ADDIS ABABA UNIVERSITY

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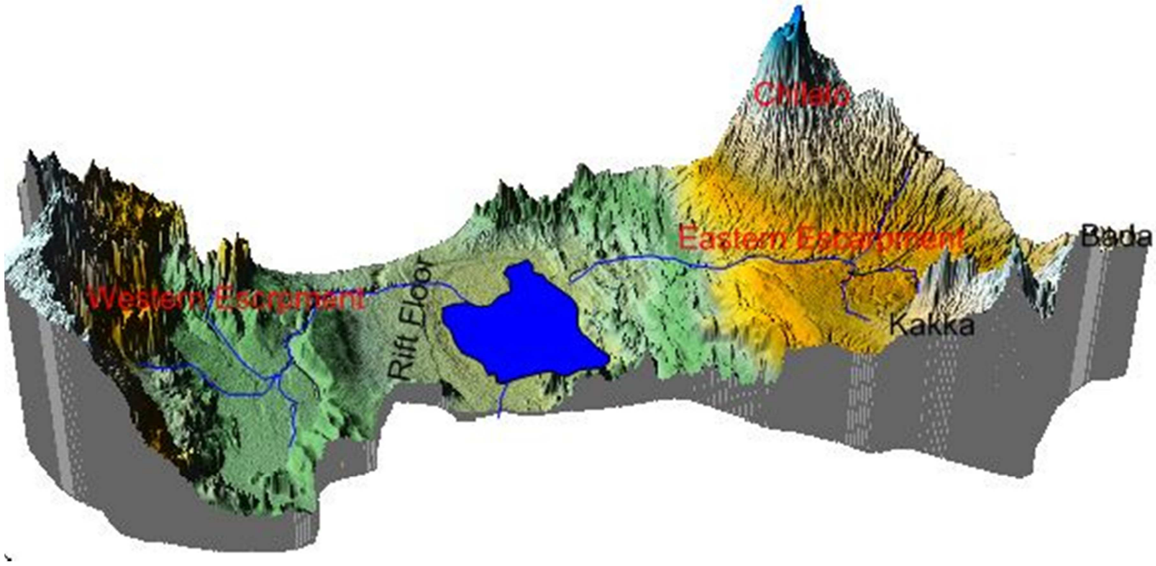
Numerical Groundwater Flow Modeling

Of the Ziway Lake Basin



A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in the Partial Fulfillment of the Requirement for the Degree of Masters in Hydrogeology

BY

Abdilbasit Hamid

July, 2013

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Numerical Groundwater Flow Modeling Of the Ziway Lake Basin, Central Ethiopia

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Approved by Board of Examiners

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This thesis is my original work and has not been presented for a degree in any other university, and that all sources of the material used for the thesis have been duly acknowledged.

Name: Abdilbasit Hamid
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Date________________

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Abstract

Ziway lake Basin is a large, heterogeneous, lithological unit that contains groundwater aquifers of domestic, agricultural, industry and environmental significance. Population growth has resulted in expanding residential developments and consequently increased demand for water. It is crucial that this resource has to be managed in a sustainable manner to safeguard it both for current users and for future generations. Eight aquifer systems having distinct groundwater potential and hydraulic properties. A shallow aquifer occurs in the lacustrine and alluvial deposits in the rift and highlands of weathered and fractured regions. Water levels in the modeled aquifers follow the topography and groundwater occurs under unconfined conditions in the system.

The aquifer system was modeled numerically using Processing Modflow Pro (Version 8.0.15) under a steady-state condition with one layer of 500 meters constant thickness. The model area which is about seven thousand four hundred fourteen square kilometer was divided into grid blocks of 250 by 250 meters. A number of data were collected from different sources for the development of this model. These data include: DEM, aquifer thickness, recharge, hydrogeological conditions of the study area, flow data, and pumping and observation wells. These data were prepared and preprocessed using ArcGIS, surfer10 and Globalmapper11.The calibration of the groundwater model was performed using trial and error calibration. The calibration was implemented by changing several parameters such as recharge, hydraulic conductivity, and river conductance. The steady-state groundwater model was calibrated successfully and the simulated heads were in a good agreement with the observed head. The calibrated model gave ME of -0.070613 m and RMS of 4.497221m.

A sensitivity analysis was conducted to examine the response of the calibrated steady State model to changes in model parameters including horizontal hydraulic conductivity, recharge, and well withdrawal. The model was most sensitive to recharge and relatively less sensitive to well withdrawal. Three different scenarios were simulated to observe the response of aquifer by considering both increased and decreased 25%, 50% and 75% in the parameters (recharge, hydraulic conductivity and pumpage). The scenario and sensitivity analysis provided important information for future transient model development and on the data gaps. This model has pertained for developing detailed predictive groundwater model, which can be readily used for groundwater management practices.

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List of Acronyms

AAiT Addis Ababa Institute of Technology

ASTER Advanced Spaceborne Thermal Emission and Reflection

D.D Draw down

DEM Digital elevation model

GIS Geographical information system

GUI Graphical user interference

ITCZ Inter Tropical Convergence Zone

JICA Japan International Cooperation Agency

K Hydraulic conductivity

MAE Mean Absolute Error

M.a.s.l Meter above mean sea level

MCM Million cubic meters

ME Mean Error

MER Main Ethiopian Rift

MODFLOW Modular 3 dimensional finite difference groundwater flow models

MoWE Ministry of Water & Energy

OIDA Ontario International Development Agency

PCG2 Preconditioned Conjugate Gradient2

Q Well yield

RMS Root Mean Squared Error

SWL Static Water Level

T Transmissivity

USGS United states geological survey

UTM Universal Transverse Mercator

WEAP Water Evaluation and Planning System

CHAPTER ONE

Introduction

1.1 Background

Groundwater is the subsurface water that occurs beneath the water table in the soils and geologic Formations that are fully saturated (Freeze & Cherry, 1979). Groundwater is one of the key natural resources of the world. Many major cities and small towns in the world depend on groundwater for water supplies, mainly because of its abundance, stable quality and also because it is inexpensive to exploit (Morris et al., 2003). Groundwater use has fundamental importance to meet the rapidly expanding urban, industrial and agricultural water requirement, especially in arid areas where surface waters are scarce and seasonal. Uneven distribution of surface water resources resulted in an increased emphasis on development of groundwater resources.

An important objective of most groundwater studies is to make a quantitative assessment of the groundwater resources in terms of the total volume of water stored in aquifer or long-term average recharge. Groundwater recharge is determined to a large extent as an imbalance at the land surface between precipitation and evaporative demand. When precipitation exceeds evaporative demand by an amount sufficient to replenish soil water storage, any further excess flows deeper into the ground and arrives at the water table as recharge.

Groundwater systems have been studied by the use of computer based mathematical models (Brassington, 1998). These essentially comprise a vast array of equations, which describe groundwater flow and the water balance in the aquifer. Finite difference method is a commonly used method to solve the equations. The equations are solved for each node and the movement of groundwater from one node to its neighbor is calculated. As discussed by Scanlon et al. (2003), numerical groundwater models are one of the best predictive tools available for managing water resources in aquifers.

These models can be used to test or refine different conceptual models, estimate hydraulic parameters and, most importantly for water-resource management, predict how the aquifer might respond to changes in pumping and climate. Groundwater abstractions that exceed the average recharge, results in a continuing depletion of aquifer storage and lowering of the groundwater table. Hence safe groundwater abstraction and proper groundwater management is crucial for sustainability of the resource. Safe yield is the amount of naturally occurring groundwater that can be withdrawn from an aquifer on a sustained basis, economically and legally, without impairing the native ground water quality or creating undesirable effects, such as environmental damage (Fetter, 2001).

Rift regions are densely populated areas that experience high demand for fresh water. In rift aquifers, water quality degradation resulting from rock- water interaction and surface water – groundwater interaction. Growing demands from industry, energy production, urban population centers and agriculture place an increasing strain on the quantity and quality of water resource.

In Ziway area, groundwater is exploited by different industries and institution in addition to wells and boreholes that are operated by Ziway Water Supply and Sewerage Authority and used for public services. In long terms, extended and uncontrolled withdrawal may result in water level declines, which causes imbalance among hydrologic stresses. Groundwater modeling is a result of careful understanding of hydrology, hydrogeology and dynamics of groundwater flow in and around the study area. So, this groundwater flow model simulation may project the risk of such uncontrolled withdrawal on the hydrologic system, In order to take the necessary measure to minimize such a problem. This model may be used as a tool to understand the flow system, to confirm that estimations of aquifer properties are reasonable.

1.2. Objectives

The general objectives of this study is to understand the groundwater system of the area and predict the variations in hydraulic head under different scenarios for planning of sustainable utilization of groundwater resource by simulating the complex groundwater system using numerical groundwater flow model(processing Modflow pro) for steady state condition.

The specific objectives of the study are:

- ✓ *To construct a GIS database based on the Modflow input files for the development of numerical model.*
- ✓ *To develop steady-state numerical groundwater flow model of the Catchment.*
- ✓ *To provide a steady-state calibrated water level, hydraulic parameters and recharge of the hydrogeological system of the area.*
- ✓ *To identify the possible boundary conditions of the basin and develop a simplified conceptual model of which approximate the physical field condition of the system.*
- ✓ *To obtain simulated groundwater budget*

- ✓ *To evaluate the behavior of the groundwater system under possible future utilization scenarios*

- ✓ *To organize and synthesize the available information and previous work*

1.3. Methodology

The methods followed to conduct the research work consists of three major phases (pre-field work, field work and post field work)

1.3.1. Pre-fieldwork

This stage includes acquiring and reviewing available previous works and data required for the objectives of the study. Data was sourced from Ministry of Water & Energy, Ethiopian Mapping Agency, AG Consult, Consulting Hydrogeologists & Engineer and Water Works Design and Construction Enterprise and National Meteorological Agency. Information reviewed included Precipitation, temperature, evapotranspiration, pumping test data, river discharge record, and water well inventory data. Acquisition of equipment and preparation of data requirement list and data collection form were the activities conducted before the field trip.

1.3.2 Fieldwork

Field program was designed to obtain site specific information which included relevant secondary data from zonal and woredas office and primary data from the study area.

The primary data collected include:

- Identifying and description of major geological features and structures controlling the groundwater systems of the study area
- Measuring river width, river bed thickness and elevation of the river head or stage
- Determining physical boundary conditions which control over the groundwater flow of the study area
- Groundwater level measurements at accessible boreholes
- Recording the location of geological outcrops and structural features
- Recording the location of river gagging stations and borehole sites

Materials used to accomplish the above task were Garmin GPS, deep meter, base map, geological map, EC meter, and geological hammer.

1.3.3 Post-field work

In this stage processing and analyzing of collected data was the main activity. The data gathered aimed to assist with understanding the groundwater occurrence and flow processes within the system and to support the development of the conceptual and numerical models. The necessity of this step is that it involves processing of the data in order to meet data requirement for the model and the input data were processed using ArcGIS10, Global mapper11, surfer12 and geostatistics.

For instance, kriging is used to interpolate point measurements of static water levels to prepare areal precipitation and groundwater contour map. In addition DEM the area was extracted from ASTER image which enabled to determine surface elevations of boreholes, to prepare surface topography cross- sections and to define top and bottom elevations of layer in the numerical modeling. Well completion data are organized and summarized to determine the aquifer thickness and vertical extent of layers in combination with geological cross-section and geophysical log data. Following the development of conceptual model based on the result obtained a rudimentary groundwater flow modeling was developed using Processing Modflow Pro Version 7.0.

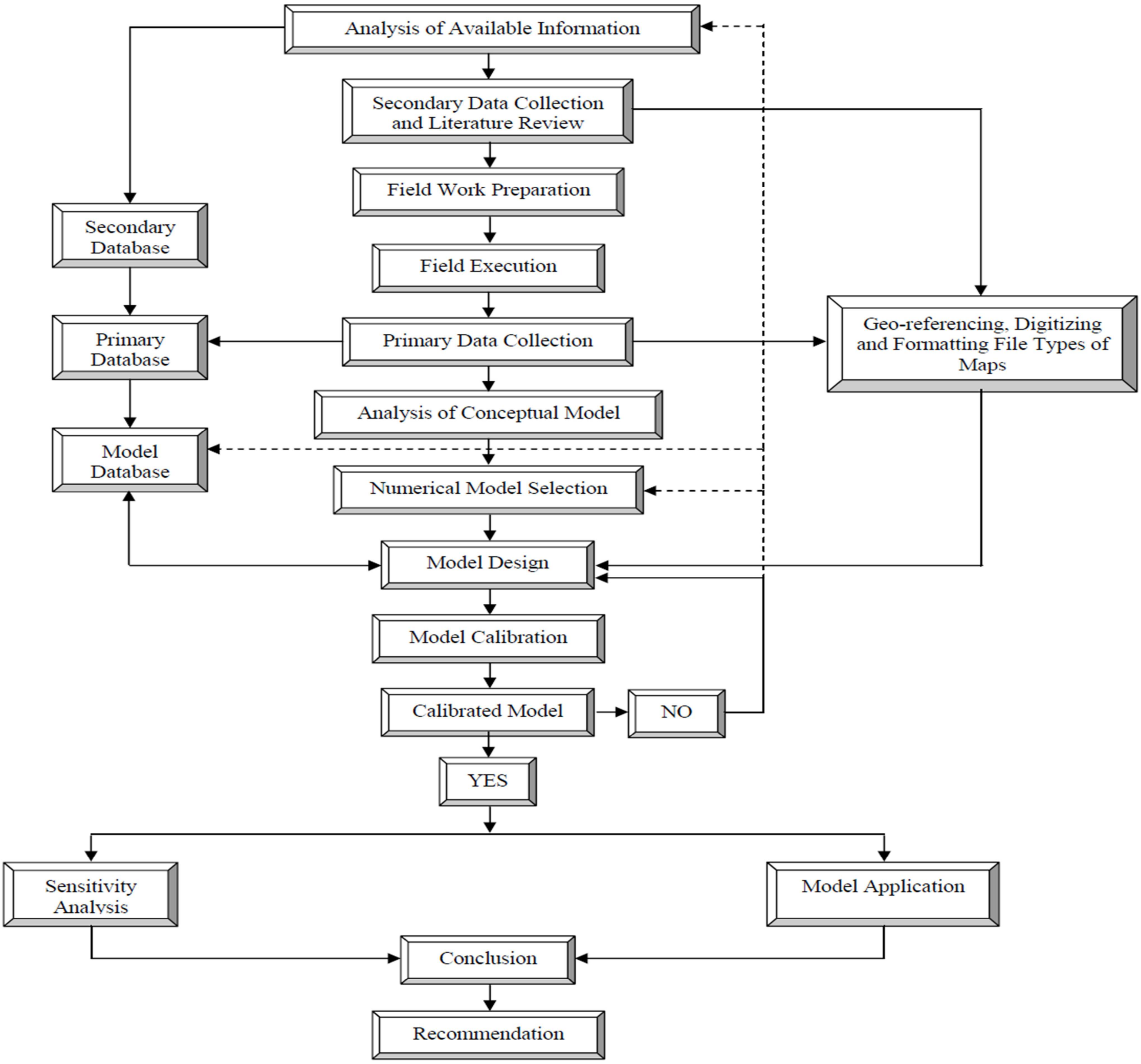


Figure 1 Numerical Groundwater Flow Modeling of Ziway Lake Basin in Central Rift valley.

1. 4. Pervious works

Many research studies have been conducted in Central Ethiopian Rift Valley that includes the study area these studies have been focused on geology, volcano-tectonics, hydrogeology, hydrology and water resource potential assessment which directly or indirectly related to the current study. Some of the works which provide well understanding of about the area under study are listed below.

Tesfaye Cherent (1993 &1982) had studied the hydrogeology of the rift valley region entitled hydrogeology of the lakes region and Hydrogeology of Ethiopia and water resources development respectively. Hydrogeology of the lakes region includes the hydrogeology description of the area with the hydrogeological map at scale of 1: 250,000.Haile Gashew (1998), Studied Hydrogeology and Hydrology of lake Ziway area and its surroundings. In his work lake water balance and hydrogeology of the current study area were investigated.

Tenalem Ayenew, (1998), in his Ph.D. thesis entitled ‘The hydrogeological system of lakes district basin, Central Ethiopian rift’, he analyzed general hydrology and hydrogeology of Ziway–Shala basin. The study encompass evaluation of groundwater and surface water interaction, water balance and recharge estimation of the sub catchments and groundwater flow modeling.

Italo consult in 1970 had conducted water resources assessment in the Ziway–Langano-Abijata-Shalla Basin. The main objective was to divert Meki River into Awash River for extension of irrigation in the Amibara area, and JICA and OIDA, 2001 in the project study of Meki irrigation and rural development; the primary emphasis was given to the assessment of water resource potential in Meki -Abijata basin Accordingly, hydrological analysis and lake water balance were part of the study.

Dagnachew Legesse (2002), presented in his Ph.D. thesis entitled ‘ Analysis of hydrological response of Ziway–Shala basin to changes in climate and human activities’, hydrological analysis, lake water balance, land use and land cover map. Halcrow, 1989 analyzed groundwater and surface water potential of the area in the work entitled „rift valley lakes integrated natural resource development master plan.In all studies conducted so far, more work is done on hydrogeology, hydrology, climate, land use of the basin and numerical groundwater modeling of Ziway–Shala basin and the Ziway lake basin catchments separately,

Furthermore groundwater flow modeling of the basin as one system necessitates because population growth has resulted in expanding residential development of the basin particularly at the downstream area. Population growth in this area has led to an increased demand for water for domestic, industrial, irrigation and horticulture use. This results in exploitation of groundwater resource excessively which alters groundwater level and intrinsic processes. These processes may influence and even control the health of associated ecosystem .Using versatile groundwater models has become a common practice in groundwater studies (Leap, 2007). As a result, it is inevitable to make use of groundwater models in predicting, managing and designing our invaluable groundwater resources (Younger, 2007).

Moreover this research study focuses on groundwater flow modeling of the basin and expected to present groundwater flow system where by enabling well understanding the flow system of the basin, development of conceptual model and model simulation. As a result changes in response to change in hydrological parameters will be easily identified and provides useful information for resource management for sustainable basis and policy making process

CHAPTER TWO

General Overview of the Area

2.1 Location

The proposed research area is located in the central main Ethiopian rift valley and the area is accessed by to main asphalt road (Addis Ababa to Hawassa and Addis Ababa to Hossahina). In addition most of the Towns and woredas are networked by gravely road. From morphological point of view Ziway basin divided into three zones: the rift, the transitional escarpment and the highlands. The rift zone is characterized by an average altitude of 1650 above sea level (m.a.s.l) is bordered by the Ethiopian plateau to the east and west, having an average altitude of 2500 m.a.s.l).The upper reaches of the catchment is steep and mountainous while the lower basin is flat with a broad valley. The area is about 7414 km^2 *and bounded between 415000 W to 540000 E and 815000 S to 940,000 N.*

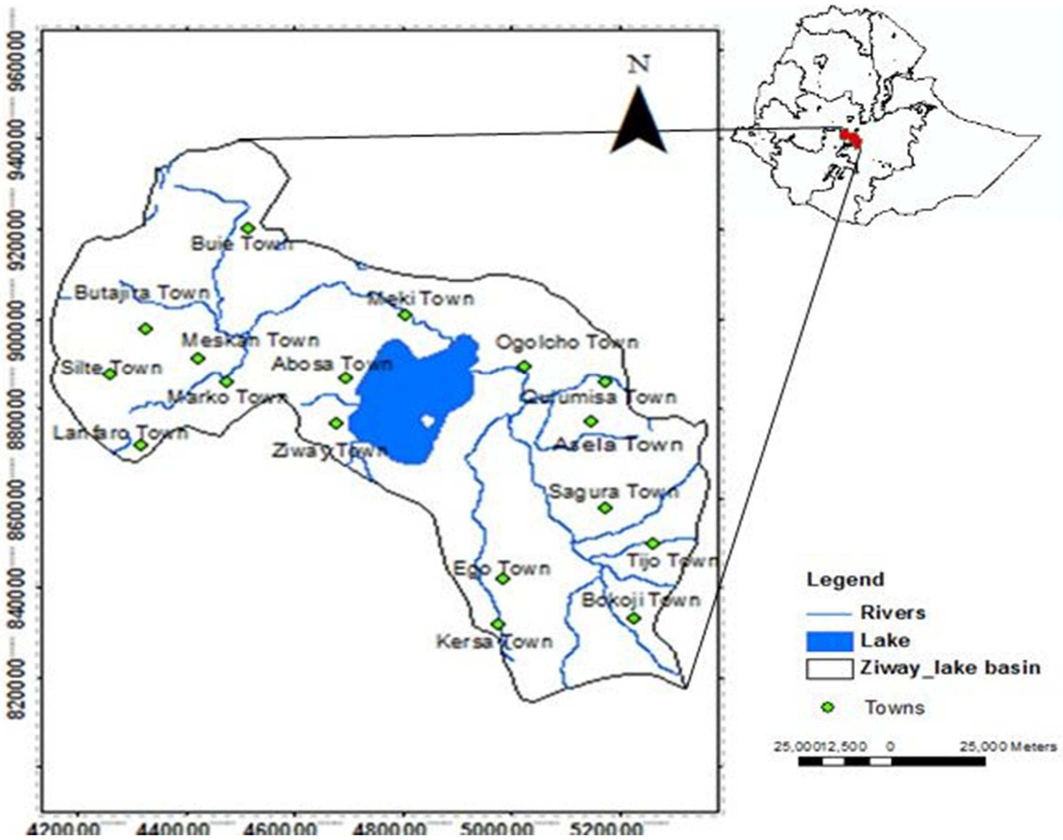


Figure 2 Location map of the study area

2.2 Topography and drainage

The study area is bounded in the east by Chilalo (4056m a.s.l), Galama (4153 a.s.l), Kakka (4167m a.s.l), Mountains and from the west by Guragie Mountains (3609 a.m.).Generally, Lake Ziway basin is divided in to three physiographic areas: the high plateaux on either side of the rift, the transitional escarpment and the rift floor. There is a topographic difference of about 2600m between the rift floor and mountains. The principal feature of the basin is that it is a graben a block fault geological structure in which the floor of the valley has become vertically displaced with respect to the valley sides.

Kater and Meki River are the two main important rivers originate from the eastern and western high lands of the study area respectively which drain in to Lake Ziway. Lake Ziway is fed principally by Meki and Kater rivers; from its western and eastern sides (Figure 1.1). Most parts of plateau area are perennial sources of these rivers while the tributaries in the escarpments and rift floor are almost intermittent sources. Steep cliff and caldera walls at the west, gently slopes and low hilly terrain at East.

Almost flat low land between East Butajira and Lake Ziway Meki River is Major River in the area and highly affected by the topographical profile which flow northerly in the west and easterly in the east .Foot of Galema mountain range (altitude of 4000m) extends to cone shaped hollow. Passing fault cliff towards lower flat land of Lake Ziway and river gradient is relatively high. Several ramiform stream networks are dominant and gather into the Kater river Flow direction which is mainly WNW-ENE .In addition, the highland is characterized by higher drainage density than the escarpment due to differences in rock permeability, climate and slope (Tesfaye Cherent, 1982, as cited).

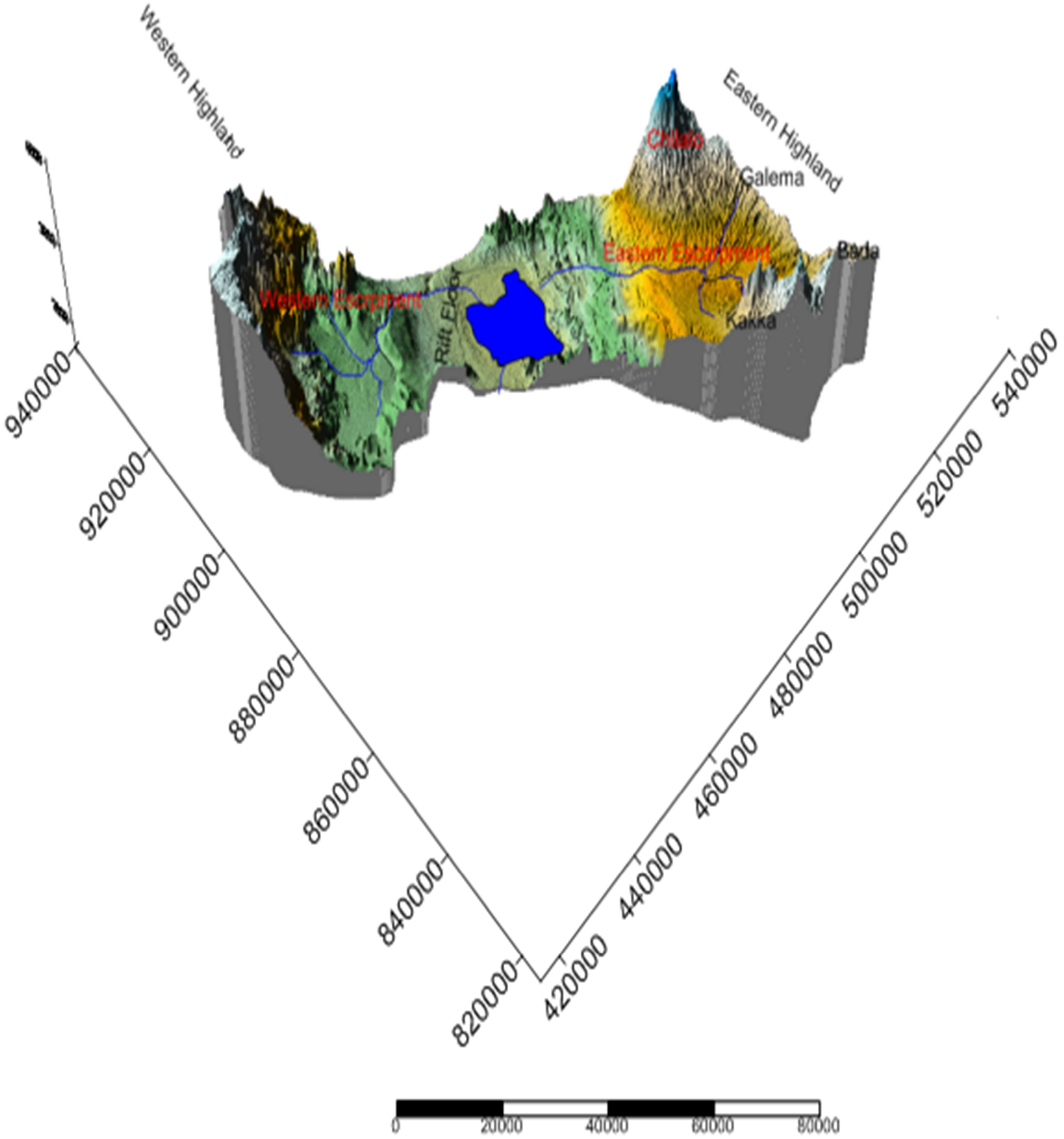


Figure 3 Topography of the catchment derived from digital elevation model

2.3 Soil

Soil in the study area is closely related to parent material and degree of weathering (Makin et al., 1976). Basalt, ignimbrite, acidic lava, volcanic ash and pumice, and riverine and lacustrine alluvium are the main parent materials (Di Paola, 1972). The gently undulating plain of the north of the RVLB comprises well to excessively drained dark grey-brown friable loams originating from volcanic ash. They are moderately deep, often stony, and generally fertile with occasionally high sub-soil exchangeable sodium values Generally the dominate soil types of the study area are Cambisol, Cambisol, Vertisol, Luvisol, Leptosol, and Andosols. The spatial distribution of the dominate soil types is shown in Figure. 2.4.

Here are some of the dominant soils found in the study area

1. Leptosols are very shallow soils limited in depth by continuous hard rock. They are commonly occurring on highly eroded areas undulating and steep slopes. The leptosols are developed on relatively young surface origin. Moreover, since they occur on steep slopes, they are exposed to a high degree of erosion.

2. Andosols in the basin are formed from largely volcanic ashes and pumice deposits. Andosols are dominantly found on flat to gently undulating topography. They are generally well to excessively drained, deep to very deep; very dark grey to brown, medium and coarse textured dominantly sandy loam.

3. Luvisols are soils having an agaric horizon, which has a base saturation of 50% or more at least in the lower parts of the B-horizon. These soils show textural differentiation in the profile showing surface horizon depletion in clay and clay accumulation in the sub surface and moderate to high clay activity. These soils are derived from different parent material. Luvisols cover an extensive area in the basin and dominantly found on gently undulating to steep topography. These soils are also found on flat to gently undulating but limited in extent. The soils are generally well drained, deep to very deep, and fine to medium texture.

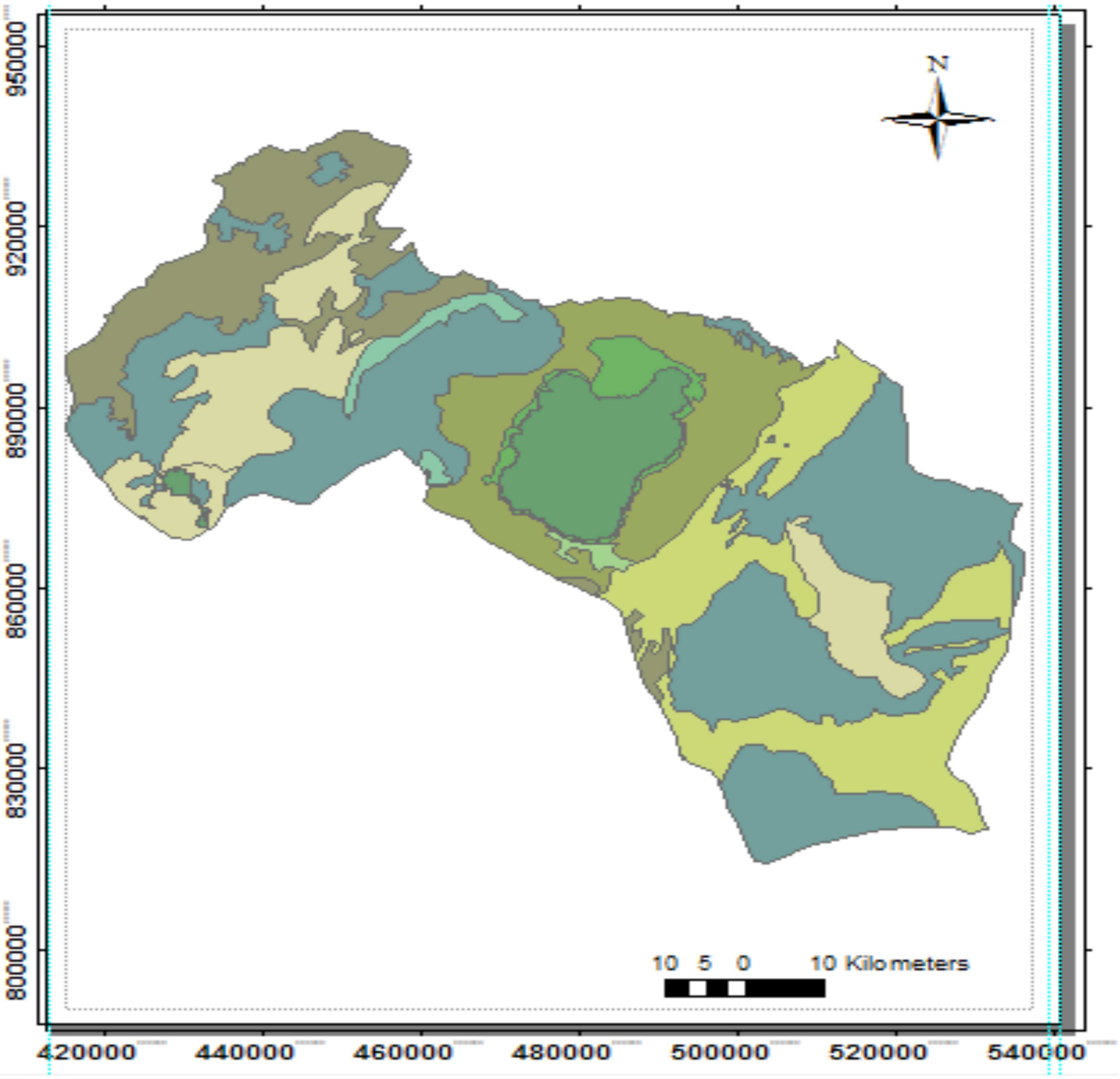
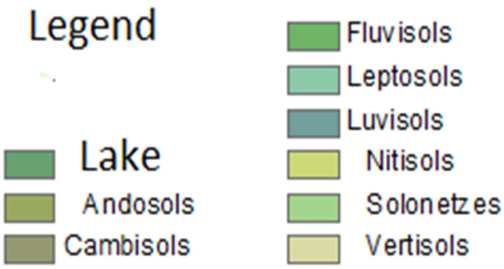


Figure 4 Simplified Soil Map of the Study Area (Extracted from Rift valley shape file)



2.4. Land use / Land cover

The land cover of the basin is a combined effect of topographic, climatic and ecological conditions. Each of which is characterized by particular associations of vegetation (Dagnachew Legesse, 2002).land cover in the area constitutes a mixture of open bush, water body and moderately to intensively cultivated land, primarily maize and sorghum. East of Lake Ziway, the Wonji Fault Belt is open and dense bush land to the Asela plain where intensive barley and wheat cultivation and open grassland rises to open woodland and grassland at the boundary. The dominant farming system in western part of the study area is Enset based complex farming except Sodo Zuria highlands where highland cereals are dominant.

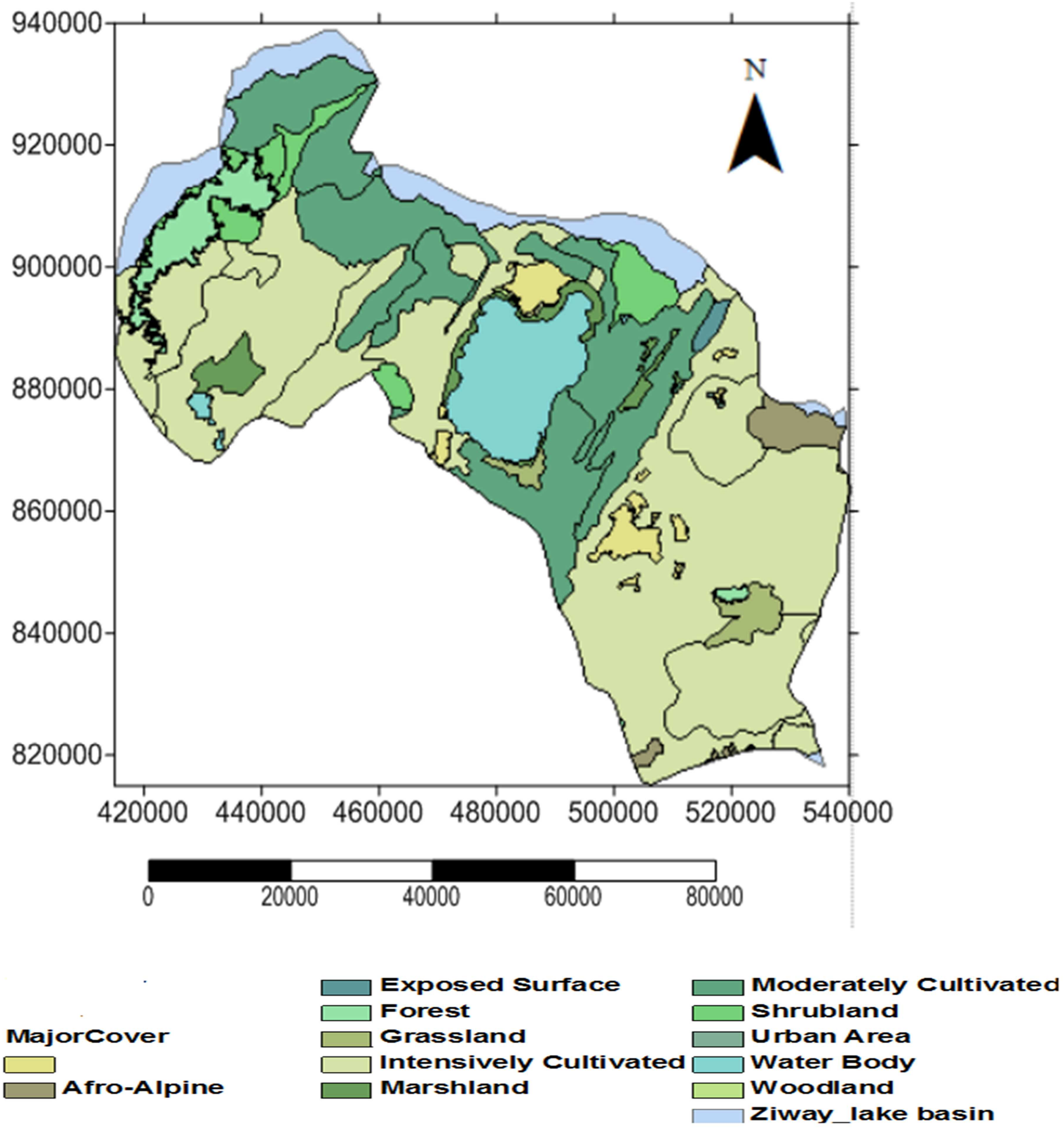


Figure 5 Land use/Land cover map of the study area (**Extracted from Rift valley shape file**)

2.5. Climate

The study area is part of the central main Ethiopian rift consists of three ecological zones: semi-arid lands, semiarid or arid lands, dry sub-humid and humid to dry humid lands(Makin M.J. et al 1975 cited in Diribssa 2006).Accordingly highland areas west of Butajira and east of Asela are categorized under humid to dry sub-humid land. The areas east of Butajira around Lake Abay and across the land between Lake Ziway and Asela are dry sub-humid lands. The remaining area which is part of the rift floor is categorized in semi-arid or arid zone. The western and eastern highlands are relatively cooler and wetter, while the central valley is hotter and drier than the adjoining highlands. The climate in the valley itself also becomes drier, with increasingly less dependable rainfall and higher temperatures at the center and from north to south.

The average annual rainfall varies spatially from about 620mm in the lowlands and over 1200mm at the extreme highlands. There is marked inter-annual variation in rainfall distribution, with a bi-modal rainfall peak, which varies along the rift valley. The main rain period is between June and September whereas the dry period ends from October to February. For example Koshe is found in the western part of the study area at an elevation of 1900mamsl. The long term average (LTA) annual rainfall is 930mm.

The data show persistence of below average rainfall for the years 1986-1988, 1990-1992 and 1994 to 2004 Following several years with above average rainfall up to the early 1980s, the cumulative departure from the mean falls from a maximum of 2000 mm towards 0 between 1985 and 2004 whereas Sagure is located on the eastern escarpment at an elevation of about 2480mams.The LTA annual rainfall is 777mm.The rainfall data show a sequence of below average dry years between 1994 and 2000, although the levels were not far below the LTA with the mean rainfall for this period being 712mm. Similar to Koshe, the cumulative departure from the mean peaks in 1984 at 800mm and declines to 2004, indicating cumulative deficit in rainfall over the period despite several years of above average rainfall the mean annual temperature ranges from 13°C on the highlands to about 20 on the valley floor during the year, mean monthly temperatures are highest in the spring prior to the start.

Table 1 Mean monthly temperature of the stations in the catchment (o_C)

No	Station	Recording. period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	Asela	1960-2010	14.3	15.6	15.9	16.4	16.5	15.8	14.9	14.7	15.9	14.9	14.1	14.0
2	Bui	1990-2010	16.6	17.3	18.4	18.6	19.5	17.5	16.2	16.3	16.7	16.4	15.8	15.7
3	Butajira	1972-2010	18.2	18.6	19.2	19.2	19.1	18.5	17.6	17.7	18.4	18.4	18.1	17.8
4	Kulumsa	1966-2010	15.7	16.7	17.8	18.2	18.1	17.2	16.1	15.8	16.0	16.6	15.9	15.4
5	Meraro	1986-2010	14.3	14.9	15.8	15.9	16.1	15.2	14.5	14.0	14.2	14.7	14.1	13.5
6	Sagure	1981-2010	14.0	15.1	15.9	15.8	15.7	14.9	14.3	14.3	14.3	14.1	13.6	13.5
7	Ziway	1970-2010	19.3	20.4	21.4	21.5	21.8	21.0	19.9	19.7	19.9	19.7	18.9	18.7

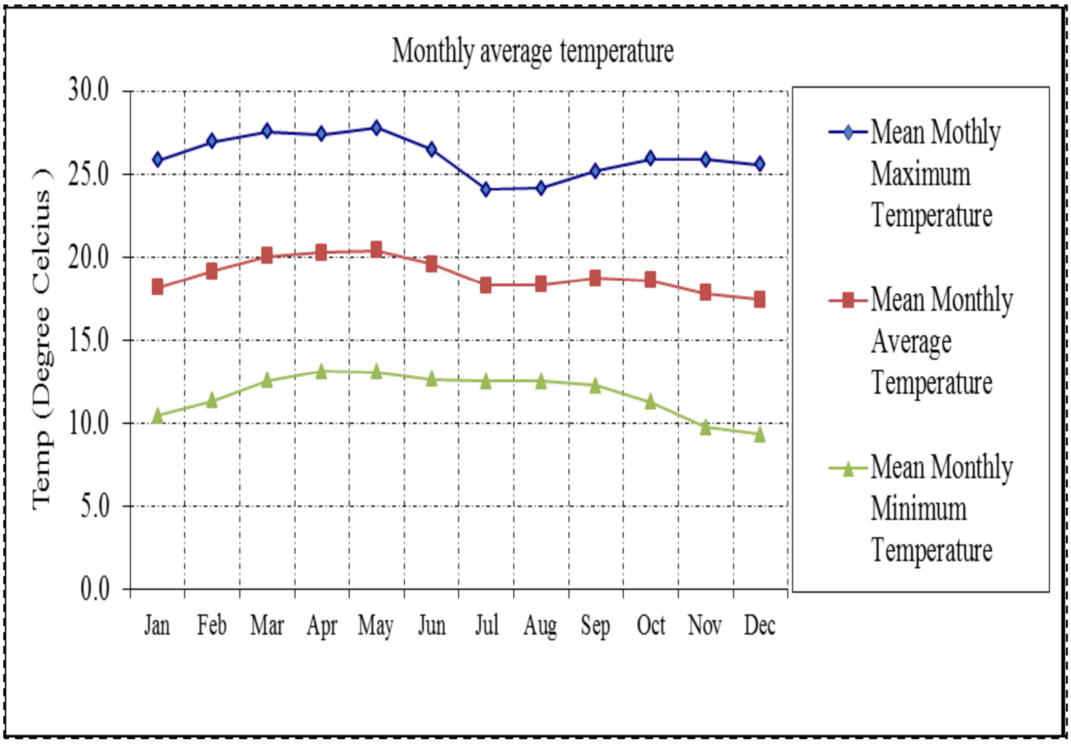


Figure 6 Mean monthly temperature of the study area (1986_2009)

2.6. Precipitation

Rainfall is recorded as a daily total value at every station using the standard rain gauge. The annual rainfall pattern and amount of precipitation is varies from place to place within the Study area. Obviously the amount of precipitation is strongly related with altitude. Thus in general, more precipitation occurs at the mountainous edge of Study Area (Chilalo, Galama, and Guragie) than in the flat plain area (rift floor). The rift valley appears to be a rain shadow area. The seasonal distribution of rainfall over the country is governed by the position of Inter Tropical Convergence Zone; ITCZ (Tenalem Ayenew, 1998; Dagnachew Legesse, 2002) .The ITCZ represents a low pressure area of convergence between Tropical Easterlies and Equatorial westerly along which equatorial wave disturbances take place.

The shifting of this low pressure area governs the availability of rain driving wind direction. This results in rainfall durations in the study area limited to specific months of the year. Thus the rainy season from June to September is controlled by ITCZ which lies to north of Ethiopia at that time. Hence, the study area intercepts most of the monsoon rainfall from Atlantic and Indian oceans. The dry period, from October to February is when the ITCZ lies to the southern of the country. In these months, the north easterly trade wind traversing Arabia dominates the region and therefore, produces very little or no rainfall in the area.

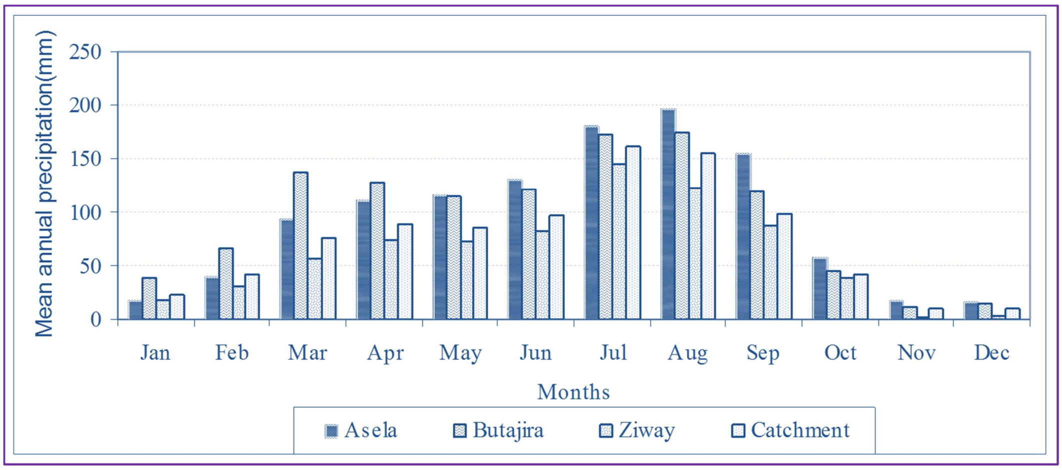


Figure 7 Mean monthly precipitations of selected stations and overall weighted catchment area

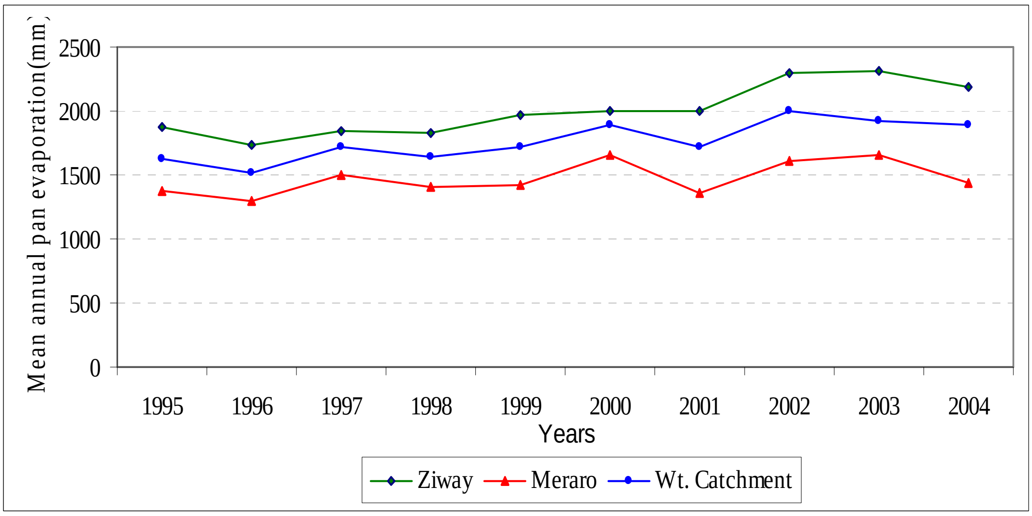


Figure 7 Pan Evaporation of Ziway, Meraro stations and weighted catchment area

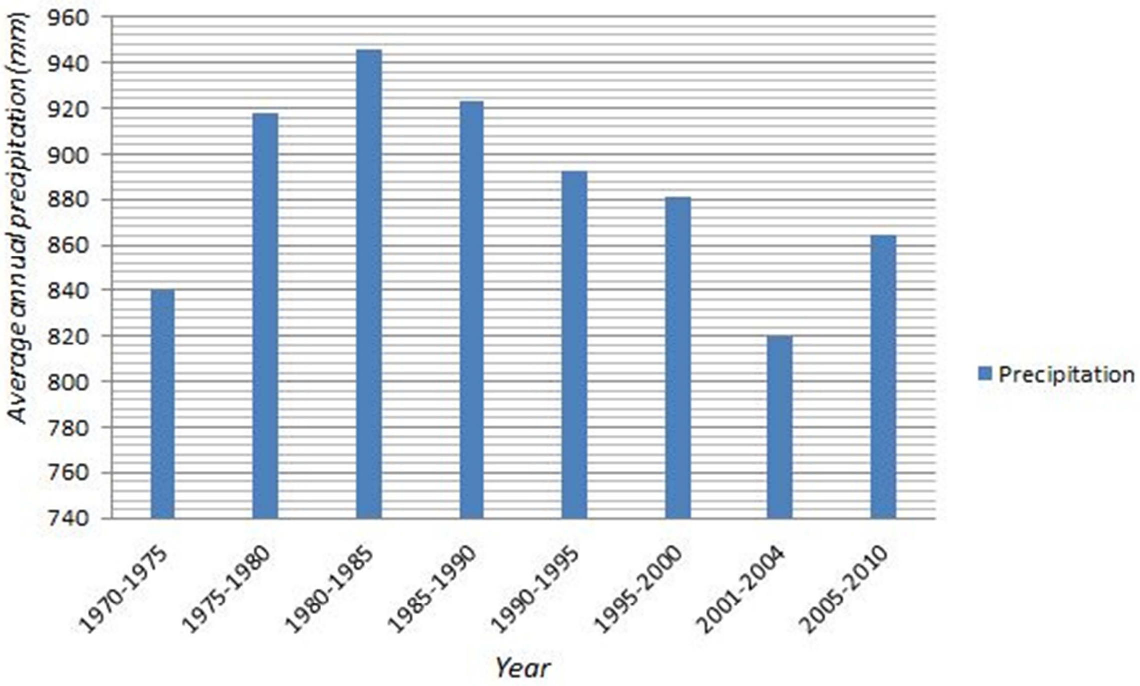


Figure 8 . Trend in five years moving average precipitations over the catchment

CHAPTER THREE

Geology and Structures

3.1 Geology

3.1.1 General

Ethiopia can be divided in to four major physiographic regions, widely known as the western Plateau, southeastern plateau, the main Ethiopian rift and the afar depression. The main Ethiopian Rift is a part of the great African continental rift which is divided geographically in to three sectors; Northern, central and southern (Tesfaye Korme, 1992).The current geologic and geomorphic features of the region are formed by Cenozoic –volcano-tectonic and sedimentation processes.

The physiography and compositional variation in the lithological units in this region indicate that there has been strong relation between magma composition and rifting (woldegabriel and Aronson, 1986; Hart et al., 1989 cited in Tewdros , 2006).The initial phase of development of the MER is attributed to the influence of a mantle plume beneath the Ethiopian Plateau resulting in widespread flood-basalt volcanism and plateau uplift with two main episodes dated at 45−30 Ma and 18−14 Ma (Davidson and Rex, 1980; Mohr, 1983; Hart et al., 1989; woldegabriel et al., 1991;Ebinger et al., 1993; Hofmann et al., 1997 cited in Tewdros 2006).

The most important volcano−tectonic event in the central sector of the MER occurred in Early Pliocene, with the eruption of voluminous flows of rhyolitic ignimbrites and the collapse of very large calderas (Di Paola, 1972; Woldegabriel et al., 1990). From early Pleistocene to the present tectonic and volcanic activity was concentrated along the Wonji Fault Belt (WFB) to the east and along the Silti Debre Zeith Fault Zone (SDZFZ) to the west (Mohr, 1962; Di Paola, 1972).

In the southern and central sectors of the MER, volcanism started as early as in Eocene time with significant basaltic eruptions, associated with an early stage of rifting characterized by uplift and faulting (woldegabriel et al., 1990, 1991; Ebinger et al., 1993). From Late Oligocene to Early Miocene times, the first major phase of rifting within the MER resulted in a series of asymmetric half-grabens with alternating polarity. This was accompanied by the formation of shield volcanoes in part of the main Ethiopian rift on both sides of the rift shoulders The abortive phase of crustal extension to the east of the proto-rift resulted in the formation of extinct Pliocene trachytic shield volcanoes of the eastern highland which rest on trap basalts (Kunz et al., 1975 in Tenalem Ayenew, 1998). The volcanoes include Chilalo, Galama, Hunkulo, Kakka, Chike and Kubsa.

The Ethiopian volcanic terrain was formed by several episodes of eruptions representing diverse volcanic sequences. The volcanic products in the area consists of fissural basaltic lava flows ,stacked one over the other, alternating with volcanoclastic deposits derived from tuff, ignimbrite and volcanic ash. The boundary faults expose crystalline basement rocks beneath tertiary volcanic rocks in the southern sector of the MER, whereas in the central and the northern sectors, the rift margins are tertiary mafic and silicic rocks. Pre-Tertiary crystalline basement and Mesozoic sedimentary rocks that are unconformabley overlain by Oligocene to Pliocene basalt flows and silicic tephra are exposed in the western margin of the central sector at the Gurage Mountains (Woldegabriel et al., 1990)

.In the rift recent continental type volcanism has developed, giving rise to lage silicic rocks from predominantly central type eruptions partly accompanied by fissural basaltic lava flows. The oldest flows are rarely exposed beneath thick younger flows, and the individual flows are only local (Barberi etal., 1975; Zanetti et al., 1978; Berhe et al., 1987). The basalts are now concealed by a cover of silicic stratoid volcanics (Di Paola, 1972). Subsequent volcanic activity has been largely confined to the active Wenji Fault Belt running parallel to the rift axes (Mohr, 1967).The highlands are dominantly covered with basic volcanic rocks mainly of tertiary age. The oldest volcanic rocks (Plateau Trap Series or Volcanites of Plateau) are exposed in the western and eastern elevated areas.

The western escarpment consists of about 1000 m of basaltic lava flows, with inter-bedded ignimbritic horizons, overlain by massive rhyolites, tuffs and basalts (Di Paola, 1972; Merla et al., 1979; Woldegabriel et al., 1990). The sediments largely exposed in the area consist of lacustrine deposits, volcano-clastic and fluvial sediment. They are mainly characterized by upper quaternary fluvio-volcano lacustrine facies, and colluvial deposits that represent weathered/remobilized volcanic rocks and silicic tephra. The sediments occupy the rift floor where in the past it was covered by a wide lake. The four present day lakes had once been a single fresh water lake (Nilsson, 1940).

3.1.2 Local Geology

The geology of the study area consists of lithological units from Precambrian age up to recent except the Paleozoic deposits. The major out croup distributed in the area are volcanic products such as Nazreth group, dino formation undifferentiated, Chilalo volcanic, the central rift volcanic complex, basalts and associated flows of the rift floor, volcano-sedimentary and lacustrine deposits. The Nazreth group and the dino formation are the dominant unit which covers the study area. The main geological formations in the basin are categorized into six groups, (Tesfaye cherent .1998).

Nazreth Group

*This group comprises ignimbrite***,** rhyolites, trachytes, unwelded tuffs, Ash-flows and alkaline and per alkaline silicic stratoid. These units cover the escarpment in the east and the highlands in the west of the study area. Their age ranges from 9 to 12 million years.

Dino formation

Consists of water lain pyroclastic with intercalated lacustrine beds, welded ignimbrites, tuff, layered pumice and reworked pyroclastic rocks. This unit out crops to the east and west of escarpments. Generally the thickness of this rock unit varies in the highlands and the lower reaches of the study area.

Chilalo volcanic

This group includes alkaline basalts and underlying trachyte lava flows having 1.5 and 4.5 million years in age .trachyte basalt is the major unit which forms the mountains of the eastern highlands such as Chilalo, Kakka, Galama and Kubsa.characterstic features of these mountains are they are formed by central type of eruption that reach about a thickness of 3000m near the center of the eruption and decreases away from the center towards west in the study area.

The Central Rift volcanic complexes

This group consists of the rift valley highlands and cinder cones and typically formed as results of rhyolitic lava flows and domes associated with the rift floor ignimbrites. Pumice and ignimbrites are result of gas rich silicic magma, most probably the same magma, having lost its gases during the explosive activity and was erupted later on the viscous lava flows and domes,(Di paola, 1972 cited in Kumo ,2006).the alkaline and per alkaline silicic are the final volcanic products in the region and is formed in the slope of Bora,Baricho and Goraa mountains. The pyroclastic volcanic products constitutes from un welded pumice flows, pumice falls and ashes and while the lava flows constitute rhyolites, (Tenalem Ayenew, 1998).

Recent Basalts of Rift floor

These are Pleistocene basalts, basaltic hyaloclasts, recent to sub recent basaltic flows and cones that cover the rift floors the study area. this formation exist in uninterrupted lava fields elongated parallel to the main trend of the rift(NNE-SSW) and formed as a result of fissural eruption.it consists of the Wonji basalt and silte volcanics. The Wonji basalt covers east of lake ziway extends to the eastern escarpment whereas the silte volcanic exposed the in the western escarpment along the main regional fault. The hyaloclasts consist of fine glassy material, generally yellowish to brown in color containing small boulders of basaltic lava.

This basalts are highly affected rift structures mainly in the eastern side of the study area particularly by Wonji fault structures which is evidence along the fault plane to be underlain by highly fractured rift floor ignimbrite, (Tenalem Ayenew, 1998) and (Tesfaye Cherent, 1982)

Volcano-sedimentary rocks and lacustrine sediments

This group consists of volcano clastic sediments, tuff, and associated lacustrine sediments. The lacustrine sediments constitute clay, silt, diatomite and ash and tuff associated with rock fragments derived from wide variety of volcanic rocks. Lacustrine sediments are deposited in the vicinity and beneath the beds of lakes.

The alluvial deposits include fan and flood plain and exist in the river beds of the study area. For example at Butajira approximately 100m thick clay, sands and gravels have been penetrated in drill holes close to Irinzaf River (HALCROW, 1989 cited in Tenalem 1998).

Eight lithostratigraphic units were observed in this group

i. *Alluvial deposit*: mainly terrace gravel, sand and silt associated locally with clay (Holocene - Present).
ii. *Colluvium*: gravels, sands, silts and volcanic pyroclastics (mid Pleistocene-Recent)
iii. *Pelite dominated lacustrine deposits*: deposits of pelite and peat (200 BP-Present)
iv. *Meki and Kater deltaic deposits*: sand, silt and clay (Holocene).
v. *Tufa fluvo-lacustrine deposits*: mainly gravel, sand, pelite, and peat (Holocene).
vi. *Deltaic and fluvio-deltaic deposits*: deposits of sand, silt, and clay (Holocene).
vii. *Bulbula deposits*: volcano-lacustrine deposits, mainly pyroclastics derived from ash
viii. *Ziway terrace and volcano-lacustrine deposits*: pyroclastic derived from ash and tuff. Also included are pelite, diatomite, silt, and clay with occasional shore sand and shell beds (Holocene).

3.2 Structure

3.2.1 Geologic Structures

The geological structures of the rift valley lake basin is characterized by two main major rift zones, the main Ethiopian rift (MER) and the south western Ethiopian rift (SWER).the MER extends from the southern Afar margin to lake chamo area where as the SWER is located to the west and represents roughly N-S trending basins related to the Kenyan rift. Fault system in northern RVLB is characterized by the development of continuous major faults which has big displacement with minor parallel faults, and fault zones associated with volcanic activity in the rift floor. While, Pre-Cambrian and Neogene fault system in southern RVLB is neither continuous nor regular.

The difference of the development of those faults is deeply related with the development of basin in RVLB, it indicates that the basin is well developed in the northern part and poorly developed in the southern part.WoldeGabriel et al., (1990) classified the distribution of those faults and considered that Rift Valley Marginal Faults were active at the formation of the valley and are still active. Furthermore, with the development of RVLB, spread of rift floor has been started through the development of Wonji Fault Belts since Pleistocene age.

The MER includes an area characterized by active extensional tectonics, due to an E-W oriented direction of extension Halcrow, 2008) Two main fault systems have been identified in the MER: a N300E – N400E trending fault system, which characterizes mainly the rift margins, and a N-S to N200E trending fault system, the Wonji Fault Belt (WFB), which shows a number of sigmoidal, overlapping, right-stepping en-echelon fault zones, obliquely cutting the rift floor. The margins of the MER are characterized by a few widely spaced faults with very large vertical displacements, to the rift floor. The eastern margin is well developed and it is defined by a more or less continuous system of boundary faults, whereas the western border is marked by only a few major faults in the Mt. Guragie area.

The present asymmetrical rift was fully defined by 3.5 million years when a paroxysm of ignimbrite of the Munisa crystal tuff erupted from large caldera located on the rift floor (Caroline et al., 1999). This is followed by a line of hundreds of young faults and volcanic centers along the rift floor close to the eastern escarpment initiated around 1.6 million years known as the Wonji Fault Belt (Mohr, 1971).

The rift floor is affected by dense fault swarms, exhibiting relatively small throws (<100m). The rift floor faults have steep scarps related to the Wonji Fault Belt (WFB), which commenced its formation around 1.6 MA. These sub parallel faults caused widespread deformation affecting the rift floor. In the center of the rift floor, these faults are orientated at 200º with respect to the main trend of the rift. The faults of the WFB, affecting the rift floor, are closely spaced, commonly en-echelon and linear or curved in plain view over distances of up to a few tens of km. They delineate many fault bounded blocks. Associated with these faults are open fissures with or without vertical displacement, splay patterns, aligned cinder cones and complex rhomb-shaped structures. These faults run in NNE - SSW direction or in few cases in NE - SW and more rarely in N - S direction.

A large number of these faults run for long stretches even hundreds of kilometers and show displacements greater than 300m.Some differences exist in the tectonic lineaments between the eastern and western escarpments. The eastern faults (part of the Wonji fault belt) forms an extensive minor graben and horst structures which resulted in a minor rift-in-rift structures. The Tectonic development and associated volcanism in the western part of the study area includes Butajira collapse structure which resulted in the crescent shaped Butajira plain, recent basaltic and cinder cones had erupted following the MER fault trend, kuntane-Inseno-Kela plain and Tora-Koshe-Dugda ridge/horst.

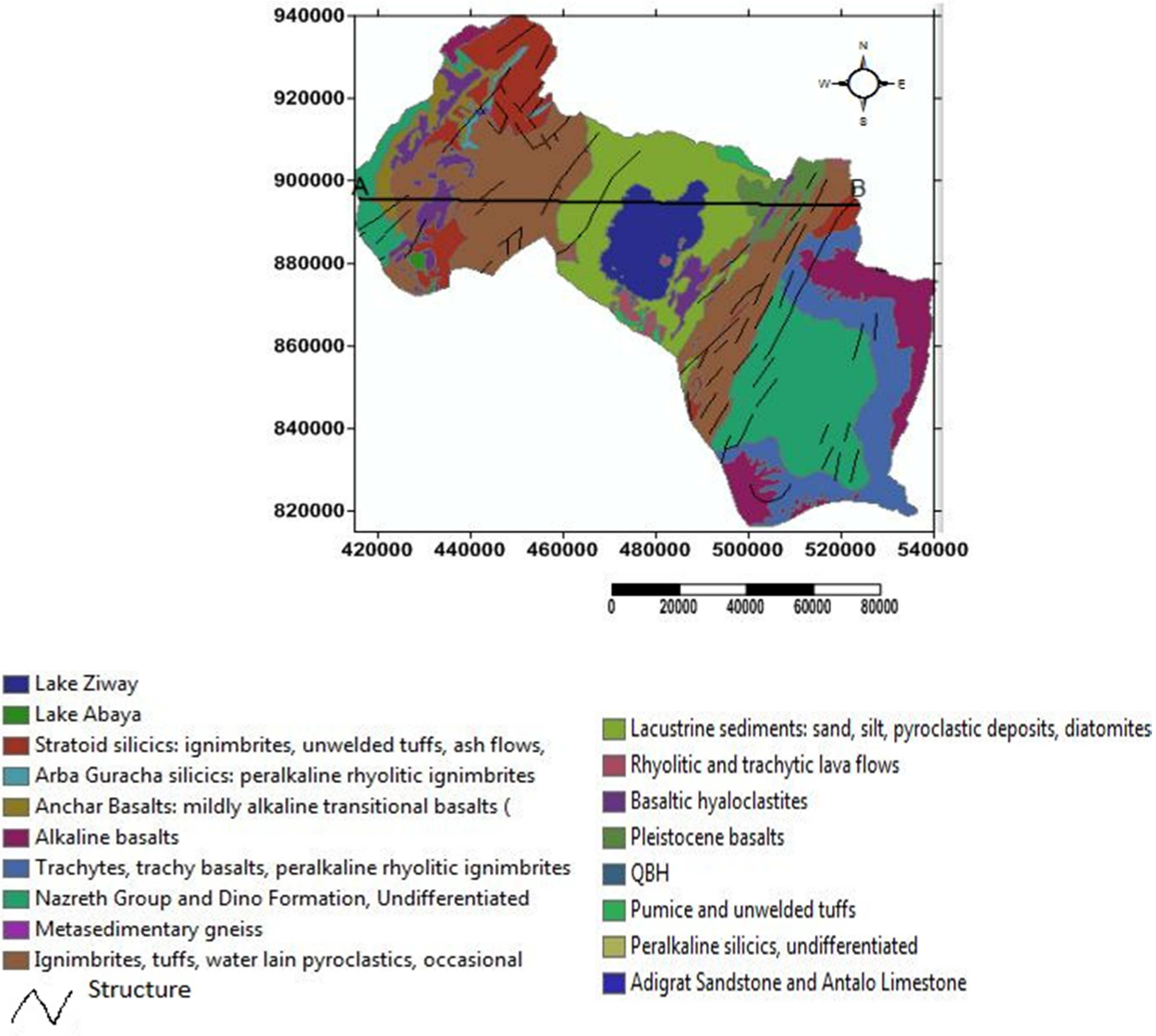


Figure 9 Geological and Structural Map of the Study Area, AB x-section (Extracted from Rift valley shape file)

CHAPTER FOUR

Conceptual Model

4.1 Introduction

Development of a valid conceptual model is the most important step in a computer modeling study. Conceptual model is a simplified representation of the essential features of the physical hydrogeological system, and its hydrological behavior, to an adequate degree of detail. The conceptual model is usually presented graphically as across-section or block diagram (Anderson and Woessner, 1992), with supporting Documentation outlining in descriptive and quantitative terms the essential system features and It forms the foundation upon which the interactive, site-specific model is built, and is itself based on an initial literature review, data collation and hydrogeological interpretation

While the conceptual model is an idealized summary of the current understanding of catchment conditions, and the key aspects of how the flow system works, it is subject to some simplifying assumptions. The assumptions are required partly because a complete reconstruction of the field system is not feasible, and partly because there is rarely sufficient data to completely describe the system in comprehensive detail. However, the conceptual model should be developed using the principle of *simplicity* (or *parsimony*), such that the model is as simple as possible, while retaining sufficient complexity to adequately represent the physical elements of the system, and to reproduce system behavior.

The principle of simplicity/parsimony is also known as Ockham's Razor - "Entia non sunt multiplicanda sine necessitate". This may be translated literally as "The number of entities should not be increased without good reason", or loosely as "It is vain to do with more what can be done with fewer" (Constable etal., 1987). This principle dates from the early 14th Century, and is fundamental to many aspects of life.

In developing an adequate (parsimonious) conceptual model, however, sufficient degrees of freedom must be incorporated to the model features to allow simulation of a broad range of responses. It must be possible for the model to predict system responses ranging from desired to undesired outcomes. In other words, the model must not be configured or constrained such that it artificially produces a restricted range of prediction outcomes. The development of this conceptual model take in to account the fact stated above and followed the major steps of defining Hydrostratigraphic unit , analyzing water budget component and defining flow system as of Anderson and Woessner, 1992, procedure of building conceptual model. The conceptual model of the Ziway lake basin, the region under study, consider every previous verified investigation, hydro meteorological data, boreholes and literature review with judgment of the modeler.

4.2 Geometric characteristics

The aquifers of the Ziway lake basin are divided in to two catchment system, namely the Meki and Kater river catchment which owned distinct hydrological and hydrogeological behavior. The aquifer area extends about 128km east to west and 74km and 68km north to south in Meki and Kater river catchment respectively. Identification of the aquifer systems in the study area including their thickness is based on the available field data and previous literature reviews.

A. Aquifers of Meki river catchment

The Butajira Crescent which is characterized by a complex mixture of sediments composed of unsorted to poorly sorted alluvial, talus or fan deposits, debris flow and volcano-clastic deposits have sediment thickness varies from 80 m to about 120m, Basaltic Cinder Cones region which is dominantly composed of Scoria Cones and associated vesicular basalts have a thickness high over 100 m in the central part where the volcanic centers and vents are located.

Kontane-Inseno-Kela plain which is covered by pyroclastic fall and reworked water lain pyroclastic deposits, lacustrine, alluvial, debris flow or talus deposits and fan deposits have sediments thickness varying from few meters in the west to several meters (more than 260 meters and more) in the center and along Weja river.

Tora-Koshe- Dugda ridge is mainly composed of pyroclastic deposits such as tuff and ignimbrite and finally Ziway plain is composed of lacustrine sediments mixed with pyroclastic fall deposits Cover the entire area having a sediments thickness from few meters in the north and northwest, south to several meters (more than 300 meters and more) in the center.

Ziway Plain; in this area existing borehole data indicates the aquifers are composed of pyroclastic fall and reworked water lain pyroclastic deposits, lacustrine and alluvial. The thickness of these sediments varies from few meters in the north and northwest, south to several meters (more than 300meters and more) in the center.

It is constituted by Chilalo volcanics, Nazreth group, (ignimbrite, tuff, rhyolite & trachyte), Rift floor ignimbrite, Alluvium, and Recent rift floor basalt, ash and pumice. These rocks are placed side by side or laterally to each other in the study area and assumed the same with in the study area. Because the lithological log for the wells also do not show the overlying unit in different sites of drilling within the depth of drilling thus the hydrogeological properties of the major units are discussed separately as follows.

A. Kater river catchment

Chilalo volcanics occur bordering the study area in east and southeast boundaries. It is the product of lava out flow from Badda, Chilalo, Honkolo, Kakka, and Kubsa volcanic eruption centers. This unit is characterized by fracturing, jointing and weathering. There are no drilled wells in this lithological unit, to evaluate its hydraulic properties. But its permeability and thickness is the function of fracturing and weathering and varies from place to place. As observed along some intermittent stream valleys, the thickness of fractured and weathered portion does not exceed few tens of meters. However, its permeability is estimated to be low, (Tesfaye Cherent, 1993). But it is characterized by high recharge and shallow and fast groundwater circulation.

Nazreth group of ignimbrite, tuff, ash, rhyolite and trachyte in composition covers large and central (plateau and escarpment) part of the study area. The main difficulties in this area were the aquifers are not well identified contrary to the Meki river catchment. This is due to the absence of sufficient geophysical data and borehole lithological data which enable to examine the spatial distribution of aquifer thickness in the area.

Estimation of the aquifer thickness is made based on the existing few well data located in different parts of the study area. As the few productive wells pump test data analysis show, this formation is characterized by variable specific capacity which range from low (0.00125 to moderate (6.25Lps) and it has low to moderate permeability (Tenalem Ayenew, 1998).in this formation the aquifer thickness is estimated to be 300m for the model input data.

The third hydrogeological units in the area are rift floor ignimbrites and basalts with the interbedded/covered by lacustrine deposit, ash and pumice. Pumice and Ash are loose with good intergranular porosity which gives it moderate to high permeability. Most of basaltic rocks of this area are characterized by vesicular texture and joint structure. Furthermore, all these rock units area are the most affected unit in the study area by faulting, fracturing and jointing. Wonji fault belt also passes through this hydrogeological unit, which intensively disturbed it thereby inducing secondary porosity and permeability to the rock. Both these secondary and primary porosity had given the rock unit high productivity.

The depths of wells in this unit range from 210m, near the escarpment at Kobo Borera village, to not more than 30m near Kater River and around the northwest end of the basin. this unit also do not have any report, that show drilling depth which fully penetrate the aquifer and end up with the lower aquifer boundary within the depth of drilling. From this the aquifer thickness is assumed to be above 210m.Thus aquifer thickness of 250m is estimated for the conceptual modeling purpose in this area.

4.3 Surface water hydrology

4.3.1 Lakes

Lake Ziway is the northernmost of Ethiopia’s Rift Valley lakes. The lake is notable for its scenic qualities – it is ringed by steep volcanic hills. Due to its accessibility, favorable location in relation to Addis Ababa and fresh water quality, Lake Ziway has been considered the most important water exploitation area in the rift valley (HALCROW, 1992).the main water source for the lake is the flow of the Kater and Meki rivers. The interaction between the lakes with the neighboring groundwater system is mainly governed by the existence of change in water level in the two systems. Lake recharges an aquifer when the groundwater level is below the lake water surface whereas aquifer recharges lake when the groundwater level is above the lake water surface. In addition there are also smaller lake within the study area such as Lake Abaya, Goletsh and Crater Lake known as Har-shetan. The area between Lake Abaya (Tuffa) and Dobena river area have very flat plain fed by flood and seasonal streams from west of Butajira area. Mostly this part of the plain gets flooded during the summer and develops temporary lake, which shrinks during the dry season. It is mostly water logged during the rainy season. This is because of the flat topography surface runoff from the west and east and the input of the springs, shallow groundwater and overflow from the lake.

4.3.2 Rivers

The major rivers in the study area are Meki and Kater rivers. Meki and Kater River replenish the Ziway Lake, which in turn gives rise to the outflow to Bulbula River that flows south west for about 30 Km before draining into terminal lake, Lake Abijata. Water flows from the river into the aquifer when there is an increase in river stage with respect to the altitude of the groundwater level. A decrease in river stage with respect to the groundwater level causes water to flow from the aquifer into the river and result in the decrease of groundwater level.

The extent of the change in the groundwater level elevation in response to river stage fluctuations depends on the magnitude of the change in the river stage, the length of time the river remains at the current river stage, the hydraulic properties of the aquifer material, and the distance from the river to the point of interest. The effect of decrease or increase in the river stage on the region of the aquifer depends on the length of time that the river stage remains at the new altitude. Groundwater level at distant locations from the river is the result of long term river-stage changes typically caused by seasonal high and low flows or long-term river-stage management.

Meki River and Kater river streambed deposits are typically composed of lacustrine sediments mixed with pyroclastic deposits such as tuff and ignimbrite, alluvial, debris flow or talus deposits and fan deposits. The lacustrine deposits vary from clayey silt to fine sand deposits and whereas the fluvial deposits vary from silt to cobble size and sometimes up to boulder size, thus it is well connected hydraulically to the underlying lacustrine sand aquifer. The main streams of Meki and Kater River are Weja, Irinzaf Lebu Akamuja and Ashebeka, worga, Tamela and Bosha streams respectively. These streams have smaller streambed hydraulic conductivities and have less effect on groundwater flow than the larger Meki and Kater River, locally the bottoms of the river channels can be above the top of the groundwater level. In the study area there are numerous smaller streams and drainage channels.

Comparison between the average flow values for Meki and Kater Rivers clearly illustrate that Kater River has more volume of flow as a result of its larger catchment size, but the specific discharges (discharge per unit area) of the two rivers are almost identical. This indicates that the similarity of rainfall in the highlands of the two catchments. Another important river in the study area is Bulbula River drains annually about 180 MCM of water on average from Lake Ziway into Lake Abijata. It does not have a significant catchment area of its own. The upper part of Bulbula River is also known as Kekeristu River the monthly discharge of the rivers is shown in the table and graph below.

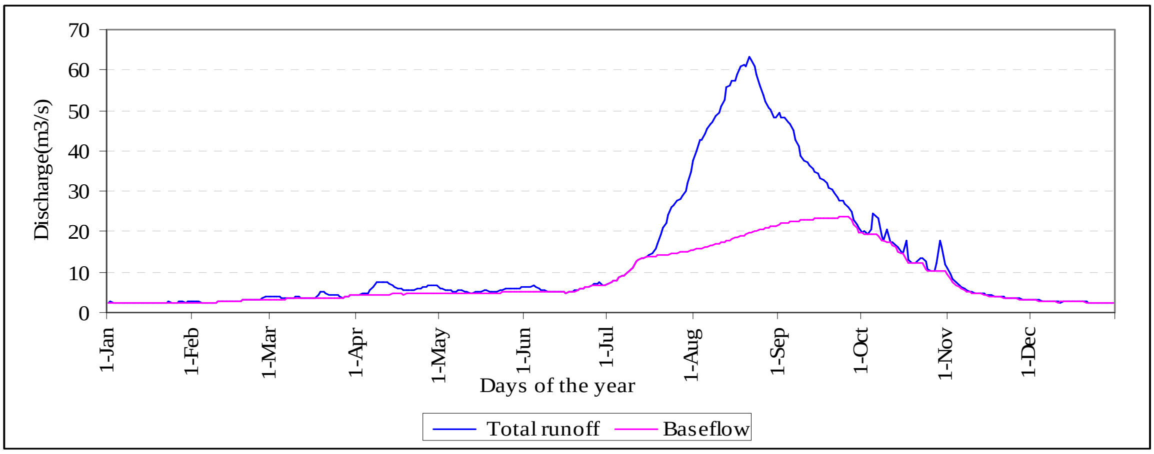


Figure 10 Base flow separation of Kater River discharge gauged at Abura station

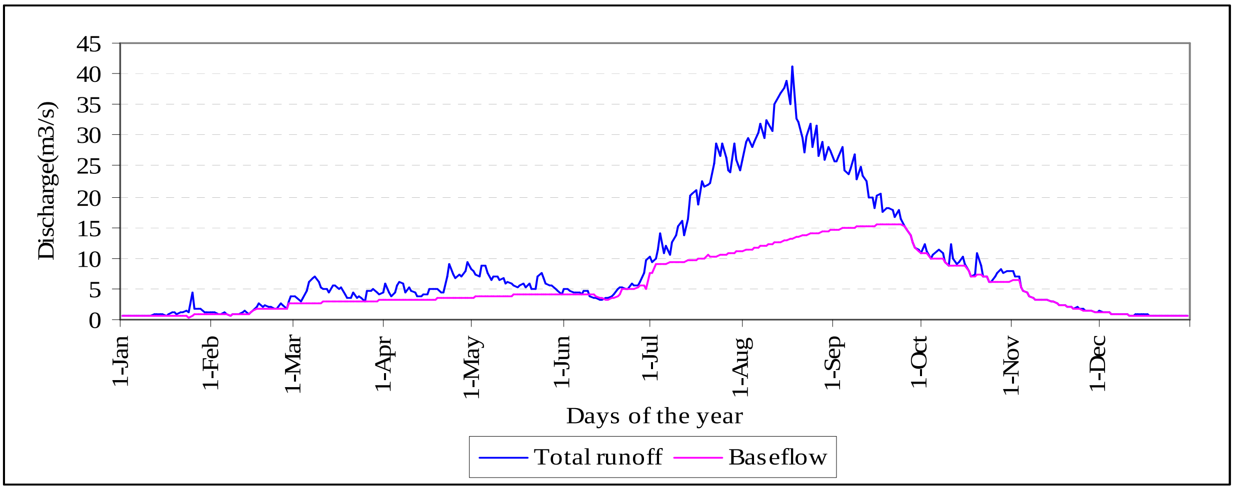


Figure 11 Base flow separation of Meki River discharge gauged at Meki town

4.4 Hydrogeology

4.4.1 Aquifer hydraulic properties

The hydraulic properties of the aquifer used in the conceptual model are key components which serve as first input for groundwater flow model. It is defined as the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The hydraulic conductivity of the material in an aquifer or confining units is a measure of the ease with which water can move through the material. It is a function of properties of both the matrix and the fluid. Water in the regional flow system was assumed to have a uniform density and viscosity, and thus the hydraulic conductivity only varies as the grain size, shape, sorting & packing (freez and cherry, 1979).

4.4.1.1 Horizontal hydraulic conductivity

The hydraulic conductivity of the aquifer in the study area is obtained from pumping tests carried out in the previous studies. The hydraulic conductivity varies spatially in the study area which is the result of variation in lithological units, effect of structure and degree of weathering. The pumping test results have been documented on a number of published and unpublished reports. The horizontal hydraulic conductivity of different geological units has been reported by (Tenalem Ayenew, 2006) as follows:

Guragie highland constituted from welded ignimbrites, tuff, rhyolite and trachyte without visible large faults, Chilalo volcanics and part of Nazreth group has hydraulic conductivity range from 0.1 to1m/day. In this region the upper weathered rock and soils are permeable; however, the underlying volcanic sequences are massive whereas the remaining part of Nazreth group in the eastern side of the study area has hydraulic conductivity value of 2.5 to5m/day.

Butajira crescent, Kuntane-Inseno-Kela plain, Tora-Koshe-Dugda ridge characteristics of fracturing and weathering grade, this unit has 5m/day hydraulic conductivity. Ziway plain characteristically composed of rock units Ignimbrite overlain by lacustrine sediments such as shale, clay, diatomite and reworked pumice.

This unit possesses hydraulic conductivity value of 1m/day to 5m/day. East of Butajira and Rift floor in the Kater catchment consists of ignimbrite, volcanoclastic deposits, lacustrine sediment and recent Basalt are characteristics of highly fractured, jointed and faulted unit and the scoria cones and highly fractured ignimbrites along the major fault which owing to fractures, joints faults and vesicles possess hydraulic conductivity range of 10m/day to 20m/day

Table 2 Hydraulic characteristic of wells in the study area

No	Location	Cased diameter(mm)	Ground elevation	Total depth (m)	Transmisivity (m2/day)	Hydraulic Conductivity (m/day)	Draw down	yield (l/s)	Aquifer lithology
1	Adami Tulu	168	1650	71	221	8.4	4.92	5.6	lacustrine sediment
2	Mitto	240	1800		416	13.87	3.8	5	ignimbrite
3	Ashebeka	250,150	2420	151	1.82	0.03	25.2	8	ignimbrite
4	Alkasa	250,150	2420	125	1.3	0.02	12.5	0.03	ignimbrite
5	Wereseni	250,150	2450	168	780	18.4		0	ignimbrite
6	Waji	250,150	2600	115	1.04	0.02	0.5	1.7	ignimbrite
7	Kulumsa	250,150	2210	120	2.6	0.08	12	0.3	ignimbrite
8	Gora	250,150	2250	105	1040	41.6	0.25	1.1	ignimbrite
9	Gonji	250,150		102	78	4.12	3	1.6	basalt
10	Dugda	203	1920	122	91	2.94	3.6	2	lacustrine sed

4.4.2 Groundwater level and movement

A groundwater flow system is a set of flow paths with common recharge and discharge areas. When developing a conceptual flow model it is crucial to understand the recharge and discharge zones of the study area which is directly related to the topography, geology, structure and degree of weathering Subsurface stratigraphy and the resulting of subsurface variations in hydraulic conductivity can exist in an initial variety. This geological heterogeneity can have a profound effect on regional groundwater flow.

It can also affect the interrelation ship between local and regional systems, surficial pattern of recharge and discharge areas and the quantities of flow that are discharged through the systems (Freeze and Cherry, 1979). The general groundwater flow in the study area emanates in the eastern and western escarpments trending north east in the west and North West in the eastern parts and flow towards lake ziway.in this region groundwater level shows significant variation. Hence this favors the groundwater flow from the escarpments to the rift floor where by following a decrease in hydraulic gradients of the system.

Previous studies revealed that the groundwater flow in the study area is divided into local, intermediate and regional flow systems the western and eastern highlands of the basin which are limited to local flow system. This is due to absence of intense fracture, presence of barrier (mainly NE-SW running horst in the west) and weathering deep through in large areal extent which resulted in the shallow groundwater circulation. This is manifested by intermittent streams and low yield springs nearby which depict the influence of local groundwater flow.in this region there is no borehole data that aid for development of groundwater level and groundwater flow system instead the elevation of springs taken for the analysis.

The regional groundwater flow originates in the escarpments of the study area and flows relatively deep through in the different aquifer units of the system. Their extended permeability persist the flow continuation. This can only be maintained by absence of fault barrier and good permeability in the aquifer units.

The characteristic feature of this flow system in the study area examined by a number of deep boreholes and high yield spring water samples showing long residence time in the analysis. The local and intermediate flow exists in the rift floor aquifer systems of the study area. In this region presence of thick aquifer thickness and good permeability enables the existence of local and intermediate flow system. They are also discharge zone of the regional groundwater flow systems the source of recharge is mainly from direct recharge from precipitation and indirect recharge from rivers and neighboring groundwater system. The hydraulic gradient show slight variations unlike that of the highlands and escarpments. Hence demonstrate the effect of topography.

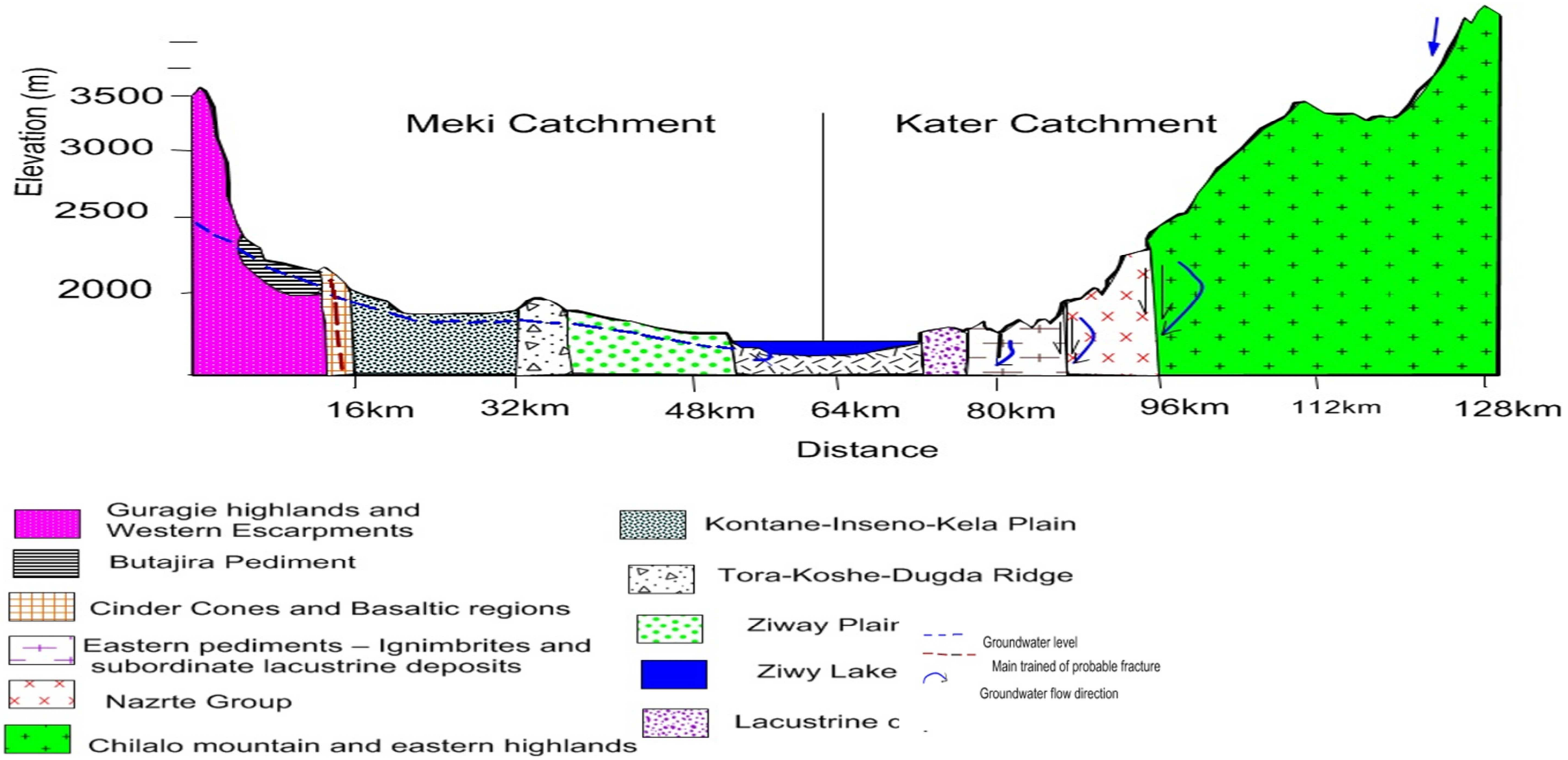


Figure 12.The conceptual profile model showing the groundwater-surface water interactions (Modified from Halcrow2008)

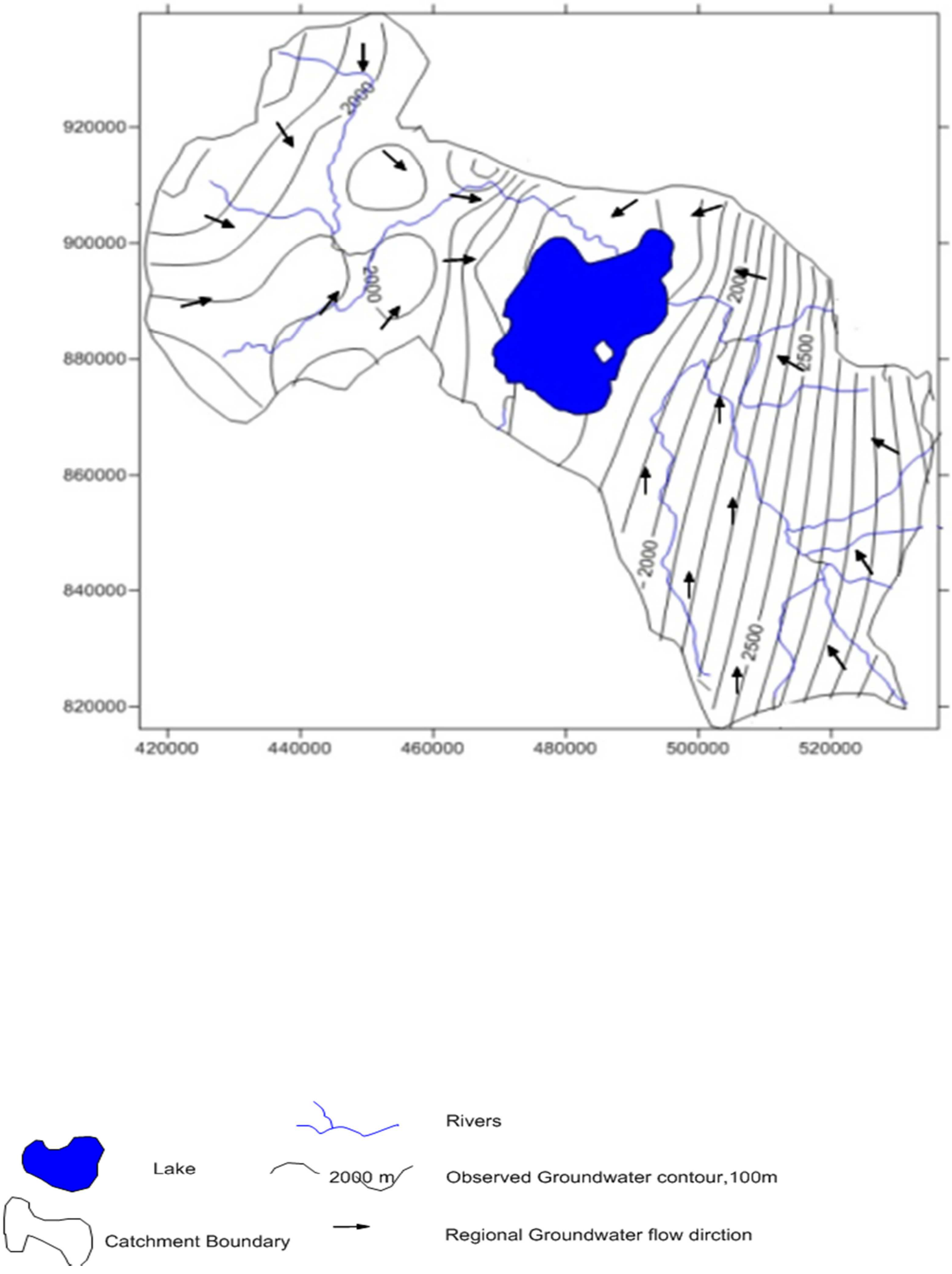


Figure 13 observed head distribution along with the direction of flow

4.4.3 Spatial distribution of recharge

Groundwater recharge is a process of water movement downward through the saturated zone under the force of gravity or in a direction determined by the hydraulic condition (Simmers, 1988). It is the net effect of precipitation, surface runoff, Evapo-transpiration, interception and overland storage. The source of recharge for a given groundwater system could be precipitation, river, irrigation loss, and inter aquifer flow recharge which are resulted from direct, indirect and /or localized recharge(Learner et al., 1990). From Kumo Kedir (page25).Simmers et al. (1997) identified two different precipitation mechanisms, diffuse and localized recharge. Direct or diffuse recharge results from wide spread infiltration of rain water at the point of impact whereas localized recharge resulted from horizontal flows that occurs into local depression that are not connected to any draining water Courses.The possible source of recharge in the study area from precipitation, lake, river, streams, and seasonal and perennial ponds.

4.4.4 Distribution of recharge in Meki river catchment

From previous water balance analysis of recharge estimation conducted by AG Consult, Consulting Hydrogeologists & Engineer, using Simple Water Balance method, Chloride method, Bucket Model and WEAP model indications that the annual recharge to Meki river catchment is 119.71 mm/year, which is 12 % of the annual rainfall. The catchment is classified into six different recharge zones based on the hydrogeological conditions of the area.

4.4.4.1 Western highlands

The western highland and Escarpment part of the study area receives high rainfall and discharges its surface and subsurface flow to the underlying areas. The analysis result obtained from Thiessen polygon, this area serves as the major recharge areas of the catchment which permits infiltration and shallow circulation of groundwater as result of large amounts of direct recharge. This is due to the characteristic features of the area such as fractures, fault zones and joints. Which are pertinent to the hydrogeological properties of the aquifer value of 0.0003 m/day is given as initial input for the model and the north eastern escarpment area have relatively smaller amount of recharge which is 3.91x10-4m/day due to its rainfall distribution difference.

4.4.4.2 Butajira crescent

This area is situated at the foot (pediment pain) of the western escarpment, and shallow groundwater and springs characterize it .this plain obtain groundwater recharge mainly from rainfall, groundwater flow from the escarpment and runoff emanating from the rainfall in the highlands. The sediment thickness varies from 80 m to about 120m.this unit possess high permeability (highly affected by fracture) can be a good aquifer in the fracture zone and an initial value of 3.81x10-4m/day is assigned.

4.4.4.3 Kuntane – Inseno – Kela Plain (including the scoria cones): the Kuntane-Insen-Kela plain is a marginal graben bounded from the west by the scoria cones region and to the east by Tora-Koshe-Dugda ridge. This plain receives recharge from several streams, groundwater inflow and direct rainfall from the western escarpment. It is covered by pyroclastic fall and reworked water lain pyroclastic deposits, lacustrine, alluvial, debris flow or talus deposits and fan deposits. The lacustrine deposits vary from clayey silt to fine sand deposits and whereas the fluvial deposits vary from silt to cobble size and sometimes up to boulder size. The base of the western escarpment around Kela is mainly characterized talus or debris flow and fan deposits. The thickness of these sediments varies from few meters in the west to several meters (more than 260 meters and more) in the center and along Woja River. During rainy season the runoff from Butajira and Kibet area drains into the Kuntane marsh and little Abaya whereas the runoff from Kela and Buie area drains to the east forming Meki River. The overflow from little Abaya (Lake) and Kontane Marsh and Dobena River forms Weja River, which flows towards North east of this plain to join Meki River. Meki River later discharges its water at Ziway Lake groundwater potential and occurs relatively at shallow depth, which is evidenced from many hangdog wells in this plain.

4.4.4.4 Tora-Koshe-Dugda ridge

This area is one of the aquifer systems of the basin and composed of mainly from pyroclastic deposits such as tuff and ignimbrites. This area serves as the eastern boundary to the Inseno-Kela valley. The topography and the hydrogeological characters tic features of this unit made it possible controlling stream flow direction and acts as surface water barrier. This is clearly indicated by all the surface water from the western part, and southeastern direction flowing streams turn to northeast direction flowing the base of the ridge while reaching the ridge.

Finally the topography is gently down slopes towards Lake Ziway and the lithology gradually changes to lake sediment. Groundwater table occurs in this unit is very deep over 130m above the ground level. Since in the model recharge is applied to the highest active cell direct recharge in this zone is considered as very small. Therefore, an initial value of 0.00001 m/day is assigned for the model input.

4.4.4.5 Ziway plain

It is one of the lacustrine sediment deposited in the study area which covers large area extent compared with the Kuntane-Inseno-Kela plain.it consists of layers of alternating silt and clay with volcanoclastic sediments, sand, ashes, transported pumice slit, clay and diatomites.the thickness of these sediments varies from few meters in the north and northwest, south to several meters (more than 300m and more) in the center. The source of recharge for this plain is mainly from groundwater inflow from neighboring aquifers and a limited amount of direct rainfall contributed as a recharge. The characteristic's feature of this area is the evapotranspiration exceeds the direct recharge contributed from rainfall.

4.4.5 Distribution of recharge in Kater River Catchment

Since there is no recent classification of the catchment into different recharge zones so that the distribution of recharge is taken from previous classification of the catchment by (Tenalem Ayenew 1998) based on the three physiographic regions, i.e. the rift, escarpment, and the highland. But there slight variation in the values of recharge according to Jika study on groundwater resource assessment in the rift valley lakes basin

4.4.5.1 The Eastern highlands

The eastern volcanic mountain consists of Badda, Kubsa, Kaka and Chilalo. These mountains receive Annual rainfall over 1400mm and the recharge from this area is mainly from the direct recharge (precipitation infiltration) and indirect recharge from stream flow infiltration.in most parts of this region the groundwater level is higher than river bed elevation thus recharge from stream is confined to specific place. This area is also characterized by fast infiltration and shallow groundwater circulation which is evidence from the very low EC values of the groundwater samples.

The Plateau and Foot slopes The main source of recharge in this area is direct recharge from precipitation which is favored by upstream well-structured drainage systems and also in relatively fast and shallow groundwater systems.in comparison the recharge amount is lower than the mountains region.in comparison with the mountainous region this area gets lower amount of recharge and the EC value shows small increase.

4.4.5.2 Escarpment areas

Unlike the upper zone of the study area, the source of recharge in this area comprises of direct and localized recharge from precipitation and indirect recharge from rivers. This is favoured by the existence active fault structures and intense fracture, particularly in the eastern half of the basin and north eastern part of the study area. The amount of recharge in this area is lower than the upper regions due to the effect of lower rainfall and high evapotranspiration.

4.4.5.3 The Rift floor

The source of recharge in this region consists a limited amount of direct recharge on top of the rift volcanoes and flow from ephemeral rivers. Groundwater flow from the highlands did not have continuation due to the low permeability and the existence of fractures and marginal faults rather the groundwater surface emerges at the surface forming discharge zones .since the recharge is from local and intermediate source the area is characterized low gradient flow in the shallow aquifers and moderate in deep aquifer systems. Later on the above different physiographic regions are reorganized into three recharge zones based on their resemblance characteristics (or using different techniques) and their respective values are assigned as low, medium and high recharge zone (Tenalem Ayenew, 1998).

Zone	low recharge (mm/ day)	Moderate recharge (mm/ day)	High recharge (mm/day)
Rift	0	0.01	0.011
Escarpment	0.09	0.1	0.11
High land	0.27	0.3	0.33

Table 3 **Recharge for the three regions (adopted from Tenalem Ayenew 1998).**

4.4.6 Groundwater discharge

The means of groundwater discharge in the study area includes abstraction of wells, evapotranspiration, springs, base flow to surface water bodies, and inter basin or aquifer system transfer. A number of high yield springs originate in the eastern and western escarpment of the basin forming the bases for the existence of large perennial rivers namely Meki and Kater River and finally flows to Lake Ziway. The base flow represent the interaction of the aquifer system with the perennial stream with a concept of groundwater maintain the flow of stream during dry season. Kater and Meki river catchment are well connected to the aquifer system which feeds water to the river as base flow during the dry season.

The groundwater discharge from the aquifer is expressed as springs and seepages along the river banks. Previous studies (Named MAWARI project) result on systematic river discharge measurements indicates that in the highland areas of the catchment, the elevation of the water table contours lie above river bed indicating effluent characteristics of the river. The elevation Meki river bed in volcano-lacustrine sediment of rift floor and that of Kater at the central and upper part of Wonji Fault Belt lies above the elevation of the contour showing loosing behavior of the rivers. Accordingly, Meki River has losses of about 43mcm between Dugda and Meki town stations in the stretch of 34.2km; while the Kater river losses about 86mcm water annually between Fite and Abura stations in 36.2km river stretch.

Springs are usually treated as nonlinear head dependent discharge boundaries that have zero flow when the head in the aquifer becomes lower than the altitude of the spring .AS part of the natural groundwater discharge, a number of high and low yield springs are identified during the fieldwork. Most of the springs are gravity springs, discharged right at the contact of permeable and less permeable units and faulted zones mostly in the highlands and escarpments regions. in the rift floor of the study area around lake ziway and following the river flow there is large irrigation activity that utilize both surface and groundwater source almost in annual basis which in turn undermine the water resource of basin.

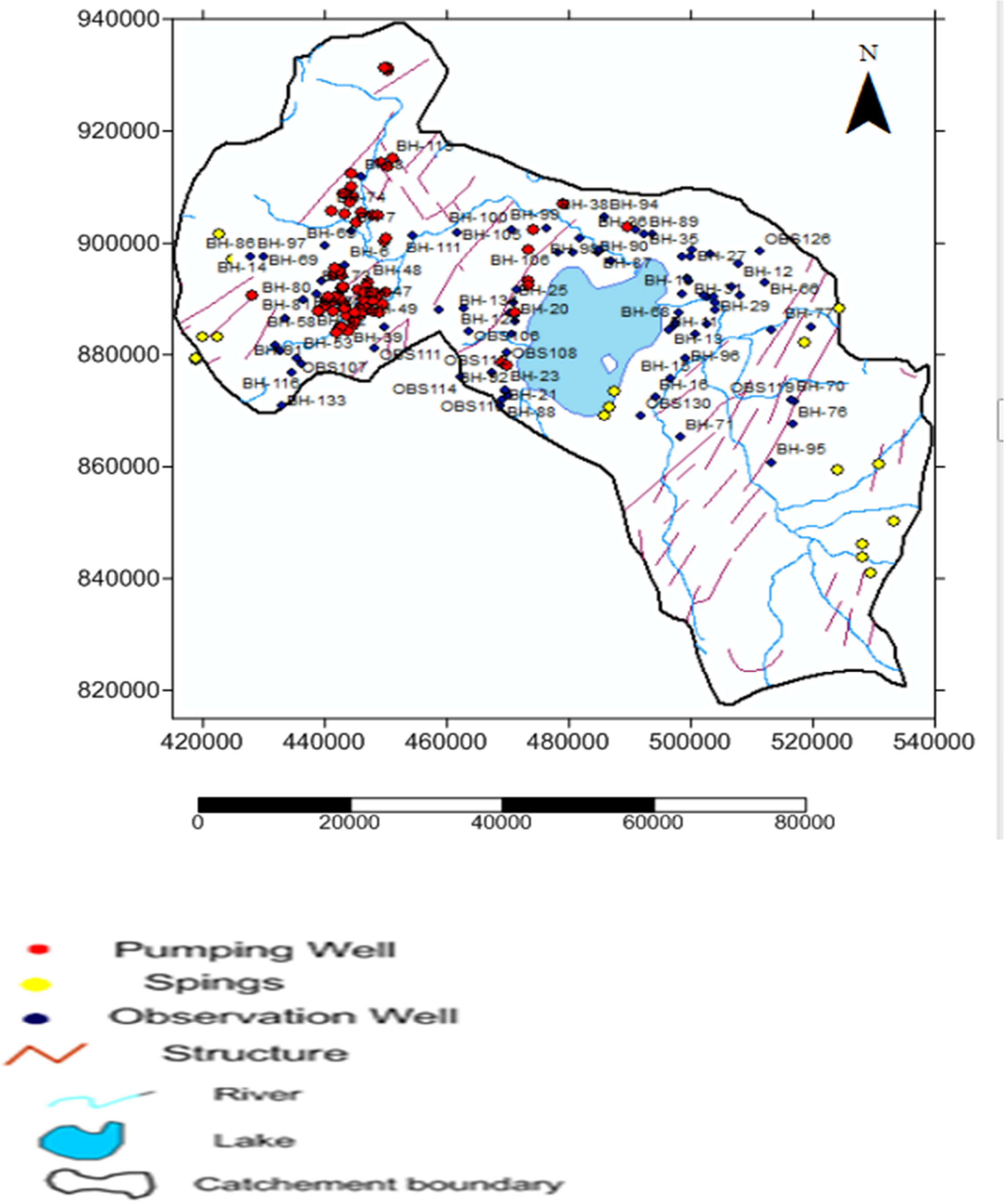


Figure 14 Water Points found within and around the study area.

CHAPTER FIVE

Numerical Model

5.1 Introduction

Numerical modeling are used to represent complex processes (Hill, 1998).Numerical models are used when complex boundary conditions exist or where the value of parameters varies with in the model (Zheng and Bennett).due to the complicated subsurface environment, conditions can rarely be replicated completely by mathematical expressions. Simplifying assumptions are usually made to solve flow equations for appropriate boundary and initial hydrologic conditions.

For study area numerical modeling is built using the U.S. Geological Survey modular three-dimensional finite difference groundwater flow model Processing Modflow Pro (Version 8.0.15) Processing Modflow Pro is an enhanced version of Modflow which allows the user to define a groundwater model using a conceptual model approach, where by properties and boundaries are defined spatially using vector-based arcs, polygons, and points. For example, aquifers, lakes, rivers, and wells which contain specific boundary condition data, such as material properties, stages, recharge, and pumping rates.

MODFLOW numerically uses block-centered finite differences to solve the flow equations in three dimensions. It consists of a main program and independent subroutines called modules (McDonald &Harbaugh, 1988). The modules are grouped into packages and each package deal with a specific hydrogeologic feature to be simulated. Groundwater levels were calculated at discrete points by solving Simultaneous equations that approximate the partial differential equation for groundwater flow. The discrete points are the result of discretization of the model area into a series of rectangular model cells with the points (or nodes) located at the center of model cells.

Ziway lake basin was simulated by MODFLOW using two dimensional steady-state option, unconfined aquifer and single layer approach. Because the model is aimed to simulate the ultimate effect on the flow system resulting from changes, could be recharge or discharge, in mean-annual basis, and the geological conditions are very complex and assumption of different model layers is difficult because of the non-uniform and highly variable and complex lateral and vertical relationship between the aquifer layers and the overlying confining beds.

5.2 Governing Equations

It is founded on the physical theory of groundwater movement: Darcy's law and the continuity equation. The steady- state groundwater flow is simulated based on the following governing differential equation ,that describes the conservation of fluid mass during flow through a porous medium, can be represented by the general flow equation in three dimensions for a heterogeneous anisotropic material

$$\frac{\partial}{\partial x}(K_{xx}\frac{\partial h}{\partial x})+\frac{\partial}{\partial y}(K_{yy}\frac{\partial h}{\partial y})+\frac{\partial}{\partial z}(K_{zz}\frac{\partial h}{\partial z})-Q=S_s\frac{\partial h}{\partial t}$$

Where,

Kxx, Kyy, Kzz = hydraulic conductivity along the x,y,z axes which are assumed to be parallel to the major axes of hydraulic conductivity;

h = piezometric head;

Q = volumetric flux per unit volume representing source/sink terms;

Ss = specific storage coefficient defined as the volume of water released
From storage per unit change in head per unit volume of porous material
t is time (T).

Equation (1) describes the distribution of hydraulic head and flow throughout a continuous region. Derivations of equation (1) can be found in Freeze and Cherry (1979) and Anderson and Woessner (1992). In order to simulate the unconfined aquifer of Lake Ziway Catchment equation (2) is used which is the Boussinesq Equation.

$$\frac{\partial}{\partial x}\left[K_x h\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_y h\frac{\partial h}{\partial y}\right]=S_y\frac{\partial h}{\partial t}-W \quad (2)$$

Assuming the transmissivity as Tx = Kxh and Ty = Kyh=
Where:
H is the saturated thickness (L), and
Sy is the specific yield (dimensionless).

Available data are limited to horizontal properties in aquifers and no relation can be established regarding the anisotropy of units. Thus, for this study, a hydraulic property within the layer is assumed isotropic. Consequently K_x and K_y are considered to be equal at any given location and K_x and K_y are replaced in this discussion by the single term K to describe horizontal hydraulic conductivity. Since the study is on a Steady-state condition there is no change in head with time, therefore, this part of the right hand side of equation (1) becomes zero and it can be re-written as:

$$\frac{\partial}{\partial x}\left[K_x h\frac{\partial h}{\partial x}\right]+\frac{\partial}{\partial y}\left[K_y h\frac{\partial h}{\partial y}\right]+W = 0 \qquad (3)$$

Because of its continuity in space and time, generally equation (3) cannot be solved analytically for practical applications involving complex systems as ziway Lake Basin.

As a result, numerical methods are employed where a set of spatially and temporally discrete points replace the continuous system described by equation (3) in a process of discretization. Equation (3) is then replaced by a set of simultaneous algebraic equations that describe.

5.3 Spatial Discretization

A fundamental aspect of numerical models is the representation of the real world by discrete volumes of material. The volumes are called cells in the finite-difference method. The center of each cell defines the point for which hydraulic head is determined and it is taken to represent the average head within the cell. The size of cells determines the extent to which hydraulic properties and stresses can vary throughout the modeled region. Hydraulic properties and stresses are specified for each cell, so the more cells in a model the greater the ability to vary hydraulic properties and stresses. If the cell size is too large, important features of the framework may be left out or poorly represented.

Accordingly the model area within the study area covers 7412km2 and it was selected on the basis of preliminary numerical modeling. Extent of the modeled area is 125km easting by 125 km northing and contains the entire study area shown in figure2.1. The model uses a uniform grid size of 500 m by 500m and contains 62,500 cells, 1 layer, and 250 columns and250 rows. The southwest corner of the model grid is located at UTM: 415000 Easting and 815000 Northing.

The irregular shape of the region under study treated with quadrangular finite difference model approach may increase the number of inactive cell and reduce the number of active cell in the model. The regular grid spacing facilitated data input from a Geographic Information System (GIS) and analysis of model output by the GIS, and the grid size minimized errors in flow-path analysis that would be caused by a large grid size (Pollock, 1994; Zheng, 1994). Figure 6.1 shows the model grid containing cells representing lateral boundary conditions (no-flow), flow packages (river and well package), active, inactive and constant head representing the two lakes.

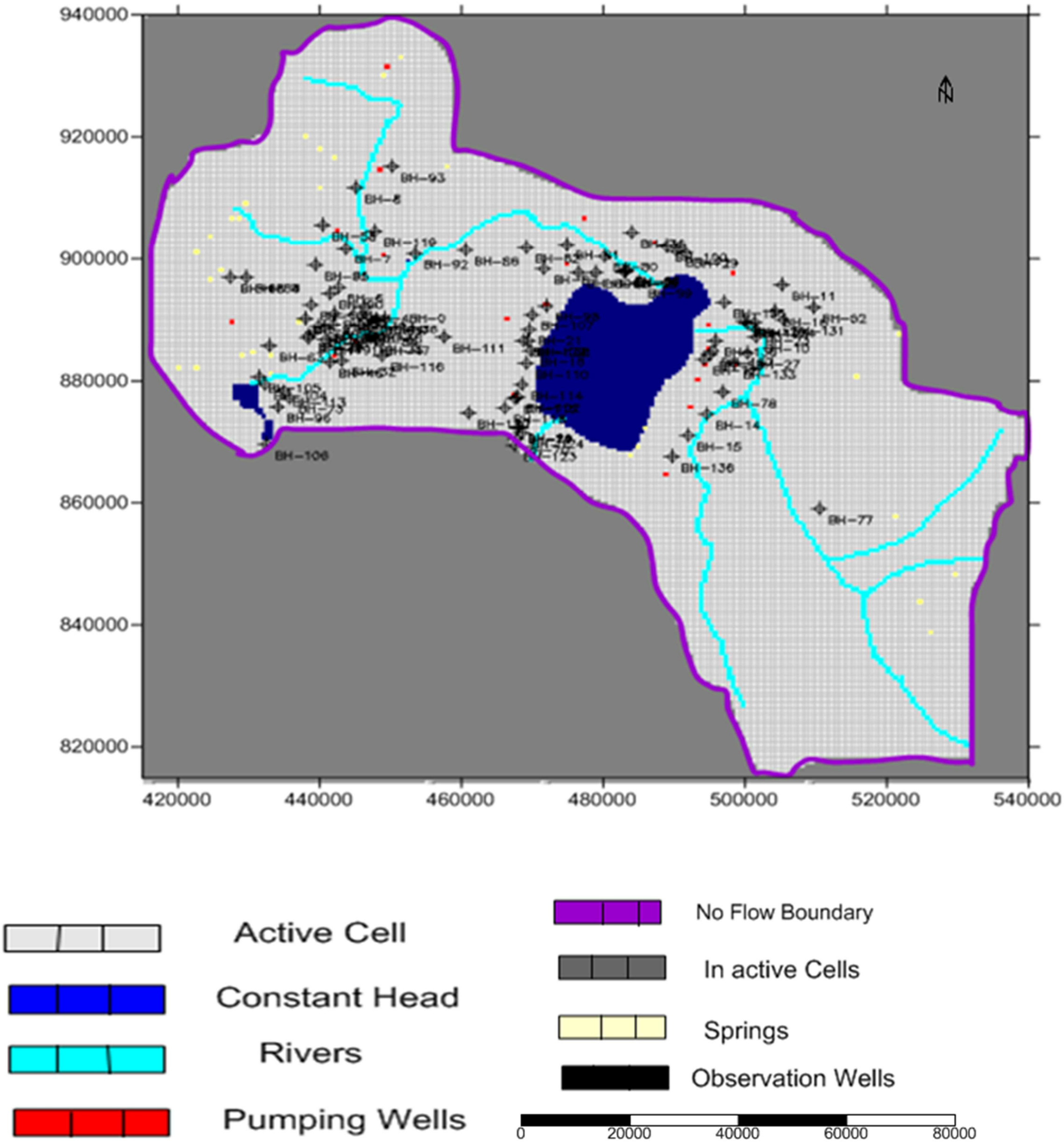


Figure 15 Model grid design and lateral boundary conditions

5.4 Boundary Conditions

Boundary conditions are a key component of the conceptualization of a ground-water system because they determine where the water enters and leaves the system. If the boundaries are inappropriate, the model will be a poor representation of the actual ground-water flow system. The topic of boundary conditions in the simulation of ground-water flow systems has been discussed in Franke and others (1987) and Reilly (2001). As discussed in Reilly (2001), computer simulations of ground-water flow systems numerically evaluate the mathematical equation governing the flow of fluids through porous media. This equation is a second-order partial differential equation with head as the dependent variable. In order to determine a unique solution of such a mathematical problem, it is necessary to specify boundary conditions around the flow domain for head (the dependent variable) or its derivatives (Collins, 1961). These mathematical problems are referred to as boundary-value problems. Thus, a requirement for the solution of the mathematical equation that describes ground-water flow is that boundary conditions must be prescribed over the boundary of the domain. Boundary conditions also represent any flow or head constraints within the flow domain. The boundaries in the model are selected following geologic feature and structures, geo-morphological features and hydro-geological evidences.

In the study area three types of boundary conditions are considered, specified head, specified flow, and head-dependent flow. Geologic and hydrologic barriers to groundwater flow are simulated using no-flow boundaries. In solving a ground-water flow problem, however, the boundary conditions are not simply mathematical constraints; they generally represent the sources and sinks of water within the system. Furthermore, their selection is critical to the development of an accurate model (Franke and others, 1987). Not only is the location of the boundaries important, but also their numerical or mathematical representation in the model. This is because many physical and the specified head includes small Abaya lake and Ziway lake, for this zone with in the active cell domain -1 value is assigned in the I-BOUND array in MODFLOW and the remaining part of the active cell which is considered as head dependent flow boundary and 1value is assigned in the I-BOUND array in MODFLOW.

5.4.1 Geographic Boundaries

Topography determines the divide between surface watersheds or catchments. When groundwater data is scarce, the surface water divide is assumed to be a proxy for the groundwater divide. This is particularly common in mountainous terrain, where groundwater wells are uncommon. No-flow boundaries are a special type of specified-flow boundary where the rate of lateral flow across the model boundary is assumed to be small or equal to zero. The geographic boundaries of Lake Ziway Basin regional groundwater model were selected accordingly as closely as possible with natural hydrologic boundaries across which groundwater flow can be assumed negligible. Major topographic divides are often considered no-flow boundaries because topographic divides are typically coincide with groundwater divides Groundwater on either side of a groundwater divides flows away from the divide and not across it, so the divide itself acts as a no-flow boundary.

Topographic divides often coincides with groundwater divides because elevated areas relatively have larger amounts of precipitation and recharge than surrounding areas, thus water table surface develops a coincident high elevation region from which groundwater flow diverges. In the study area the periphery that enclose the permeable groundwater flow system which is less permeable unit is considered as no-flow boundary condition except the Bulbula river out let to the south and 0 value is assigned in I-BOUND array in MODFLOW.

5.4.2 Hydrologic-Process Boundaries

In the ziway lake basin this boundary condition is the main component that linked to the hydrological processes consisting of recharge, groundwater flow to and from streams well withdrawal, and river out flow from the lake ziway. Groundwater recharge represented by specified-flux boundary condition. Recharge to the groundwater system was given by considering sources of groundwater from infiltration of precipitation and deep percolation of applied irrigation water. It is simulated as a specified flux to the uppermost layer of the model using five Different zones based on the previously developed conceptual model.

The first zone in the conceptual model is the eastern and western highlands which are characterized by high direct recharge; initial value of 3.9×10^{-4} m/day is given in the model. Butajira crescent and Nazreth group in the eastern part are characterized by moderate recharge; initial value is given as 3.8×10^{-4} m/day. The third zone which is intermediate recharge zone consists of the scoria cones in the west and Kontane-Inseno-Kela plain is given a value of 3.7691×10^{-4} m/day. The fifth zone is the rift floor including ziway plain characterized by lower recharge initial value is given 1×10^{-4} m/day. The final zone, Tora-Koshe-Dugda ridge receives minimum recharge since it is relatively found at deeper depth compared with all the other zones as a result initial value of 6.0x10-6 m/day is assigned finally, during model calibration these recharge values were adjusted.

5.5 Initial Conditions

Initial conditions refer to the hydraulic head distribution in the system at the beginning of the simulation and thus are boundary condition in time (Anderson & Woessner, 1992). The initial conditions in numerical groundwater models are initial head distributions and have only to be entered to fulfill the convergence criteria of the numerical scheme.

If the hydraulic gradient between heads of Boundary elements and non-boundary elements become too large, many computer codes will fail in their calculations by numeric instabilities. So for steady state models initial heads should be only in the range with the values of the hydraulic head conditions at the boundary element of the model. If the field measured head values were used as initial conditions, the model response in the early time steps would reflect not only the model stress under study but also the adjustment of model head values to offset the lack of correspondence between model hydrologic inputs and parameters and the initial head values

(Franke et al., 1991).in this model the initial hydraulic head used for the first run of the flow simulation is obtained by subtracting 15m from the top elevation of model layer ,which is calculated from 90m resolution Shuttle Radar Terrain Model (SRTM) data using computer software (Surfer-8 and Global Mapper).

5.6 Hydraulic Properties

The hydraulic properties of the aquifer used in the conceptual model are key components which serve as first input for groundwater flow model. It is defined as the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow. The hydraulic conductivity of the material in an aquifer or confining units is a measure of the ease with which water can move through the material. It is a function of properties of both the matrix and the fluid. Water in the regional flow system was assumed to have a uniform density and viscosity, and thus the hydraulic conductivity only varies as the grain size, shape, sorting & packing (freez and cherry, 1979).

The hydraulic property of the aquifer in the study area is obtained from pumping tests carried out in the previous studies. The hydraulic conductivity varies spatially in the study area which is the result of variation in lithological units, effect of structure and degree of weathering. The pumping test results have been documented on a number of published and unpublished reports. The horizontal hydraulic conductivity of different geological units have been reported by (Tenalem Ayenew, 2006) as follows

Guragie highland constituted from welded ignimbrites, tuff, rhyolite and trachyte without visible large faults, Chilalo volcanics and part of Nazreth group has hydraulic conductivity range from 0.1 to1m/day. In this region the upper weathered rock and soils are permeable; however, the underlying volcanic sequences are massive whereas the remaining part of Nazreth group in the eastern side of the study area has hydraulic conductivity value of 2.5 to5m/day.

Butajira crescent, Kuntane-Inseno-Kela plain, Tora-Koshe-Dugda ridge characteristics of fracturing and weathering grade, this unit has 3.25m/day hydraulic conductivity.

Ziway plain characteristically composed of rock units Ignimbrite overlain by lacustrine sediments such as shale, clay, diatomite and reworked pumice. This unit possesses hydraulic conductivity value of 1m/day to 5m/day.

Rift floor in the Kater catchment consists of ignimbrite, volcanoclastic deposits, lacustrine sediment and recent Basalt are characteristics of highly fractured, jointed and faulted unit and the scoria cones and highly fractured ignimbrites along the major fault zone east of Butajira which owing to fractures, joints faults and vesicles possess hydraulic conductivity range of 10m/day to 20m/day.

5.7 Stresses

5.7.1 Recharge

Groundwater recharge is a process of water movement downward through the saturated zone under the force of gravity or in a direction determined by the hydraulic condition (Simmers, 1988). It is the net effect of precipitation, surface runoff, Evapo-transpiration, interception and overland storage. The source of recharge for a given groundwater system could be precipitation, river, irrigation loss, and inter aquifer flow recharge which are resulted from direct, indirect and /or localized recharge(Learner et al., 1990). Recharge was applied to the active model area as a spatially varying, specified flux to the highest active cell. In general, precipitation recharge varies spatially with land surface permeability, which is a function of soil characteristics and land use, and spatial distribution and intensity of rainfall.

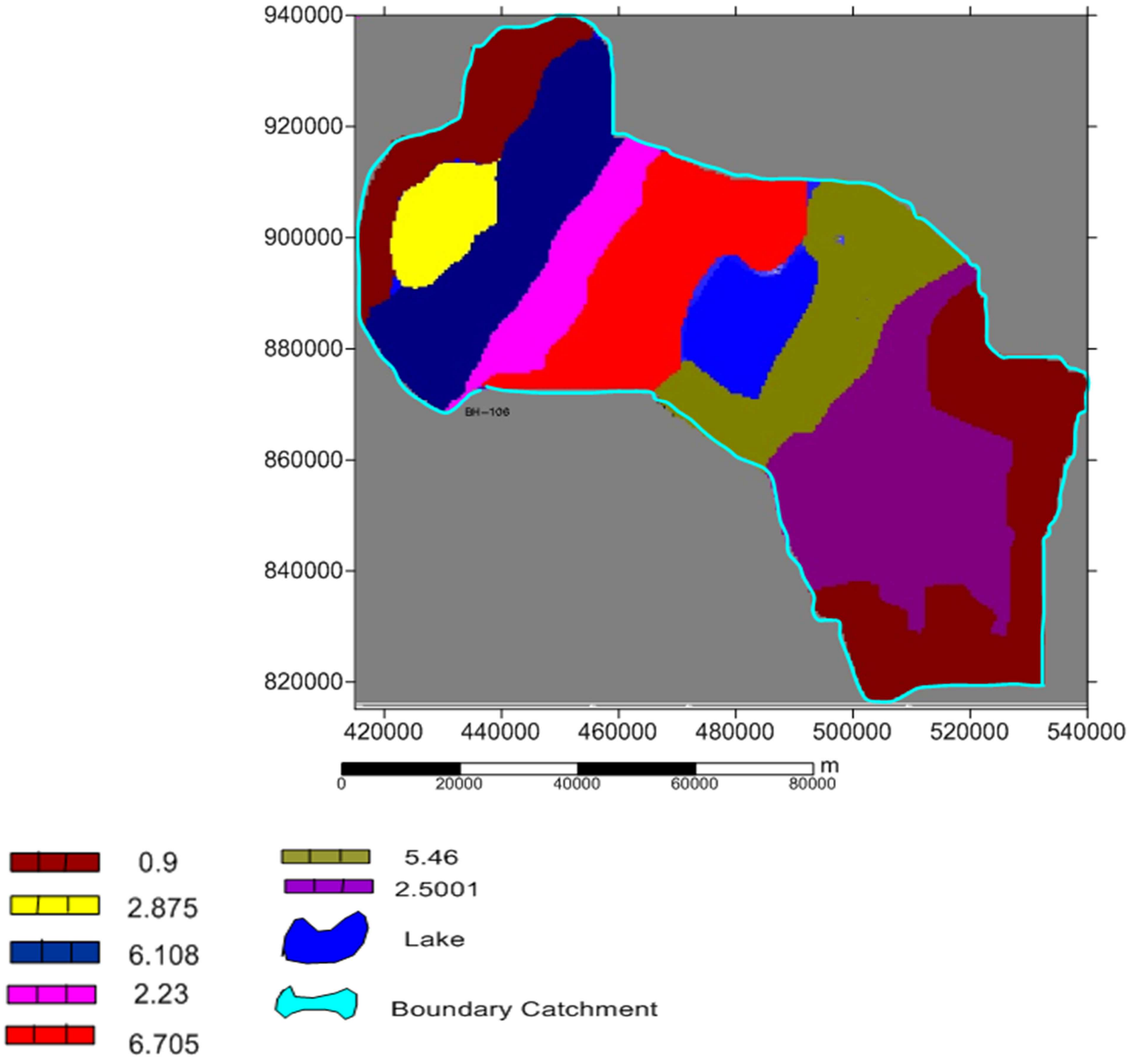


Figure 16 Adjusted hydraulic conductivity zonation and values, in meter per day

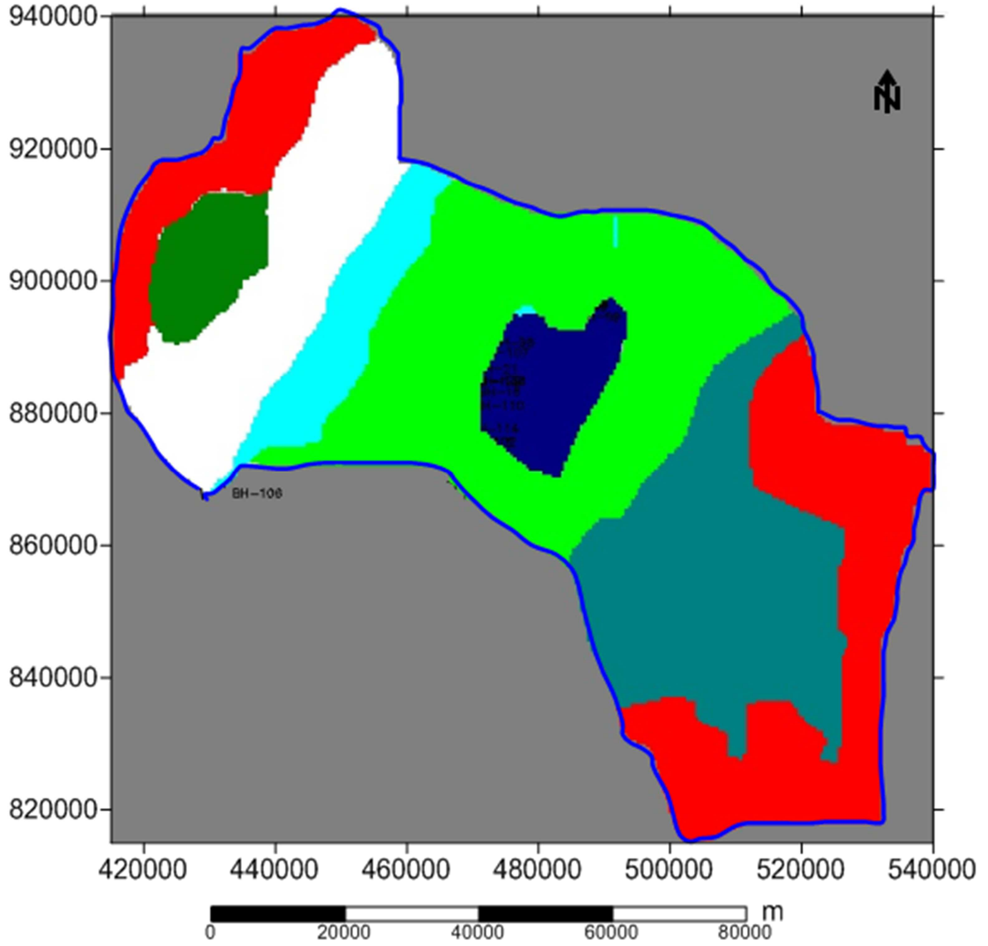


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Figure 17 Simulated recharge zonation and values, in meter per day.

5.7.2 Discharges

The means of groundwater discharge in the study area includes abstraction of wells, evapotranspiration, springs, base flow to surface water bodies, and inter basin or aquifer system transfer. A number of high yield springs originate in the eastern and western escarpment of the basin forming the bases for the existence of large perennial rivers namely Meki and Kater River and finally flows to Lake Ziway. The base flow represent the interaction of the aquifer system with the perennial stream with a concept of groundwater maintain the flow of stream during dry season. Kater and Meki river catchment are well connected to the aquifer system which feeds water to the river as base flow during the dry season.

The groundwater discharge from the aquifer is expressed as springs and seepages along the river banks. Previous studies (Named MAWARI project) result on systematic river discharge measurements indicates that in the highland areas of the catchment, the elevation of the water table contours lie above river bed indicating effluent characteristics of the river. The elevation Meki river bed in volcano-lacustrine sediment of rift floor and that of Kater at the central and upper part of Wonji Fault Belt lie above the elevation the contour showing loosing behavior of the rivers. Accordingly, Meki River has losses of about 43mcm between Dugda and Meki town stations in the stretch of 34.2km; while the Kater river losses about 86mcm water annually between Fite and Abura stations in 36.2km river stretch.

Springs are usually treated as nonlinear head dependent discharge boundaries that have zero flow when the head in the aquifer becomes lower than the altitude of the spring.AS part of the natural groundwater discharge, a number of high and low yield springs are identified during the fieldwork. Most of the springs are gravity springs, discharged right at the contact of permeable and less permeable units and faulted zones mostly in the highlands and escarpments regions. in the rift floor of the study area around lake ziway and following the river flow there is large irrigation activity that utilize both surface and groundwater source almost in annual basis which in turn undermine the water resource of basin.

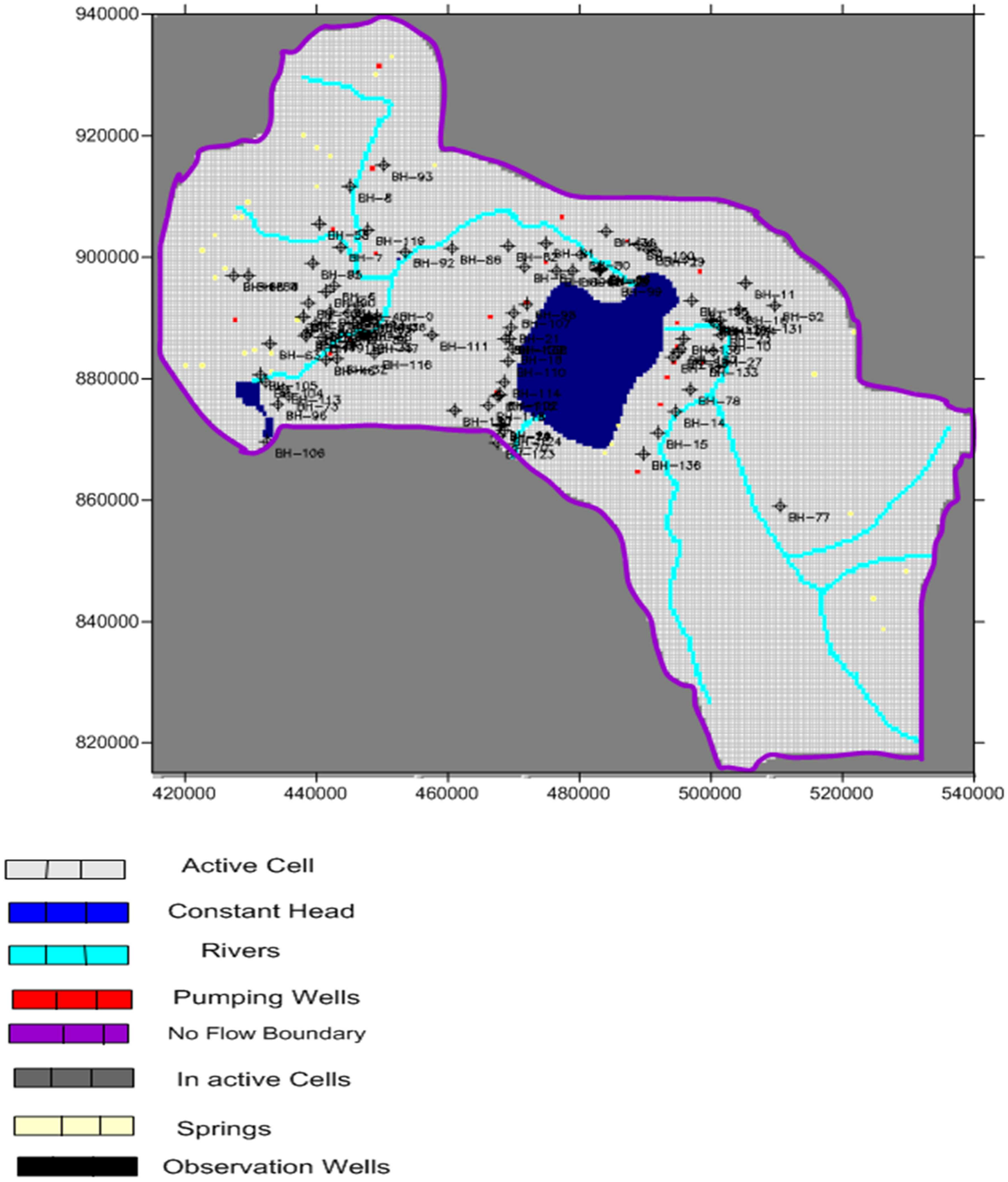


Figure 18 A map showing discharge (Stream, Well & spring, Head observation wells and Drainage

CHAPTER SIX

Calibration and Sensitivity Analysis

6.1 Model Calibration

Model calibration consists of changing values of model input parameters in an attempt to match field conditions within some acceptable criteria. This requires that field conditions at a site be properly characterized. Lack of proper site characterization may result in a model that is calibrated to a set of conditions which are not representative of actual field conditions. A model that is “calibrated” is required to address many hydrologic problems. Adjustment of parameters can be done manually or automatically by using nonlinear regression statistical techniques. Key aspects of the model, such as the conceptualization of the flow system that influences the capability of the model to meet the problem objectives also are evaluated and adjusted as needed during calibration. For example, it may be noticed that some of the parameters that result in the best match to observations are not reasonable based on other knowledge of their values. This may indicate that there is a conceptualization problem with the model. Thus, the closeness of fit between the simulated and observed conditions, and the extent to which important aspects of the simulation are incorporated in the model are both important in evaluating how well a model is calibrated.

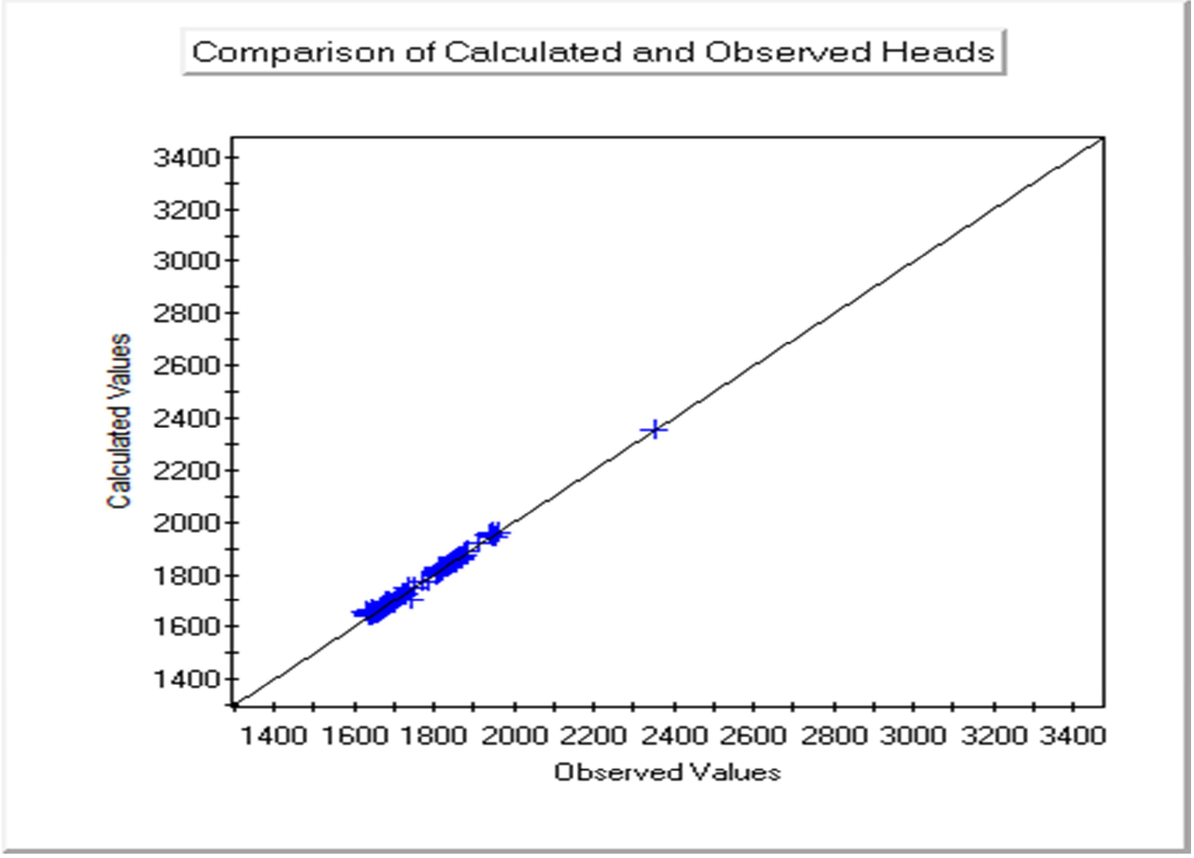
The amount of effort that is required in calibrating a ground-water flow model is dependent upon the intended use of the model (that is, the objective of the investigation). Most models of specific ground-water systems that are used to estimate aquifer properties, understand the past, understand the present, or to forecast the future are calibrated by matching observed heads and flows. Determining if the calibration is sufficient for the intended use of the model is very important in evaluating whether the model has been constructed appropriately.

The model was calibrated by a trial-and-error process in which model parameters are adjusted within reasonable limits from one simulation to the next to achieve the best model fit. Model fit is commonly evaluated by visual comparison of simulated and measured heads and flows or by listing measured and simulated heads together with their differences and some type of average of the differences, which is then used to quantify the average error in the calibration The objective of calibration is to minimize this average error which is called calibration criterion.

To provide an overall indication of the quality of the calibration, summary statistics on the difference between simulated and measured water levels were calculated after model calibration. The root mean squared error (RMS) and the mean error (ME) are common ways to express the average difference between simulated and measured water levels (Anderson and Woessner, 1991).The calibration processes considers qualitative and quantitative measures of the simulation result. The qualitative measures includes the comparison of expected water level contours ,hydraulic gradients and flow directions with those simulated by the model whereas the quantitative measures involve calculating the differences in the observed and predicted water levels within the model.

During calibration the sensitivity of the parameters related to the change in head was examined simultaneously. The analysis revealed that water levels were most sensitive to recharge rates, river hydraulic conductance, and hydraulic conductivities. Following calibration focused on adjustment to river conductance and hydraulic conductivity values, based on the assumption that uncertainties in the infiltration rate were small relative to uncertainties in the hydraulic conductivities.Initally hydraulic conductivity was based on field hydraulic test conducted on the area. Due to poor representation of distribution of wells. This was limited the accuracy of the value obtained which resulted in poor calibration. The model was unable to simulate realistic water levels, particularly in the western and eastern highlands of the modeled area. Due to lack of available water level data and interpolation error of the measured gradient. Many discrete zones were chosen for calibrating the hydraulic conductivities.

Calibrated hydraulic conductivities were in the range between 0.9 and 6.70 m/day.figure29 shows the spatial distribution of hydraulic conductivity in the study area. The pattern of water level contours and groundwater flows predicted by the calibrated model are qualitatively similar to the inferred water level expected by the conceptual model. Groundwater flow is parallel to the steepest gradient in the area. Flow direction is dominated by east-west from the topographically higher volcanic ridges down to the low lying rift floor area, reaching Lake Ziway. The calibrated steady state model for the ziway catchment simulates the observed groundwater levels and the groundwater flow processes in the area. Water level simulated by the steady-state model is presented in the figure30.contains the simulated and observed water levels. A scatter diagram of observed heads verses modeled heads for steady state calibration is included in figure5.6.The correlation.



R^2=0.933

Figure 19 scatter diagram comparing observed vs calibrated head

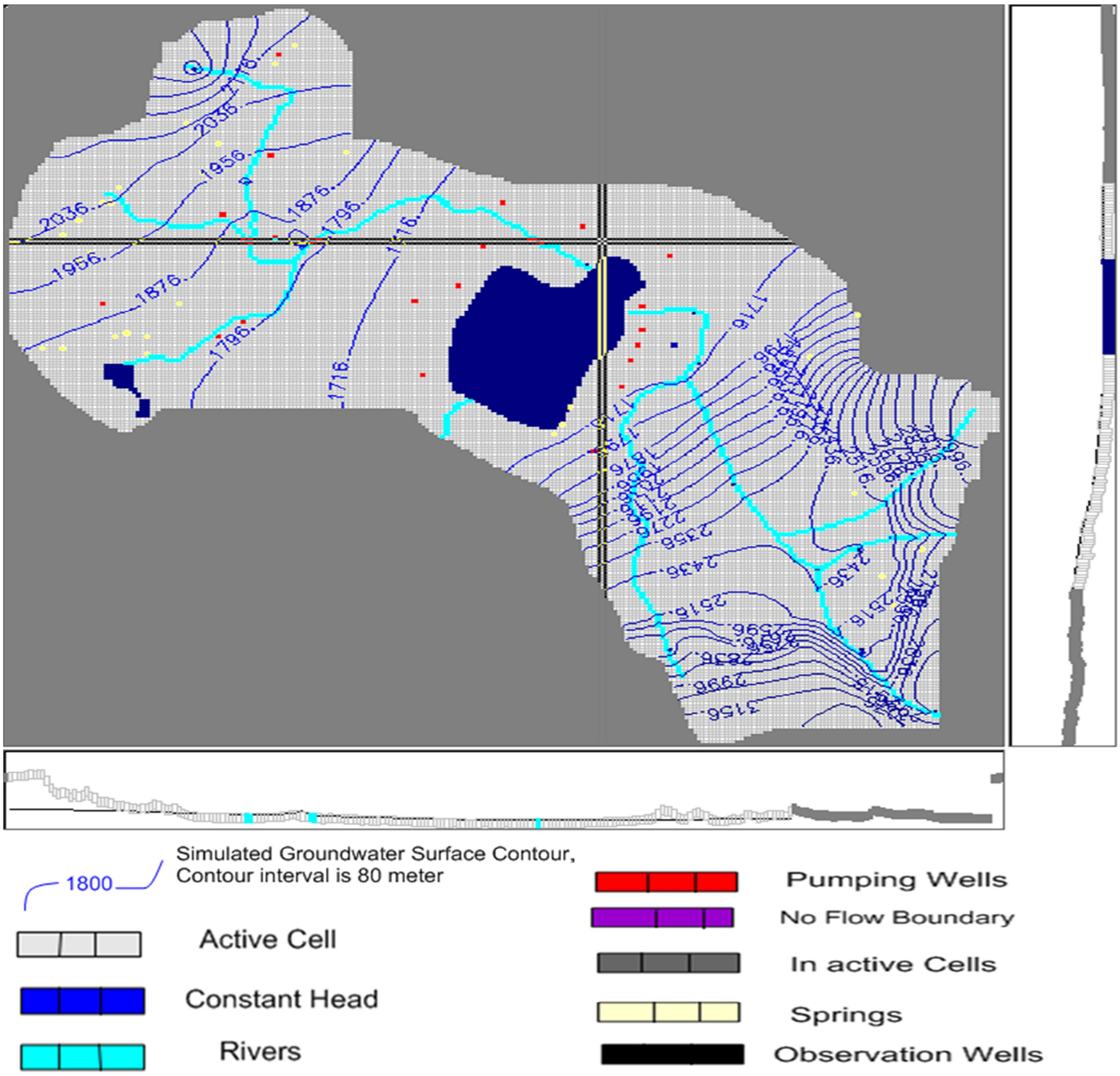


Figure 20 . Model-calculated and observed steady-state water table and X _ section along Row-80 and Column 150.

		Groundwater altitude, in meters				
No.	**Observation name**	**Calculated Heads(S)**	**Observed Heads(M)**	**(M-S)**	**│M - S│**	**$(M-S)^2$**
1	BH-6	1859.997	1856.12	-3.877	3.877	15.03113
2	BH-7	1868.168	1864.16	-4.008	4.008	16.06406
3	BH-8	1947.522	1942.31	-5.212	5.212	27.16494
4	BH-10	1682.324	1671.32	-11.004	11.004	121.088
5	BH-11	1692.958	1688.47	-4.488	4.488	20.14214
6	BH-12	1659.489	1643	-16.489	16.489	271.8871
7	BH-13	1957.924	1949.29	-8.634	8.634	74.54596
8	BH-14	1723.35	1718.22	-5.13	5.13	26.3169
9	BH-15	1746.699	1738	-8.699	8.699	75.6726
10	BH-16	1692.451	1679.14	-13.311	13.311	177.1827
11	BH-18	1658.026	1652	-6.026	6.026	36.31268
12	BH-19	1655.713	1651.57	-4.143	4.143	17.16445

13	BH-20	1655.799	1653	-2.799	2.799	7.834401
14	BH-21	1664.738	1669	4.262	4.262	18.16464
15	BH-23	1681.558	1685.56	4.002	4.002	16.016
16	BH-25	1641.949	1644.1	2.151	2.151	4.626801
17	BH-27	1690.21	1702	11.79	11.79	139.0041
18	BH-29	1651.729	1648.76	-2.969	2.969	8.814961
19	BH-31	1654.784	1653.41	-1.374	1.374	1.887876
20	BH-32	1802.375	1802.5	0.125	0.125	0.015625
21	BH-33	1846.464	1839.27	-7.194	7.194	51.75364
22	BH-34	1846.827	1841	-5.827	5.827	33.95393
23	BH-35	1800.654	1812.05	11.396	11.396	129.8688
24	BH-36	1804.779	1805.3	0.521	0.521	0.271441
25	BH-37	1812.115	1816.8	4.685	4.685	21.94922
26	BH-38	1812.123	1816.5	4.377	4.377	19.15813
27	BH-39	1839.921	1844.78	4.859	4.859	23.60988
28	BH-4BH-0	1834.803	1832.44	-2.363	2.363	5.583769
29	BH-42	1825.329	1822.8	-2.529	2.529	6.395841
30	BH-43	1830.182	1816.3	-13.882	13.882	192.7099
31	BH-44	1818.957	1821.9	2.943	2.943	8.661249
32	BH-45	1844.605	1844.125	-0.48	0.48	0.2304

33	BH-46	1808.673	1821.9	13.227	13.227	174.9535
34	BH-47	1793.117	1806.3	13.183	13.183	173.7915
35	BH-48	1847.39	1847.89	0.5	0.5	0.25
36	BH-49	1845.355	1851.54	6.185	6.185	38.25422
37	BH-50	1850.3	1846.76	-3.54	3.54	12.5316
38	BH-51	1889.633	1880.8	-8.833	8.833	78.02189
39	BH-52	1717.238	1721.35	4.112	4.112	16.90854
40	BH-53	1662.838	1671.667	8.829	8.829	77.95124
41	BH-54	1944.437	1951.98	7.543	7.543	56.89685
42	BH-57	1850.689	1849.475	-1.214	1.214	1.473796
43	BH-58	1917.719	1914.22	-3.499	3.499	12.243
44	BH-63	1854.947	1861	6.053	-6.053	36.63881
45	BH-65	1647.187	1638.08	-9.107	9.107	82.93745
46	BH-66	1641.925	1637.22	-4.705	4.705	22.13702
47	BH-68	1957.924	1957.62	-0.304	0.304	0.092416
48	BH-69	1641.949	1644.1	2.151	2.151	4.626801
49	BH-70	1653.729	1662	8.271	8.271	68.40944
50	BH-71	1650.806	1646	-4.806	4.806	23.09764
51	BH-73	1815.14	1820.8	5.66	5.66	32.0356
52	BH-74	1655.713	1627.5	-28.213	28.213	795.9734

53	BH-76	1654.784	1651.776	-3.008	3.008	9.048064
54	BH-77	2353.228	2351.668	-1.56	1.56	2.4336
55	BH-78	1701.536	1708	6.464	6.464	41.7833
56	BH-80	1650.132	1652.223	2.091	2.091	4.372281
	BH-81	1669.825	1671.559	1.734	1.734	3.006756
57	BH-82	1697.817	1689.1	-8.717	8.717	75.98609
48	BH-83	1846.952	1845.334	-1.618	1.618	2.617924
59	BH-84	1813.6	1809.9	-3.7	3.7	13.69
60	BH-85	1847.39	1854.89	7.5	7.5	56.25
61	BH-86	1747.804	1748.778	0.974	0.974	0.948676
62	BH-87	1676.289	1678.441	2.152	2.152	4.631104
63	BH-88	1944.437	1947.1	2.663	2.663	7.091569
64	BH-6	1652.495	1648.97	-3.525	3.525	12.42562
65	BH-88	1863.301	1866.75	3.449	3.449	11.8956
66	BH-89	1836.827	1842.88	6.053	6.053	36.63881
67	BH-90	1857.131	1871.881	14.75	14.75	217.5625
68	BH-91	1950.28	1942.2	-8.08	8.08	65.2864
69	BH-92	1641.822	1641.9	0.078	0.078	0.006084
70	BH-93	1889.633	1880.8	-8.833	8.833	78.02189
71	BH-94	1818.058	1815	-3.058	3.058	9.351364
72	BH-95	1862.032	1862.22	0.188	0.188	0.035344

73	BH-96	1657.388	1651.21	-6.178	6.178	38.16768
74	BH-97	1640.12	1636	-4.12	4.12	16.9744
75	BH-98	1651.334	1652	0.666	0.666	0.443556
76	BH-99	1659.624	1641.74	-17.884	17.884	319.8375
77	BH-100	1868.436	1871.814	3.378	3.378	11.41088
78	BH-102	1823.018	1814.8	-8.218	8.218	67.53552
79	BH-103	1829.647	1820.7	-8.947	8.947	80.04881
80	BH-104	1823.359	1816.5	-6.859	6.859	47.04588
81	BH-105	1666.688	1667.867	1.179	1.179	1.390041
82	BH-106	1662.516	1665	2.484	2.484	6.170256
83	BH-107	1666.271	1645	-21.271	21.271	452.4554
84	BH-108	1659.281	1627	-32.281	32.281	1042.063
85	BH-109	1727.597	1731.967	4.37	4.37	19.0969
86	BH-110	1817.475	1821.45	3.975	3.975	15.80063
87	BH-111	1659.266	1643	-16.266	16.266	264.5828
88	BH-113	1661.953	1667.422	5.469	5.469	29.90996
89	BH-114	1771.984	1784	12.016	12.016	144.3843
90	BH-115	1669.673	1665.458	-4.215	4.215	17.76622
91	BH-116	1876.206	1879	2.794	2.794	7.806436
92	BH-118	1698.305	1701	2.695	2.695	7.263025
93	BH-119	1652.541	1647	-5.541	5.541	30.70268
94	BH-120	1652.633	1658.87	6.237	6.237	38.90017
95	BH-123	1672.149	1675	2.851	2.851	8.128201

96	BH-124	1670.044	1677.89	7.846	7.846	61.55972
97	BH-126	1657.412	1662.36	4.948	4.948	24.4827
98	BH-129	1701.582	1741	39.418	39.418	1553.779
99	BH-130	1711.754	1713.5	1.746	1.746	3.048516
100	BH-131	1678.141	1687.5	9.359	9.359	87.59088
101	BH-133	1653.792	1663	9.208	9.208	84.78726
102	BH-134	1770.832	1769.1	-1.732	1.732	2.999824
103	BH-135	1662.396	1663.669	1.273	1.273	1.620529
104	BH-136	1859.997	1856.12	-3.877	3.877	15.03113
105	BH-137	1868.168	1864.16	-4.008	4.008	16.06406
106	BH-88	1947.522	1942.31	-5.212	5.212	27.16494
107	BH-89	1682.324	1671.32	-11.004	11.004	121.088
108	BH-90	1692.958	1688.47	-4.488	4.488	20.14214
109	BH-91	1659.489	1643	-16.489	16.489	271.8871
110	BH-92	1957.924	1949.29	-8.634	8.634	74.54596
111	BH-93	1723.35	1718.22	-5.13	5.13	26.3169
112	BH-94	1746.699	1738	-8.699	8.699	75.6726
113	BH-95	1692.451	1679.14	-13.311	13.311	177.1827
114	BH-96	1658.026	1652	-6.026	6.026	36.31268
115	BH-97	1655.713	1651.57	-4.143	4.143	17.16445
116	BH-98	1655.799	1653	-2.799	2.799	7.834401
117	BH-99	1664.738	1669	4.262	4.262	18.16464
118	BH-100	1681.558	1685.56	4.002	4.002	16.016

119	BH-102	1641.949	1644.1	2.151	2.151	4.626801
120	BH-103	1690.21	1702	11.79	11.79	139.0041
121	BH-104	1651.729	1648.76	-2.969	2.969	8.814961
122	BH-105	1654.784	1653.41	-1.374	1.374	1.887876
123	BH-106	1802.375	1802.5	0.125	0.125	0.015625
124	BH-107	1846.464	1839.27	-7.194	7.194	51.75364
125	BH-108	1846.827	1841	-5.827	5.827	33.95393
126	BH-109	1800.654	1812.05	11.396	11.396	129.8688
127	BH-110	1804.779	1805.3	0.521	0.521	0.271441
128	BH-111	1812.115	1816.8	4.685	4.685	21.94922
129	BH-113	1812.123	1816.5	4.377	4.377	19.15813
130	BH-114	1839.921	1844.78	4.859	4.859	23.60988
131	BH-115	1834.803	1832.44	-2.363	2.363	5.583769
			MAE= 0.0706125	**ME=** -0.070613	**MAE=** 0.0706125	**RMS=** 4.497221

Table 4 Model-calibrated steady-state water levels and observed water levels for all wells.

6.1. Simulated water budget

An essential part of the conceptual model is the amounts and the pathways with which water enters (inflows) and leaves (outflows) the groundwater flow system. The inflows can be groundwater recharge from precipitation, surface water bodies, e.g. lakes and streams, and overland flow. The outflows can be natural such as base flow, spring flow, and evapotranspiration or artificial such as pumping (Anderson and Woessner, 1992). During calibration, water budget acquired based on field data should be compared with calculated water budget obtained from the mathematical model (Anderson and Woessner, 1992; Rushton, 2003).Although models are rarely useful for quantitative prediction of consequence.

The mass balance graph and table shows that (figure21and table6.1) plots the volume of water entering and leaving the flow boundary conditions. The final steady-state model produced a mass balance error of 0 %.the percent discrepancy of a model should be less than 1 percent (Anderson, 1993).As usual the mass balance data shows that rainfall is the primary model input with 3.1508075x10^6.The second and third model input data are constant head and river leakage with value of 1.1819701x106 m^3/day and 7.0665138x10^6 m^3/day respectively. Groundwater discharge from wells is 13276 m^3/day and the least loss occurs via the drains 1.8324932x10^3 m^3/day.

6.1.2 Sub-regional water budget

In general, the movement of groundwater between the different water budget zones is as expected according to the conceptual model. The total groundwater flow in and out of ziway Lake basin is 697.0416 m3/d the majority of inflow to the lake comes from the upgrading aquifer, whereas the majority of outflow from the lake is controlled by the constant head boundary to maintain the average annual lake stage. The graph presents the quantitative results of the water balance. Groundwater generally enters the lake as horizontal flow along the ends of the lake; minimal groundwater inflow occurs through the lake bottom. The rivers are gaining in the upper zones of the model domain. The inflow and outflow along the lower and middle zone of the study area indicates that the aquifer is recharging from the rivers along the lower reach.

WATER BUDGET OF THE WHOLE MODEL DOMAIN			
FLOWTERM	IN	IN-OUT	IN-OUT
STORAGE	0	0	0
CONSTANT HEAD	1212657	2009004	-796347.5
WELLS	0	1327.6	-1327.6
DRAINS	0	1821.813	-1821.8126
RECHARGE	2644423	0	2644422.8
ET	0	0	0
RIVER LEAKAGE	707895.8	2552594	-1844698.5
HEAD DEP BOUNDS	0	0	0
STREAM LEAKAGE	0	0	0
INTERBED STORAGE	0	0	0
RESERV.LEAKAGE	0	0	0

SUM	4564975	4564748	227.3999
DISCREPANCY [%]	0		

6.1. Model-calculated steady-state hydrologic budget

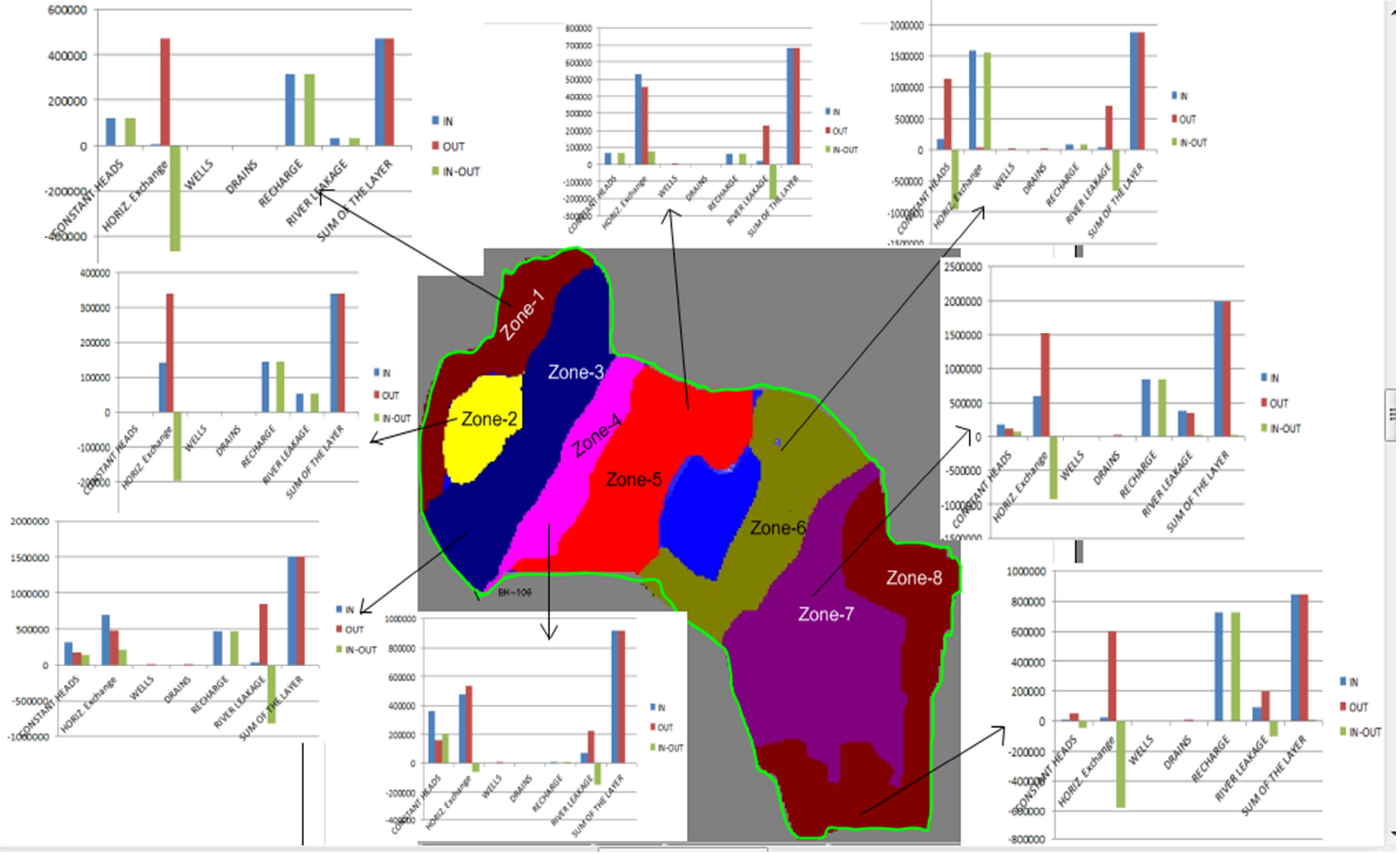


Figure 21 Model-calculated steady-state sub regional hydrologic budget with their respective graph.

6.2 Model sensitivity

Sensitivity analysis is the evaluation of model input parameters to see how much they affect model outputs, which are heads and flows. The relative effect of the parameters helps to provide fundamental understanding of the simulated system. Sensitivity analysis also is inherently part of model calibration. The most sensitive parameters will be the most important parameters for causing the model to match observed values. For example, an area in which the model is insensitive to hydraulic conductivity generally indicates an area where there is relatively little water flowing. If the model is being calibrated, then changing the value of hydraulic conductivity in this area will not help much in causing the model to match observation. The calibration will not provide much certainty about the value of the parameter, but the uncertainty will not matter provided the model is not used in situations where large amounts of water will flow in that area. Such a model, however, would probably not be suitable for evaluation of recharge or withdrawal in this area because the amount of flow in the area would be much greater than it was when the model was calibrated, and the uncertainty from the calibration would be unacceptable.

Source of uncertainty in numerical models can include geological, parameters (e.g. hydraulic conductivity and recharge) and boundary condition uncertainty (Fabritz, eta l., 1998).geological uncertainty related to the degree to which the stratigraphy assumed in the model represents the geology of the area. The eastern portion of the model contains small number of observation wells in comparison with the western area This result in higher uncertainty than the western portion of the model area .Parameter and boundary condition uncertainty describes the uncertainty in the model from imposed parameters and characterization of the hydrogeological conditions along the boundary of the model.

The recharge rate has large effect on the total volume of water that enters the flow field. Model sensitivity was determined for variations in hydraulic conductivity, pumpage and recharge. The results of the sensitivity analysis for this study were evaluated by calculating the Sum of Square Deviation between measured and simulated heads in the modeled area for a decrease or increase in percent, from the calibrated value, of that parameter.

To assess the sensitivity of the above parameters, the calibrated values of each parameter were independently increased and decreased by 25, 50 and 75 percent and then Simulated to see the resulting heads. Results of the sensitivity analysis clearly show that simulated water levels were most sensitive to the change in the values of recharge. Sensitivity of the model to recharge in comparison with hydraulic conductivity is significant and the model is moderately sensitive to variation in hydraulic conductivity. The model is relatively less sensitive to increase in the amount of pumpage. The results are displayed in the diagram plot in ME, MAE and RMSE with the respective parameter.

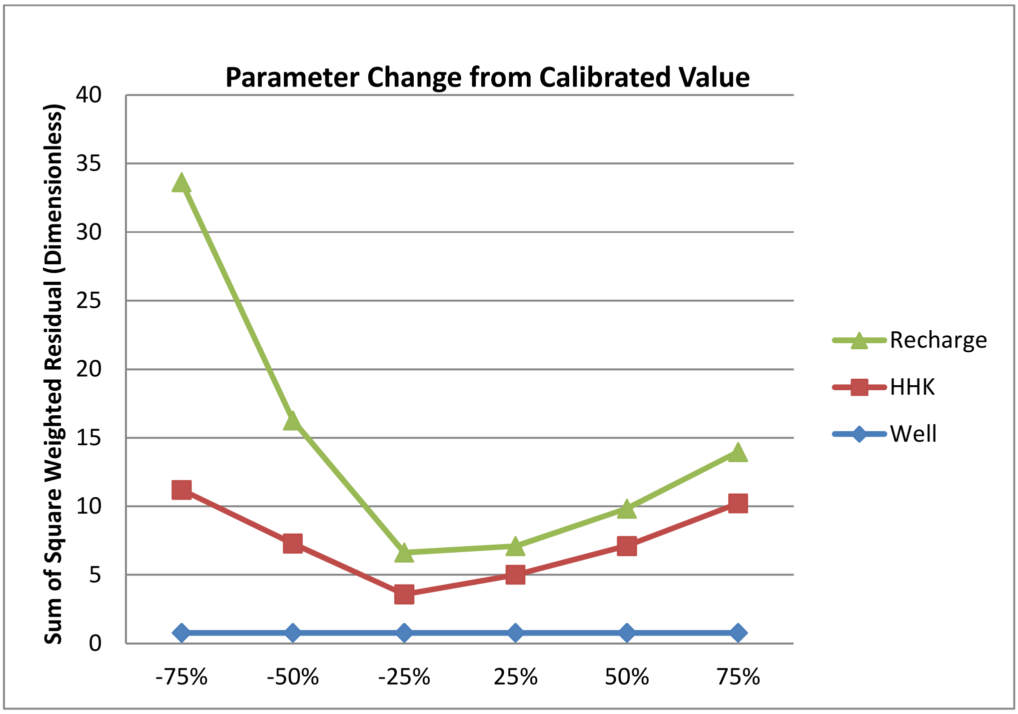


Figure 22 **Plot of model parameter sensitivity.**

No	Change in sensitivity parameter from the calibrated value, in %	Respective AME head change from the calibrated value, in %
1	Recharge increased by 25,50& 75	4.243,6.34,9.45
2	Recharge decreased by 25, 50 & 75	10.43,6.52,2.81
3	Hydraulic conductivity increased by 25,50& 75	2.08,2.73,3.74
4	Hydraulic conductivity decreased by 25,50& 75	22.45,8.96,3.04
6	Well withdrawal increased 25,50& 75	0.766,0.766,0.766,
7	Well withdrawal decreased 25,50& 75	0.766, 0.766, 0.766

Table 5 Results of Sensitivity Analysis Test on Water Levels

6.3 Scenario analysis

The calibrated groundwater flow model can be used to simulate the potential effect of alternative water management plans on hydraulic head and groundwater movement in the study area. It can also be used as a tool to evaluate and compare the responses of an aquifer system to potential future stresses. As it is stated in the Objectives, numerical groundwater flow model simulated in this study was designed to test the response of the hydrologic system to different scenarios. System responses were evaluated by using fluxes and heads of the calibrated model as base line and compared with resulting changes in stream leakage and changes in water table elevation in the new scenario simulation. Thus different alternative scenarios were developed to test the responses of the hydraulic system to changes in water uses or hydrologic stresses under steady-state condition.

It should be noted that the results of the scenarios depends on the future land use, population growth, weather condition, hydrologic stresses etc. and may not be used as predictive tool to generate absolute measurement in the future, but used primarily to test the response of the system. In general, the results of the scenarios or their accuracy depend on the validity of the assumptions behind the scenarios. Moreover, errors introduced due to limitations associated with the model also affect the result of the scenarios and should be taken in to consideration during interpretation and application of results. In all scenarios, other model parameters were kept to the steady-state values except the stress for which the projection was carried out.

The resulting changes in water level and fluxes were interpreted as the response of the system to the changes introduced on it. In the first scenario, three increased withdrawal amounts were distributed among exciting wells in proportion to the current contribution of each source to the daily withdrawal rate. The current withdrawal rate estimated under steady state simulation was 1327.6m3/day. The current estimated groundwater withdrawal rate from the catchment can be considered as the minimum reasonable amount.

Generally, as withdrawal rate is increased, initially it induces decline in water level but eventually, if stress continues, the increasing groundwater pumping will begin reduce natural discharge of groundwater. This can be manifested by reduced river leakage in the study area. In addition, it also can induce recharge from surface water bodies such as streams or reservoirs (the lake). The steady state withdrawal rates were increased by 25%, 50% and 75% to study the response of the system in this scenario. These increased are equivalent to withdrawing 1659.5,1991, and 2323.3 m3/day over the whole catchment respectively and the increased withdrawal rate distributed among the exciting wells. Then model simulated results of water table elevation in the scenario is compared with model calculated steady-state result and the head calculated for this scenario shows a maximum decline of the water level by 11m near Ziway lake and a minimum of 0.21m at Kuntane -Inseno-Kela Plain. Table 6.4 System response to increased groundwater withdrawal.

Flow term	**IN**				**OUT**				**IN-OUT**			
	Calculated	**Increased pumpage**	**Decresed recharge**	**Increased K value**	**Calculated**	**Incread pumpage**	**Decresed recharge**	**Increased K value**	**Calculad**	**Increased pumpage**	**Decreasd recharge**	**Increased K value**
Storage	0	0	0	0	0	0	0	0	0	0	0	0
Constant head	278342	1212332.2	1410670.4	1959088.4	743113.7	2011416.8	1764259	2864698.5	-464772	-799084.5	353588.62	-905610.13
Wells	0	0	0	0	1327.6	1327.6	417.60001	1327.6	-1327.6	-1327.6	417.60001	-1327.6
Drains	0	0	0	0	15422.39	1832.3436	816.50122	1130.2316	-15422.4	-1832.3436	-816.50122	-1130.2316
Recharge	2485875	2650805	1325531.5	2650805	0	0	0	0	2485875	2650805	1325531.5	2650805
ET	0	0	0	0	0	0	0	0	0	0	0	0
River leakage	317954.5	707298.81	867887.81	825310	2321610	2555631	1838481.5	2567818	-2003656	-1848332.2	-970593.69	-1742508
SUM	3082171	4570436	3604089.8	5435203.5	3081474	4570207.5	3603974.5	5434974.5	697.0416	228.3689	115.08627	229.04346
DISCREPANCY"[%]"	0.02	0	0	0								

Table 6 Water balance of the three scenarios and the steady state model in m3/day.

		Groundwater altitude, in meters		Difference Between Calibrated and Scenario Water Levels		
No.	**Observation name**	**Calculated Heads(S)**	**Observed Heads(M)**	Recharge Decreased by 25%	Pumpage Increased by 50 %	K increased by 25%
1	BH-6	1682.324	1671.32	-3.986	-3.986	1.884
2	BH-7	1651.334	1652	-4.05	-4.05	-4.873
3	BH-8	1659.624	1641.74	-5.24	-5.24	-7.335
4	BH-10	1868.436	1871.814	-11.005	-11.005	-12.042
5	BH-11	1823.018	1814.8	-4.494	-4.494	1.793
6	BH-12	1829.647	1820.7	-16.49	-16.49	-16.951
7	BH-13	1823.359	1816.5	-9.313	-9.313	25.663
8	BH-14	1666.688	1667.867	-5.131	-5.131	-4.98
9	BH-15	1662.516	1665	-8.701	-8.701	-5.558
10	BH-16	1666.271	1645	-13.316	-13.316	-8.976
11	BH-18	1692.958	1688.47	-6.028	-6.028	-5.573
12	BH-19	1659.281	1627	-4.145	-4.145	-4.19
13	BH-20	1727.597	1731.967	-2.8	-2.8	-2.816
14	BH-21	1817.475	1821.45	4.26	4.26	4.722
15	BH-23	1659.266	1643	4.001	4.001	3.661
16	BH-25	1661.953	1667.422	2.151	2.151	0.87

17	BH-27	1771.984	1784	11.789	11.789	10.49
18	BH-29	1669.673	1665.458	-2.97	-2.97	-2.027
19	BH-31	1876.206	1879	-1.375	-1.375	-1.966
20	BH-32	1659.489	1643	0.089	0.089	1.196
21	BH-33	1698.305	1701	-7.328	-7.328	-0.557
22	BH-34	1652.541	1647	-5.989	-5.989	1.205
23	BH-35	1652.633	1658.87	11.379	11.379	13.557
24	BH-36	1672.149	1675	0.498	0.498	4.595
25	BH-37	1670.044	1677.89	4.652	4.652	8.401
26	BH-38	1957.924	1949.29	4.347	4.347	7.38
27	BH-39	1657.412	1662.36	4.771	4.771	9.916
28	BH-41	1701.582	1741	-2.43	-2.43	1.581
29	BH-42	1711.754	1713.5	-2.585	-2.585	1.166
30	BH-43	1678.141	1687.5	-13.947	-13.947	-9.717
31	BH-44	1653.792	1663	2.899	2.899	6.659
32	BH-45	1770.832	1769.1	-0.598	-0.598	5.664
33	BH-46	1662.396	1663.669	13.185	13.185	13.77
34	BH-47	1723.35	1718.22	13.168	13.168	15.653
35	BH-48	1746.699	1738	0.347	0.347	7.53
36	BH-49	1692.451	1679.14	6.026	6.026	12.93
37	BH-50	1658.026	1652	-3.693	-3.693	3.904
38	BH-51	1655.713	1651.57	-8.981	-8.981	1.083

39	BH-52	1655.799	1653	4.101	4.101	14.19
40	BH-53	1664.738	1669	8.828	8.828	8.185
41	BH-54	1681.558	1685.56	7.003	7.003	37.548
42	BH-57	1641.949	1644.1	-1.338	-1.338	5.564
43	BH-58	1690.21	1702	-3.573	-3.573	2.489
44	BH-63	1651.729	1648.76	5.763	5.763	15.254
45	BH-65	1654.784	1653.41	-9.107	-9.107	-9.926
46	BH-66	1802.375	1802.5	-4.705	-4.705	-6.13
47	BH-68	1846.464	1839.27	-0.983	-0.983	33.993
48	BH-69	1846.827	1841	2.151	2.151	0.87
49	BH-70	1800.654	1812.05	8.269	8.269	7.937
50	BH-71	1804.779	1805.3	-4.807	-4.807	-4.178
51	BH-73	1812.115	1816.8	5.631	5.631	6.179
52	BH-74	1812.123	1816.5	-28.215	-28.215	-28.26
53	BH-76	1839.921	1844.78	-3.009	-3.009	-3.6
54	BH-77	1825.329	1822.8	-1.588	-1.588	29.738
55	BH-78	1830.182	1816.3	6.463	6.463	4.836
56	BH-80	1818.957	1821.9	2.091	2.091	0.677
	BH-81	1844.605	1844.125	1.732	1.732	0.134
57	BH-82	1808.673	1821.9	-8.72	-8.72	-9.565
48	BH-83	1793.117	1806.3	-1.77	-1.77	5.333
59	BH-84	1847.39	1847.89	-3.729	-3.729	-1.178

60	BH-85	1845.355	1851.54	7.347	7.347	14.53
61	BH-86	1834.803	1832.44	0.968	0.968	1.273
62	BH-87	1850.3	1846.76	2.15	2.15	1.671
63	BH-88	1889.633	1880.8	2.123	2.123	32.668
64	BH-6	1717.238	1721.35	-3.526	-3.526	-4.145
65	BH-88	1662.838	1671.667	3.315	3.315	10.979
66	BH-89	1944.437	1951.98	5.942	5.942	10.954
67	BH-90	1850.689	1849.475	14.744	14.744	9.195
68	BH-91	1917.719	1914.22	-8.128	-8.128	-5.302
69	BH-92	1859.997	1856.12	0.078	0.078	-1.28
70	BH-93	1854.947	1861	-8.981	-8.981	1.083
71	BH-94	1647.187	1638.08	-3.073	-3.073	-2.572
72	BH-95	1641.925	1637.22	-0.017	-0.017	10.016
73	BH-96	1957.924	1957.62	-6.18	-6.18	-6.038
74	BH-97	1641.949	1644.1	-4.12	-4.12	-5.218
75	BH-98	1868.168	1864.16	0.665	0.665	0.97
76	BH-99	1653.729	1662	-17.886	-17.886	-17.381
77	BH-100	1650.806	1646	3.186	3.186	13.646
78	BH-102	1815.14	1820.8	-8.258	-8.258	-7.334
79	BH-103	1655.713	1627.5	-9.053	-9.053	-6.406
80	BH-104	1654.784	1651.776	-6.872	-6.872	-6.365
81	BH-105	2353.228	2351.668	1.177	1.177	1.527
82	BH-106	1701.536	1708	2.482	2.482	2.982
83	BH-107	1947.522	1942.31	-21.274	-21.274	-20.708

84	BH-108	1650.132	1652.223	-32.283	-32.283	-31.762
85	BH-109	1669.825	1671.559	4.362	4.362	5.994
86	BH-110	1697.817	1689.1	3.941	3.941	4.44
87	BH-111	1846.952	1845.334	-16.269	-16.269	-15.735
88	BH-113	1813.6	1809.9	5.466	5.466	6.017
89	BH-114	1847.39	1854.89	11.999	11.999	14.12
90	BH-115	1747.804	1748.778	-4.218	-4.218	-3.542
91	BH-116	1676.289	1678.441	2.775	2.775	-1.152
92	BH-118	1944.437	1947.1	2.687	2.687	4.07
93	BH-119	1652.495	1648.97	-5.543	-5.543	-6.007
94	BH-120	1863.301	1866.75	6.236	6.236	5.935
95	BH-123	1836.827	1842.88	2.85	2.85	2.726
96	BH-124	1857.131	1871.881	7.844	7.844	7.925
97	BH-126	1656.323	1942.2	4.947	4.947	3.838
98	BH-129	1685.164	1641.9	39.412	39.412	44.65
99	BH-130	1710.963	1880.8	1.746	1.746	1.344
100	BH-131	1673.169	1815	9.357	9.357	9.834
101	BH-133	1650.06	1862.22	9.207	9.207	9.988
102	BH-134	1760.992	1651.21	-1.734	-1.734	4.412
103	BH-135	1661.251	1636	1.273	1.273	0.531
104	BH-136	1839.211	1671.32	-3.986	-3.986	1.884
105	BH-137	1856.314	1652	-4.05	-4.05	-4.873
106	BH-88	1934.056	1641.74	-5.24	-5.24	-7.335
107	BH-89	1679.198	1871.814	-11.005	-11.005	-12.042
108	BH-90	1675.459	1814.8	-4.494	-4.494	1.793

109	BH-91	1658.447	1820.7	-16.49	-16.49	-16.951
110	BH-92	1879.818	1816.5	-9.313	-9.313	25.663
111	BH-93	1719.046	1667.867	-5.131	-5.131	-4.98
112	BH-94	1740.388	1665	-8.701	-8.701	-5.558
113	BH-95	1678.582	1645	-13.316	-13.316	-8.976
114	BH-96	1656.468	1688.47	-6.028	-6.028	-5.573
115	BH-97	1653.818	1627	-4.145	-4.145	-4.19
116	BH-98	1653.908	1731.967	-2.8	-2.8	-2.816
117	BH-99	1662.863	1821.45	4.26	4.26	4.722
118	BH-100	1679.17	1643	4.001	4.001	3.661
119	BH-102	1641.178	1667.422	2.151	2.151	0.87
120	BH-103	1687.415	1784	11.789	11.789	10.49
121	BH-104	1647.376	1665.458	-2.97	-2.97	-2.027
122	BH-105	1651.874	1879	-1.375	-1.375	-1.966
123	BH-106	1796.297	1643	0.089	0.089	1.196
124	BH-107	1826.782	1701	-7.328	-7.328	-0.557
125	BH-108	1826.218	1647	-5.989	-5.989	1.205
126	BH-109	1796.035	1658.87	11.379	11.379	13.557
127	BH-110	1797.845	1675	0.498	0.498	4.595
128	BH-111	1804.063	1677.89	4.652	4.652	8.401
129	BH-113	1805.33	1949.29	4.347	4.347	7.38
130	BH-114	1824.031	1662.36	4.771	4.771	9.916
131	BH-115	1821.333	1741	-2.43	-2.43	1.581

Table 6. Water level difference between simulated and those resulting from scenarios.

6.4 Model Limitations

A groundwater flow modeling is a representation of a complex, natural system with a set of mathematical equations that describe the system. Hence the conceptual model is an idealized summary of the current understanding of catchment conditions, and the key aspects of how the flow system works; it is subject to some simplifying assumption. These results in the model to have a degree of uncertainty mainly because of uncertainties in many model input parameters (hydraulic conductivity and aquifer thickness) and boundary conditions applied, For instance structurally highly affected areas can have wide range of hydraulic conductivity values in a single discretized model cell.

From beginning, discretization of model area or the node 500m by 500m, the hydraulic parameters, such as groundwater level and flow, are assumed to be one average value of the nodes surrounding the cell .This is because partly the model is not efficient for analysis of site-specific problems or error introduced on the assumption of hydrological parameters. Aquifer units are considered as uniform thickness in the same hydrogeological unit and unconfined for the entire model rather there exists overlying clay layers randomly in the study area. Model uncertainty could also arise from random error in the field measurements used for model calibration. Lack of proper site characterization may result in a model that is calibrated to a set of conditions which are not representative of actual field conditions. The main constraints in the modeling process, most of the existing well data were concentrated in the rift valley and western sides and scarce in the eastern plateau and high land.

Intensely fractured and tectonically affected areas can have highly variable hydraulic conductivity accordingly the groundwater level and flow in these area may be simulated indirectly by increasing hydraulic conductivity values ,the effects of these structures on the aquifer system may not be appropriately addressed within the model. In addition uncertainty results from defining boundary conditions of the model domain.

The model boundary conditions were defined based on the surface physical features such as upland areas where the geological units assumed is impervious and surface water divides. However, the locations of the groundwater catchment boundaries are uncertain since they might not coincide with their surface expressions. Absence of long-term or short –term monitored well data which can provide information related to system response to change in stress conditions. However the data collected at different time range was used in the model development with the assumption that no significant changes occurred in the system. Because of this the model results should be used into consideration all the limitations and assumptions which were lead to uncertainties.

The uncertainties or errors are clearly stated in the calibrated model using different statistical and simple observations that were used to check convergence criteria. Therefore the model may not be readily used for the detail groundwater management purposes because of the stated limitations. The results should be interpreted and applied considering all the limitations and assumptions related to the input parameters.

CHAPTER SEVEN

7. Conclusion and Recommendations

7.1 Conclusion

A numerical groundwater flow model was developed to increase understanding of the groundwater system and assist future management of the Ziway lake basin. This model incorporates our current understanding of the groundwater flow system so as to evaluate management environmental issues such as impacts of contamination, and estimating sustainable aquifer withdrawals. One important result from this study is identification of critical knowledge gaps and the further work required to ensure that model predictions of aquifer response to management scenarios are as accurate as possible. This model is generally capable of simulating the groundwater flow of the regional aquifer system in the Ziway lake basin. It accounts for the hydraulic interaction between the different geological water bearing Formations, Lakes and the river systems.

The site conceptual model consists of an unconfined, heterogeneous and isotropic aquifers bounded at the bottom by an impermeable layer. Water enters the model from several sources: mountain-front recharge along the eastern and western highlands; the Kater and Meki Rivers; areal recharge; and operational discharges, primarily concentrated in the rift area where industries and large irrigation activities exist. Water leaves the model via the Bulbula River, springs, evapotranspiration and several pumping wells .Standard data gathering and encoding techniques were used to develop the model extents, gridding, top and bottom elevation of the layers, location and elevation of the Kater and Meki Rivers, lithology and withdrawals. These elements of the model were encoded directly from site-specific data. The recharge used in the model is adopted from the work of (Tenalem Ayenew 1998) and (JIKA 2008). Initial estimates for Drain conductance and riverbed conductance were encoded and refined through a flow calibration process.

Well withdrawals in the study area consists utilizing irrigation, domestic, stock wells and industries. The amount of well withdrawal was a rough estimate because most of the consumption rate is not well recorded and the major conception is mainly from open hand dug wells.it is indirectly estimated from the average daily conception from individual household which is estimated to be 0.477936 MCM per year. In the study area there are more than 140 water points with location and some have pumping data, and all are active including deep boreholes, machine drilled shallow wells, hand dug wells, protected springs, and ponds

The groundwater flow model was calibrated to observed hydraulic heads containing 130 water points during the calibration period (2006–2012). The objective of the head calibration was to minimize the difference between the model-simulated head values and the field-observed head values during the calibration period. Hydraulic conductivity, recharge, and river hydraulic conductance were altered within the acceptable limit during model calibration. This data set was used to assess the ability of the model to accurately simulate water levels and flow direction at present, which is an indication of its ability to accurately simulate water levels and flow direction in the future. The calibration criteria define acceptable model performance in terms of measures of similarity (difference) between observed and simulated values. The model calibration criteria are as follows:

- Residuals (differences between observed and modeled heads) should be reasonably distributed.
- Residual distribution should be reasonably normal.
- The mean residual should be approximately 0.
- The number of positive residuals should approximate the number of negative residuals.
- The correlation coefficient (calculated versus observed) should be greater than 0.9.

- The RMS error (calculated versus observed) should be less than 5 meter, approximately 10 percent of the gradient in the water table elevation.

- The calibrated parameters should compare reasonably well with field-measured values

The sensitivity analysis indicated that the model is highly sensitive to recharge and moderately sensitive to hydraulic conductivity values, and relatively less sensitive to well withdrawal, as it is commonly the case. Refined ranges in input values may allow for improved calibration of the model in the future. Three scenario cases were performed using increased and decreased 25%, 50%, and 75% for parameters such as recharge, hydraulic conductivity and well withdrawal. The results of these scenarios were evaluated with respect to changes on groundwater heads that signify the response of the aquifer, the magnitude and direction of river leakage to the aquifer system compared to the steady-state simulated values.

7.2 Recommendations

The Lake Ziway basin groundwater flow model provides insight into the groundwater system in terms of water budget and groundwater flow directions .however it should be viewed as basic model that could be improved with additional data such as hydrologic, hydrogeological data and advanced Modflow options and packages. The model can be used to identify and priorities gaps that exist in the data. Specific areas in which improvements may be beneficial are summarized below.

- Refining hydraulic conductivity based on different lithological units, specifically in areas where data availability are minimal and structurally affected areas. The model by necessity assumes averages across large areas with limited data to validate against. While this may not affect the average water budget, it may affect the local flow directions and flow rates.

- Transient modeling to evaluate effects of seasonal fluctuations. The current model is a steady –state model which estimates flow under average conditions. It could be run as transient model to evaluate the impact of seasonal changes on the groundwater system.

- The hydraulic connection between the groundwater system and the rivers in the study area is not well understood. As a result the current simulated model was based on simplifying assumptions such as uniform river sediment thickness but in reality the upstream and down steams of the river systems may have different sediment thickness and river hydraulic conductance. Future research studies on river hydraulic properties and their connection with groundwater system needed to provide better simulation results of groundwater flow modeling of the area.

- Natural groundwater resources have been impacted by extraction of groundwater for industry and human supply. Groundwater extraction can lower water levels and cause significant water level drop in groundwater system. Changes to the quantity and quality of the groundwater resource could impact ecosystem .we need to understand the processes in aquifers of the study area and develop an adequate monitoring bore network to research and ultimately protect these resource further research studies with adequate field monitoring and subsequent recalibration of the model will improve performance and increase accuracy of Ziway lake basin

- . Since the modeled basin is unconfined aquifer which is dominated by diffuse recharge. Thus has close connection between the climate and hydrologic cycle. The basic controls on diffuse groundwater recharge include climate, vegetation, soils, and topography. The result of scenario analysis indicates that recharge has significant effect on the change in hydraulic head, further work on increasing recharge will provide the sustainability of the groundwater resource on the ziway lake basin

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Annex

Stat-ion	Abura	Areta	Asela	Bokoji	Bui	Butaira	Diga-lu	Ejer-salele	Katarguent	Kersa	Koshe	Kul-umsa	Meki	Meraro	Sag-ure	Tora	Ziway
Abura	1.00	0.93	0.88	0.84	0.97	0.76	0.84	1.00	0.88	0.87	0.96	0.90	1.00	0.85	0.88	0.91	0.94
Areta	0.93	1.00	0.96	0.83	0.90	0.69	0.86	0.93	0.93	0.86	0.95	0.89	0.93	0.84	0.93	0.90	0.93
Asela	0.88	0.96	1.00	0.84	0.85	0.64	0.87	0.88	0.88	0.87	0.90	0.90	0.88	0.85	0.88	0.85	0.88
Boko-ji	0.84	0.83	0.84	1.00	0.81	0.75	0.99	0.84	0.78	0.83	0.86	0.80	0.84	0.93	0.90	0.81	0.84
Bui	0.97	0.90	0.85	0.81	1.00	0.79	0.81	0.97	0.85	0.84	0.93	0.87	0.97	0.82	0.85	0.88	0.91
Butaj-ira	0.76	0.69	0.64	0.75	0.79	1.00	0.72	0.76	0.70	0.72	0.75	0.75	0.76	0.79	0.70	0.73	0.76
Diga-lu	0.84	0.86	0.87	0.99	0.81	0.72	1.00	0.84	0.81	0.83	0.86	0.83	0.84	0.93	0.93	0.81	0.84
Ejer-salele	1.00	0.93	0.88	0.84	0.97	0.76	0.84	1.00	0.88	0.87	0.96	0.90	1.00	0.85	0.88	0.91	0.94
Katarguent	0.88	0.93	0.88	0.78	0.85	0.70	0.81	0.88	1.00	0.81	0.93	0.87	0.88	0.79	0.88	0.85	0.94
Kersa	0.87	0.86	0.87	0.83	0.84	0.72	0.83	0.87	0.81	1.00	0.89	0.83	0.87	0.90	0.81	0.96	0.87
Koshe	0.96	0.95	0.90	0.86	0.93	0.75	0.86	0.96	0.93	0.89	1.00	0.88	0.96	0.87	0.90	0.93	0.99
Kulumsa	0.90	0.89	0.90	0.80	0.87	0.75	0.83	0.90	0.87	0.83	0.88	1.00	0.90	0.81	0.84	0.81	0.87

Meki	1.00	0.93	0.88	0.84	0.97	0.76	0.84	1.00	0.88	0.87	0.96	0.90	1.00	0.85	0.88	0.91	0.94
Mera-ro	0.85	0.84	0.85	0.93	0.82	0.79	0.93	0.85	0.79	0.90	0.87	0.81	0.85	1.00	0.85	0.88	0.85
Sagu-re	0.88	0.93	0.88	0.90	0.85	0.70	0.93	0.88	0.88	0.81	0.90	0.84	0.88	0.85	1.00	0.85	0.88
Tora	0.91	0.90	0.85	0.81	0.88	0.73	0.81	0.91	0.85	0.96	0.93	0.81	0.91	0.88	0.85	1.00	0.91
Ziway	0.94	0.93	0.88	0.84	0.91	0.76	0.84	0.94	0.94	0.87	0.99	0.87	0.94	0.85	0.88	0.91	1.00

Annex 1. Correlation matrix between precipitations in different stations

No	L ocation	XUTM	YUTM	GWL altitude		No	Location	XUTM	YUTM	GWL
1	Meki nucplity	479988	900609	1610		39	Doya	497823	884832	1608
2	Ate Meti	474664	902456	1615		40	Golbe	496185	890206	1774
3	Laluna Dero	469030	901999	1640		41	Hallo	501517	887144	1669
4	Dugda	460343	901488	1829		42	Horde	505307	895726	1669
5	Choroke	471543	898467	1622		43	Kararu	494143	883539	1607
6	Korke Adi	476314	897861	1630		44	Kiyansho	494534	874497	1676
7	Abonn	471774	892430	1635		45	Kobota	491921	870986	1724
8	Chefe	484943	896277	1636		46	Korbeyyi 3	504121	891438	1672
9	Welinbula	461393	887564	1625		47	Lammaffo	500706	897575	1782
10	Abosa	469237	886519	1623		48	Oda Dima	497883	898267	1644
11	Beda Gosa	469806	890976	162 6		49	Ogolcho	501573	888485	1639
12	Negallign	468657	886623	1645		50	Sango Lakke	497443	892522	1552

13	Edo Kontola	469071	882855	1627
14	Gubiba	457350	887119	1661
15	Galo Fechasa	462131	883354	1619
16	Hesbawi Batele	468296	879413	1643
17	Ziway prison	467438	877282	1611
18	Koshe	448573	884180	1830
19	Faka	447136	880164	1891
20	W. Gerbi	465881	875514	1625
21	Boromo	460735	874769	1604
22	Woleyie	463164	870844	1617
23	Shisho Tabo	462052	866226	1614
24	Adami Tulu	467301	869468	1609
25	Garbi	468448	871433	1624
26	Waji	514202	870371	2528
27	Abura	500220	889567	1675
28	Gonde	521570	887113	2265
29	Burkitu	510611	883617	2120
30	Abargeda	499840	889943	1699
31	Adulala	495776	886600	1636
32	Andode	505428	890015	1740
33	Arba	508715	897993	1694
34	Baddara	498435	882864	1613
35	Bowenni	501266	889596	1595
36	Burka	497049	892945	1641
37	Ch.e Burkitu	489704	867598	1793

51	Shanan	496332	896999	1662
52	Sheled Goto	500226	884570	1711
53	Tirratti	497648	896992	1649
54	Toya Leman	509634	892212	1764
55	Udada	495014	884350	1643
56	Hellanna	513788	870666	2557
57	Mulqiicha	495969	863601	1898
58	Shola Chabetti	514055	866034	2566
59	Wanji Gora	516954	884109	2278
60	Totoke	473605	827856	1623
61	Kurteta	480132	824147	1811
62	Buku	476682	829321	1621
63	Gubeta	477268	830389	1622
64	Digalu	510579	859046	2409
65	Doddoba	496886	878152	1675
66	Mereko Woreda	429307	897130	1871
67	Meskan oreda	449039	891512	1825
68	Meskan Woreda	440217	886397	1833
69	Meskan Woreda	439248	896637	1873
70	Meskan Woreda	428001	877580	1824
71	Meskan Woreda	441911	891294	1817
72	Meskan Woreda	442504	904859	1832
73	Meskan Woreda	424189	892802	2179
74	Soddo Woreda	434853	907907	2054
75	Soddo Woreda	440353	918436	2702

38	Choba	495299	884905	1644	76	Soddo Woreda	449186	933018	2651

Annex 2 Groundwater table elevation (m)

		Groundwater altitude, in meters		Difference Between Calibrated and Scenario Water Levels		
No.	**Observation name**	**Calculated Heads(S)**	**Observed Heads(M)**	Recharge Decreased by 25%	Pumpage Increased by 50 %	K increased by 25%
1	BH-6	1682.324	1671.32	-3.986	-3.986	1.884
2	BH-7	1651.334	1652	-4.05	-4.05	-4.873
3	BH-8	1659.624	1641.74	-5.24	-5.24	-7.335
4	BH-10	1868.436	1871.814	-11.005	-11.005	-12.042
5	BH-11	1823.018	1814.8	-4.494	-4.494	1.793
6	BH-12	1829.647	1820.7	-16.49	-16.49	-16.951
7	BH-13	1823.359	1816.5	-9.313	-9.313	25.663
8	BH-14	1666.688	1667.867	-5.131	-5.131	-4.98
9	BH-15	1662.516	1665	-8.701	-8.701	-5.558
10	BH-16	1666.271	1645	-13.316	-13.316	-8.976
11	BH-18	1692.958	1688.47	-6.028	-6.028	-5.573
12	BH-19	1659.281	1627	-4.145	-4.145	-4.19
13	BH-20	1727.597	1731.967	-2.8	-2.8	-2.816
14	BH-21	1817.475	1821.45	4.26	4.26	4.722
15	BH-23	1659.266	1643	4.001	4.001	3.661

16	BH-25	1661.953	1667.422	2.151	2.151	0.87
17	BH-27	1771.984	1784	11.789	11.789	10.49
18	BH-29	1669.673	1665.458	-2.97	-2.97	-2.027
19	BH-31	1876.206	1879	-1.375	-1.375	-1.966
20	BH-32	1659.489	1643	0.089	0.089	1.196
21	BH-33	1698.305	1701	-7.328	-7.328	-0.557
22	BH-34	1652.541	1647	-5.989	-5.989	1.205
23	BH-35	1652.633	1658.87	11.379	11.379	13.557
24	BH-36	1672.149	1675	0.498	0.498	4.595
25	BH-37	1670.044	1677.89	4.652	4.652	8.401
26	BH-38	1957.924	1949.29	4.347	4.347	7.38
27	BH-39	1657.412	1662.36	4.771	4.771	9.916
28	BH-4BH-0	1701.582	1741	-2.43	-2.43	1.581
29	BH-42	1711.754	1713.5	-2.585	-2.585	1.166
30	BH-43	1678.141	1687.5	-13.947	-13.947	-9.717
31	BH-44	1653.792	1663	2.899	2.899	6.659
32	BH-45	1770.832	1769.1	-0.598	-0.598	5.664
33	BH-46	1662.396	1663.669	13.185	13.185	13.77
34	BH-47	1723.35	1718.22	13.168	13.168	15.653
35	BH-48	1746.699	1738	0.347	0.347	7.53
36	BH-49	1692.451	1679.14	6.026	6.026	12.93
37	BH-50	1658.026	1652	-3.693	-3.693	3.904

38	BH-51	1655.713	1651.57	-8.981	-8.981	1.083
39	BH-52	1655.799	1653	4.101	4.101	14.19
40	BH-53	1664.738	1669	8.828	8.828	8.185
41	BH-54	1681.558	1685.56	7.003	7.003	37.548
42	BH-57	1641.949	1644.1	-1.338	-1.338	5.564
43	BH-58	1690.21	1702	-3.573	-3.573	2.489
44	BH-63	1651.729	1648.76	5.763	5.763	15.254
45	BH-65	1654.784	1653.41	-9.107	-9.107	-9.926
46	BH-66	1802.375	1802.5	-4.705	-4.705	-6.13
47	BH-68	1846.464	1839.27	-0.983	-0.983	33.993
48	BH-69	1846.827	1841	2.151	2.151	0.87
49	BH-70	1800.654	1812.05	8.269	8.269	7.937
50	BH-71	1804.779	1805.3	-4.807	-4.807	-4.178
51	BH-73	1812.115	1816.8	5.631	5.631	6.179
52	BH-74	1812.123	1816.5	-28.215	-28.215	-28.26
53	BH-76	1839.921	1844.78	-3.009	-3.009	-3.6
54	BH-77	1825.329	1822.8	-1.588	-1.588	29.738
55	BH-78	1830.182	1816.3	6.463	6.463	4.836
56	BH-80	1818.957	1821.9	2.091	2.091	0.677
	BH-81	1844.605	1844.125	1.732	1.732	0.134
57	BH-82	1808.673	1821.9	-8.72	-8.72	-9.565
48	BH-83	1793.117	1806.3	-1.77	-1.77	5.333

59	BH-84	1847.39	1847.89	-3.729	-3.729	-1.178
60	BH-85	1845.355	1851.54	7.347	7.347	14.53
61	BH-86	1834.803	1832.44	0.968	0.968	1.273
62	BH-87	1850.3	1846.76	2.15	2.15	1.671
63	BH-88	1889.633	1880.8	2.123	2.123	32.668
64	BH-6	1717.238	1721.35	-3.526	-3.526	-4.145
65	BH-88	1662.838	1671.667	3.315	3.315	10.979
66	BH-89	1944.437	1951.98	5.942	5.942	10.954
67	BH-90	1850.689	1849.475	14.744	14.744	9.195
68	BH-91	1917.719	1914.22	-8.128	-8.128	-5.302
69	BH-92	1859.997	1856.12	0.078	0.078	-1.28
70	BH-93	1854.947	1861	-8.981	-8.981	1.083
71	BH-94	1647.187	1638.08	-3.073	-3.073	-2.572
72	BH-95	1641.925	1637.22	-0.017	-0.017	10.016
73	BH-96	1957.924	1957.62	-6.18	-6.18	-6.038
74	BH-97	1641.949	1644.1	-4.12	-4.12	-5.218
75	BH-98	1868.168	1864.16	0.665	0.665	0.97
76	BH-99	1653.729	1662	-17.886	-17.886	-17.381
77	BH-100	1650.806	1646	3.186	3.186	13.646
78	BH-102	1815.14	1820.8	-8.258	-8.258	-7.334
79	BH-103	1655.713	1627.5	-9.053	-9.053	-6.406
80	BH-104	1654.784	1651.776	-6.872	-6.872	-6.365
81	BH-105	2353.228	2351.668	1.177	1.177	1.527
82	BH-106	1701.536	1708	2.482	2.482	2.982

83	BH-107	1947.522	1942.31	-21.274	-21.274	-20.708
84	BH-108	1650.132	1652.223	-32.283	-32.283	-31.762
85	BH-109	1669.825	1671.559	4.362	4.362	5.994
86	BH-110	1697.817	1689.1	3.941	3.941	4.44
87	BH-111	1846.952	1845.334	-16.269	-16.269	-15.735
88	BH-113	1813.6	1809.9	5.466	5.466	6.017
89	BH-114	1847.39	1854.89	11.999	11.999	14.12
90	BH-115	1747.804	1748.778	-4.218	-4.218	-3.542
91	BH-116	1676.289	1678.441	2.775	2.775	-1.152
92	BH-118	1944.437	1947.1	2.687	2.687	4.07
93	BH-119	1652.495	1648.97	-5.543	-5.543	-6.007
94	BH-120	1863.301	1866.75	6.236	6.236	5.935
95	BH-123	1836.827	1842.88	2.85	2.85	2.726
96	BH-124	1857.131	1871.881	7.844	7.844	7.925
97	BH-126	1656.323	1942.2	4.947	4.947	3.838
98	BH-129	1685.164	1641.9	39.412	39.412	44.65
99	BH-130	1710.963	1880.8	1.746	1.746	1.344
100	BH-131	1673.169	1815	9.357	9.357	9.834
101	BH-133	1650.06	1862.22	9.207	9.207	9.988
102	BH-134	1760.992	1651.21	-1.734	-1.734	4.412
103	BH-135	1661.251	1636	1.273	1.273	0.531
104	BH-136	1839.211	1671.32	-3.986	-3.986	1.884
105	BH-137	1856.314	1652	-4.05	-4.05	-4.873
106	BH-88	1934.056	1641.74	-5.24	-5.24	-7.335

107	BH-89	1679.198	1871.814	-11.005	-11.005	-12.042
108	BH-90	1675.459	1814.8	-4.494	-4.494	1.793
109	BH-91	1658.447	1820.7	-16.49	-16.49	-16.951
110	BH-92	1879.818	1816.5	-9.313	-9.313	25.663
111	BH-93	1719.046	1667.867	-5.131	-5.131	-4.98
112	BH-94	1740.388	1665	-8.701	-8.701	-5.558
113	BH-95	1678.582	1645	-13.316	-13.316	-8.976
114	BH-96	1656.468	1688.47	-6.028	-6.028	-5.573
115	BH-97	1653.818	1627	-4.145	-4.145	-4.19
116	BH-98	1653.908	1731.967	-2.8	-2.8	-2.816
117	BH-99	1662.863	1821.45	4.26	4.26	4.722
118	BH-100	1679.17	1643	4.001	4.001	3.661
119	BH-102	1641.178	1667.422	2.151	2.151	0.87
120	BH-103	1687.415	1784	11.789	11.789	10.49
121	BH-104	1647.376	1665.458	-2.97	-2.97	-2.027
122	BH-105	1651.874	1879	-1.375	-1.375	-1.966
123	BH-106	1796.297	1643	0.089	0.089	1.196
124	BH-107	1826.782	1701	-7.328	-7.328	-0.557
125	BH-108	1826.218	1647	-5.989	-5.989	1.205
126	BH-109	1796.035	1658.87	11.379	11.379	13.557
127	BH-110	1797.845	1675	0.498	0.498	4.595
128	BH-111	1804.063	1677.89	4.652	4.652	8.401
129	BH-113	1805.33	1949.29	4.347	4.347	7.38

Annex 3 Water level difference between simulated and those resulting from scenarios.