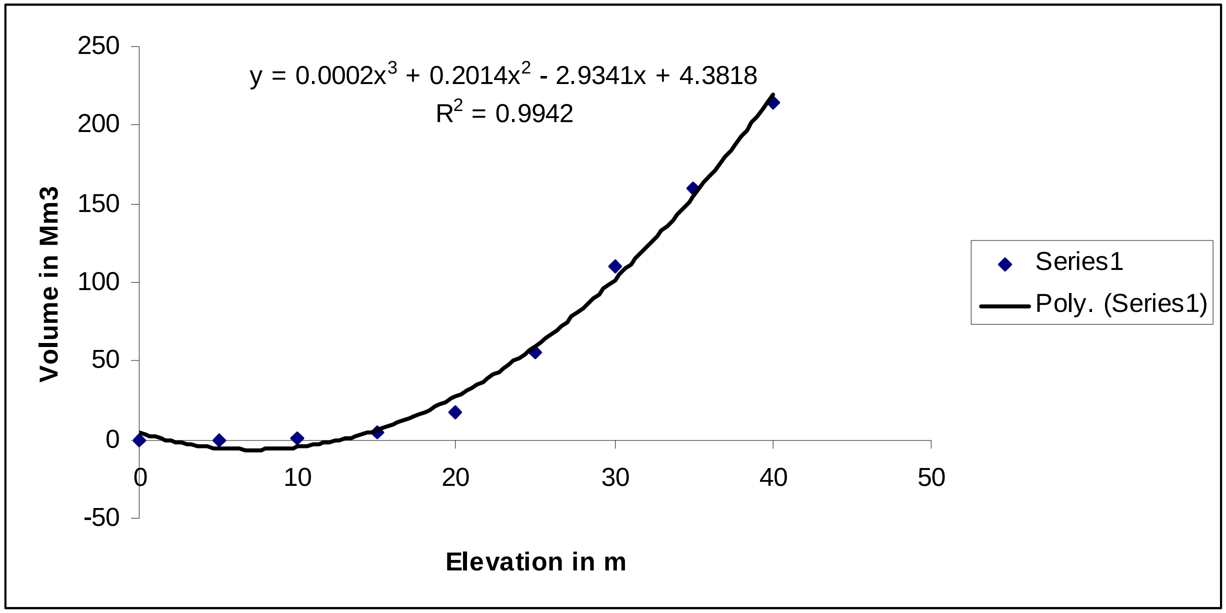
Annex 1. 12: Estimated Ziway lake open water evaporation (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	158.2	162.4	167.4	172.5	175.0	174.2	171.7	167.4	162.4	157.3	155.7	155.7	1979.9

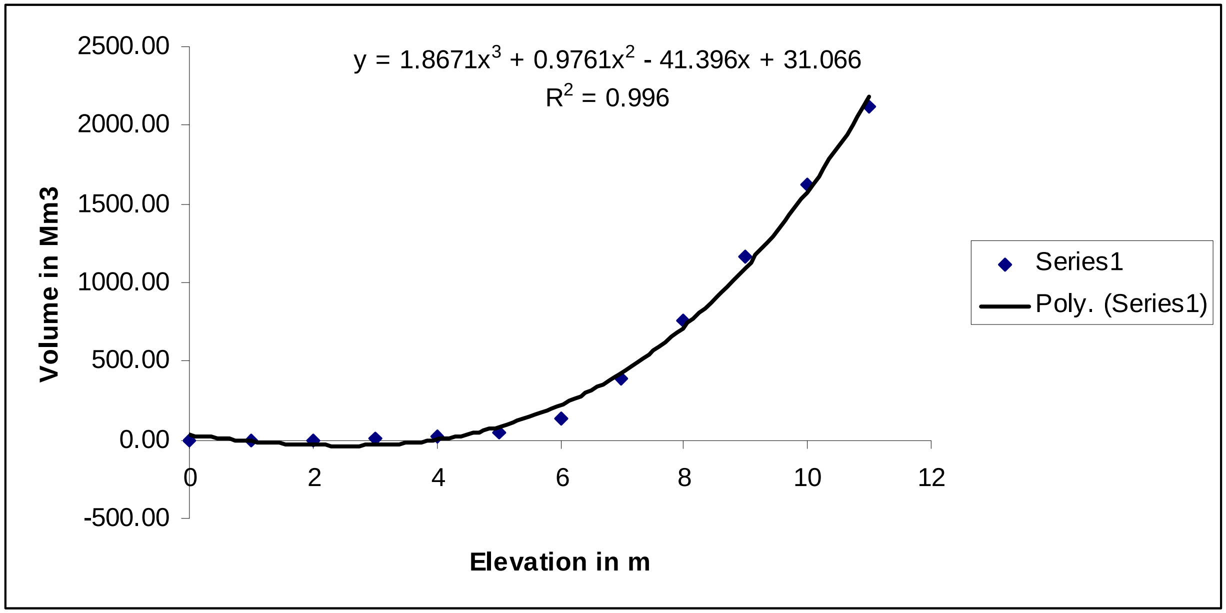
Annex 1. 13: Estimated Abiyata lake open water evaporation (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1980	173	141	159	207	181	132	127	128	149	212	257	193	2059

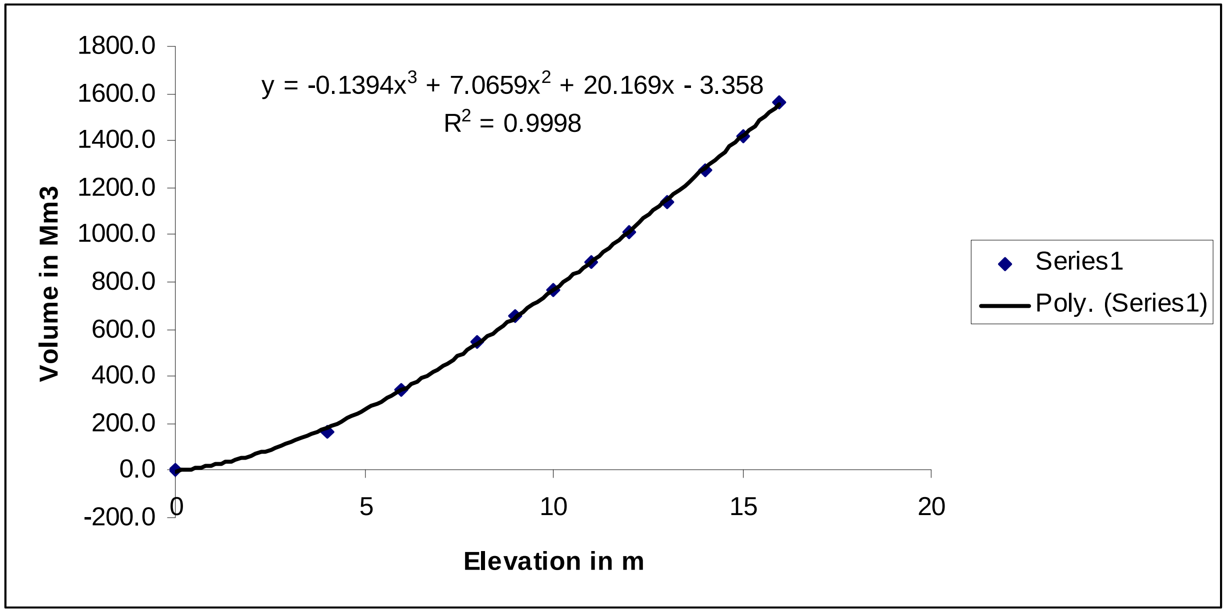
Annex 1.14 Reservoir capacity curve for Meki Dam **(0 is for 1760 m a s l – 40 is for 1800 m a s l)**



Annex 1. 15 Reservoir capacity curve for Ziway Lake (0 is for 1627m a s l – 11 is for 1638 m a s l)

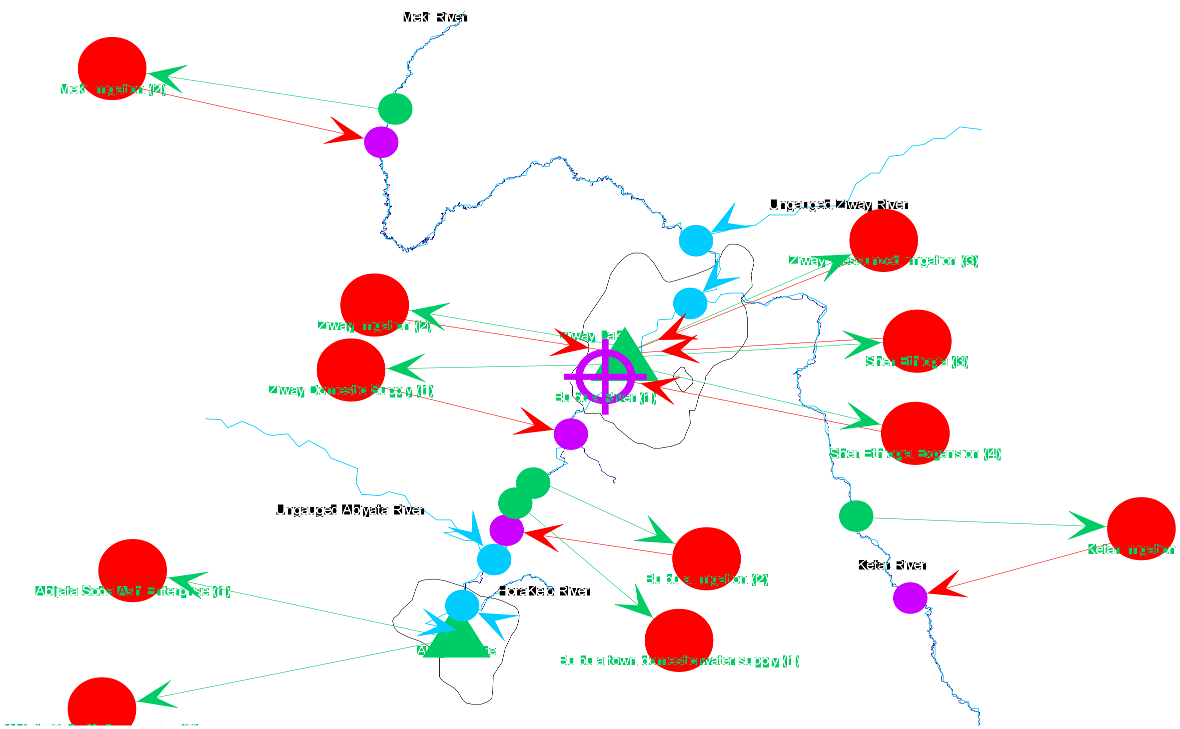


Annex 1. 16 Reservoir capacity curve for Abiyata Lake (0 is for 1568.4 m a s l – 16 is for 1584.4 m a s l)

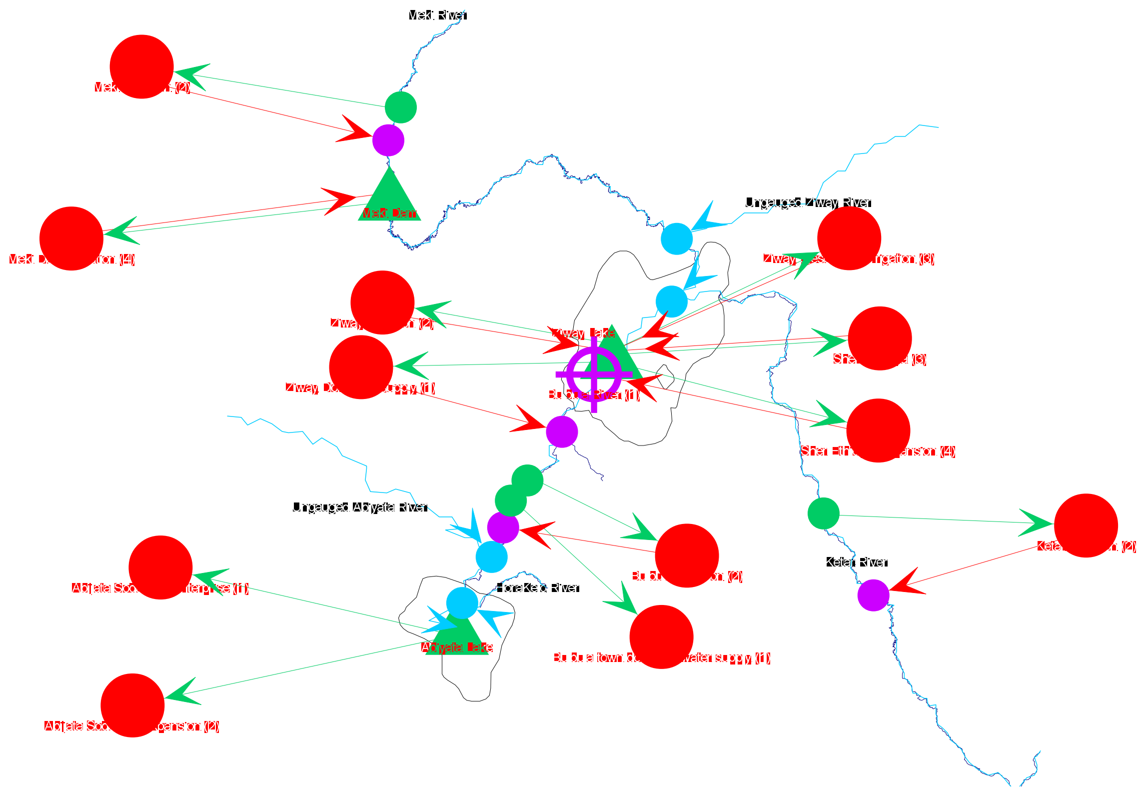


Annex 2: Sample schematics used in the Modeling

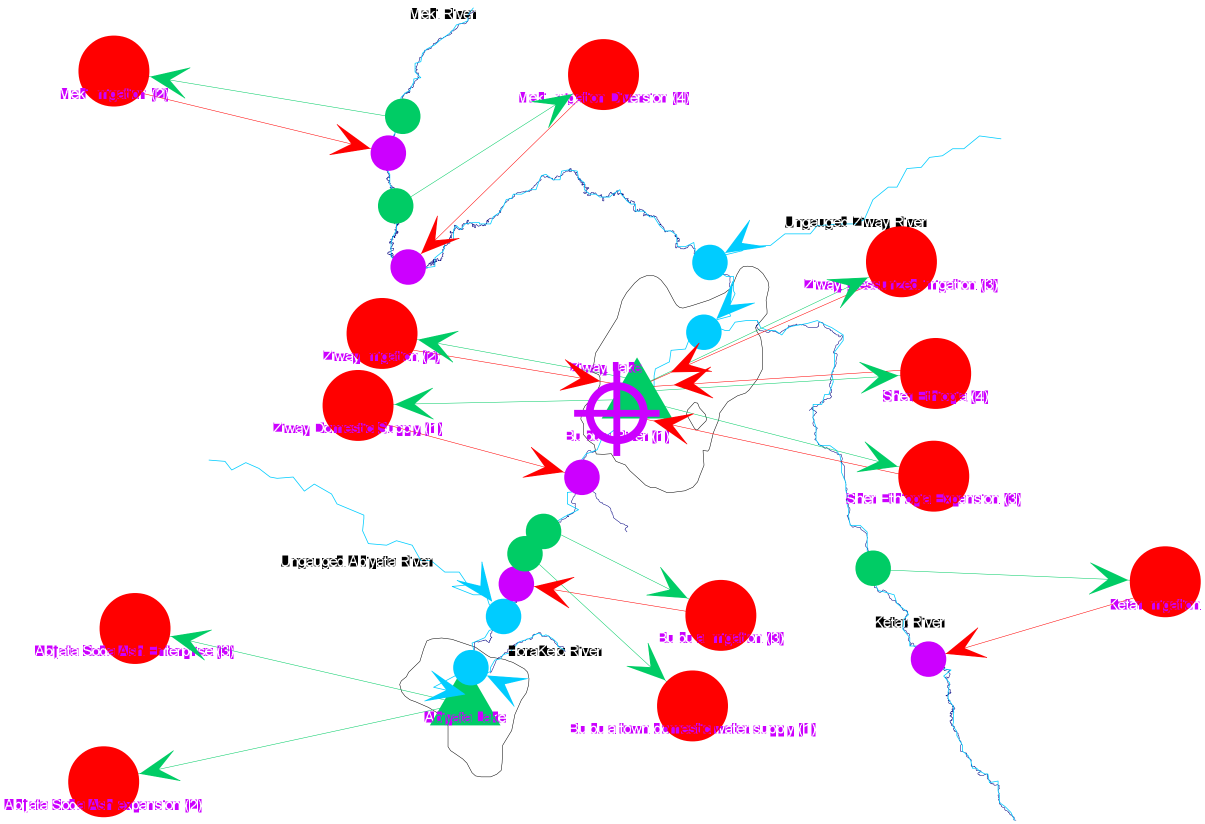
Annex 2.1 Scehmatics of the model for the SN1 scenario



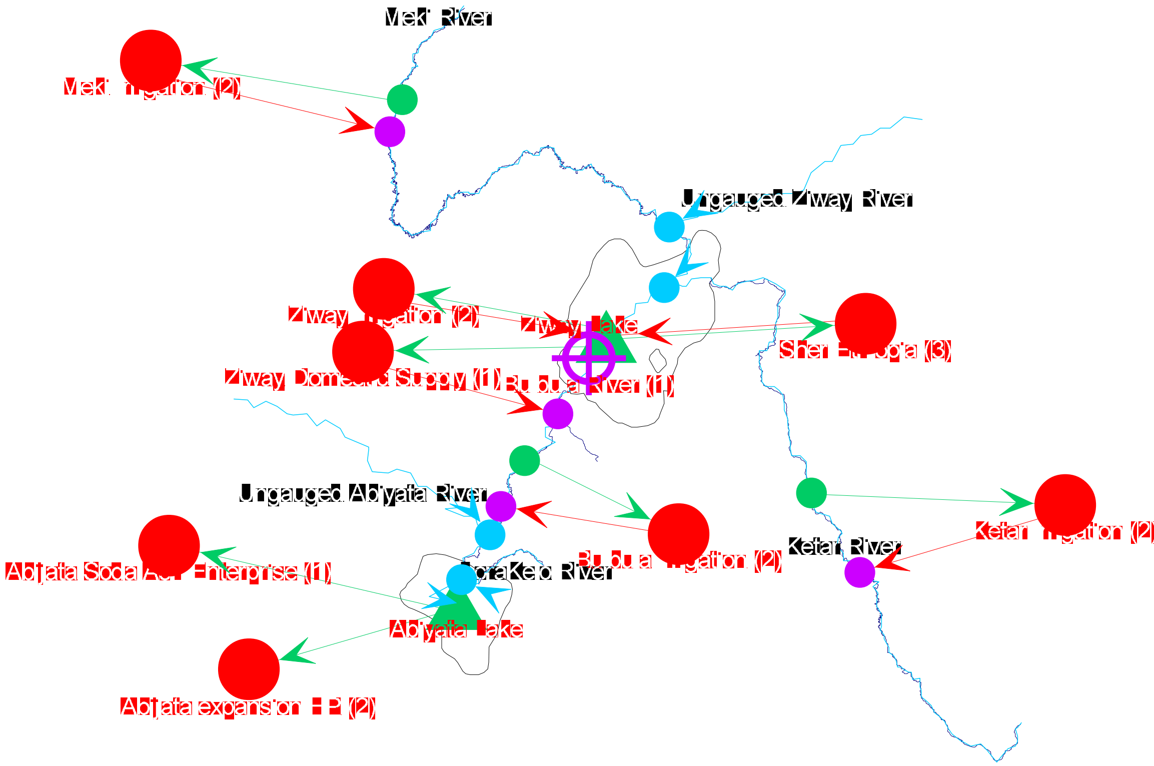
Annex 2.2 Schematic of the Model for the SN2 scenario



Annex 2.3 Schematic of the Model for the SN3



Annex 2.4 Schematic of the Model for expansion of Abijata Soda Ash Enterprise as the only development.



Annex 2.5 Mean annual simulated lake level for all scenarios for Lake Ziway.

Mean Stage-Level (m 0 Gauge height is at 1635.1m a.s.l)

Year	Baseline	SN1	SN2	SN3	SN11	SN22	SN33
1980	0.70	0.47	0.48	0.45	0.50	0.51	0.49
1981	0.98	0.48	0.40	0.45	0.56	0.47	0.52
1982	1.18	0.52	0.35	0.46	0.71	0.55	0.65
1983	1.50	0.68	0.42	0.60	0.93	0.77	0.88
1984	0.88	-0.01	-0.18	-0.05	0.39	0.30	0.34
1985	0.46	-0.38	-0.46	-0.40	-0.10	-0.15	-0.13
1986	0.63	-0.08	-0.16	-0.12	0.11	0.00	0.05
1987	0.79	-0.01	-0.05	-0.03	0.10	0.03	0.08
1988	0.54	-0.17	-0.25	-0.20	-0.04	-0.15	-0.07
1989	0.82	0.05	0.00	0.04	0.23	0.10	0.20
1990	1.11	0.20	0.10	0.17	0.38	0.21	0.34
1991	1.02	0.06	0.01	0.05	0.18	0.05	0.12
1992	1.03	0.17	0.08	0.14	0.20	0.11	0.16
1993	1.39	0.45	0.33	0.41	0.55	0.43	0.51
1994	1.25	0.39	0.31	0.38	0.51	0.42	0.48
1995	1.08	0.29	0.18	0.26	0.44	0.33	0.40
1996	1.29	0.46	0.34	0.41	0.65	0.54	0.62
1997	0.98	0.00	-0.07	-0.05	0.44	0.32	0.39
1998	0.94	0.17	0.07	0.13	0.52	0.39	0.48
1999	0.98	0.09	0.03	0.08	0.58	0.44	0.53
2000	0.80	-0.06	-0.10	-0.07	0.41	0.30	0.38
2001	1.23	0.49	0.39	0.47	0.75	0.59	0.72
2002	1.08	0.16	0.05	0.13	0.37	0.22	0.32
2003	0.82	0.06	-0.08	0.02	0.18	0.04	0.15
2004	0.82	0.02	-0.08	-0.04	0.05	-0.02	0.04
Mean	0.97	0.18	0.08	0.15	0.38	0.27	0.35

Annex 2.6 Mean annual simulated lake level for all scenarios for Lake Abiyata.

Mean Stage-Level (m 0 Gauge height is at 1576.4m a.s.l)

Year	Baseline	SN1	SN2	SN3	SN11	SN22	SN33
1980	5.17	5.13	5.12	5.13	5.03	5.03	5.03
1981	4.33	3.98	3.98	3.98	3.74	3.71	3.73
1982	4.76	3.86	3.86	3.86	3.21	3.08	3.17
1983	4.98	4.06	4.06	4.06	3.09	2.70	2.98
1984	5.77	5.69	5.63	5.64	3.92	3.16	3.71
1985	4.64	4.47	4.36	4.41	2.52	1.74	2.30
1986	3.39	3.13	3.02	3.07	1.08	0.30	0.87
1987	2.41	2.08	1.97	2.02	-0.21	-1.01	-0.43
1988	1.43	0.92	0.79	0.84	-1.69	-2.52	-1.92
1989	1.18	0.62	0.45	0.51	-2.68	-3.60	-2.91
1990	1.28	0.61	0.43	0.50	-2.98	-3.95	-3.22
1991	1.43	0.74	0.48	0.63	-2.82	-3.80	-3.08
1992	1.33	0.55	0.29	0.43	-2.89	-3.76	-3.13
1993	2.34	1.76	1.54	1.66	-1.48	-2.33	-1.66
1994	2.92	2.88	2.73	2.81	-0.06	-1.07	-0.26
1995	2.81	2.79	2.79	2.79	0.36	-0.64	0.19
1996	2.83	2.82	2.81	2.81	0.42	-0.59	0.25
1997	2.95	2.87	2.86	2.86	0.82	-0.22	0.66
1998	2.63	2.38	2.34	2.34	0.13	-0.96	-0.05
1999	2.84	2.83	2.82	2.83	0.71	-0.49	0.50
2000	2.92	2.76	2.73	2.76	0.28	-1.02	0.03
2001	3.60	3.29	3.27	3.29	0.60	-0.70	0.39
2002	3.59	3.53	3.53	3.53	1.16	-0.16	0.95
2003	2.51	2.18	2.17	2.17	-0.32	-1.66	-0.54
2004	1.14	0.73	0.71	0.72	-1.85	-3.21	-2.08
Mean	3.01	2.67	2.59	2.63	0.40	-0.48	0.22

DECLARATION

This thesis is my original work, and it has not been presented for a degree in any other university and the source materials used for the thesis are fully acknowledged.

Tigist Tadesse

Signature_____________________

Date.____

This thesis has been submitted for the examination with our approval as a university advisor

1. **Dr. Seifu Kebede (AAU)**

Signature.____________________________________

Date.____

2. **Ato Deksyos Tarekegn (NBI-WRPM)**

Signature______________________________

Date.____