ADDIS ABABA INSTITUTE OF TECHNOLOGY
DEPARTMENT OF CIVIL AND ENVIRONMENTAL ENGINNERING

GROUND WATER - SURFACE WATER INTERACTION AND IMPACT ASSESSMENT,
IN THE CASE OF WESTERN ZIWAY- MEKI catchment

BY

SOLOMON KASSA HAYI

A THESIS SUBMITTED TO THE SCHOOL OF GRADUATE STUDIES OF ADDIS-ABABA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CIVIL engineering (HYDRAULIC STREAM)

Advisor Dr.Ing. Asie Kemal

July, 2021

ADDIS ABABA

ETHIOPIA

Addis Ababa University
School of Graduate Studies
Institute of Technology

GROUND WATER- SURFACE WATER INTERACTION AND IMPACT ASSESSMENT, IN THE CASE OF WESTERN ZIWAY-MEKI RIVER CHACHMENT

BY

SOLOMON KASSA

DEPARTMENT OF CIVIL ENGINEERING

Approval by Board of Examiners:

Dr. Ing Asie Kemal
Advisor Signature

---------------------------- **--------------------**

Signature

Internal Examiner Signature

------------------------------------ **------------------**

Signature

External Examiner Signature

------------------------------------- **------------------**

Signature

Chairman (Department of graduate Committee)

-- **------------------**

Signature

CERTIFICATION

The undersigned certify that he has read the thesis entitled**: ground water- surface water interaction and impact assessment, in case of western Ziway- Meki river catchment**, Central Ethiopia and hereby recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements for the degree of Master of Science.

Dr. Ing Asie Kemal
(Supervisor)

Date

DECLARATION

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

Solomon Kassa Hayi
school of graduate studies
institute of technology
July, 2021

The Thesis has been submitted for the examination with my approval as university advisor.

Dr. Ing Asie Kemal
Addis Ababa University

ACKNOWLEDGMENT

The preparation and completion of this thesis work would not have been possible without the assistance and contribution of kind persons around me. First, I thank the almighty God for the gift of giving me the strength to get this far and for giving me the courage to go even further in my study time and also I would like to gratefully acknowledge my advisor Dr. Ing Asie Kemal for advising me for the research problem, continued support, sharing me valuable comments, encouragement, data condition and provision of material helpful for the paper.as well as, I gratefully acknowledge all organizations and individuals who directly or indirectly supported me in my study. Specially, I greatly acknowledge AG Consult, Ministry of Water and Energy, National Meteorological Service Agency, Ethiopian mapping agency and Ethiopian geological agency for allowing me to use their data. Finally, I would like to add my acknowledgment to the administrative and teaching staff of the department of civil engineering.

ABSTRACT

As the combined pumping rate of the water supply and irrigation of the towns and rural areas ,were the cause of the depletion of groundwater resources in the groundwater basin and the drying up of stream water. The goal of this research was to enhance the current understanding of the interaction of surface water-ground water and impact assessment using a numerical model. Initially, to measure the natural recharge of the aquifer and to model streamflow, the surface water hydrology of the sub basin was researched using the HEC-HMS (SMA)model. The ground flow mechanism was analyzed by using 3D numerical groundwater flow model (Processing Modflow Pro (Version 5.3.0.1)). The required model inputs were obtained from the results of field observation, secondary data and previous work carried out in the area. As calibration parameters, horizontal hydraulic conductivity from 0.1 m/day to 15 m/day and ground water recharge 64.6 mm/year, which constitute the main groundwater model parameters, were considered. The HEC-HMS(SMA) model was used to measure the recharge rate for the sub-basin in order to achieve a recharge. Model calibration was subsequently carried out using the process of trial-and-error calibration using groundwater contours formed from heads collected at 56 observation points. Therefore, the average RMSE for simulated hydraulic heads was approximately 20.65m. The calibrated model is used to assess the groundwater-surface water interactions, and groundwater system activity under various potential use scenarios. Simulated water levels in the model were more sensitive to decreases in recharge values and sensitive to decreases in hydraulic conductivity values. However, relative to recharge and hydraulic conductivity, the model is not as sensitive to decreases or increases in pumpage. According to the simulation, groundwater flows from the western escarpment to the east eventually join Lake Ziway. Lakes and rivers are significant sources of aquifer recharge. Increased pumping rate results substantial regional groundwater level decline, which leads to the drying of springs and shallow hand dug wells, according to simulations conducted under various potential future use scenarios. Finally, the model's water budget results showed that groundwater recharge comprised 81.48%, through river leakage 3.28 % and constant head was 15.24% *of the total water input for the entire study region. Because of this, it can be noted that the surface water impacts to the water budget of the sub-basin.*

Key Words: Meki River, SMA, Hec-Hms,Modflow, Hec-GeoHms, Surface Water-Ground Water Interaction

Table of contents

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDIXES

LIST OF ACRONYMS

AAiT	Addis Ababa Institute of Technology
ASTER	Advanced Spaceborne Thermal Emission and Reflection
DEM	Digital elevation model
ELV	elevation
GIS	Geographical information system
GW	ground water
ha	hectare
M.a.s.l	Meter above mean sea level
m/d	meter per day
ME	Mean Error
mm^3	millimeter cube
MoWIE	Ministry of Water ,irrigation & Energy
RMS	Root Mean Squared Error
SMA	Soil Moisture Accounting
SPAW	Soil-Plant-Air-Water
SW	surface water
SWL	Static Water Level
USGS	United states geological survey
UTM	Universal Transverse Mercator
WGS84	World Geodetic System dating from 1984

CHAPTER ONE

1. INTRODUCTION

1.1 BACK GROUND

surface water and Groundwater interaction is a natural phenomenon dictated by the fact that the two-water media are critical components of one system intimately linked by hydrologic cycle (Hamilton, 2005). Surface and groundwater processes are in continuous complex interaction and They are the two elements of hydrological cycle that are not separated from the interaction. However, Surface water and groundwater supplies are typically managed as separate structures. Therefore, this can contribute to resource over/under-allocation and detrimental impacts on the climate. Production of land and water supplies affects the quantity and quality; thus, understanding the connectivity between surface water and groundwater systems is required to plan and manage surface water and groundwater resources accordingly.

Groundwater is discharged to the surface through natural springs, transpiration by plants, seepage under rivers and streams. On the other hand, groundwater is recharged by surface water from direct precipitation and indirectly from losing rivers and streams. This is due to the fact that surface and groundwater flow systems, in many cases, interact with each other. Krause et al. (2007) found out that there is high spatial and temporal variability in interactions between surface and groundwater and the exchange of fluxes between them. In that respect, the direction of the flux exchange determines the type of interaction. Whereas, Groundwater recharge is a function of the volume of residual rainfall, surface infiltration, and geological percolation rates(Hamilton, 2005).

In Ethiopia currently, water supply and small-scale irrigation schemes have been implemented in the area and water abstraction from surface water and groundwater resources puts an increasing claim on scarce water resources in the area understanding of the existing and future water demand with negative impact on economic development and environment of the basin enables to identify and design hearty development options. This was creating shortage of water resources for irrigation and water supply purposes. In addition, the increasing pressure on land and water resources intensifies conflicts between various stakeholders.

the Central Ethiopian Rift Valley with Lakes Ziway, Langano, Abyata and Shalla is one of those rain fall deficit areas where the surrounding agroclimatic and geological factors are believed to have major effect on the hydrological system. Among the rift valley basin western Ziway-Meki river catchment has an abundance surface and groundwater resources. However, due to climatic change, high population growth, the amount of water available is decreasing.in order to access both surface and groundwater appear to be more feasible and consistence as demand can be met from several sources instead of using one source. Therefore, initial assessment of (SW-GW)interaction and their effects were imperative, in order to use surface and ground water supplies in conjunctively. For the sake of (SW-GW) relationship evaluation the following major components will be included: like, GW recharge/discharge, precipitation recharge, land use/cover, run-off, river leakage, boundary condition, geology, aquifer type and boundary condition of the basin. Generally, these components will be used for modelling the ground water flow and its interaction with surface water. To use Modeling software is critical because it can simulate a time period very quickly which saves time and money over an experimental monitoring study. Therefore, for this study used modeling software to investigate aquifer interactions with surface water components by combines two important modeling software's: HEC-HMS for surface water modeling and processing MODFLOW for groundwater modeling. Finally, the aim of this research is to improve understanding of the relationships between surface and ground water and to investigate the effect of one over the other for sustainable use and to influence future elective decision making in water resource management in the catchment Moreover, it aims to improve more societal benefits by ensuring availability of water for agricultural activities and sustenance of ecological systems in the study area.

1.2 STATEMENT OF PROBLEMS

In case of increase in population, topographic condition, agriculture and climate change, the capacity of the available water to satisfy the demand is insufficient in some parts of the study area(Resour et al., 2016).currently the main causes for the problem are both natural (climate change) and manmade (ground water pumping). This is due to deforestation and accelerated land degradation as a result of soil erosion, free grazing, topography and inappropriate land use all of which has been driven by the increase in population and in land pressure. In addition, increasing of pumping groundwater for irrigation purpose has the cause for: The decrease of groundwater potential in the groundwater basin and dry up of streams, river nearby. Such aggressive ground water abstraction will result conflicts between the users of groundwater and river. Therefore, Assessment of GW-SW interaction were important to fill the knowledge gap in the community and water managers in the study area.

1.3.OBJECTIVE OF STUDY

1.3.1 GENERAL OBJECTIVE

The goal of this study is to improve current understanding of the interaction of surface water-ground water and impact assessment of the catchment of the western Ziway-Meki river.

1.3.2 SPECIFIC OBJECTIVES

The specific objectives are the following:

1. To estimate the natural recharge to the aquifer and assess the catchment's surface water condition.
2. To evaluate surface water- ground water interactions of the sub basin.
3. To assess the behavior of the groundwater system in the context of potential future consumption scenarios.

1.4 RESEARCH QUESTIONS

To address the objective, necessary research questions have been established:

- How much Percolation results were input into ground water as direct recharge?
- How does groundwater-surface water system work and the surface water impacts to the water budget?
- What is the effect on water balances due to groundwater pumping and recharge change?

1.5.STUDY OUT COMES

- To understand the surface water impacts to the water budget in the Sub basin.
- To improve the groundwater simulation.
- To predict expected man made or natural change in the catchment.

In general, these studies would facilitate municipal and water managers' which create a better understanding of where their water originate from and could help with developing sustainable management strategies for the western Ziway-Meki river catchment.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 CONCEPTS AND IMPORTANCE OF SW-GW INTERACTION

The interaction of groundwater and surface water is critical for both physical and chemical fluxes in the hydrologic cycle (In et al., 2018). Groundwater and surface water systems are frequently examined independently, making quantifying flows challenging. Nonetheless, the relevance of understanding how this interface affects hydrologic budgets, ecosystems, and global change is becoming more widely recognized. The structures of surface and groundwater are in constant complex interaction. The essential features of each system must be analyzed in order to understand these systems properly. These characteristics are grouped into components called the component of the soil, the component of the unsaturated region, and the (saturated) component of the groundwater. On the surface and in the unsaturated and saturated region, the flow of water is driven by gradients from high to low potential. Figure 2-1 depicts the essential flow components of a surface water-groundwater system. It was critical to review various conceptual information about flow components of the SW-GW system in order to meet my study objectives.

2.1.1 Surface water component

Water running directly on top of the soil is surface water. Generally, surface water contains visible features of streams, lakes, and reservoirs, as well as the less noticeable features of sheet flow and spring and spring runoff. Runoff across the surface occurs whenever precipitation accumulation (either as rain or snow) exceeds the subsurface strata's penetration capacity and evapotranspiration rate, or whenever the rate of discharge of groundwater exceeds the rate of evapotranspiration. As a result, it was critical to describe or understand the surface water component information diagram before simulating the stream flow on the catchment.

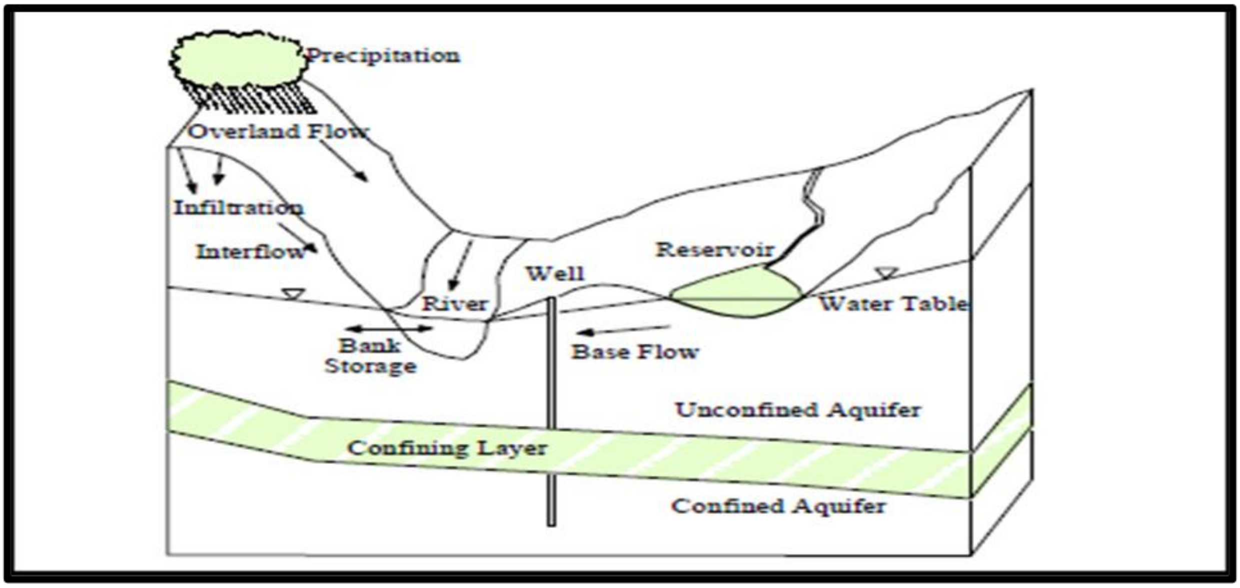


Figure 2.1 Flow components of the surface-ground water flow system(modified from: DEPARTMENT OF THE ARMY U.S. Army Corps of Engineers manual,1999)

2.1.2 Subsurface water component

firstly, direct precipitation, overland flow, and leakage into stream beds are the result of water infiltrating through the unsaturated region. In response to gravity, flow in the unsaturated zone is usually thought to be downward. However, poorly permeable strata (for example, a clay layer) may build barriers to downward flow that by deflecting flow laterally until it is discharged as evapotranspiration or as infiltration to the surface, can restrict the amount of water reaching the underlying saturated zone (referred to as interflow). Secondly, in the hydrological cycle, groundwater is an essential component as it serves as a large storage reservoir that accepts and discharges water from and to the surface. The peak flow of a flood is attenuated because of drainage from the stream into the subsurface in areas were streams flow over permeable strata. As the stage decreases, much of this water returns to the stream, which results in prolonged flow. This relatively short-term flow of water into and out of the subsurface is generally called bank storage during a flood event.in the same manner, prior to simulating the GW on the subsurface water portion of the basin It was critical to describe the general and schematic diagrams in order to achieve my study goal.

2.2. PREVIOUS STUDIES MADE ON WESTERN ZIWAY- MEKI RIVER CHACHMENT

Groundwater-Surface water interaction and Analysis of Recent Changes in Hydrologic Environment of Lake Ziway Catchment by Dr. Tenalem Ayenew, Alemu Diribssa (June ,2006)

In order to understand the relationship between groundwater and surface water, various specified calculations were made in this report. The region has mean annual precipitation, possible evapotranspiration and real evapotranspiration of 887 mm, 1284 mm and 856 mm respectively, among the estimates. After that the value of the direct groundwater recharge of the catchment was calculated using analytical formula, soil moisture budgeting (57mm) and groundwater balance techniques (57mm). In comparison, the interaction of groundwater and surface water in the region should be investigated Apply the following techniques: contour of the groundwater table, measurements of field base river drainage, water balance of the channel and hydrographic analysis. As a result, the Meki River in the volcano-lacustrine deposit of the rift floor and the Katar River in the Upper and Central Wonji Fault Belt are losing reach. But, except the western catchment areas of Ziway-Meki, rivers and streams are gaining momentum. In addition, the annual and monthly lake water balances provide the available and required requirements for performing them. The result thus shows that the outflow of groundwater is greater than the inflow of groundwater. Finally, patterns in short and long-term precipitation, evaporation, abstraction, river drain lake level and direct groundwater recharge were analyzed in the evaluation of existing changes in the hydrological environment. All these parameters reflect changes in the hydrological environment; both climate change and human interference are due to them.

Numerical Groundwater Flow Modeling of the Ziway Lake Basin (Groundwater & Modeling, 2013)

The following major discussions and outcomes were summarized according to this study as follows: The Ziway Lake Basin is a large heterogeneous lithological unit containing domestic agricultural, industrial and environmental groundwater aquifers. Growth in the population has led to the expansion of residential developments and thus increased demand for water. It is essential that this resource be managed in a sustainable manner in order to protect it, both for current users and for generations to come. Eight aquifer systems with distinct potential and hydraulic characteristics for groundwater. In the lacustrine and alluvial deposits of the rift and highlands of weathered and fractured regions, a shallow aquifer occurs. The topography is followed by water levels in the model aquifers, and groundwater occurs in the system under unrestricted conditions. Using Processing Mod Flow Pro (Version 8.0.15), the aquifer system was modeled numerically under a steady-state condition with one layer of 500 meters of constant thickness. The model area of about seven thousand four hundred and fourteen square kilometers was divided into 250 by 250 meters of grid blocks. A number of input data for the development of this model were collected from different sources. These data include: DEM, thickness of aquifer, recharge, study area hydrogeological conditions, flow data, and wells for pumping and observation. These data were prepared and pre-processed using ArcGIS, surfer10 and Globalmapper11. Using trial and error calibration, the groundwater model calibration was performed. By modifying several parameters, such as recharge, hydraulic conductivity, and river conductance, the calibration was implemented. The groundwater steady-state model was successfully calibrated and the simulated heads were in good agreement with the observed head. The calibrated model yielded -0.070613 m for ME and 4.497221 m for RMS. To examine the response of the calibrated steady state model to changes in model parameters, including horizontal hydraulic conductivity, recharge, and well withdrawal, a sensitivity analysis was conducted. The model was most susceptible to recharge and relatively less susceptible to well removal. Three different scenarios were simulated to observe the aquifer's response by considering both increased and decreased parameters of 25 %, 50 % and 75 % (recharge, hydraulic conductivity and pumping). Significant information for potential transient model creation and data gaps was generated by the scenario and sensitivity analysis. This model has been used to build a comprehensive groundwater predictive model that can be effectively used for groundwater management practices.

Numerical Groundwater Flow Modeling of the Meki River Catchment, Central Ethiopia(Mitiku, 2011b)

The following major discussions and outcomes were summarized according to this study: The Meki river catchment aquifer is situated in the central rift valley of Ethiopia. The aquifer is one of the country's most critical groundwater reservoirs, and a total catchment of 2319 km^2 was chosen using a numerical groundwater flow model to analyze the groundwater flow mechanism (Processing Mod Flow Pro (Version 8.0.15)). Firstly, a three-dimensional steady-state finite difference groundwater flow model is used to measure the groundwater fluxes and analyze the sub-surface hydrodynamics in the Meki- river catchment. The model is then calibrated using 95 head observations of wells and the simulation is performed under feasible boundary conditions in a one-layer unconfined aquifer with spatially variable recharge and hydraulic conductivity. The calibrated model is therefore used to forecast groundwater flow patterns, the relationship of groundwater and surface water, and to test the activity of the groundwater system under potential future usage scenarios. According to a sensitivity study carried out, the model is more susceptible to reducing recharge and growing hydraulic conductivity, yet less susceptible to increasing or decreasing pumping quantity. The groundwater flows from the western escarpment to east directions eventually enter Lake Ziway according to the result and indicate that the lakes and rivers play a significant role in the aquifer's recharge. In addition, the simulations carried out under various potential future usage scenarios, including a rise in pumping intensity, result in a substantial decrease in regional groundwater level, which will lead to spring drying and shallow hand dug wells. Sensitivity and scenario analysis offered valuable information on the data gaps and the particular monitoring sites to be chosen, which could be of great help to the development of the transient model.

Numerical ground water flow modelling of the central man Ethiopia rift lakes basin by (Tenalem Ayenew,2001)

According to this report, the following major discussions and results were summarized as follows: A three-dimensional steady-state finite difference numerical groundwater flow model (mod flow) was used to analyze the groundwater-surface water interactions in the Central Main Ethiopian Rift Lakes Basin. Special importance is given to the quantification of the groundwater fluxes and the subsurface hydraulic relationship of the rift valley lakes. The result implies that, given the geographical proximity of the reservoirs, the groundwater flux is highly variable, largely due to geological factors. The net groundwater flux for Lake Abiyata ranges from 7,011 m 3 / day to 651,022 m 3 / day for Lake Shala. From all sides of the basin to the center of the rift where the lakes are clustered, the flow of groundwater converges, and eventually to the terminal of Lake Shala. Local, intermediate and regional flow systems have been identified. The location and magnitude of the faults have a direct effect on the occurrence and motion of the groundwater. The main flow systems and groundwater flux into the lakes are strongly influenced by Rift faults.

The Ziway–Shala lake basin system, Main Ethiopian Rift: Influence of volcanism, tectonics, and climatic forcing on basin formation and sedimentation(Le et al., 1999)

According to this report, the following major discussions and outcomes were summarized as follows: The Ziway-Shala Lake basin system comprises four existing residual lakes in the central sector of the Main Ethiopian Rift, lakes Ziway, Langano, Abijata, and Shala from north to south. This region of East Africa is under the influence of seasonal migration through the Intertropical Convergence Zone. The ERICA Project ('Environmental Research for Intertropical Climate in Africa') has thus been designated as a potential core site. The four lakes were subject to strong changes in water level and water salinity during the Late Pleistocene at least. The purpose of this study is to establish a model of basin formation and sediment deposition for this system of lakes in order to differentiate the effects of climate change from environmental variability induced by local or regional variables such as volcano-tectonic forcing. In addition to an exhaustive synthesis of available data, numerous studies have been used to construct this model: 3D remote sensing, seismic, coring, and high resolution structural, sedimentological, and hydrological field studies. New radiocarbon dating from AMS helped refine the pre-existing stratigraphic framework for this region, and mean rates of sediment deposition were used to calculate estimates of basin age. The history of the Ziway-Shala Lake basin system has been reconstructed from the Late Pliocene-Early Pleistocene era (10^6 yr.), mainly characterized by devastating explosive volcanic eruptions. The Early-Middle Pleistocene-Late Pleistocene Period (10^4-10^6 years) was characterized by a regional volcano-tectonic paroxysm, resulting in major changes in the morphology of the area, with the formation of the Abijata, Ziway and Shala Lake basins. The eastward movement of volcano-tectonic activity, leading to the formation of the Langano Basin, the youngest basin of the Ziway-Shala system, characterizes the development of the Ziway-Shala basin from 0.20 Ma. During the early-Late Pleistocene period (10^1-10^4 years), the joint history of sedimentation in the lake basins of Ziway, Langano, Abijata, and Shala started and is characterized by a series of climatically influenced lake level rises and falls from this period to the present day.

Stream flow sensitivity to land cover and climate changes: Meki River, Ethiopia(Legesse et al., 2020)

According to this report, hydrological modeling has been used to determine the effects of climate and land cover changes on stream flow. Firstly, the precipitation runoff modeling framework of the US Geo- Logical Survey was analyzed in order to consider wetlands as a separate hydrological response unit. From(1981-1986) (1986-1991) and (1996-2002) for calibration and validation cycles. After that, model output was assessed by using joint plots of daily and monthly observed and simulated runoff hydrographs and various efficiency coefficients. Therefore, the model coefficients for the calibration cycle were 0.71 and for validation periods 1 and 2, 0.69 and 0.66, respectively. In addition, to formulate climatic scenarios, a "delta-change" approach was used. That means, one land cover shift scenario was also used to determine the possible effects of these changes on the runoff. After that, the results of the scenario analysis show that the basin is more prone to rainfall increase (+80 % for +20%) than to a decrease (-62 % for −20 %) and the elasticity of rainfall is 4:1 for a 20 % rainfall increase whereas it is 3:1 for a 20 % decrease. In addition, the proposed land cover scenario of converting areas from 2000 to 3000m a.m.s.l. to forest also resulted in a substantial decrease of up to 11.8% in stream flow. Finally, the study shows that adequately tuned and validated models will help to explain the possible impacts on the catchment water balance of climate and land cover changes.

The Impact of Existing and Proposed Irrigation scheme on Hydrology of lake Ziway(Fekadu, 2016)

According to this report, the following major discussions and outcomes were summarized as follows: Lake Ziway is situated near the town of Ziway at the northern end of the southern Rift Valley, some 150 km south of Addis Ababa, in the Oromia Regional State. The lake occupies an area of some 450 km2 at its mean surface level of 1,636.12 m and has a maximum depth of 8 m. The two principal rivers flowing to the lake are the Meki and Katar rivers, and there is the Bulbula river as an outflow from the lake. In addition to its importance, the lake is a critical water resource in the study area; due to the rapid shift in the lake water balance inputs and output components, the lake level has changed dramatically over the past decades. Ethiopia's national government has developed regional irrigation development policies and strategies to mitigate current development constraints, which require further attention from the Ziway-Meki pressurized irrigation development project aimed at irrigating a gross area of 15500 hectares (net 14657.2 ha) of land. This study is carried out to determine the water balance of Ziway lake on the basis of the available components of the water balance and by considering the existing and planned irrigation scheme of the Ziway-Meki irrigation project by designing various scenarios. And also, to reflect the distinct stage of irrigation creation and variance in the river flow patterns that flow to and from the Ziway Lake and the rainfall pattern within the Ziway Lake basin. The water balance was developed on the basis of the excellent spreadsheet that regulates both the inflow (from rivers and runoff alongside the lake shore) and outflow patterns from the lake (irrigation and water supply need and Bulbula river). The water balance was basically seen through the lake water level through the implementation of the current abstraction and suggested irrigation scheme of 14657.2 ha of land. From the outcome of the water balance model, the lake reduces its level from the maximum level (1638m) by 0.568m from September to August, of which 0.33m is due to the new irrigation scheme and 0.238 m is due to the difference in inflow rivers. The real abstraction and total irrigation area of 14657.2 ha reduces the Bulbula outflow from the model result by 20 m^3/s, of which the proposed scheme is responsible for 17.51 m^3/s. Finally, such an annual variation would result in a drastic decrease in the amount of lake water and the flow of the Bulbula river in the coming years.

Gap and Opportunity Analysis of Hydrological Monitoring in the Ziway-Shala Sub-basin, Ethiopia(Donauer et al., 2020)

This paper provides an overview of the current situation of hydrological monitoring in the Ziway-Shala sub-basin in the Central Rift Valley of Ethiopia, including details of existing river and lake gauging sub-basin stations. The purpose of the analysis was to analyze the collection of hydrological data by the Rift Valley Lakes Basin (RVLBDO) Development Office and obtain a systematic understanding of the quality and availability of data. Interviews with stakeholders showed that insufficient budget allocation and dedication to hydrological regulation contributed to major gaps in the data collection process. Damaged gauging stations, outdated rating curves for most stations and the lack of capacity to digitize the data at the basin office are the main problems in the current data collection process. The physical condition assessment of 13 gauging stations showed that most stations are not well maintained, with staff gauges sometimes damaged by floods or vandalism at some places, such as at Meki station in Meki Village. Interviews were held with local observers who are responsible for documenting water level data at the gauging stations. While their salaries are poor, observers are typically inspired and all have undergone adequate training to perform their duties. However, some analysts have indicated that they can reveal inaccurate data without being known because of the lack of transparency and cross-checking of the data collected. The Hawassa main basin hydrological technician stated that the frequency of velocity calculation has decreased, indicating that for several years the rating curves have not been modified to convert water level to discharge data. Water level data is currently only available in written form at the RVLBDO in Hawassa, and there is a complete lack of transparency and data digitization encouragement. Recommendations for enhancing the physical condition of the measurement sites; (ii) transferring water data immediately from the printed copy to the electronic copy and then to the discharge data, and (ii) transferring water data immediately from the printed copy to the electronic copy and then to the discharge data. (iii) improving the accuracy and exchange of data have been put forward in this paper. Opportunities are also provided for novel, non-traditional hydrological monitoring, with its applicability and gain to complement traditional data collection from the Ziway-Shala sub-basin. Remote sensing technology can be easily used to fill existing data gaps (e.g., Data on precipitation), but involves calibration and validation of ground data. Community-based surveillance programs (e.g., using the approach to citizen science) have the capacity to complement traditional data collection. In order to fill the gaps, research and development work would also help generate additional hydrological data. However, if external organizations are involved in data collecting, this needs to be well incorporated with the RVLBDO. The uncoordinated behavior of various initiatives, as well as political and institutional instability, could undermine the current monitoring structure.

Effects of Irrigation Practices and Lacustrine Aquifer Development on Water Availability in Ziway-Abijata Corridor by Tibebu Terefe (Submitted, 2007)

The current area of research is located on the floor of the Ethiopian Rift Main, where the interconnected surface water bodies are located in a fine balance state. The main objective of the analysis is to determine the use of water and its effects on the area's water supplies. Upstream water supply abstraction would have a significant effect on the downstream water bodies. This is obvious in the River Bulbula flow regime. Interconnectivity is not limited to bodies of surface water, but there is also a strong interplay between bodies of surface water and subsurface water. In this research work, therefore, it became apparent that the abstraction from the subsurface has an impact on the total resources of water. Interpretation of hydrological data from stream flow and lake level measurements clearly showed the pattern and status of the Ziway-Abijata Corridor water supply is at risk. In the case of Lake Abijata being closed downstream, the danger is extreme. As no quantitative data on groundwater patterns and status are available, qualitatively speaking, the groundwater resource base is also at risk in the Main Ethiopian Rift in general and in the Rift Floor in particular. The condition is justified by the conjunctive existence of the surface and subsurface water supplies in the region.

Assessment of Water Balance of Lake Ziway and Its Temporal Variation Due to Water Abstraction(Eresso, 2010)

The general idea of this thesis is summarized as follows, locally called "Hara Danbal," Lake Ziway is a naturally occurring exoreic reservoir situated in Ethiopia's Central Rift Valley with an average water surface area of 440 km2, an average depth of 2.5 m and a total drainage area of 7488 km2 and located at 1636 m.a.s.l. The rivers of Katar and Meki are two main seasonal rivers drained into the lake and the river Bulbula spills out of the lake. The lake is currently used for irrigation, domestic water sources, fishing, transport and recreation. New construction activities around the lake and uncontrolled water diversion from the lake have undoubtedly disturbed the hydrological equilibrium of the lake. The aim of this research was to analyze the water balance components. This procedure was carried out by applying the continuity equation of the Water Balance Model. Inflow components (direct rainfall, rivers of Katar and Meki and runoff from un-gauged watershed regions) and outflow components were used to determine Lake Zipway's monthly water budget (evaporation, Bulbula river and water abstraction from the lake) Using a simple arithmetic mean method, average rainfall over lake surface was calculated and evaporation from the lake was evaluated by Penman method from agricultural land, though CropWat was estimated. Data from the Ministry of Water Resources, Department of Hydrology and inflow were collected from measured inflow from un-gauged parts of the watershed, data from outflow from the Bulbula river and the lake level were computed using the method of area ratio. Water abstraction from the lake was determined on the basis of irrigated land and average seasonal crop water requirements. Using the values of the sections of each water budget, the model was then developed. The mean annual inflow to the lake was approximately 1096.83Mm^3 and 1114.30 Mm^3 was that of the outflow. Around 74.04 % of total annual inflows were absorbed by evaporation, while about 11.72 %of it was consumed by annual water abstraction (inflows). It was estimated that the outflow from the lake to the River Bulbula was about 15.84 % of the total annual water expenditure inflow components of the lake. In the annual inflow components of the lake water budget, there was a decreased trend, while outflow components (evaporation and abstraction) showed a rising trend. But not only was the effect of drought a recent decrease in lake level, but over medium to low rainfall years, water diversion played a major role in temporal variation in lake level. For the near future transformation from this lake to an endorheic lake, the decrease in the outflow of the Bulbula River from this lake and the increase in the annual evaporation rate from the surface of the lake water would probably be responsible. For its possible sustainability, a solution to mitigate the magnitude of the outflow components (rate of evaporation and overuse of water from this lake) is therefore recommended.

Groundwater–surface water interaction in the case of lake Ziway catchment. By Selam legesse (march 2016)

The general concept of this study is summarized as follows: Lake Ziway catchment is situated in the northern part of the Central Main Rift Valley of Ethiopia, bounded by A wash Basin in the west and north; and Wabishebele catchment in the east. The major rivers draining west and east of the catchment are Meki and Katar, respectively, and both feed Lake Ziway before departure to the Bulbula River in the southwest. The average annual precipitation, potential evapotranspiration and actual evapotranspiration of 887mm, 1284mm and 856mm respectively are based on data collected from the National Meteorological Service Agency region. Using the soil moisture budgeting process, the direct groundwater recharge of the catchment was calculated. Using the groundwater table contour process, groundwater and surface water interaction in the region was analyzed. The study outcome indicates that Meki River is losing reaches in the volcano lacustrine deposit of the rift floor and Katar River in the Upper and Central Wonji Fault Belt. The rivers and streams are gaining reach in the rest of the catchment areas. In identifying the reaches that are continually recharged by the groundwater, this fact is significant. Since their capacity is continually being recharged, these reaches are favorable for abstraction. On the other hand, this knowledge allows one to prevent over abstraction for the loosening reaches.

Assessing the Impact of Existing and Future Water Demand on Economic and Environmental Aspects (Rift Valley Lake Basin Case Study: Meki-Ziway Sub Basin), Ethiopia.(Resour et al., 2016)

The general concept of this study is summarized as follows: There is an increased and widespread usage of water resources in the construction of water supply projects, which contributes to the exploitation of existing structures and the ecosystem of the natural world. The Water Evaluation and Planning (WEAP) model is used to determine water demand by taking into account the current development situation and future development of water supply with scenario analysis in the study area (Ziway Meki Sub Basin, Ethiopia). To simulate water, use at demand sites, three distinct development scenarios were developed. The catchment was divided into 5 major sub-catchments in the simulations, where the nodes of supply and demand were spatially located.

The competing water sectors were irrigation production, domestic users, the soda ash industry and environmental flow requirements. Hydro meteorological data, net evaporation from Lake Reservoir, and monthly demand for water from the consumer sectors were the basic inputs to the model. The results of the reference scenario were verified using observed flows. The results of the simulation have therefore shown that the overall average annual inflow volume to the study area decreases significantly in comparison scenarios and that water availability is reduced in January (17 Mm^3) and December (17 Mm^3) respectively (171 Mm^3), though availability is successful in the other months and 100 percent coverage is available to all users. Others gain full coverage, with the exception of Langano irrigation sites, which have an average coverage of between 33.33% to 86.5% during the month of Feb to May (2.57 Mm^3) and 95.2 % in April in Bulbula. The minimum reliability has mostly been observed in the current and probable future development scenarios at Bulbula irrigation demand sites, which have 92.11% and 66.67% reliability at Langano irrigation demand sites in all development scenarios. On the other hand, in the expansion of Sher-Ethiopia, 51.75%reliability is observed in ongoing and probable future development scenarios and 51.75% is observed in likely future development scenarios in the Katar irrigation diversion demand site and Meki dam irrigation.

Application of geophysical method for delineating shallow and deep ground water flow system along Ziway-Butajira and Meki-Midrekebd traverses, central mer, and show their implication for fluoride concentration by Mandefro Ararso(Sciences, 2017)

This study's general concept is summarized as follows: An integrated geophysical survey using Vertical Electrical Sounding (VES) and Audio Magneto Telluric (AMT) method was conducted to distinguish shallow and deep ground water flow systems and the role geological structure play in the movement of these waters from Rift Floor to Western Escarpment sectors, specifically through geophysical work along the Ziway-Butajira and Meki-MidreKebd traverses. These methods were chosen to map the shallow to intermediate depth (VES) and deeper horizons (AMT) in the subsurface for their resolution and ability. In the Central Main Ethiopian Rift between Oromia and Southern Nations, Nationalities and Peoples Regional State in Ethiopia, the Ziway-Butajira and Meki- Midrekebd areas are situated geographically. The regions are also located on volcanic and lacustrine deposit terrain.

Twenty-three (23) VES points using the Schlumberger array of maximum half-current electrodes AB/2 = 750 m and twenty-seven (27) 2DAMT measuring points were included in the geophysical survey. In order to infer the subsurface geoelectric stratification of the region and therefore the geology as well as the main geological structures over the transects, these data were interpreted both qualitatively and quantitatively. Details on the presence of groundwater bearing horizons, including their position and depth, in the subsurface could also be extracted.

The qualitative analysis of VES data was performed using apparent pseudo depth resistivity sections built in a close collinear direction for VES points, while the qualitative interpretation of 2D AMT data was also performed using geoelectric sections of 2D MT.

The individual VES data were interpreted for quantitative interpretation using the modeling software ResixIP and Win Resist to obtain the layer parameters beneath each VES and to create the geoelectrical sections along selected survey lines. During modeling, the VES interpretation was limited by lithological logs from two nearby boreholes. In the 2D MT modeling carried out on four survey lines, the data from VES data and the borehole were also used to restrict the depth details.

Impact of water abstraction on the water level of lake Ziway, Ethiopia(Goshime, 2019)

The following major discussions and outcomes were summarized according to this study as follows: Significant changes in the water level of Lake Ziway in Ethiopia have been observed, hampering its services to a wide range of ecosystems. The contribution of water withdrawal and its effects on the difference in the lake water level has not yet been quantified, however. We performed a water abstraction survey (WAS) in this study to estimate real water withdrawal from the lake. We then applied a model of water balance coupling with simulated river inflow from rainfall-runoff model output data to determine the isolated effect of water withdrawal from 1986-2000 at monthly time stages on the lake water level. For irrigation water use, the quantity of water drained from the lake is 37×10^6 m^3 per year. This resulted in a reduction in the lake level of 0.36 m, which corresponded to a decrease in the lake surface area of 18 km^2. This resulted in a decline in the mean annual lake volume from 1986 to 2000 by 162×10^6 m^3, which accounts for 23% of the overall lake inflow from rivers. The findings show that abstraction from the lake is a major contributor to Lake Ziway's drop in water level. This calls for serious measures to control the absorption of water from the lake.

Impact of Land Use Land Cover Dynamics on Water Balance, Lake Ziway Watershed, Ethiopia(Abraham & Nadew, 2018)

According to this report, the following major discussions and findings were summarized as follows: Quantification of Land Use Land Cover (LULC) change effects on river basin hydrology would enable local government and policy makers to devise and enforce efficient and adequate strategies to mitigate the impact of potential change in LULC. In this analysis, In the Rift Valley of Ethiopia, LULC changes in the water balance of the Katar and Meki River Basins were investigated using the Soil and Water Assessment System (SWAT) with Sequential Uncertainty Fitting Intervals (SUFI-2). The LULC map of 1996 and 2014 was used for the shift analysis and the findings showed that reducing forests and expanding agriculture and built-up areas had an effect on the spatial distribution of surface water and the water balance components. During the land use transition period, the increase in annual surface runoff from 67.54 mm to 129.14 mm resulted from the Katar river basin and 40.64 mm to 59.56 mm resulted from the Meki river basin. This result has shown that the above-described changes in land use are the main contributors to the surface runoff increase in both river basins. Dramatic shifts have resulted in an increase in the depth of runoff from the Forested region on both river basins in this respect. In the Katar river basin, for example, a runoff depth increases of 4-53 mm to 10-65 mm and a range of 2-34 mm to 23-60 mm in the Meki river basin resulted primarily from forested areas. As a result, the LULC transformation is becoming a serious threat to the river basins of the Katar and Meki rivers, so the regional development plan should take appropriate measures to stabilize the shift in land cover. Furthermore, in planning the best policies and priorities for land management in the region, the results of this study serve as valuable information for policymakers.

Trends and Variability of Precipitation: Implications for Water Resources in Lake Ziway Watershed, Central Ethiopian Rift(Ayenew et al., 2020)

The following key discussions and findings were summarized according to this study as follows: Precipitation is the major climate variable that governs the availability of water supplies in the country, Ethiopia, but on a spatial-temporal scale it is highly errant and variable. The purpose of this paper was to examine patterns and rainfall variability in the Ziway Lake Watershed during seasonal to annual sales. The non-parametric estimate of Mann-Kendall (MK) and Sen's Slope (SS) was used to identify patterns and measure slope magnitudes, respectively. To show the differences in rainfall, the Variation Coefficient (CV) was used. The mapping of spatial interpolations was performed using IDWW (Inverse Distance Weighting). The findings showed that more rainfall variability had been experienced in the western Ziway Lake watershed than in the eastern Ziway Lake watershed. The findings also showed that no clear signs of a monotonic pattern were shown in the annual and summer rainfall. On the other hand, almost all rainfall stations revealed decreasing trends in the spring season (important and non-significant), for example, three stations (Ogalcho, Butajira, and Koshe) showed significantly decreasing trends at 5 percent of the significant level and the two stations (Kulumsa and Meki) show significantly decreasing trends at a significant level of 10%. In addition, the slope magnitudes (changes in mm/year) calculated by the SS for spring season stations showing significantly decreasing trends were as follows: -8,702, -6,58, -4,018 and -3,681,-3,667 respectively for Butajira, Koshe, Kulumsa, Ogalcho and Meki. Droughts can be expected to grow if the pattern of declining precipitation continues. This might lead to water supplies being over-exploited. The similarity in intra-annual variability patterns of precipitation and river discharges suggest that any changes in the pattern of rainfall will have an effect on the supply of water. The results of this research will greatly contribute to directing water managers and decision-makers to prepare and manage water supplies more effectively.

Impact of pumping for irrigation on groundwater potential: case of eastern part of Guraghe zone (Of et al., 2015)

To assess the impact of groundwater abstraction in its availability and nearby rivers this study was made a 3D conceptual groundwater model which consists of the catchment divide in the west (Guraghe High Mountain) and two adjacent rivers (Weja and Meki rivers) to fix the boundary condition the catchment divide is taken as a hydraulic –Neumann-boundary and the two adjoin rivers are taken as Dirichlet- boundary. Then, the bottom and groundwater surface are between these boundaries is taken as a flux-boundary. This means, the top ground takes recharge while the bottom is taken as a no-flow boundary. The four different geologic structure found are consider as different hydro geologic settings where by hydraulic conductivity is assigned as a trial value, to make sure that the hydraulic heads collected in 94 hand dug wells in the study area are estimated reasonably. After that, the conceptual model is used as an input of TAGSAC software whereby the model area is decertified in to 22301 nodes and 21710 triangular prism elements of 200mx200mx200m all the 94 inventoried wells were represented by nodes. Thiessen polygon based on rainfall distribution is also used as an input but with a reduced rate to represent the effective recharge. The four different geologic setting were also represented by the finite elements generated, so that different hydraulic conductivity is given to each of the four geologic settings. Then, the model is calibrated with, 8.74m, 7.45m, and 0.83 RMSE, ME and R^2 values respectively. After that, the impact of pumping is analyzed by assigning the current groundwater abstraction rate of 21,186,913m^3/year to the nodes representing the impact zone. Finally, the result clearly shows that the region of influence reaches the existing perennial river. Thus, the current trend of pumping will result in drying up of these rivers. Therefore, to come up with optimum pumping rate trial values were given to the model area representing the pumping site and an optimum pumping rate of 16,666,214m^3/year would minimize the impact of pumping on the adjacent rivers. But this study did not identify the impact of pumping on the catchment as a whole. Therefore, additional analysis is required to give general justification.

other basic studies were made by Tenalem Ayenew (1998) in his PhD. thesis assess general hydrology and hydrogeology of Ziway–Shalla basin and the study includes evaluation of groundwater and surface water interaction, water balance and recharge estimation of sub-catchments and numerical groundwater flow modeling of the central main Ethiopian rift lake basin investigations were made by (Tenalem Ayenew,2001),in addition, Tenalem Ayenew (2003) also done evapotranspiration estimation using thematic map per spectral satellite data in the Ethiopian rift and adjacent highlands and Alemu Dribssa (2006) in his MSC Thesis study groundwater–surface water interaction and analysis of recent changes in hydrologic environment of Lake Ziway catchment. According to the Rift valley lakes integrated natural resource development master plan, groundwater and surface water potential of the area was analyzed with detail assessment (HALCROW, 1989).finally, In all studies conducted so far, more work is done on hydrology, hydrogeology, climate, and land use of the basin as well as, 3D groundwater model in Meki-river catchment is done by (Mitiku, 2011b) and the numerical groundwater flow modeling of the central main Ethiopian rift lake basin which is done by Tenalem Ayenew, 2001).but, until know there was no studies conducted on the combined effect of surface water -ground water interaction assessment in the Meki-river catchment.

SOCIO-ECONOMIC BENEFIT OF WETLAND ECOSYSTEM (IN CASE OF LAKE ZIWAY)(Environment & Ababa, 2016)

The socio-economic benefits of the Lake Ziway ecosystem's western shoreline was the subject of this report. Data collected from two woredas, Adami Tulu Jidu Kombolch (ATJK) and Dugda woreda, were from fishermen and small-scale irrigation users. Lake Ziway has significant significance for food and water for both groups of respondents and additional sources of raw materials, energy, irrigation, organic fertilizers, genetic and medicinal plants. Lake Ziway also has a major economic benefit for both classes of respondents. An average quantity of 2,524 Kg per year was recorded by the sampled fishermen with a minimum and maximum quantity of 504 Kg and 16,800 Kg per year respectively and an average annual revenue of 51,398 Birr ($2,570) with a range of 7,200 Birr ($360) and 288,000 Birr ($14,400) per year with that catch. The production of cereal crops, fruits and vegetables, like small-scale irrigation by fishermen, has also received economic benefits. With an average revenue of 7,727 Birr ($386) and an annual range of 13,714 Birr ($686), they produce an average of 13.47Quintal of cereal crops and 69.56Quintal of fruits and vegetables per year. This has resulted in a great deal of socioeconomic benefit to the wetland ecosystem for people living nearby, particularly for developing countries such as Ethiopia, which are more dependent on natural ecosystems such as Lake Ziway. Lake Ziway and associated wetland areas have to be preserved and managed and used sustainably because of its high importance.

Current Ecological Scenario of some Rift Valley Lakes of Ethiopia:(Lemma, 2016)

According to this report, the following key discussions and results were summarized as follows: Lake Ziway and Abiyata are located in the region of the Central Ethiopian Rift Valley and form a complex and fragile hydrological system with specific ecological characteristics and biodiversity.

Precipitation and river inflow are the most significant components of the lakes' water supplies, and the lakes are used for large-scale smallholder agriculture, domestic water use, fisheries, industrial water use and related eco-tourism. Based on these facts, due to the appropriateness of environmental conditions and other infrastructures, different organizations have settled in the region. Water use conflicts; unplanned use of land; pollution; deforestation; urbanization and population relocation for resource demand; interruption of wetlands without taking into consideration their natural environment and others are the key challenges that are widespread and need due attention. Both the lake level and its ecology have been dramatically altered by recent abstraction of water for irrigation and soda ash production. Therefore, the problems of effective management systems are urgent requirements for the creation of capital at that time.

Enset-Based land use land cover change detection and its impact on soil erosion in Meki river watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia(Woldesenbet et al., 2020)

According to this report, the following major discussions and findings were summarized as follows: In the Meki river watershed, water erosion, upland depletion and deforestation are main environmental problems. Over the past 30 years, the research evaluated the land use land cover transition (LULCC), examined the contribution of the indigenous Enset-Based Land Use System (EBLUS), which have not been studied so far in minimizing soil erosion and preventing sedimentation from Lake Ziway. Based on the findings, the study recommended effective management interventions to sustainably manage the watershed, based on priority mapping. For soil erosion modeling, GPS based Ground truth data sampling and compilation, Geo-statistical interpolation and RUSLE model were applied. The identification and analysis of the LULCC was performed using ERDAS Imagine 2014 to produce the spatial inputs. system (41.5 %), Enset-Based Land Use System (EBLUS) (10.65%), Bush and Chat Land Use System 30 (25.6%), Forest and Plantation Land Use System (14.14%), Built Up (7.4%) and Water Bodies Meki River Watershed has an area of 2110.4 km^2 dominantly covered by a cultivated land use system (0.75%).Severity class High to extreme range (18-125tha^{-1} yr^{-1}) reported in sub-watersheds regardless of land use systems and facing severe problem of degradation that increased soil loss from 1987 to 2017 in all land use systems. Average soil loss of 30.5tha^{-1} yr^{-1} and 34 31.905tha^{-1}yr^{-1} confirmed from the watersheds of the Enset growing zones and non-Enset growing zones. Despite the steepness of slopes of the Enset growing zones of the watershed, the Enset-Based Land Use Scheme (EBLUS) saves large amounts of soil. Therefore, EBLUS expansion will contribute to the maintenance of

Lake Ziway by reducing the rate of soil loss and sedimentation issue for watershed ecological sustainability. Such EBLUS extension, integrated water management and protection of the natural environment in the watershed are therefore mandatory for separate land use policy and awareness development.

2.3. Infiltration

The method by which water seeps from the soil into the subsurface is infiltration. The unsaturated area comprises the land, air, and water (which may be in the form of ice or vapor). Within the soil medium, varying amounts of air and water fill the pore space. In the unsaturated zone, quantifying flow is a far more complex process than that of the saturated zone, largely because soil properties that control penetration rates appear to change over time, such as hydraulic conductivity and soil moisture content.

Gravity and humidity are both capable of pulling water from the surface into the unsaturated area. Gravity power is proportional to the head of the lift (or hydraulic). The moisture potential is the negative pressure (or suction) exerted by the soil due to soil-water attraction. In unsaturated flow, total potential h is defined as:

$$h = \psi(\theta) + Z \text{ ………………………. } \quad (2\text{-}1)$$

were

$\psi(\theta)$ = moisture potential

Z = gravity potential

The vertical hydraulic conductivity $K(\theta_v)$ of the soil medium, and the moisture potential, regulate downward flow through the unsaturated region. As the moisture content increases, the $K(\theta_v)$ value increases. The vertical hydraulic conductivity $K(\theta_v)$ is equal to the saturated hydraulic conductivity defined by Darcy's Law at saturation and downward flow is governed by hydraulic conductivity and head of elevation. The capacity of moisture varies with the medium's moisture content and pore size. When the soil is dry, the potential for moisture is usually many orders of magnitude greater than the potential for gravity. A dry soil, due primarily to free surfaces within the pore space, will have a greater initial infiltration rate than that of a moist soil. The pores serve as capillary tubes to draw in water, and as they fill, the capillary forces decrease along with the infiltration rate.

Infiltrating moisture from rainfall events tends to move vertically downward as a wave front of saturated soil. Eventually, this wave front reaches the water table and moisture conditions in the soil profile stabilize and return to their pre-rain state. Therefore, the basic infiltration definition, principles and concepts were important to simulate SMA(soil moisture accounting) algorism and also, a frame work for conceptual ground water development.

2.4 INTERACTION BETWEEN LAKES AND GROUND WATER

A lake's hydrological regime is highly determined by the regional framework of groundwater flow in which it is situated. In determining the water budget for the lake, this relationship plays a critical role. The superiority of the annual water expenditure on surface water or groundwater may be based on a system of hydrogeologic ally classifying lakes. There are usually inflow and outflow streams in lakes dominated by surface water, while seepage lakes are dominated by groundwater. Almost always, large permanent reservoirs have areas of discharge from the local groundwater. Watershed topography and the hydrogeologic climate regulate the rates of groundwater inflow.(Hamilton, 2005)concluded that if the water table on all sides of a seepage lake is higher than the lake level, it will seep into the lake from all sides, even upstream contributed by groundwater), assuming a homogeneous flow mechanism through the lake bottom. The lake/groundwater interaction system's three-dimensional numerical analysis showed that upward seepage appears to occur along the lake margins, while in the center of the lake it tends to occur to seep out of the lake. Therefore, the interaction between GW and lake concepts on inflow and outflow was relevant to understand the interaction between the Meki-sub basin and Lake Ziway at the outlet stage, based on the above definition.

2.5 SURFACE WATER AND GROUNDWATER SYSTEM NUMERICAL SIMULATION

The benefits of using numerical modeling of surface water and groundwater processes over theoretical methods. While mathematically precise, analytical models can generally be applied only to simple one-dimensional issues due to rigid boundary conditions and simplistic assumptions. However, studying one-dimensional flow is not sufficient for certain studies. Complex systems are not appropriate for analytical solutions, particularly if the types of stresses change the system's behavior over time. Without many of the simplifying assumptions required for empirical solutions, numerical models allow the approximation of more complex equations and can be applied to more complicated problems. The mathematical explanation of transient effects on potentially complex water table configurations requires computer simulation of the interrelationships between surface water and groundwater systems. Ideally, three-dimensional variable-saturated flow should be simulated by a computer model of the surface water/ground water regime. Including: surface-water body variability, infiltration, flow in the unsaturated region, and flow in the saturated zone. In addition, completeness will be enabled by simulation of watershed runoff, surface-water flow routing, and evapotranspiration. This is still a complex work, however, and it requires simplifying assumptions, no matter how powerful the machine or sophisticated the model becomes. Therefore, in order to analyze the condition of surface water -ground water interaction numerical ground water flow modelling was chosen.

2.5.1. Modeling stream-aquifer interaction.

The most effective instruments for study of the surface-water/groundwater regime are numerical models. The relationship between groundwater and surface water is typically discussed only in the most rudimentary terms. Of primary importance is the perspective of the model. "The relationship between surface water and groundwater is often interpreted as a "black box" source/sink term in surface-water models(*Groundwater Modelling*, 2000). Conversely, surface water is sometimes described as an infinite supply of water in groundwater models, irrespective of availability. However, depending on the goals of the modeling analysis, a more accurate simulation of the effects of this interaction may be needed.

Theoretical aspects: A common simplifying assumption made to ease groundwater numerical simulation is that unsaturated flow simulation is not addressed and immediate leakage from surface water to an aquifer is presumed; i.e., no head loss occurs in the unsaturated area. In a typical case, where the thickness of the unsaturated zone between the stream and the aquifer is not high, this assumption is generally rational. A partial differential equation of the groundwater flow equation below can describe the relationship between surface water and the underlying aquifer.

$$\frac{Kx\partial^2\mathrm{h}}{\partial x^2}+\frac{Ky\partial^2\mathrm{h}}{\partial y^2}+\frac{Kz\partial^2\mathrm{h}}{\partial Z^2}-W=\frac{Ss\ \partial\mathrm{h}}{\partial t}\text{...........equation (2.1)}$$

Where W = flow rate per unit volume of water added to or taken from the groundwater system Most, but not all, contact between groundwater and surface water is lumped into the “W” term. Therefore, a 3D ground water flow equation was critical to model surface water -ground water interaction numerically.

2.5.2.Specified head and specified flux boundaries

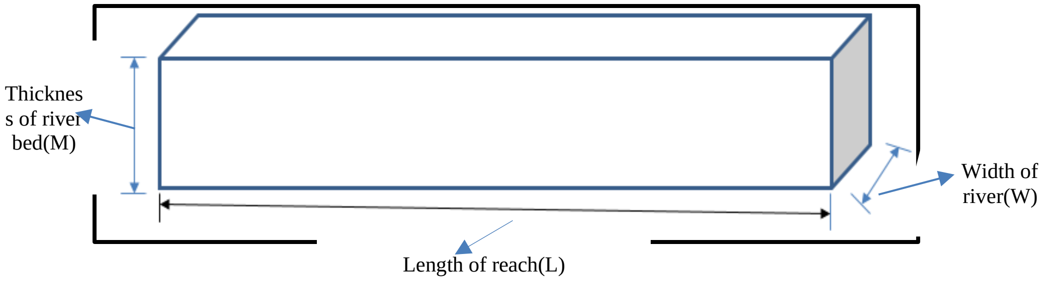
The simplest approach to stream-aquifer interaction modeling is to view surface water within the groundwater model grid as a specified (constant) head or a specified (constant) flux boundary. In the case of a given head boundary, the head is specified as the water surface elevation at the surface-water position. Using Darcy's rule, the flow rate to or from the limit is computed from heads at adjacent grid points. This type of boundary does not require a 'W' term in the partial differential equation of groundwater flow. For the case of the constant, or specified flux boundary, the flow rate is specified in the model grid as a “known” value of recharge or discharge, and the model computes the corresponding head value through the application of Darcy's law. This form of boundary includes the "W" term in the partial differential equation of groundwater flow. A major drawback of defined head and flux stream boundary representations is that they do not allow or account for the elevation of the stream bed bottom for lower hydraulic conductivity across the seepage interface. Thus, as the water level drops below the streambed, leakage from the river begins to increase.

2.5.3. Head-dependent flux boundary

A second approach is to represent the stream as a head dependent flux boundary. A head-dependent flux boundary is a common type of value-dependent boundary. The flow measured at the stream-aquifer interface is calculated as a function of the relative water level for each stress cycle in this form of boundary state. In the "W" term of the partial differential equation of groundwater flow, this functional relationship is both included and is usually derived from the law of Darcy. Therefore, in the "W" term, and in the space derivatives, the value of the groundwater head exists, which can add complexity to the solution.(a) Most groundwater flow models have one or more functions built in to deal with this functional relationship. This can be expressed as: for stream-aquifer relationships:

$Q=C_{RIV}(H_{RIV} - H_{GW})$…….equation (2.2).Where , flow between the stream and the aquifer, *CRIV* = streambed conductance, *Hriv* = river stage and H_{GW} = groundwater elevation.

The term stream conductance reflects the hydraulic conductivity product K and the cross-sectional flow area LW, separated by the flow path length M*:*



Stream bed conductance(C_{RIV})=KLW/M

figure 2.2 determination of stream conductance

CRIV = KLW/M ……...equation (2.3). If accurate field measurements of stream infiltration are available, effective conductance can be measured using them. Otherwise, during model calibration, a conductance value must be chosen more or less arbitrarily and modified. Usually, values for the cross-sectional area of flow can be used to direct the initial conductance option. In general, however, it should be recognized that it is inherently an analytical exercise to formulate a single conductance term to account for three-dimensional flow processes, and that adjustment during calibration is almost always required(McDonald & Harbaugh, 1984).

(b) A significant assumption common in head-dependent stream-aquifer relationship flux limits are that the head difference between the stream and the aquifer is never greater than the sum of the depth of the stream and the thickness of the stream. In other terms, when the groundwater elevation falls below the stream bed, the value of leakage to groundwater does not increase, and groundwater recharge is instantaneous. The value of stream bottom elevation is thus also included in the method of computation.

2.6 HYDROLOGIC MODEL SELECTION CRITERIA

There are a number of parameters for selecting the best hydrological model that can be used. Since each project has its own unique specifications and needs, these standards are often project based. In addition, certain user-specific parameters are also dependent, such as personal preference for graphical user interface, computer operating system, management and structure of input/output, or extensibility added by users. There are four key universal, fundamental criteria among the different project-dependent selection criteria that must always be considered (Cunderlik 2003).

1. Does the model predict the variables needed by the project, such as quantifying natural recharge to the aquifer and simulating streamflow for the required model outputs appropriate for the necessary purpose and therefore to be estimated by the model?

2. Is the model capable of simulating the soil moisture balance of a watershed over a long-term duration, single event or continuous processes, hydrologic processes that need to be modelled to accurately estimate the desired outputs?

3. Input data availability-Can all the inputs needed by the model be provided within the project's time and cost constraints?

4. Price: does the investment seem to be worthwhile for the project's goals?

In addition to the above parameters, the hydrological model's adaptability is also considered the type of problem I am describing. As a result, prior knowledge of model selection criteria was needed to select the SW and GW models.

2.7 MODEL CALIBRATION AND VALIDATION

Hydrological models are mathematical models with unknown coefficients, which are referred to as parameters(Lohani, 2018). The estimation of those characteristics from historical input-output records is referred to as model calibration. Model validation refers to evaluating the calibrated model's performance over the fraction of historical records that were not used in the calibration. The approaches that have been commonly utilized for model calibration include (i)manual parameter assessment using the "Trial and Error" procedure, (ii)automatic parameter assessment using the "Numerical Optimization Procedure," and (iii)a combining of I and (ii) (ii). For the model validation, various validation criteria, developed based on the observed and computed output records, are used.

2.7.1 Hydrological Processes Considered in Stream Flow Simulation Models

To simulate the time series of stream flow, various stream flow simulation models commonly consider the following hydrological processes(Lohani, 2018). (a)Land Surface Processes I Interception (ii) Infiltration (iii) Overland flow (iv)Evapotranspiration (v)Snow Accumulation and Melt. (ii) Soil moisture storage and Movement(iii) Ground water storage and flow(c)Channel Processes (i) Channel flow(ii) Flood plain storage(iii) Lakes, Reservoirs and Diversions

2.7.2 Hydrological Modelling Procedures

According to (Lohani, 2018)**In most cases, the procedures for hydrological modeling are as follows:**

- ✓ Develop a suitable model framework to simulate multiple component processes, taking into account the quantity and quality of data available as well as the nature of the problems that require modeling.
- ✓ Calibrate the developed model using the past records.
- ✓ Validate the model with past data that was not taken into account during calibration.
- ✓ Conduct a sensitivity analysis to identify the model's most sensitive parameters, which must be thoroughly investigated before the final parameter values are determined.
- ✓ Use the calibrated and validated model to solve the specific hydrological problem that the model was developed to solve.

2.8 GROUND WATER RECHARGE

Under the force of gravity or in the direction defined by hydraulic conditions, the phase of downward flow of water through the saturated zone is called ground water recharge. The groundwater recharge varies in a broad range depending on the distribution of rainfall, topography, land use and geology due to various parameters Precipitation and river channel losses are the primary recharge to the aquifer and main direct recharge is assumed to take place in all areas except where there are low permeable lacustrine soils (Tenalem et.al. 2008). The optimum capacity for groundwater originates initially as a recharge from the highland areas of the Kela-nurena mountains. The precipitation infiltrates the groundwater aquifer region on the other hand. But by infiltrating from the bottom of surface waters, some water reaches the subsurface, a condition more prevalent in arid climates than in humid climates. First in low-lying areas typically at springs or the bottom of surface water, the groundwater discharges from the flooded zone back to the ground surface. These exit points are often at a lower elevation than the water table where groundwater reaches the system as a recharge as groundwater often moves towards the lower end. In areas with wet climates and permeable soil or rock types, recovery is highest. Since in permeable materials, with little overland flow, the recharge rate can be as much as half the precipitation rate. In low-permeability materials, however, only a small fraction of the precipitation is recharged.

That means that the recharge rate can be less than 1% of the precipitation rate with large clay soils (Fitts, 2002)The downstream catchment of the study region is lowland relative to the sources of the replenishment. Therefore, in this lowland catchment, there is maximum recharge from the highlands. As a result, the northern and western parts of the study area are highly rainfall region, since the maximum recharge is in the lowland area due to this region. There is a steep slope in the highland portion of the study region, so maximum runoff is present relative to the lowland area. Therefore, ground water recharge was one basic component to analyze GW-SW interaction and their impact assessment through the MODFLOW model software processing (version 5.2.0.1), which is based on the finite-difference method, the three-dimensional groundwater flow equations that form the groundwater flow model of this study were solved. As a one-layered and steady-state condition, the groundwater flow model was set up in general, the purpose of the model was to simulate the groundwater flow of the unconfined aquifer and thus analyze the distribution of water table elevations and groundwater fluxes in order to manage the sustainability of the sub-basin groundwater system in order to create a numerical model, it is necessary to analyze the movement of water within the hydrological units that set up the groundwater system. On the basis of the U.S. The flow in the upper-Meki catchment was simulated by a modular three-dimensional finite-difference groundwater flow model geological survey.

2.9 GROUND WATER MODELLING

The main objective of the groundwater model is to assess the extent of the availability of groundwater and whether it is practicable and feasible to utilize groundwater resources for irrigation and other purposes. The following considerations usually help to describe the nature of an assessment of groundwater resources:

- Production wells place, and achievable pumping rates.
- The effect of the proposed pumping system on the level and flow of regional groundwater

The situations.

- The aquifer's long-term yield capabilities,
- The impact of the production of groundwater resources on other elements of the

Cycle hydrology,

The first phase in the assessment of groundwater resources using models will include the analysis of the available capacity under current conditions of growth and stress. Predicting the aquifer yield under various conditions is another essential aspect of groundwater resource assessment. By carrying out flow computations using numerical modeling techniques, the study and prediction of aquifer output can be achieved Numerical models are generally favored because in heterogeneous aquifers of irregular form, they are able to account for multiple-well systems. Wells and piezometers are needed to obtain information about the aquifer's hydraulic parameters and the groundwater table levels in the study area. Until defining model conditions, all details available will have to be carefully evaluated. The main work for modeling was the assembly of data relevant to the modeling work. The following were therefore, considered.

- Identify recharge areas, amount of recharge,
- Identify aquifer types and number of layers,
- Define lateral and vertical extension of aquifer layers and associated thickness,
- Define aquifer parameters, for the modeling work,
- Assemble relevant data and identify the groundwater flow direction based on inventory of
- water level elevations and results of test drilling,
- In order to define hydro stratigraphic units for the conceptual model, geological information including geological maps, cross sections and well logs are combined with information on hydro geologic properties. The functioning of the aquifer system and the interaction between various hydrogeological components are identified based on available data.
- Source of water to the system which includes: precipitation recharge, surface water recharge, underflow or discharge into the system
- Flow directions of the groundwater predicted
- Expected outflow direction
- Interaction points with bodies of surface water, or exit points.
- Number and interaction between hydro stratigraphic layers Boundary conditions and locations: the model was planned and input data such as model size, grid cell size, boundaries and parameters of the aquifer were prepared based on the conceptualization.

The UTM coordinate was used for the model design in order to link the model to the actual geographic coordinate and also make it easy for GIS and other geographical spatial data sources to access data. The groundwater model was optimized based on observed aquifer and hydraulic parameters in steady condition. As an initial input to the model, aquifer parameters such as hydraulic conductivity and transmissivity computed from field data were used. As input to the model, the computed recharge and discharge from the water balance analysis was used. Groundwater simulation using hydro geological circumstances, aquifer units, and aquifer coefficients in the target sub-basin defines the groundwater climate that comes close to the actual conditions. By forecasting groundwater variability as groundwater use rises or decreases, the groundwater model plays a role in groundwater management.

2.9.1 GOUND WATER FLOW

Groundwater is always flowing, and the direction of flow is determined by the location of higher groundwater elevation. Note, however, that groundwater does not flow downhill; rather, it flows from higher hydraulic heads (or higher water elevation) to lower hydraulic heads. The distribution of hydraulic heads in the saturated zone determines the direction in which the water will flow. The velocity with which groundwater flows, also called the flux, is determined by the difference in hydraulic head and the permeability of the sediment or rock through which it flows. Permeability is a number which describes the ease with which a fluid (like water) will move through a porous medium (i.e., a rock, soil, or sediment which has enough pore space to allow water to move through it).

2.9.2 ground water modelling approach

For better groundwater-surface water interaction and groundwater potential assessment in a given study area, groundwater modeling input data should be accurate and reliable. PMWIN MODFLOW (VERSION 5.2.0.1) is a groundwater model used in this analysis that is based on the finite-difference method. Groundwater modeling typically has two components: first the conceptual groundwater model is an idealized representation of the hydrogeological sympathy for the classification of groundwater and the future evaluation in the research area of the aquifer environment. Secondly, the mathematical groundwater model is a series of equations that model the physical processes active in the aquifer system of the study area, subject to certain assumptions. The mathematical groundwater model obviously lacks the groundwater system's comprehensive reality; the behavior of a true model approximates that of the aquifer (s). A groundwater model provides a scientific means of bringing the available data together into a numerical characterization of the groundwater system. The groundwater model also characterizes the groundwater aquifer system of the study area to a sufficient level of detail and provides a predictive scientific instrument for estimating the possible residual hydraulic head in the aquifer system of the study area. In general, groundwater modeling includes knowledge of groundwater hydraulics, hydrology, hydrogeology, geology, metrology, the link between groundwater surface water interaction and engineering skills for analysis, as well as a better definition of the study area of a groundwater aquifer system. Furthermore, groundwater modeling often involves an innovative thinker to represent a PMWIN MODFLOW groundwater model (VERSION 5.2.0.1) software for the specific study area's dynamic natural groundwater aquifer system. This groundwater model query, however, requires a thorough understanding of groundwater hydrology and groundwater hydrogeology in the study area, which is decided with their correct answers, relating to the residual hydraulic head capacity of the groundwater aquifer system for the study area. The local groundwater system involves both the rocks and groundwater in the study area during groundwater simulation, such as recharging. The following steps should be considered in order to examine and evaluate the capacity of groundwater resources in the study area:

1. The relative hydro-geological properties of the rocks in the field of research
2. Distribution and quantities in the research region of the projected annual and monthly average recharge.

The groundwater model built for the study area is complex enough to better represent the hydro-geological and groundwater; thus, a three-dimensional steady state model is chosen for the actual groundwater system. Thereafter a three-dimensional conceptual and numerical model of groundwater characterization and potential evaluation in the unconfined aquifer and flow system method for the research area is implemented for this study. Finally, a test and error approach were used during the groundwater model validation, modeling with the observed data at the boreholes. The method includes a test set of real hydraulic parameters, and the groundwater model is given a surface recharge and the result is calculated with the measured data according to its suitability.

2.9.3 Groundwater Modeling Assumption

In general, groundwater modeling includes certain assumptions for the study area that the researcher can model:

1. The law of Darcy is true, which implies that the groundwater flow in the region of analysis is believed to be laminar. Fortunately, most underground flow occurs with NR<1(laminar, NR is number of Reynolds). Thus, the rule of Darcy is valid
2. The fluid is known to be homogeneous and slightly compressible. The broken medium and the spectrum of the study region which be described by the same hydraulic properties of the equivalent porous medium.
3. The model has only one layer and has distinct hydraulic conductivity.
4. A constant head boundary is assumed by the lakes in the study area and the boreholes are a constant flux boundary.

2.10 IMPACT ASSESSMENT

The Meki River sub-basin is undergoing rapid changes as a result of a lack of understanding of GW-SW interactions, as well as intensive water development plans. Although various development projects are thought to be important for economic development, the potential negative effects on demand, supply, ecosystems and livelihoods are estimated to be significant. Established impact evaluation systems, on the other hand, seem to be woefully insufficient in certain situations, failing to capture even the severity of the impacts at various levels in Meki-Catchment. Therefore, this study examines the effects of GW-SW interactions and the changes they pose in the sub-basin. Effect evaluation in this type of continuous interaction and different hydrogeological environment, it is argued, necessitates better collaboration between assessments at various levels i.e., at kebele,wereda & Zone level. Based on the interaction assessment result, laid a foundation for A more flexible, multilevel approach to sub basin wide impact assessment that allows greater use of assessments from kebele to zone levels and builds on more participatory and interdisciplinary approaches will be beneficial.

CHAPTER THREE

3. METHODOLOGY

3.1. STUDY AREA

3.1.1 LOCATION

Western Ziway- Meki river catchment is located in the central main Ethiopian rift valley and originate in the highlands of Gurage (Nurena dega mountains) and travels a distance of about 100 Km from the highlands at altitude of 3,500 m to 1, 636 m at point draining into Lake Ziway and the name western Ziway indicate that the extent of the project area and boundary condition include lake Ziway in western part as indicated in yellow color figure 3.1 below. And also, the headwaters of the Meki River are at an altitude of about 3000 m, the river rapidly descends the rift valley escarpment to below 2,000 m.a.s.l before being joined by several major tributaries. As well as, its geographical location approximately between $7^0$51‟E and $8^0$27‟E longitude $38^0$15‟N and $38^0$51‟N latitude (UTM: 415131-489329E and 865165-935680N, zone 37, northern hemisphere) respectively. Additionally, the total area of western Ziway- Meki river catchment is about 2318. 6km^2.And the figure3.1 shows the 12 Ethiopian basins. among them, the study area is found within upper Rift valley basin which is found at the southern and Oromia part of Ethiopia.

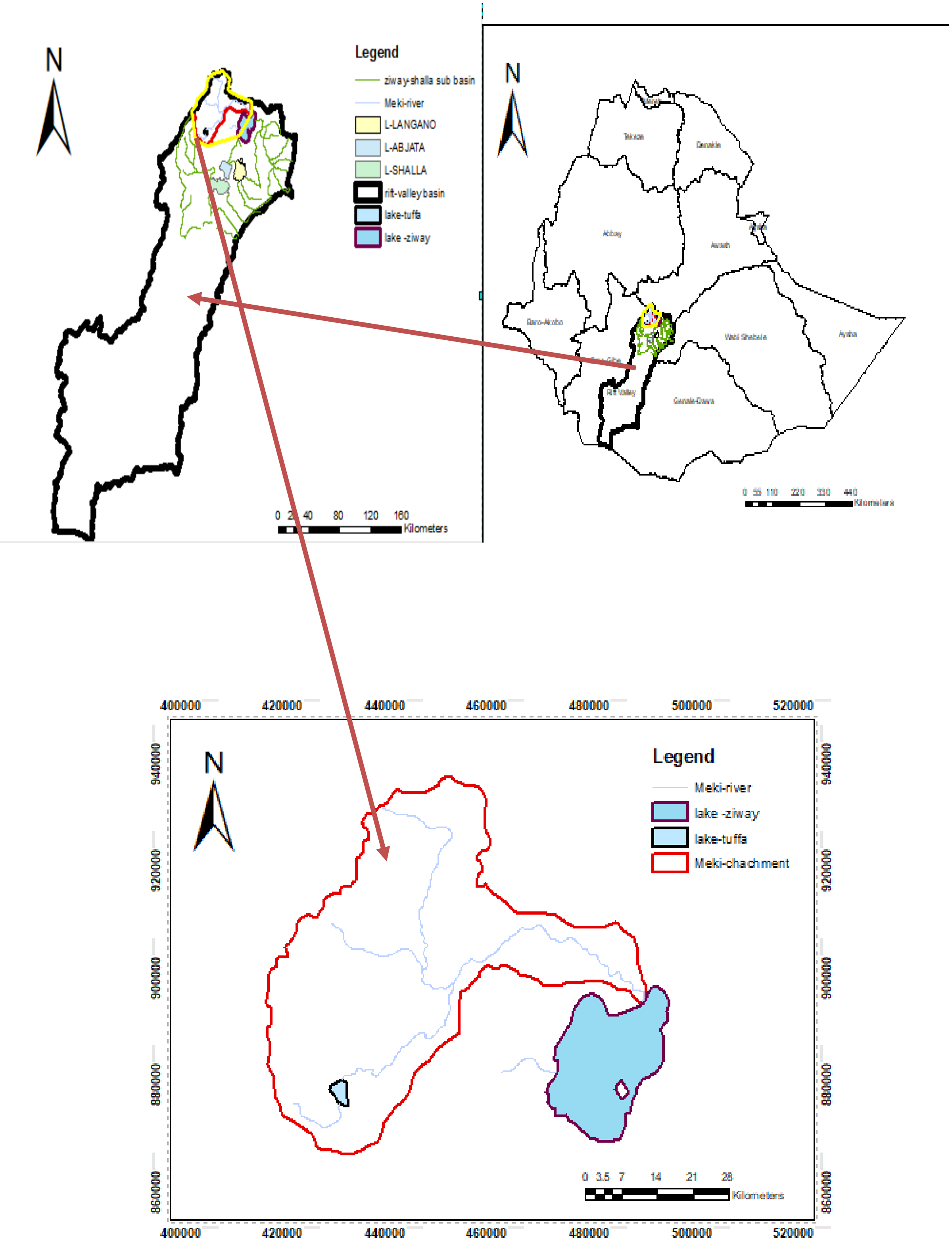
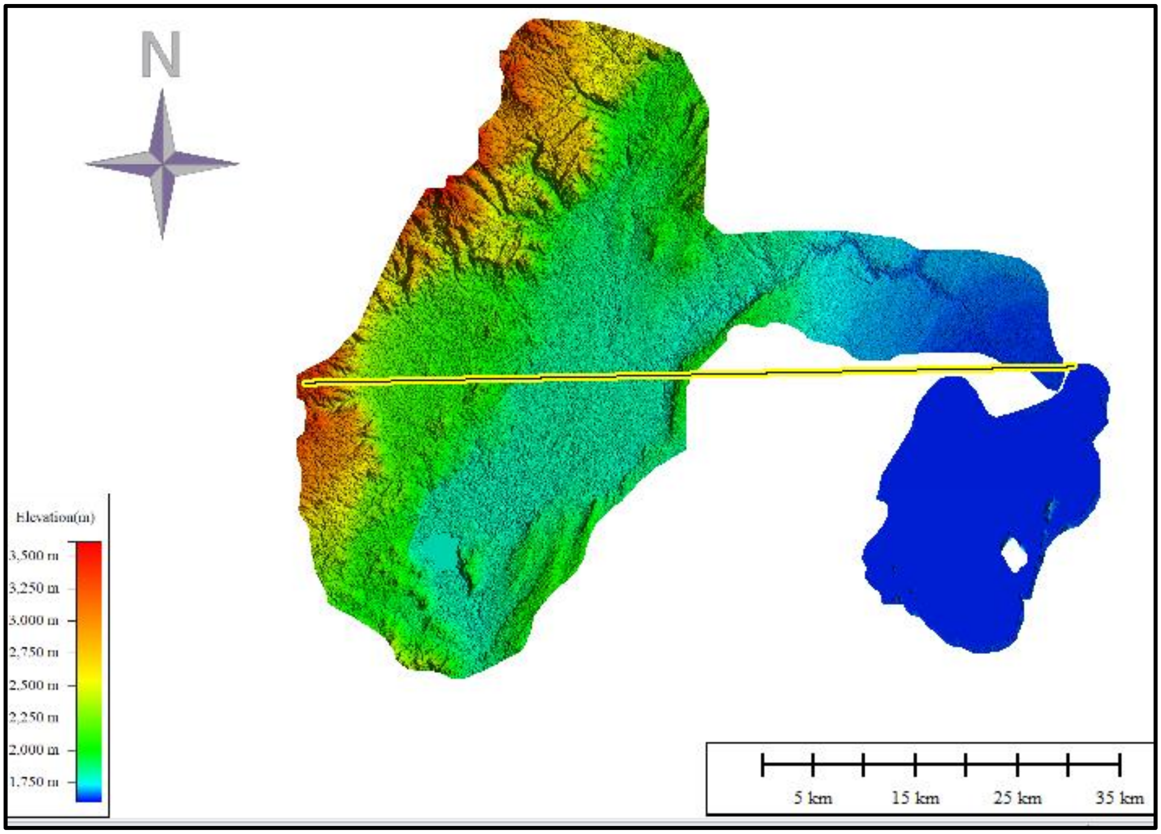


figure 3. 1 location map of western Ziway-Meki catchment within the rift valley basin

3.1.2. Topography and drainage

The study area is steep and mountainous in the western half into the highlands and while the lower basin is flat with a wide valley. The rift system of faulting determines the topography of the Meki catchment. The altitudes of this catchment range from 3554m.a.s.l. in the west to 1617m.a.s.l. in the east, with a mean elevation of 2150m.a.s.l. at Lake Ziway (Figure 3.2). The Meki river rises in the highlands and escarpments, passing through a wide swampy forest, and flows for about 100 kilometers before emptying into the Ziway Lake. This is also divided physio graphically into highland zones, transitional regions, and broader rift floors. Akamuja, Irenzaf, Weja, Kebet, Tufa, and Meki are the major rivers that drain this catchment.



— Cross section line

figure 3. 2 study area DEM

The head waters of the Upper- Meki River are at an elevation of about 3500m.a.s.l. in addition, there are some important tributaries from different directions like, Lebu, Akamuja, Irenzaf and Weja river. Whereas, the general direction of flow of the upper-River catchment is eastern wards, towards the Lake Ziway and the figure 3.3 below shows the longitudinal profile of the study area and it shows the total topographic features and arrangement used for this study.

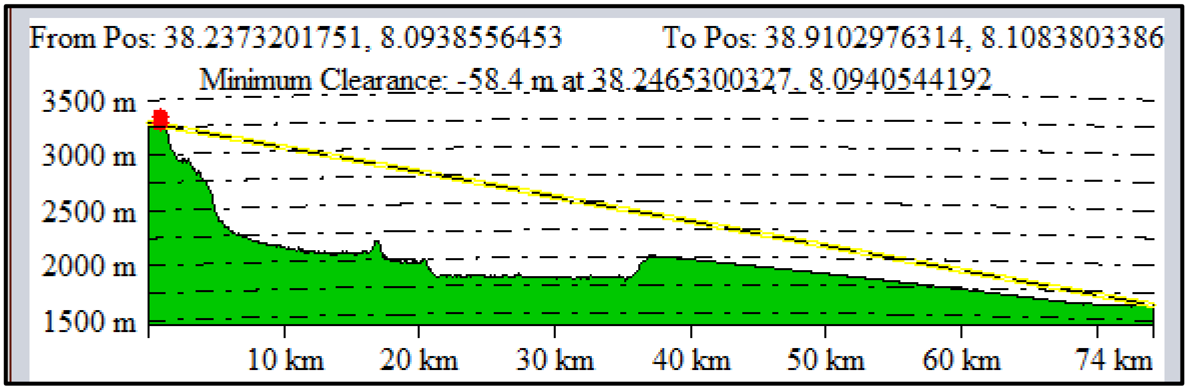


figure 3. 3 longitudinal profiles of the study area and line of sight

3.1.3 Climate

The Meki Meteorological Station is a class III station that only records rainfall data. However, a complete set of data is recorded at a class I Ziway Meteorological Station, which is located 30 kilometers south of Meki town at nearly the same altitude as Meki. The data from the Ziway Meteorological Station characterize the climate of the study area. The NMSA collected climatic records such as monthly minimum and maximum temperatures, relative humidity, sunshine duration, and wind speed observed at the Ziway Meteorological Station. The time period covered is 1998 to 2008. The average values of the climatic parameters are summarized in the table below, and the seasonal variation of the climatic parameters is plotted and presented in Figure 3.5.The area's precipitation and temperature show high altitudinal variations. The basin's average monthly temperature is 22.130°C, with temperatures ranging from 20.64°C in December and 23.79°C may. The table below depicts the average monthly temperature.

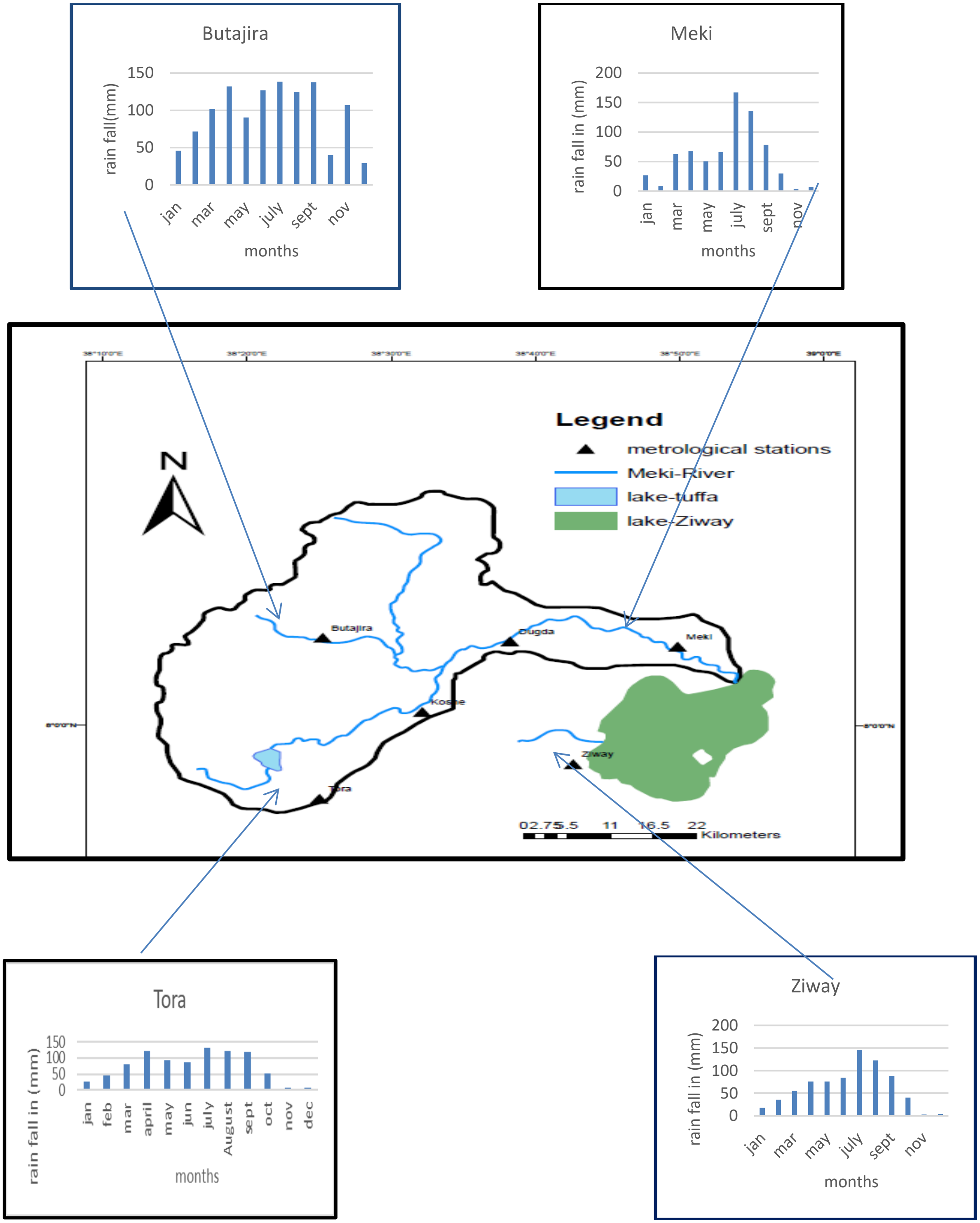


figure 3.4 the rainfall distribution patterns and meteorological stations in the study area

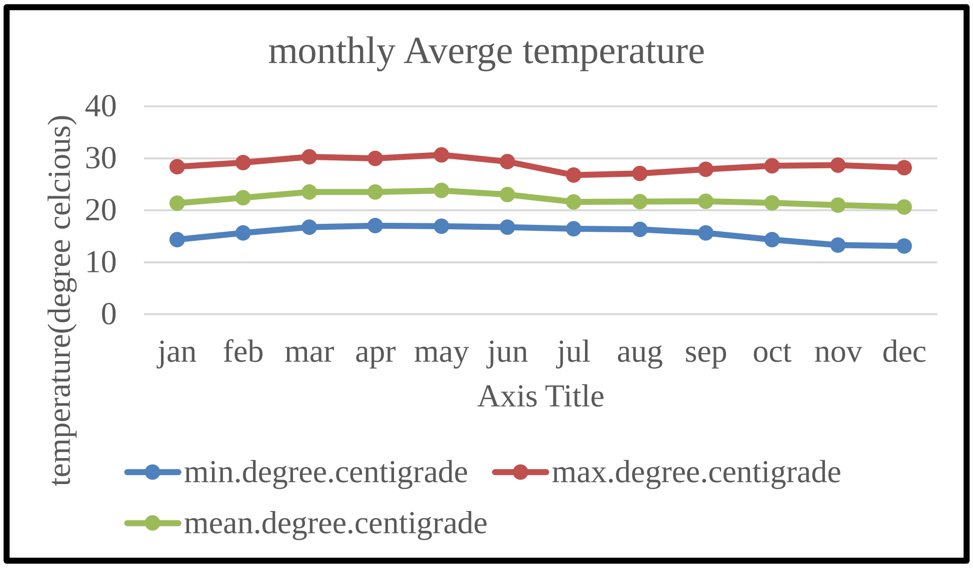


Figure 3. 5 Mean monthly temperature of the study area (1998_2008)

Table 3.1 Average climate parameters

month				relative humidity (%)	wind speed (m/s)	sunshine duration (hrs.)
	min.C^o	max.C^o	Mean C^o			
Jan	14.32	28.36	21.34	64.5	2.19	10.77
Feb	15.62	29.16	22.39	64.9	2.21	10.45
Mar	16.72	30.26	23.49	65.5	2.08	9.77
Apr	17.02	29.96	23.49	62.4	2.02	9.58
May	16.92	30.66	23.79	65.9	2.25	10.31
Jun	16.72	29.36	23.04	67.9	2.88	9.75
Jul	16.42	26.76	21.59	73.8	2.68	7.58
Aug	16.32	27.06	21.69	75.1	2.37	7.94
Sep	15.62	27.86	21.74	71.8	1.8	8.37
Oct	14.32	28.56	21.44	64.3	2	10.37
Nov	13.32	28.66	20.99	61.2	2.2	11.58
Dec	13.12	28.16	20.64	64.1	2.26	11.59
Annual	15.53	28.735	22.1325	66.78	2.245	9.83

The basin's average monthly wind speed is 2.24 m/s, with 9.83 hours of sunshine per day. A monthly temperature drop is linked to a low sunshine hour, high wind speed, and relative humidity. Furthermore, the average monthly relative humidity in the area is 66.78 %. This varies from 61.2 % to 75.1% in August, with the highest relative humidity occurring between August and September.

3.1.4. land use and cover

Topographical, climatic and ecological conditions govern the land cover of the catchment. In conjunction with the population growth of the rift valley basin, the land cover has made dramatic changes in recent years. According to figure 3.6 below the main land use and cover is categorized as forest, grassland, intensively cultivated, marshland, moderately cultivated, shrub land, and water body.

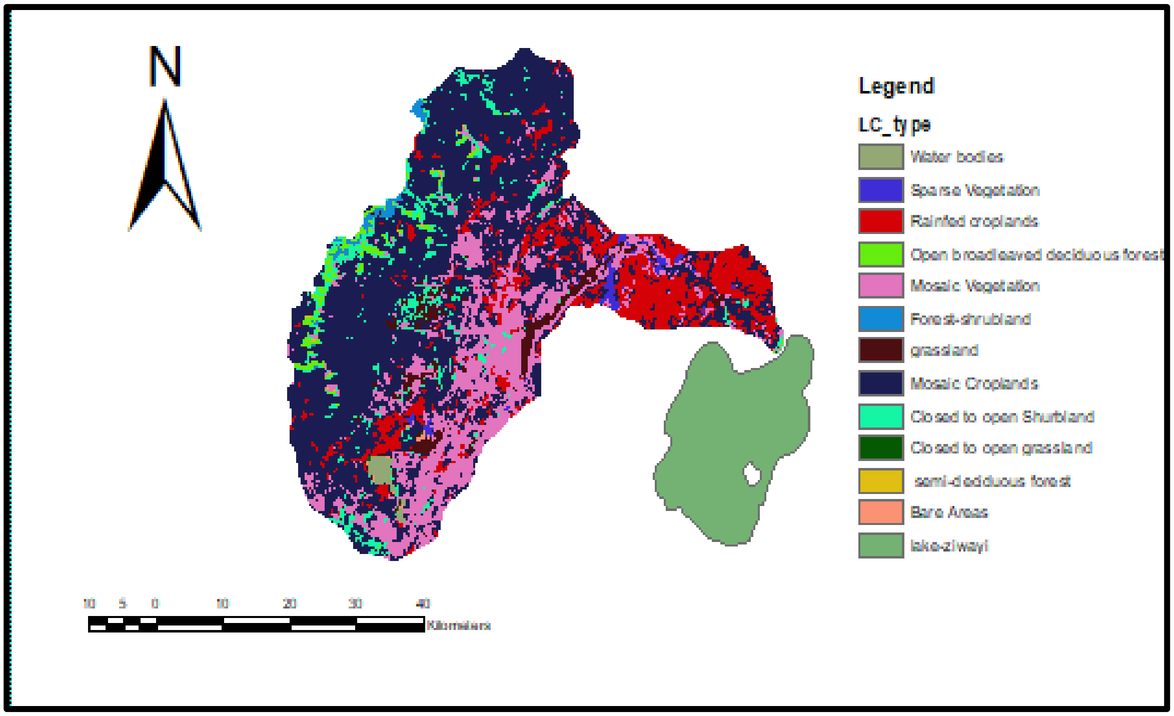


Figure 3.6 land use land cover of the Meki catchment

3.1.5. soil type

The soil is closely linked to the parent material and the degree of weathering in the research field (Anuary, 2008a). The principal parent materials are basalt, ignimbrite, acidic lava, volcanic ash and pumice, and riverine and lacustrine alluvium, according to (Di Paola, 1972). Chromic Cambisol, Eutric Cambisol, Eutric Vertisol, Haplic Luvisol, Latosols, and Vitric Andosol are generally the dominant soil types in the research field. The spatial distribution of the dominant soil type is as shown figure below.

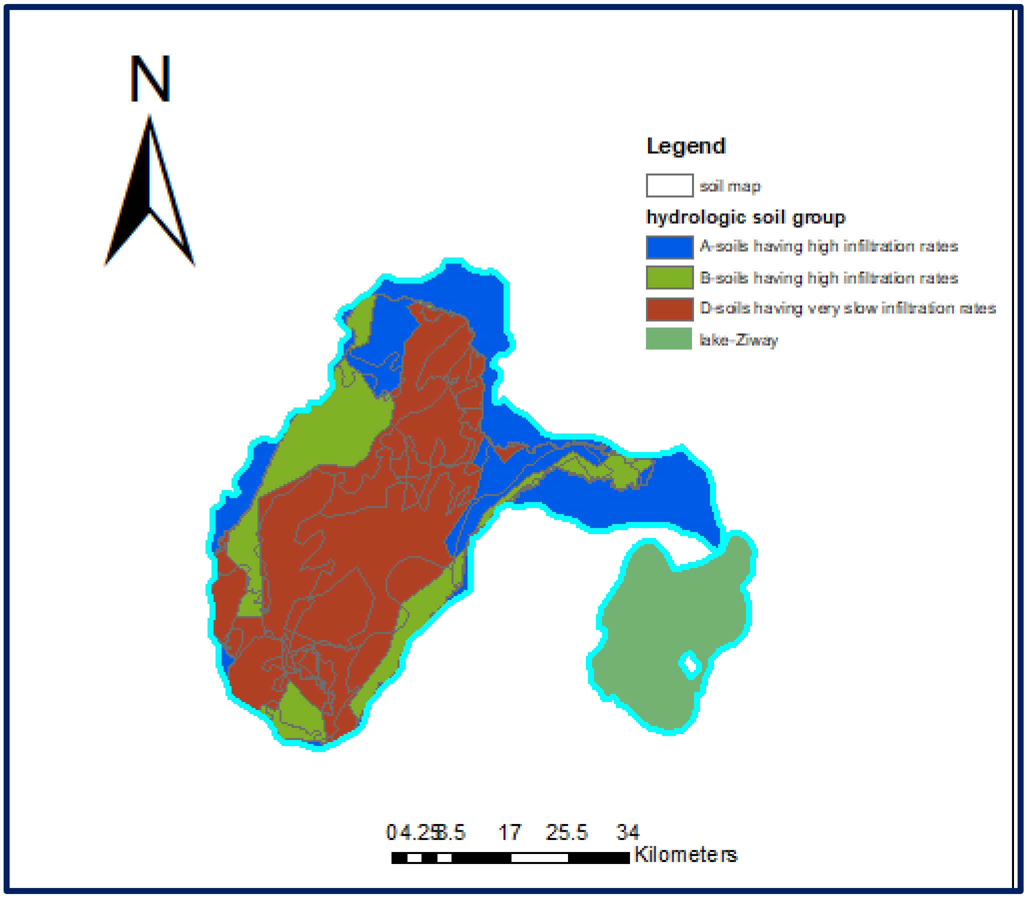


Figure 3.7 hydrologic soil groups of the Meki catchment .

3.1.6 water resources and water use of meki- catchment

The water resources in the study region are assessed for the aim of water supply planning. Surface water and groundwater are the two types of water resources that can be found. In any case, the main notion of selecting suitable water resources for the provision of water should satisfy the following things (Report, n.d.): 1) Water use sustainability, 2) Year-round availability, and 3) Safety as a potable water source.

3.1.6.1 Potential and prospects of usage of surface water and ground water

Non-perennial streams are the tributaries of the Meki- river in the study area. During the dry season, the amount of discharge is quite limited. During the dry season, the flow rate of these rivers also decreases. Even if an intake facility is built, a year-round supply of drinking water is not possible. As a result, stable water volume and supply are no longer an option, as drinking water from tributaries is no longer an option. The river in the study area lacks the capacity to provide a consistent supply of potable water, and the turbidity treatment facility is large, expensive, and difficult to maintain (Report, n.d.). As a result, river water's potential as a source of drinking water is limited. Due to that, the potential drinking water source may be limited to the groundwater resources in accordance with the review of surface water potential as a potable water source. The following is a summary of the benefits of using groundwater, particularly deep groundwater, as a potential potable water source:

1) In terms of water quality, the water is generally safe to drink, and seasonal fluctuations have little effect on it.
2) The amount of water remains constant throughout the year, and the required volume of water can be extracted using the appropriate type of water supply facility.
3) Knowing that good aquifers exist beneath allows for greater flexibility in the point of extraction. As a result, the water supply facility can be provided in the community's immediate vicinity.

Several wells and springs have been used as potable water sources in the Study area, according to (Anuary, 2008b). It should be noted that not all point sources have the aforementioned potable water source characteristics. Hand dug wells and shallow wells that target the shallow aquifer in the Alluvium can be easily impacted not only by surface pollution such as cattle waste and fertilizer, but also by seasonal water level fluctuations. This means that they will not provide a consistent supply of water. As a result, identifying a good aquifer that meets the aforementioned criteria should be prioritized. The distribution of good aquifers, as well as its quality and quantity as an aquifer unit, clarified the investigation of groundwater potential.

3.1.7 geological formations

The dominant geological units in the study region are the Quaternary sedimentary deposits and the groundwater occurrence of volcanic formations. As can be estimated from the rift displacement in the region, the Mesozoic sedimentary formations exclude the small outcrop at the escarpment near Kela village typically occurs at greater depth, probably over 1000 m(Mitiku, 2011b).

3.1.7.1 quaternary sedimentary deposits

The composition of sediment deposits in the region ranges from clay to gravel and the depositional condition varies from lacustrine to fluvial, fan and tulus deposits. This sediment consists of layers of clay and silt alternating with pyroclastic deposits such as pumice, ash, volcanic shards reworked. This sediment is primarily composed of gravel and sand derived from pyroclastic materials in the coastal areas. In general, the thickness of this deposit is over 200m. This formation is one of the main aquifers in the study field, in addition to its variability. Because of this, one of the main aquifers to be considered for groundwater production is Ziway plain sediment. The Kuntane - Inseno-Kela plain was the other area of sediment deposition. Sediment deposits consisting of lacustrine, fluvial, pyroclastic, talus and fan deposits are distinguished by this plain. It has over 200 m of thick sediment deposits. The other important aquifer zone in the study region is this area. The last area of sediment deposition is the Crescent of Butajira. This area is characterized by deposits of gravel and sand with clay and silt derived from deposits of fans, talus and rivers with an average thickness of approximately 80 m and is also considered a good aquifer except for its limited area(Mitiku, 2011b).

3.1.7.2 volcanic formations

The primary volcanic formations are the Quaternary pyroclastic deposits in the study region. In the escarpment areas and deep under the Quaternary formations, the earlier volcanic formations (Tertiary Volcanic Rocks) are located. To the east of Lake Ziway, west of Lake Ziway and around Butajira, there are minimal rhyolite and basaltic formations. According to Butajira-Ziway developmental study report(Anuary, 2008b), the main formations are rift pyroclastic deposits and can also be regarded as major volcanic aquifers in the study region. In the escarpment and deep beneath the Quaternary formations in the rift valley region, the older volcanic rocks composed of rhyolites and basalts are found. Such rocks may be effective aquifers for fractures in fractured areas. These formations may therefore be important aquifers, especially in the rift fracture zones(Mitiku, 2011b).

3.1.7.3 Mesozoic sedimentary formations

Under the present ground surface below the Tertiary volcanic rocks, the Mesozoic sedimentary formations (the Limestone and Sandstone) occur over 1000m and these formations are deep potential groundwater aquifers. Furthermore, in the escarpment, the minimum effect around Kela village is aligned and is not so much functional as a possible groundwater source.

3.1.7.4 Precambrian metamorphic rocks

In addition, the Precambrian Metamorphic rocks are found about 1000m under the present ground surface below the Mesozoic Sedimentary formations and Tertiary volcanic formations, close to Mesozoic sedimentary formations. So, for groundwater, the metamorphic rocks are not usable formations(Mitiku, 2011b)

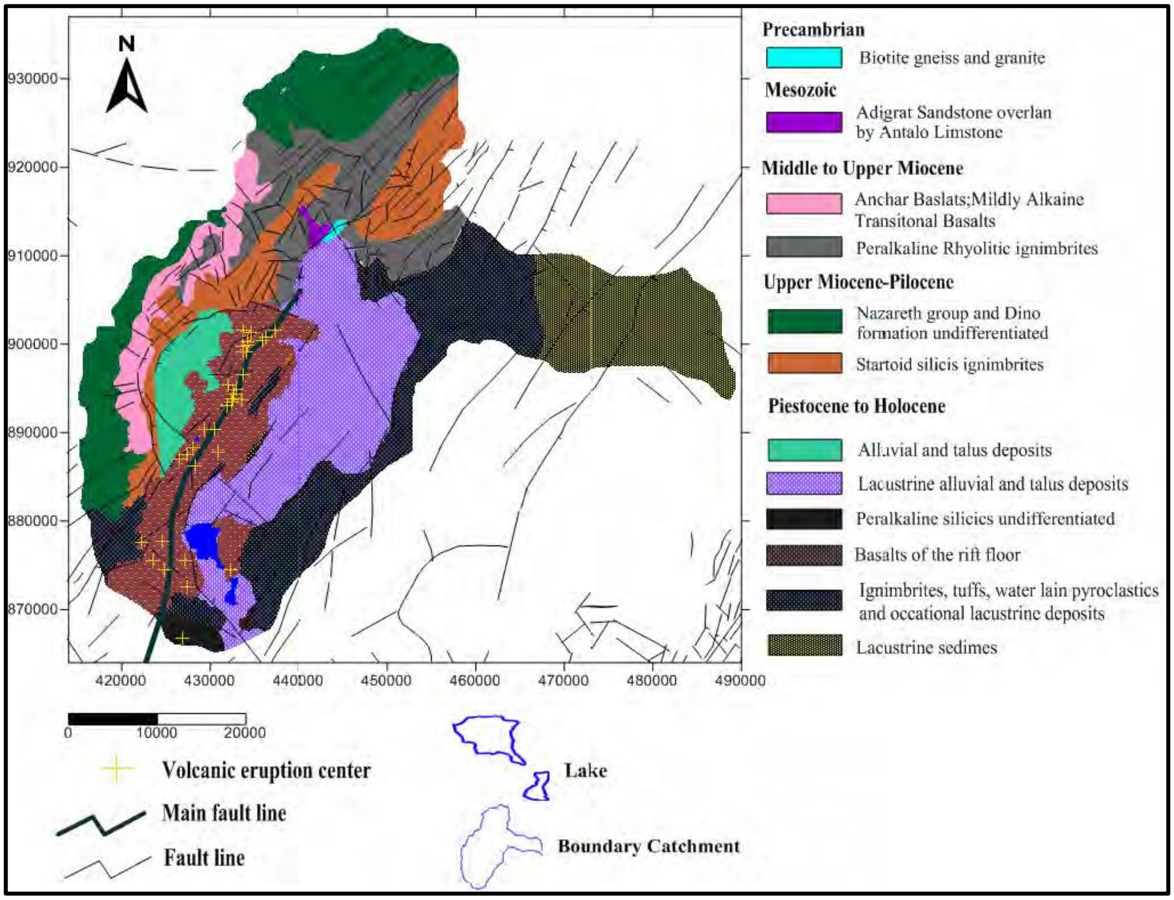


Figure 3.8 Geological map of meki-catchment source:(Anuary, 2008b)

3.1.8 hydrogeology

The hydrogeological importance of the geomorphological characteristics is categorized in this study into the Western Escarpment, Butajira Crescent, Kuntane-Inseno-Kela Plain, Tora-Koshe-Dugda Plateau, Cinder cones and basaltic regions. The hydrogeological characteristics of the formations in each geomorphological area are summarized as below, according to (Anuary, 2008a)

3.1.8.1 the western escarpment

In addition, the region receives high precipitation and discharges its surface and subsurface flow to the low-lying areas. This area is primarily characterized by the Tertiary volcanic consisting of basalts, rhyolites ignimbrites and tuffs. In terms of thermal springs, most springs originate in the escarpment and these springs occur as springs of touch and fracture. In general, the rift valley region is mainly the dominant source of runoff in this area(Mitiku, 2011b).

3.1.8.2 Butajira pediment

This area is situated on the western rift escarpment plain, and it is characterized by shallow groundwater and springs. The depth of water level varies from surface to approximately 20 m meters below ground and is characterized by a complex mixture of sediments consisting of alluvial, talus or fan deposits, debris flow and volcanic-clastic deposits that are unsorted to poorly sorted, arising from the volcanic basaltic centers in the east and around Koto. The thickness also ranges from 80 m to about 120 m. Finally, the aquifer receives a recharge of groundwater mostly from erosion, the flow of groundwater from the escarpment and the runoff from the mountain rainfall. The fracture has permeability due to tertiary volcanic formations and can be strong aquifers in fracture zones(Mitiku, 2011b).

3.1.8.3 basaltic cinder cones region

This region is situated east of the Butajira pediment and consists predominantly of scoria cones and associated basaltic vesicles. With respect to the Crescent area and direct recharge from rainfall, groundwater occurs at a relatively deeper level. In addition, the main source is the topography of the groundwater surface compared to the Butajira front and Kontane-Inseno-kela plain. Scoria cones and associated vesicular basalts are also underpinned by Quaternary volcanic rocks and sediments. Tertiary and Mesozoic Sedimentary formations are also expected to occur in the aquifer deep under the Quaternary formations. Most wells built in this area use motorized pumps because of the relatively deep-water table(Mitiku, 2011b).

3.1.8.4 Kontane-Inseno-Kela plain

Recharge from numerous streams from the western escarpment and direct rainfall and groundwater inflow is received by this plain. Pyroclastic collapse and reworked water often cover pyroclastic deposits, lacustrine, alluvial, debris flow or talus deposits, and the thickness of these sediments' ranges from a few meters in the west to several meters in the middle and along the Weja River (more than 260 meters and more). Quaternary and Tertiary volcanic deposits underlie the quaternary sediments. In addition, deeper sections of Mesozoic sedimentary deposits are also expected to occur. Generally, the surface water drains from Butajira and Kibet areas to Kontane Marsh and Little Abaya, while the surface water drains from Kela and Bui areas to the east to this plain and forms the upper Meki River, and the overflow from Little Abaya (Lake) and Kontane Marsh and Dobena River forms the Weja River, which flows to the northeast of this plain to form the Meki River. In this region, the groundwater is typically shallow and abundant; in this plain, many dug and shallow wells are found(Mitiku, 2011b).

3.1.8.5 Tora-Koshe- Dugda ridge

This region was used as the eastern frontier of the valley of Inseno-kela and consisted mainly of pyroclastic deposits such as tuff and Ignimbrite. Often it serves as a barrier to surface water. Since the topography slopes gently down to Lake Ziway and the lithology gradually transitions to lake sediment. The groundwater is also deep and there is no shallow groundwater available in this zone. Generally, the depth of the main table of groundwater is over 130 m(Mitiku, 2011b)

3.2 DATA COLLECTION

In order to address the study objectives, this section of the work involves primary and secondary data.

The basic literature review on modeling books and prior study will be carried out by the main. Moreover, in this thesis, the following details was used

- (30m by 30m) SRTM DEM data from Ministry of Water and energy
- Geological and hydro geological maps of Ethiopia and the rift valley area from Geological Survey of Ethiopia

- Meteorological Data from the national Meteorological Agency
- Stream Flow Data from the Ministry of water, irrigation and energy
- Ground water modelling report document from AG consult
- Ground water point data base from Ministry of water resource

In addition, modeling software: Arc GIS 10.4.1, Surfer 12, HEC-geo HMS, Global Mapper 18, mod flow processing (version 5.2.0.1),(HEC-HMS),SPAW and a field observation was performed after the primary data collection for the purpose of observing; hydro geological characteristics, confirmation of secondary data collected at the deskwork. Data sources were generally provided by the Ministry of Water & Electricity, the Ethiopian Mapping Agency, the National Meteorological Agency, the Ethiopian Geological Survey and AG Consult.

3.2.1. input data processing for surface water and ground water model simulation.

Several forms of input data are required to build a reliable model that will provide meaningful results for the parties involved. This study required an extensive data gathering period like, Meki-River stream flow data, precipitation, well logs and location, well production data, ground and surface water elevation, soil types and land use were the different types of information gathered for the mapping and analysis. The spatial data was combined to form a base map created by Arc Map, a visual mapping program for the Geographic Information System (GIS). GIS was used to show some of the characteristics of the area, such as topography, types of soil, monitoring locations and rivers. Daily runoff was simulated by HEC-HMS 4.2.1 in this study and compared with measured daily records and essential data for the hydrological simulation techniques considered are: catchment area, land use patterns, daily rainfall, daily river discharge, base flow, catchment soil types, and impermeable area coverage. Although some of these data are collected at the meteorological station on a daily basis, some of them have been derived from maps or sources of literature. Regardless of the source, data plays an important role in the modeling of simulation and in the initial catchment conceptualization considered and outlined below(USGS, 2012).

3.2.1.1 Precipitation

The location of the Inter Tropical Convergence Zone; ITCZ (Dagnachew Legesse et al., 2003) regulates the seasonal distribution of rainfall over the region. The ITCZ is a low-pressure convergence area between Tropical Easterlies and Equatorial Westerlies along which equatorial wave disturbances take place. The availability of the rain driving wind direction is controlled by the shifting of this low-pressure area. The rainy season from June to September is dominated by ITCZ which lies to north of Ethiopia at that time. Thus, much of the monsoon rainfall from the Atlantic and Indian oceans is intercepted by the study region. The dry season, between October and February, is when the ITCZ lies in the south of the country. The north-eastern trade wind that crosses Arabia dominates the region during these months and therefore produces very little to no rainfall in the city(Mitiku, 2011b).The ITCZ is situated in southern Ethiopia during March and travels northwards. In Sudan and Arabia, low pressure is produced at that time, while high pressure develops over the Gulf of Aden and the Indian Ocean. The high pressure generates a humid eastern air current that produces spring (Bulg) rain from March to May over south-east Ethiopia(Mitiku, 2011b).The catchment rain fall analysis is a very important part of the research that essentially governs the study area recharge.

3.2.1.1.1.Spatial distribution of rainfall

More than one gauge was chosen for the region due to spatial precipitation variability in the Sub basin. Therefore, the use of the various precipitation stations enables the creation of a model that can evaluate the spatial information of the study area more accurately. Precipitation of the study area was analyzed based on the 8 stations found in and around the catchment and the average aerial depth of precipitation over the catchment has been determined using Thiessen polygon method in Arc Gis software. The Thiessen polygon has been constructed using all 8 stations. According to figure below 3.9 the four stations were out of the study area .therefore, the chosen adequate gauges stations were: Ziway, Meki, Butajira and Tora. These gauges had daily rainfall data (January 1998 to December 2018).Accordingly, the catchment gets mean annual precipitation of 872.13 mm.

Table 3.2 Arial mean depth of precipitation using Thiessen polygon method

Stations	Area enclosed by polygon(km^2)	Weighted area(%)	Mean annual ppt(mm)	Weighted precipitation
Butajira	520	0.2849	1145	326.246
Tora	604	0.3309	892.5	295.380
Meki	441	0.2416	702.82	169.832
Ziway	260	0.14246	748.23	106.597
∑=	1825	100		898.055

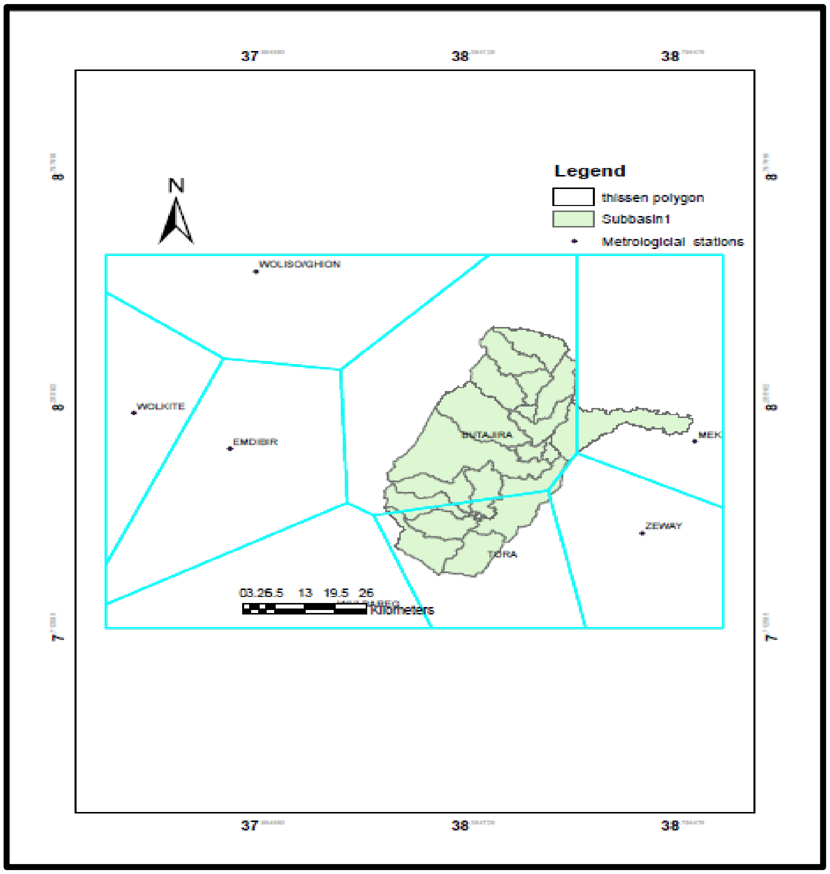


Figure 3.9 selected metrological stations using Thiessen polygon

3.2.1.1.2.Estimation of Missing Data

To begin, the missing flow data was filled in the data processing phase using Spatial interpolation techniques, which are commonly used methods for filling gaps in daily rainfall series by estimating the unknown rainfall amount for a point using known data from adjacent stations, the Simple arithmetic average method and inverse distance. (M. Le, 2020) used the normal-ratio and 3-station-average interpolation methods to fill in missing values in daily rainfall results .the extent of missing daily rainfall data for station :Meki, Tora, Ziway and butajira were:7.57%,8.33%,2.27% and 6.8% respectively. During (1998-2008). After that a double mass curve was used to verify the accuracy of rain fall data (ADELOYE & MONTASERI, 2002).

3.2.1.1.3 Consistency of the precipitation record

Hydrological data consist of time series data that are collected at a particular location. The use of raw data without checking for consistency in hydrologic modelling can bring lots of error and uncertainty. therefore, before hydrological data are used in such study ,they should be tested by comparing the annual rainfall, plotting daily values and by employing the double mass curve analysis. The double- mass curve is plotted as cumulative of one station (y-axis) against the average cumulative of nearby stations(x-axis)(*Engineering Hydrology_Sabremanya.Pdf*, n.d.) as wells as
Deviation from or break in the slope of the double mass curve means that is a change in the consistency of proportionality b/n the variable or simply it shows the degree of change in relation. Such deviation might be due to gauge location, observation method /exposure. The precipitation records can usually be adjusted by correlation coefficients determined from the double mass curve (equation 3.1).

$Pa= \frac{\partial a}{\partial b} Pb$…………………………………equation (3.1) Where P_a-adjusted precipitation

observed precipitation ,∂a-the slope of the graph at the time was observed and ∂b-the slope of the graph to which record are determined.

3.2.1.2 Stream flow Data

There are two stream flow stations in the Sub Basin, the upper Meki in Meki city (downstream) from (1998-2010)and the Irenzaf in Butajira station (upstream)from(1996-2007). In the basin, the Meki-town River Gage is near the Sub basin outlet below figure 3.10.

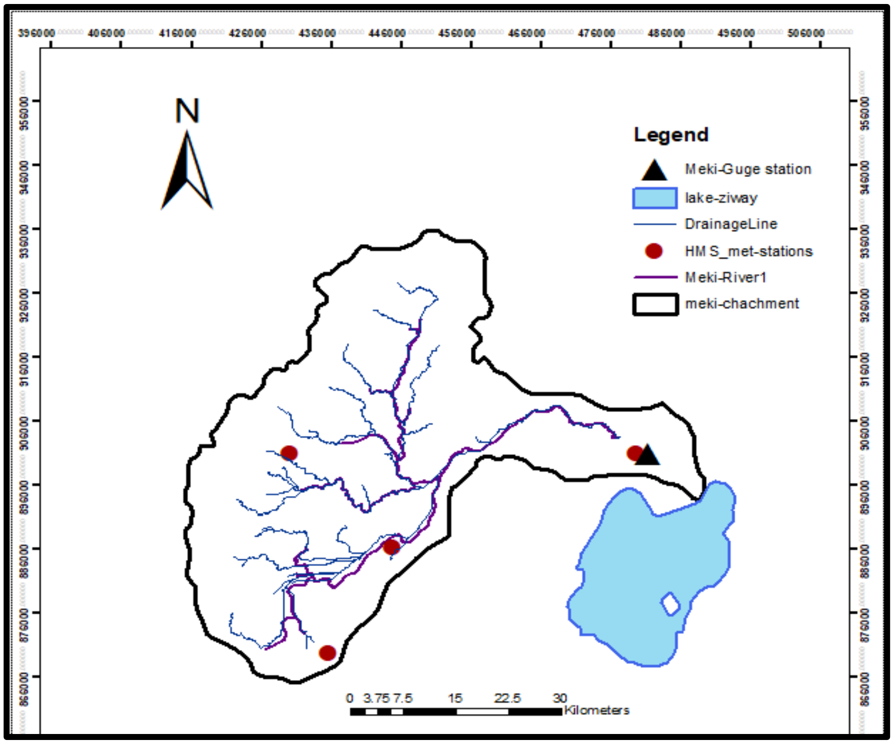


Figure 3.10 location of river gauging station

Therefore, at this stage, the stream flow data was collected for several years from(1998-2010) and the data was old. Because, the available flow data were only from (1998-2010) at the time of data collection. the extent of missing daily flow data for Meki Gauge station was 15.9%.in addition, Missing discharge data and consistency was adjusted as the same manner as precipitation and later summarized into mean monthly discharges (appendix-2) in order to calibrate the surface water simulation, The stream flow data collected from(1998-2008) provides a daily dataset covering the study period. Figure 3.10 shows the net daily streamflow at Meki-gauge station.

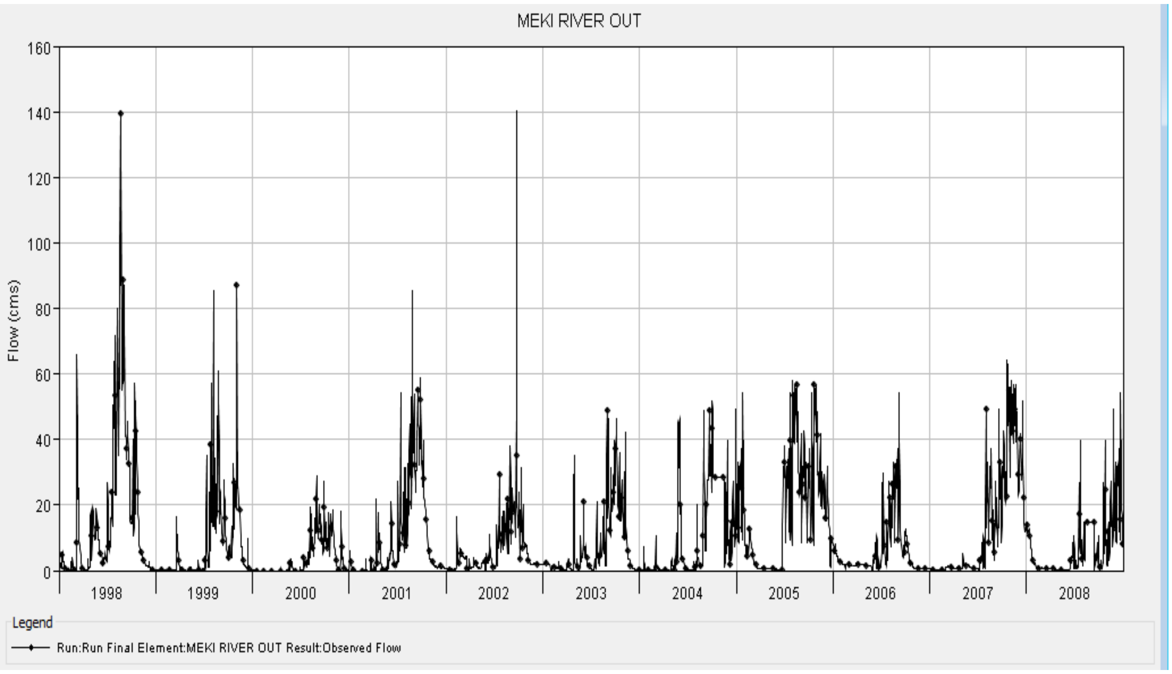


Figure 3.11 Plot of the daily stream flow data at Meki-gauge

3.2.1.3 well inventory data

The important data gathered from different sources and field observation have different format for the model. For the sake of constructing the model using the information gathered from different time and sources needs a process of; checking, selection, format conversion and organization had to be carried out to obtain the appropriate data for the model input. Most of the investigations carried out around the Meki- river to Ziway lake catchment areas have been spread among a number of different organizations, and it is difficult to gather and combine the existing information needed for the new research activity.in addition, analyze their reliability of ground water level or observation wells were used for ground water calibration.

The necessary steps in data processing are including wells where water levels might be measured inappropriately because of problems with the datum, organizing all important information in Appendix- 3, using excel, citation of secondary source data and converting maps in a format that is acceptable by the modeling software. Geographic Information System (GIS) was used to get the best general picture of the study area and assist in making some important decisions, like boundary condition and catchment delineation.

Since the well inventories data are the constraint input parameters for the groundwater model, collecting them is needed for this thesis and collected at date of drilled(1993-2005).

- Shallow wells inventory.
- Deep wells inventory for irrigation and water supply

  The data on well inventories contains the following:-
- The location, X and Y coordinates of (borehole, wells) in UTM
- the static water level of the well collected(1993-2005)

For more clarity in the data, the well yield and geology of the borehole site are also essential.

3.2.1.4 Land use land cover, Land Elevation and Soil Types

MOWE provided data on land elevation and land use. The ground surface elevations for both HEC-HMS and processing MODFLOW, as well as the layer elevations in MODFLOW, include land elevation. The land elevation (30m by 30m) was chosen to allow for greater precision in the watershed delineation process, demonstrating the elevation difference between the valley floor and surrounding hills and mountains. In addition, FAO soil type data was collected for use as inputs to the soil moisture accounting (SMA)HEC-HMS model. The data were used in the HEC-HMS model to determine soil runoff and percolation characteristics.

The digital elevation model used for the study area is the ASTER DEM of the Main Ethiopian with resolution of 30 meter by 30 meters. The DEM covered a large area than the intended study region so a sub catchment has been selected to improve the computing and processing speed of the computer therefore, by selecting shape file of study area and to extract 30m by 30m of Ethiopia DEM to the shape file of study area. As well as, Global Mapper is also used to prepare top elevation of the model area from ASTER DEM data to Surfer Grid (ASCII Format) by specifying the mesh size used in MODFLOW in the x and y direction then the working environment of the study area is assigned as input by specifying the projection UTM, Zone 37(Northern Hemisphere), and datum WGS84 is used in this study. Because, the Global Positioning System (GPS) uses the World Geodetic System (WGS84) as its reference coordinate system, the coordinate origin is the Earth's center mass. and the working environment lies within (UTM 414000-490000 E and 864000-937000 N) and using Surfer 12 different maps of segment, polygon and point were overlaid for differentiating zonation of hydrogeological parameters, location and distribution of observation wells, model boundaries, water point alignment with respect to structures, model boundaries and for other analysis using as background during the construction of the numerical model and in different variations of the conceptual model for the period of calibration process by importing it to MODFLOW. Afterall, the file is ready to import to MODFLOW processing (version 5.2.0.1) and to conceptualize the individual model structure figure 3.12 and 3.13 below shows the surface water and ground water model layout respectively.

In general, For the various stages of the analysis, many kinds of software were used. Most of the research was done in HEC-HMS and processing mod flow. In addition, model configuration for each of the software packages used and calibration outcomes for the HEC-HMS and mod flow models will be addressed in the next Section. The surface water and ground water models were both calibrated. In modeling, this step is important because they confirm a model's reliability and estimation capacity. A calibrated model also has greater credibility since it can be concluded that the results derived from the model are more accurate if it fits well with observed data.

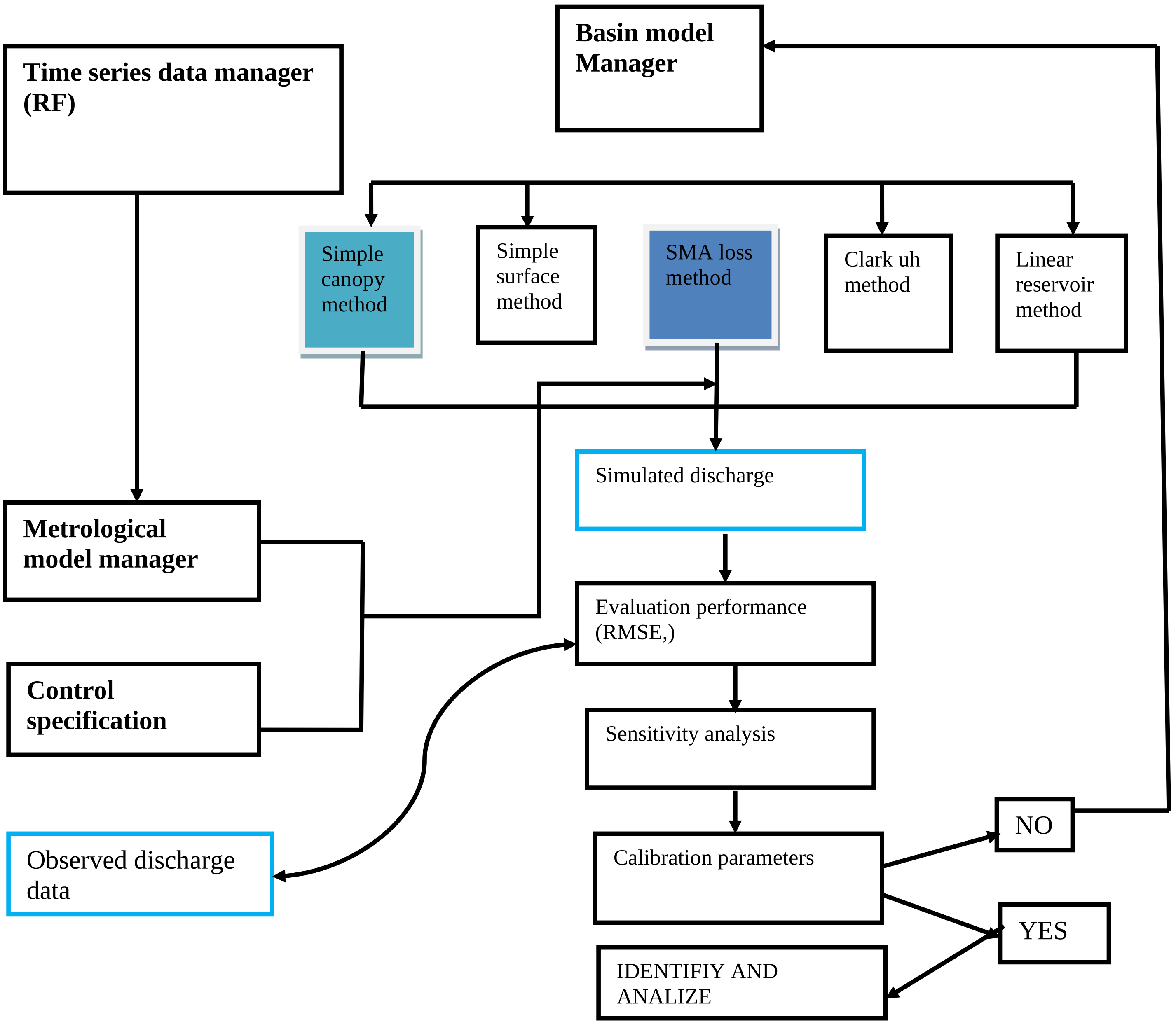


figure 3. 12 skeleton of HEC-HMS model flow chart

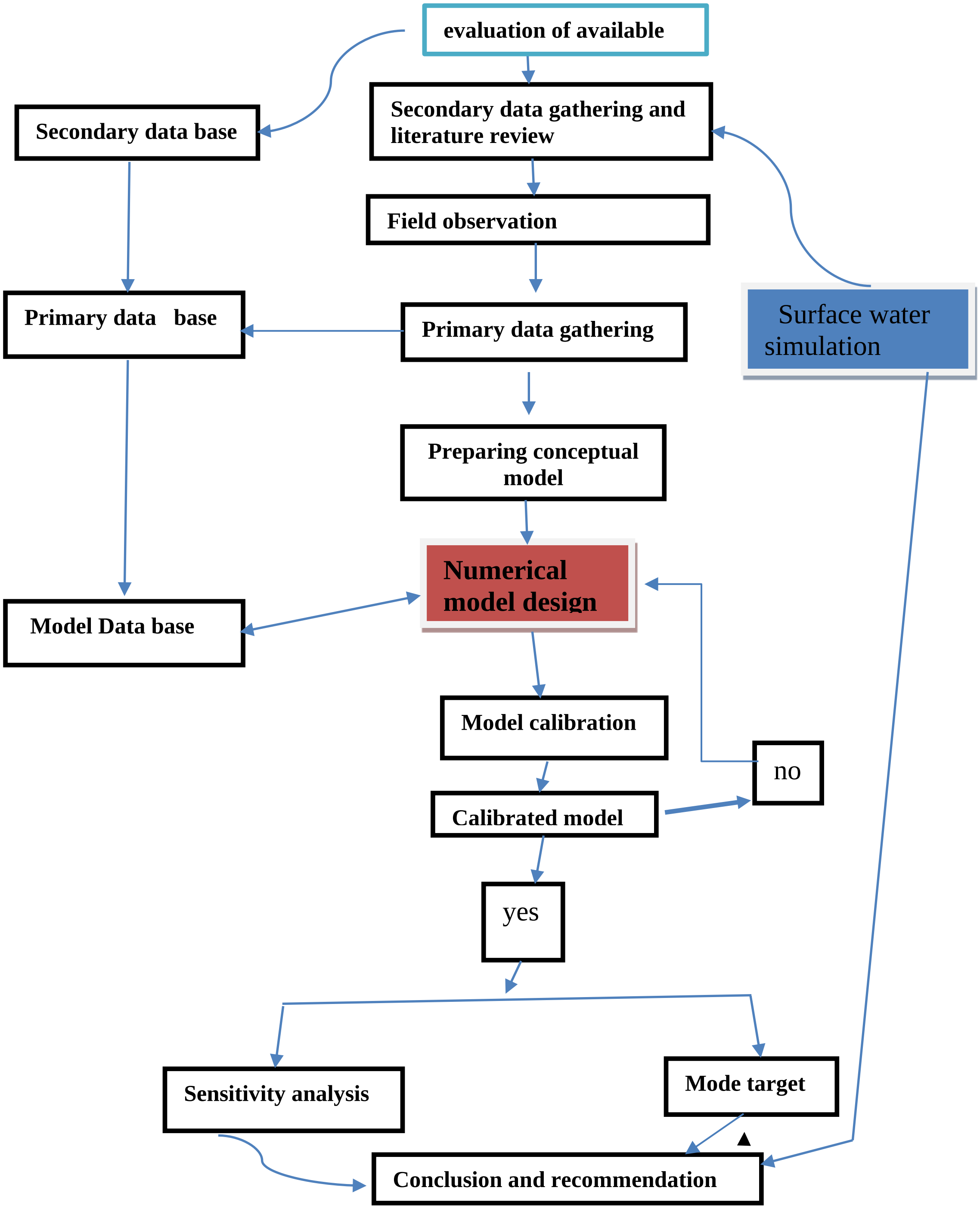


figure 3. 13 ground water model protocol

3.3. SURFACE WATER MODELLING

3.3.1 Models description

3.3.1.1 HEC-GEOHMS

The first data package used for the analysis was the HEC-HMS add-on package HEC-Geo HMS (Hydrologic Engineering Center – Geospatial Hydrologic Modeling System Extension) produced by the U.S. Army Corps of Engineers and is available with The GIS software, Arc Map. HEC-Geo HMS creates background map files, basin model Files, meteorological model files, and grid cell parameter files that are then utilized by the HEC-HMS model (Hydrologic & Extension, 2000) The files relevant to the surface water Analysis of this study is the basin model files. The basin model files contain data for physical properties of the soil and soil types as well as data for hydraulic elements (sub basins, river junctions, and river reaches) and their connectivity (Hydrologic & Extension, 2000) To create basin model necessary data are collected like, input elevation data, soil type data, and impervious surface data, and land use data. Then, HEC-Geo HMS has created terrain processing by following different sequences to recreate the basin for the Meki River Watershed. Finally, after this process was complete, data were imported into HEC-HMS for running the simulation.

3.3.1.2 HEC-HMS model setup

Basin model manager, meteorological model manager, control specifications manager, input data manager are four key components produced for the HEC-HMS project development (time series, paired data and gridded data). For example, the Basin model manager involves the hydrological elements (sub-basin, reach, intersection, reservoir, diversion, source and sink) and their connectivity, which reflects the flow of water through the drainage system(W. A. Scharffenberg, 2013). One of the project's key components is the Control Requirements Manager, which is primarily used to control simulation time intervals. The meteorological component is also the first computational component in which the input of precipitation is distributed spatially and temporally across the river basin. The spatiotemporal distribution of precipitation is achieved by the inverse distance method and for estimating basin-average rainfall, the hydrological model also needs time-series precipitation data. A time series, often referred to as observed flow or observed discharge, of flow data. Both meteorological data such as rainfall, observed discharge, were entered into this main component. By forming and recreating the sub-watersheds and the Meki River using the HEC-

Geo HMS in ARC GIS, the HEC-HMS model was developed. The knowledge was exported from HEC-Geo HMS to HEC-HMS following the delineation of the sub-watershed and river reach forms. The HEC-Geo HMS information was imported into the HEC-HMS model and receives sub-watershed characteristics such as location, slope, infiltration parameters, river routing parameters, and connectivity of the sub-watershed-stream network. Additional watershed data necessary for the creation of the HECHMS model were then defined after exporting HEC-geo HMS data. That includes, for the upper Meki, precipitation and historical streamflow. This data is then entered as time-series data controls. Time-series data is used to specify time-dependent data from various methods of measurement. Several types of time series data ranging from precipitation and discharge (used in this study) to wind speed, snow water equivalent, crop coefficient and concentration options can be accepted by HEC-HMS (HEC, 2000). Start and stop times and dates, the interval of time between readings, and the data values are the necessary information for time series input. The interval of time will vary from one minute to one day, with many alternatives in between(W. A. Scharffenberg, 2013).For this study, both precipitation and flow time series data were entered from midnight (00:00) January 1,1998 to midnight January 1, 2008 as daily data. In order to describe and format (e.g., observed vs. statistical rainfall) and spatial pattern (e.g., grid or gauge position based) of precipitation, HEC-HMS also has meteorological controls. This control enables various methods to evaluate and apply precipitation to a watershed and also shows the basin model in the HEC-HMS projection in the figure below.

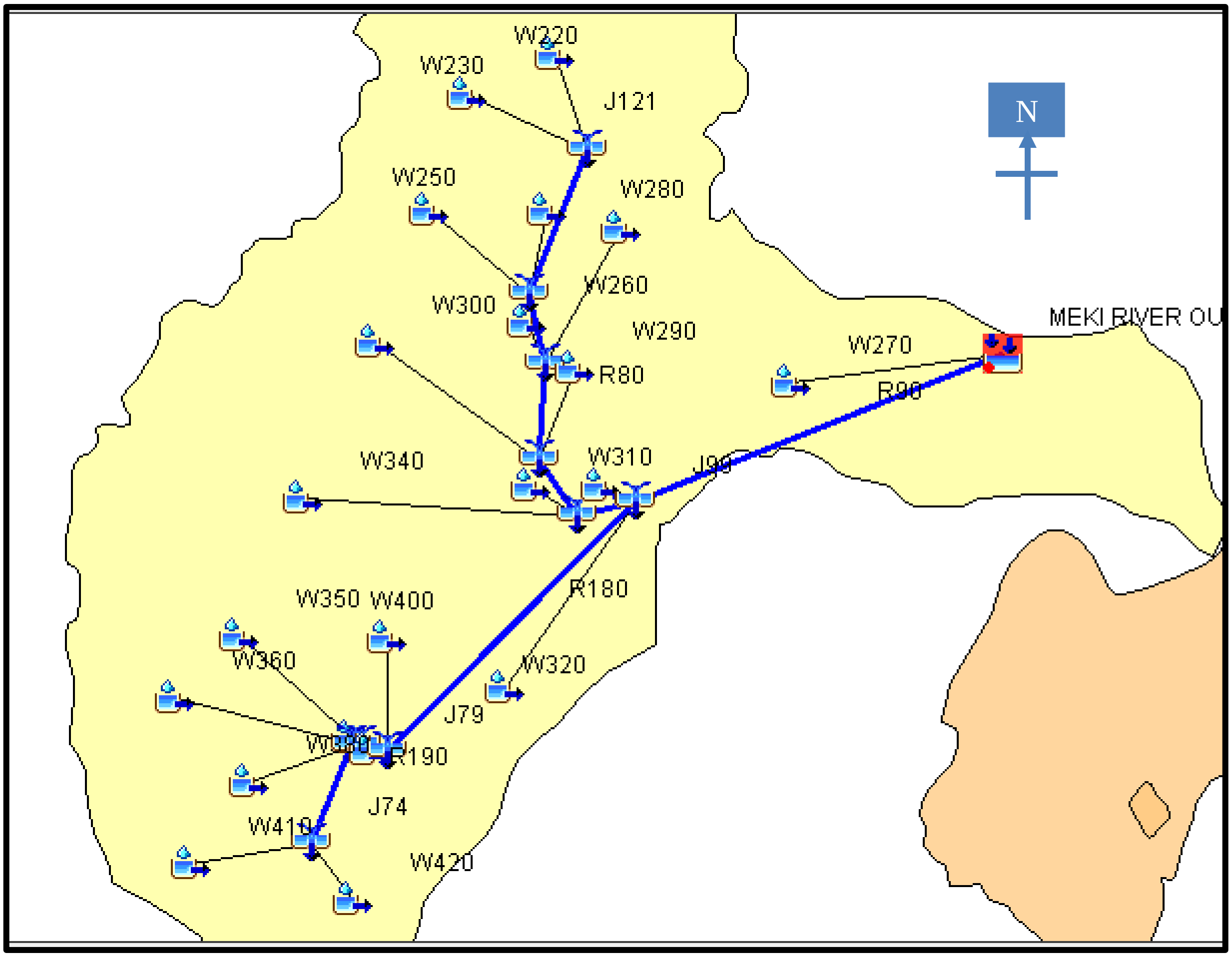


figure 3.14 basin model components of the project

3.3.2. HEC-HMS Model application

(USACE, 2016) The Hydrologic Engineering Center-Hydrologic Modeling System (HEC-HMS) is software developed by the U.S. Army Corps of Engineers and has a tool bar extension in the ArcMap GIS program. The HEC-HMS model is therefore used for the surface water simulation of the Meki- River flows in this analysis. To conduct simulations to assess the amount of water percolating along the length of the Meki- River and adjacent watersheds to the aquifer based on precipitation during the aquifer. As part of this surface water simulation, the volume of water percolated from the Meki River and surrounding watershed rainfall-runoff in HEC-HMS known as Soil Moisture Accounting (SMA) was used to assess the quantity of water percolated to the groundwater. This package was chosen because, rather than an event model, a continuous hydrological model was needed. A continuous model accounts for the long-term balance of soil moisture in a watershed as is appropriate for the simulation of daily, monthly, and seasonal streamflow(W. Scharffenberg, 2016). For full simulation of the eleven-year study period, the SMA package allows moisture accounting. Therefore, the parameter of interest is the percolation of groundwater from the soil profile. Instead of the soil infiltration data, the percolation results are chosen because soil storage and evapotranspiration are also accounted for by the SMA process. The amount of water transferred to the groundwater depends on the soil's moisture and will not always be the same as the rate of soil infiltration. SMA has parameters that need to be determined for the sub-watersheds before simulating the watershed rainfall-runoff relationship, according to the soil moisture accounting algorithm schematic(W. Scharffenberg, 2016). The selected parameters for this model represent: storage of canopy interception, storage of surface depression, maximum infiltration rate, maximum soil storage, storage of tension zone, percolation rate of soil zone, percolation of groundwater 1 and storage depth of groundwater 1 due to unconfined depths. The surface water model can be adapted to the parameters using these tools to better fit the wet or dry periods that occur throughout the year. Instead of creating an annual average that is a fit for both wet and dry periods, these modifications help minimize model error by fitting the parameters to a shorter time period. The Lag Routing Method for the river reach segments was selected for the estimation of flow in the Meki River. This is a method that represents flood wave translation and does not include any representation of processes of attenuation or diffusion(W. Scharffenberg, 2016). In translating the water in the river from upstream to downstream, the Lag Routing Method was chosen for simplicity. However, for short stream segments with predictable travel time, this technique is best suited(W. Scharffenberg, 2016), The method was adequate for the purposes of this study and this assumption is confirmed through the calibration process shown in the following sections. The lag time in minutes is the only parameter. The inflow in a range is delayed by HEC-HMS by the time specified for lag in the river range and then the flow becomes outflow (W. Scharffenberg, 2016).

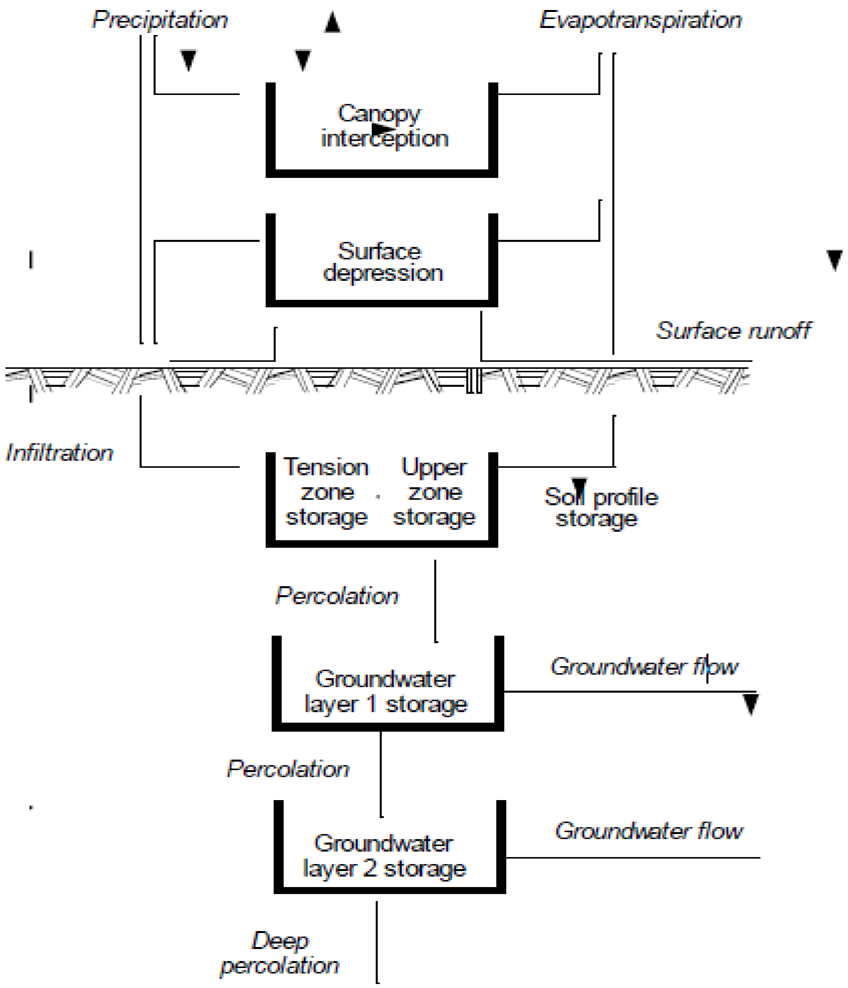


figure 3. 15 soil moisture accounting conceptual frame work(HEC, 2000)

According to Figure 3.10, in this model, the catchment is defined as different storage layers. That means that each storage has the rate of inflow, outflow and storage capacity that the excess amount of water that causes runoff is described in total. The canopy interception component, on the other hand, shows the amount of precipitation captured by trees and all vegetation types. Before precipitation can reach other storages and the water held, it is the first storage that must be filled. The surface interception storage that represents the portion of water held in the surface depressions is the next storage module. In this case, precipitation that is not absorbed by the canopy is the input to this storage. In this storage, water evaporates or infiltrates into the soil layer as well. But if the rate of infiltration is lower than the excess precipitation, then the excess water accumulates in the surface depressions and the excess water generates runoff after filling it.

To model infiltration losses combined with canopy and surface methods, the Soil Moisture Accounting (SMA) Loss System used in HEC-HMS was used. The canopy is a sub-basin portion that is intended to reflect the presence of plants in the region. For continuous simulations, the canopy method defined in the HEC-HMS settings is mainly used. When the canopy storage capacity is filled, all precipitation is trapped. Subsequently, after going through the canopy, the excess precipitation falls on the soil surface. Depression of the ground surface where water accumulates after the pores in the soil are filled to the field capacity of the soil is defined by the surface method stated in the HEC-HMS settings in the depression storage, the water on the surface then accumulates until runoff starts to occur as part of the precipitation percolating deep into the groundwater region. Runoff starts when the rate of precipitation reaches the rate of soil penetration (Figure 4) and the storage in the depressions is complete. Values for the canopy and surface storage were obtained from the Land Use and DEM maps review, as derived from Tables 3.1 and 3.2 respectively, according to (Awa et al., 2018).

Table 3.3 Values of Canopy Interception

Type of vegetation	Canopy interception(mm)
General vegetation	1.270
Grasses and deciduous trees	2.032
Trees and coniferous trees	2.540

Table 3.4 Storage Values for Surface Depression

description	Slope(%)	Surface storage(mm)
Paved impervious areas	NA	3.18-6.35
Flat, furrowed land	0-5	50.8
moderate	5-30	6.35-12.7
Steep, smooth slopes	>30	1.02

The required inputs for the SMA model are provided in Table 3.3 . The maximum infiltration rate was determined to be the upper limit of the rate of water entry from surface storage into the soil. The values for maximum infiltration rate have been obtained and represent the saturated hydraulic conductivity based on the soil analysis in the catchment (Table 3.4).According to(Awa et al., 2018), the impermeable area was identified as the percentage of the area under urban civilization for the sub-basin using Google Earth with the help of the Land Use Map. The storage of soil water was described in Table 3.4 as porosity, which is the available space that can be occupied by water in the soil. Computer Soil-Plant-Air-Water (SPAW) program the tension storage was measured by the U.S. Department of Agriculture (6.02.75, U.S. Department of Agriculture-USDA, Washington, DC, USA) by considering the soil field capacity based on soil texture values. The average hydraulic conductivity of all sub-basins was chosen as the rate of soil percolation and the rate of percolation of the first groundwater layer (GW1) as obtained from soil texture-based SPAW software. The storage coefficients and depths of GW1 and GW2 have been developed based on a stream flow recession analysis of historical flow data. The values of the GW2 percolation rate were obtained during the calibration process.

TABLE 3.5 PARAMETRS FOR SMA MODEL

canopy	Initial canopy storage(%) Maximum canopy storage(mm) Crop coefficient
Surface	Initial surface storage(%) Maximum surface storage(mm)
SMA	Soil(%) Ground water 1(%) Maximum infiltration rate(mm/hr.) Impervious(%) Tension storage(mm) Soil percolation (mm/hr.) Ground water 1 storage (mm) Ground water 1 percolation rate (mm/hr.) Ground water 1 coefficient(h) Ground water 2 storage (mm) Ground water 2 percolation rate (mm/hr.) Ground water 2 coefficient(h)

Table 3.6 textures and properties of soil

No	Name	Basin's slope(%)	Area HMS(km2)	SOIL TYPE	SOIL NAME	TEXTURE	H.COND(CM/HR)	POROSITY(n)
1	W220	40.426731	33.178856	Chromic Luvisols	CHLUVIS+F2:K22OLS	loam	0.34	0.463
2	W230	26.640568	30.591845	Chromic Luvisols	CHLUVISOLS	loam	0.34	0.463
3	W240	27.065989	16.132197	Lithic Leptosols	LTLEPTOSOLS	Sandy loam	1.09	0.453
4	W250	28.221163	34.513379	Lithic Leptosols	LTLEPTOSOLS	Sandy loam	1.09	0.453
5	W260	16.614624	4.999699	Eutric Vertisols	EUVERTISOLS	Clay	0.03	0.475
6	W270	11.14712	70.631555	Lithic Leptosols	LTLEPTOSOLS	Sandy loam	1.09	0.453
7	W280	13.074535	29.782855	Vertic Cambisols	VTCAMBISOLS	Clay	0.03	0.475
8	W290	10.944016	24.402282	Eutric Vertisols	EUVERTISOLS	Clay	0.03	0.475
9	W300	32.29327	67.755959	Chromic Luvisols	CHLUVISOLS	loam	0.34	0.463
10	W310	12.117591	5.781223	Lithic Leptosols	LTLEPTOSOLS	Sandy loam	1.09	0.453
11	W320	11.982708	68.301267	Eutric Cambisols	EUCAMBISOLS	Clay	0.03	0.475
12	W330	10.736011	9.525137	Eutric Cambisols	EUCAMBISOLS	Clay	0.03	0.475
13	W340	16.835007	111.660071	Chromic Luvisols	CHLUVISOLS	loam	0.34	0.463
14	W350	18.116096	34.439402	Chromic Luvisols	CHLUVISOLS	loam	0.34	0.463
15	W360	17.513962	29.37305	Chromic Luvisols	CHLUVISOLS	loam	0.34	0.463
16	W370	7.489333	0.514179	Fibric Histosols	FBHISTOSOLS	Clay	0.03	0.475
17	W380	13.636549	29.813984	Eutric Cambisols	EUCAMBISOLS	Clay	0.03	0.475
18	W390	25.540686	1.032387	Fibric Histosols	FBHISTOSOLS	Clay	0.03	0.475
19	W400	9.185478	27.695008	Eutric Cambisols	EUCAMBISOLS	Clay	0.03	0.475
20	W410	16.828367	38.656845	Eutric Vertisols	EUVERTISOLS	Clay	0.03	0.475
21	W420	11.642405	35.583121	Eutric Cambisols	EUCAMBISOLS	Clay	0.03	0.475

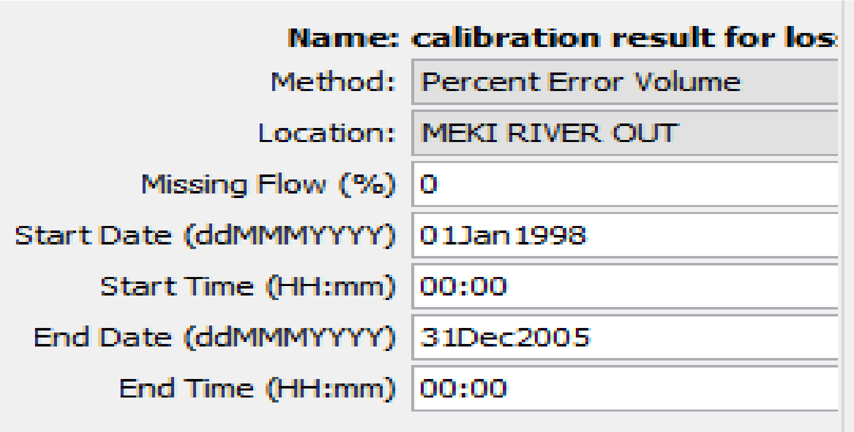
In order to model the transformation of precipitation excess into direct surface runoff, the SCS (Soil Conservation Service) unit hydrograph system was used. Lag time (TLAG), an important term in linear basin response modeling that was measured using Equation(1), is the other significant parameter.$TLAG = L^{0.8}(S + 1)^{0.7} \,/ 1900\sqrt{Y}$………Equation (1). Were. TLAG = lag time (h),L = hydraulic length of the watershed (ft.),Y = watershed slope (%),S = maximum retention in the watershed (mm) as defined by:$S = 25400/CN - 254$ ……Equation(2).

CN = SCS curve number for the watershed Based on the hydrologic soil group (SHG) and the land cover type, the Curve Number (CN) was manually calculated for the sub-basins. The CN was calculated for each unit of the sub-basin after determining the necessary soil and land cover characteristics, followed by area-weighting for the whole sub-basin. Then after, base flow was extracted using base flow extracting rule based on the manual : Groundwater 1 initial (m^3/s): initial base flow for the first layer of groundwater at the beginning of the simulation and Groundwater 1 coefficient (h): as defined in the SMA model, the response time of the sub-basin.

3.3.3 model calibration

The Control specifications are set prior to simulation and calibration of a model and determine when a simulation begins and ends and the calculation time step. The Control Specification for this model therefore extends from 1 January 1998 to 31 December 2005 with a time increase of one day and the Control Specifications for the calibration attempts have also been established. Calibration is an iterative process for minimizing an objective function (USACE, 2016). After model setup, an initial simulation was performed to obtain a base point from which to start the calibration. The model was simulated again for the entire period after the calibration was completed and the flows used to derive the river boundary inputs to the MODFLOW model were derived. To calibrate models, HEC-HMS has an integrated optimization tool(W. A. Scharffenberg, 2013) .in addition, To calibrate, an optimization test is generated by choosing a previous simulation trial to be calibrated and attempting to fit the observed dataset. Several parameters can be chosen for the program to use during the calibration process once the optimization trial is developed. To calibrate the HEC-HMS model, the twelve parameters of the SMA and river lag times were used. The purpose of the calibration is to evaluate the optimum value (i.e., non-measurable inputs) of model parameters. This time has been chosen as it includes the area's normal rainfall pattern. Flows observed and simulated are pushed to get nearer. In this case, for the Eight-year period from January 1998 through December 2005, two types of calibration runs were completed, with a time interval set at one hour for better resolution of the daily data. Therefore, the first calibration attempt was aimed at reducing the difference between the streamflow volume simulated by HEC-HMS and the streamflow volume observed.

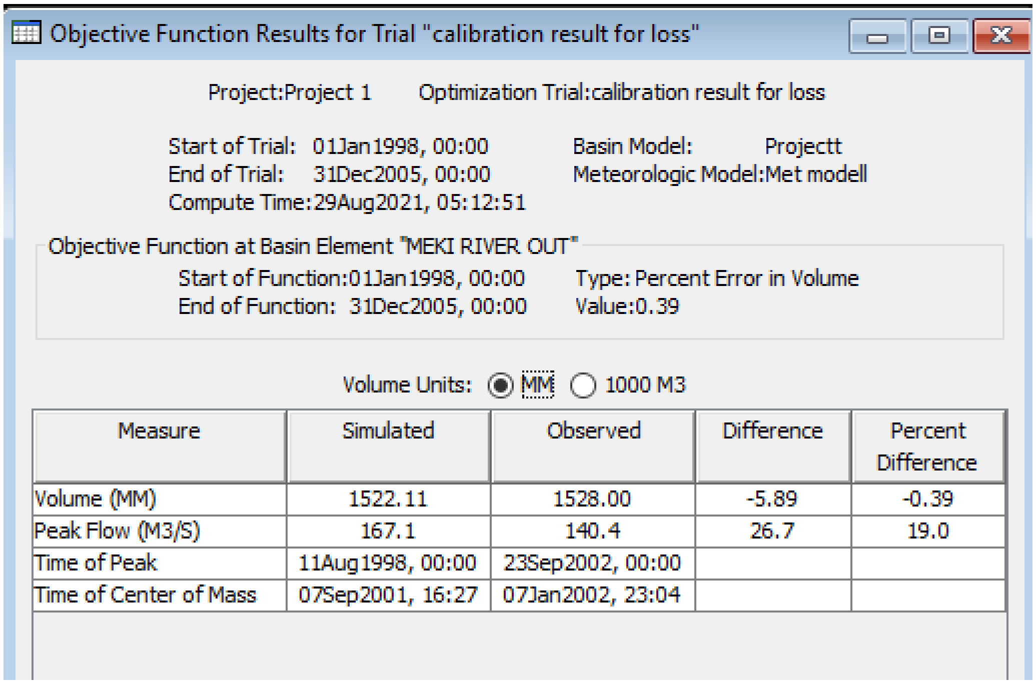
The objective function was set to Percent Error in Volume for the volume calibration. This objective feature ignores timing factors to decrease the overall volume difference over the calibration duration.(W. A. Scharffenberg, 2013) The Sum of Absolute Residuals was the objective function for the calibration of peak flow.



Name:	**calibration result for los**
Method:	Percent Error Volume
Location:	MEKI RIVER OUT
Missing Flow (%)	0
Start Date (ddMMMYYYY)	01Jan1998
Start Time (HH:mm)	00:00
End Date (ddMMMYYYY)	31Dec2005
End Time (HH:mm)	00:00

Figure 3.16 Objective function for HEC-HMS calibration for volume.

table 3. 7 Results for HEC-HMS calibration for volume.



Objective Function Results for Trial "calibration result for loss"

Project:Project 1 Optimization Trial:calibration result for loss

Start of Trial: 01Jan1998, 00:00
End of Trial: 31Dec2005, 00:00
Compute Time:29Aug2021, 05:12:51

Basin Model: Projectt
Meteorologic Model:Met modell

Objective Function at Basin Element "MEKI RIVER OUT"

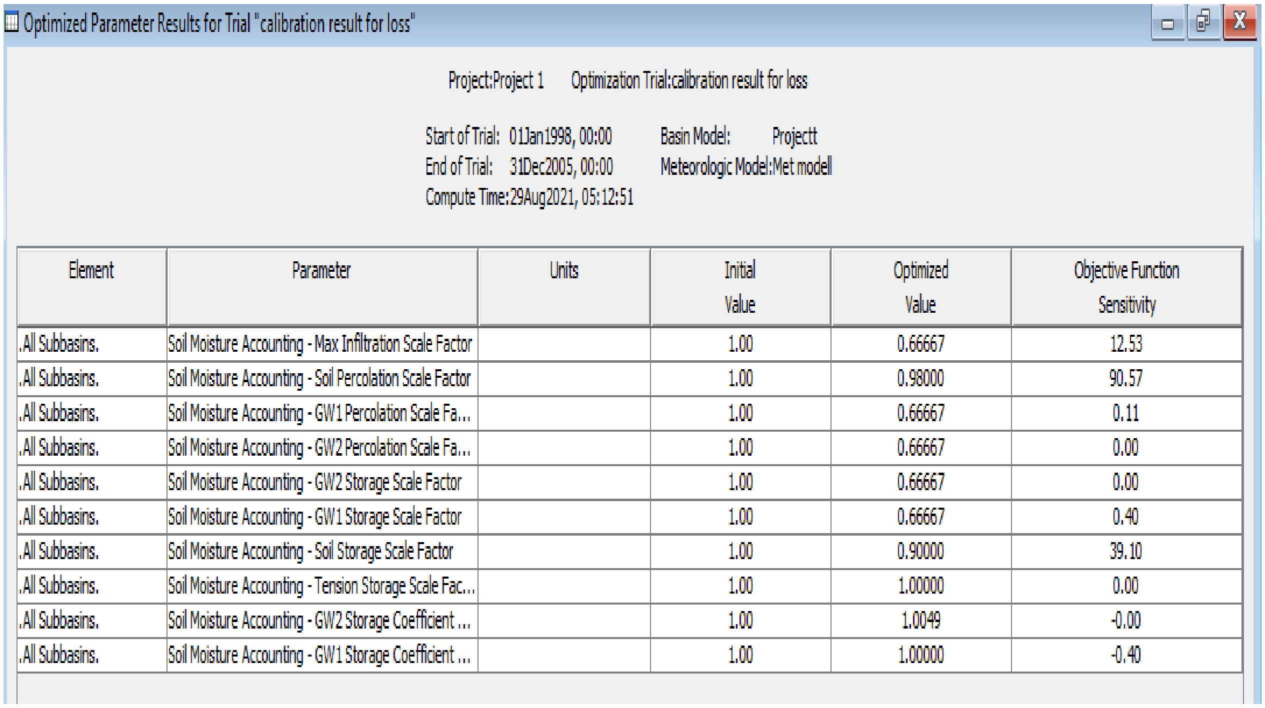
Start of Function:01Jan1998, 00:00
End of Function: 31Dec2005, 00:00

Type: Percent Error in Volume
Value:0.39

Volume Units: ● MM ○ 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	1522.11	1528.00	-5.89	-0.39
Peak Flow (M3/S)	167.1	140.4	26.7	19.0
Time of Peak	11Aug1998, 00:00	23Sep2002, 00:00		
Time of Center of Mass	07Sep2001, 16:27	07Jan2002, 23:04		

Table 3.8 Sensitivity results from calibration for volume



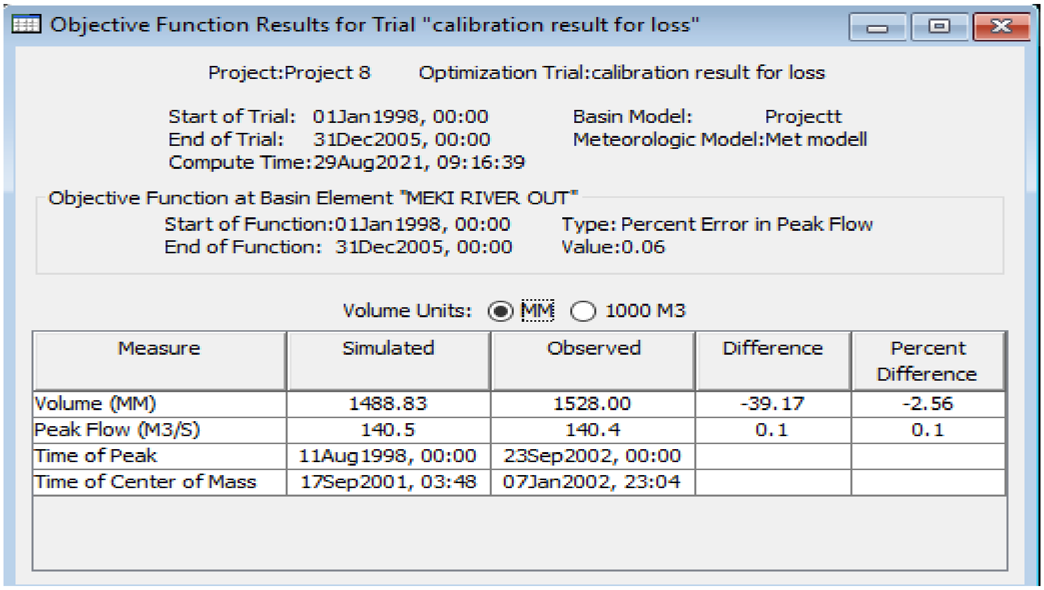
Optimized Parameter Results for Trial "calibration result for loss"

Project:Project 1   Optimization Trial:calibration result for loss

Start of Trial: 01Jan1998, 00:00   Basin Model: Projectt
End of Trial: 31Dec2005, 00:00   Meteorologic Model:Met modell
Compute Time:29Aug2021, 05:12:51

Element	Parameter	Units	Initial Value	Optimized Value	Objective Function Sensitivity
.All Subbasins.	Soil Moisture Accounting - Max Infiltration Scale Factor		1.00	0.66667	12.53
.All Subbasins.	Soil Moisture Accounting - Soil Percolation Scale Factor		1.00	0.98000	90.57
.All Subbasins.	Soil Moisture Accounting - GW1 Percolation Scale Fa...		1.00	0.66667	0.11
.All Subbasins.	Soil Moisture Accounting - GW2 Percolation Scale Fa...		1.00	0.66667	0.00
.All Subbasins.	Soil Moisture Accounting - GW2 Storage Scale Factor		1.00	0.66667	0.00
.All Subbasins.	Soil Moisture Accounting - GW1 Storage Scale Factor		1.00	0.66667	0.40
.All Subbasins.	Soil Moisture Accounting - Soil Storage Scale Factor		1.00	0.90000	39.10
.All Subbasins.	Soil Moisture Accounting - Tension Storage Scale Fac...		1.00	1.00000	0.00
.All Subbasins.	Soil Moisture Accounting - GW2 Storage Coefficient ...		1.00	1.0049	-0.00
.All Subbasins.	Soil Moisture Accounting - GW1 Storage Coefficient ...		1.00	1.00000	-0.40

table 3. 9 objective functions for HEC-HMS calibration for peak flow



Objective Function Results for Trial "calibration result for loss"

Project:Project 8   Optimization Trial:calibration result for loss

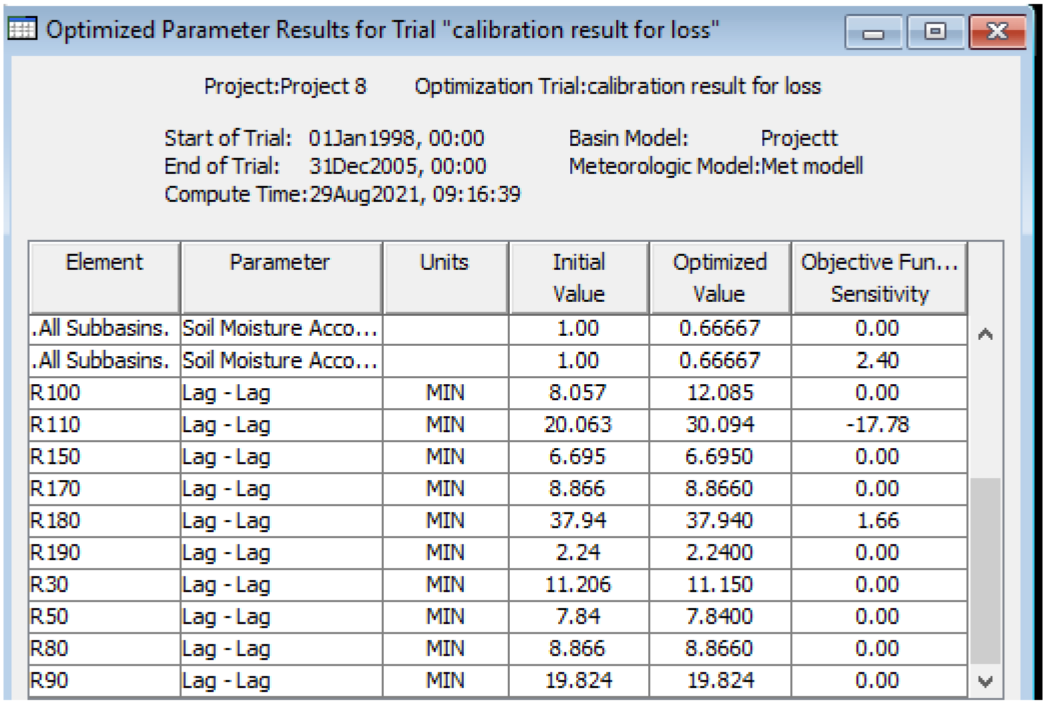
Start of Trial: 01Jan1998, 00:00   Basin Model: Projectt
End of Trial: 31Dec2005, 00:00   Meteorologic Model:Met modell
Compute Time:29Aug2021, 09:16:39

Objective Function at Basin Element "MEKI RIVER OUT"
Start of Function:01Jan1998, 00:00   Type: Percent Error in Peak Flow
End of Function: 31Dec2005, 00:00   Value:0.06

Volume Units: ● MM ○ 1000 M3

Measure	Simulated	Observed	Difference	Percent Difference
Volume (MM)	1488.83	1528.00	-39.17	-2.56
Peak Flow (M3/S)	140.5	140.4	0.1	0.1
Time of Peak	11Aug1998, 00:00	23Sep2002, 00:00		
Time of Center of Mass	17Sep2001, 03:48	07Jan2002, 23:04		

Table 3.10 Sensitivity analysis for calibration for peak flow.



Optimized Parameter Results for Trial "calibration result for loss"

Project:Project 8 Optimization Trial:calibration result for loss

Start of Trial: 01Jan1998, 00:00
End of Trial: 31Dec2005, 00:00
Compute Time:29Aug2021, 09:16:39

Basin Model: Projectt
Meteorologic Model:Met modell

Element	Parameter	Units	Initial Value	Optimized Value	Objective Fun... Sensitivity
.All Subbasins.	Soil Moisture Acco...		1.00	0.66667	0.00
.All Subbasins.	Soil Moisture Acco...		1.00	0.66667	2.40
R100	Lag - Lag	MIN	8.057	12.085	0.00
R110	Lag - Lag	MIN	20.063	30.094	-17.78
R150	Lag - Lag	MIN	6.695	6.6950	0.00
R170	Lag - Lag	MIN	8.866	8.8660	0.00
R180	Lag - Lag	MIN	37.94	37.940	1.66
R190	Lag - Lag	MIN	2.24	2.2400	0.00
R30	Lag - Lag	MIN	11.206	11.150	0.00
R50	Lag - Lag	MIN	7.84	7.8400	0.00
R80	Lag - Lag	MIN	8.866	8.8660	0.00
R90	Lag - Lag	MIN	19.824	19.824	0.00

In addition to improving the model's peak flow prediction capability, calibration for peak flow was carried out, which also yielded very good results. The resulting percent difference was 0.1 % for the objective function of the Total of Absolute Residuals . The SMA parameters recognized by the first calibration attempt were used in this calibration, and the model was calibrated by changing the lag times in each of the river reaches. It takes runoff to flow through the river as flow gets to junctions to mix with flows from other reaches to adjust the length of time. Instead of many flows merging to form a very large peak flow, changing lag times to offset the flows may result in a smaller peak flow. In addition, the table of sensitivity analysis indicates that none of the river reaches is significantly sensitive to the simulated streamflow, even with drastic adjustments between initial and optimized values of up to (50 %) modification.

It can be pointed out that the model produced relatively reasonable results taking into consideration average (time invariant) parameters were used for the whole calibrated period (8 years) and lumped parameters values for the whole area of the Meki- watershed. The Nash-Sutcliffe (1970) coefficient of efficiency (D^2) was used to judge the model performance. The estimated D^2 value for the calibration period is 0.535 which will be moderate to judge on the similarity and consistency between the observed and estimated hydrograph shape

$$\mathbf{D^2 = \frac{\sum(Y-Y_m)^2 - \sum(Y-Y_{sf})^{\ 2}}{\sum(Y-Y_m)^2}}$$

D^2= 0.535=53.58% Where: Y_{sf} : estimated flow discharges by the model , Y: observed flow discharges, Ym: mean of y in the calibration period as depicted from Fig. (3.14) the model produced moderate estimated results.

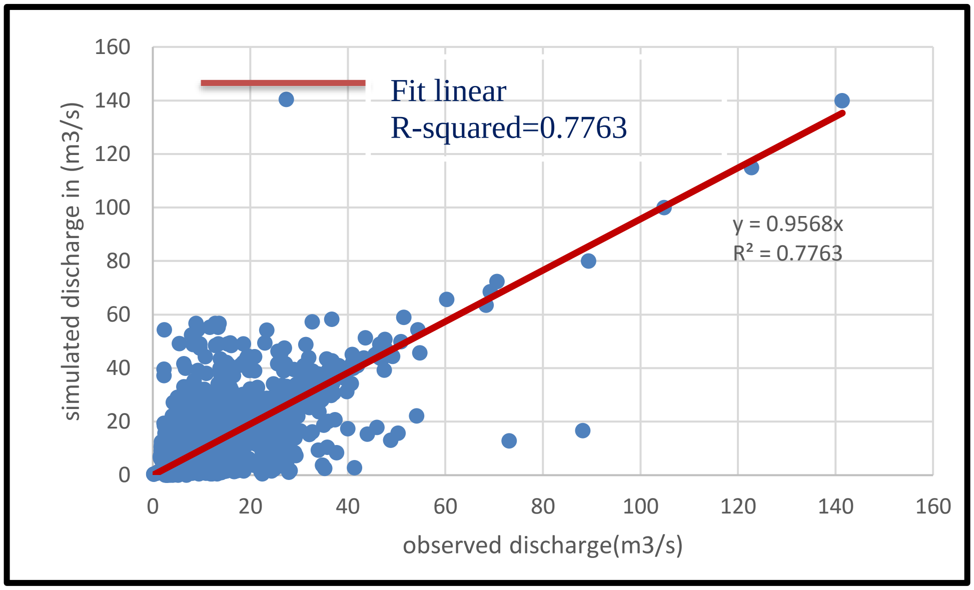


Fig. 3.17: Scatter diagram of Observed versus estimated discharge for the calibration period (1/1/1998 - 31/12/2005)

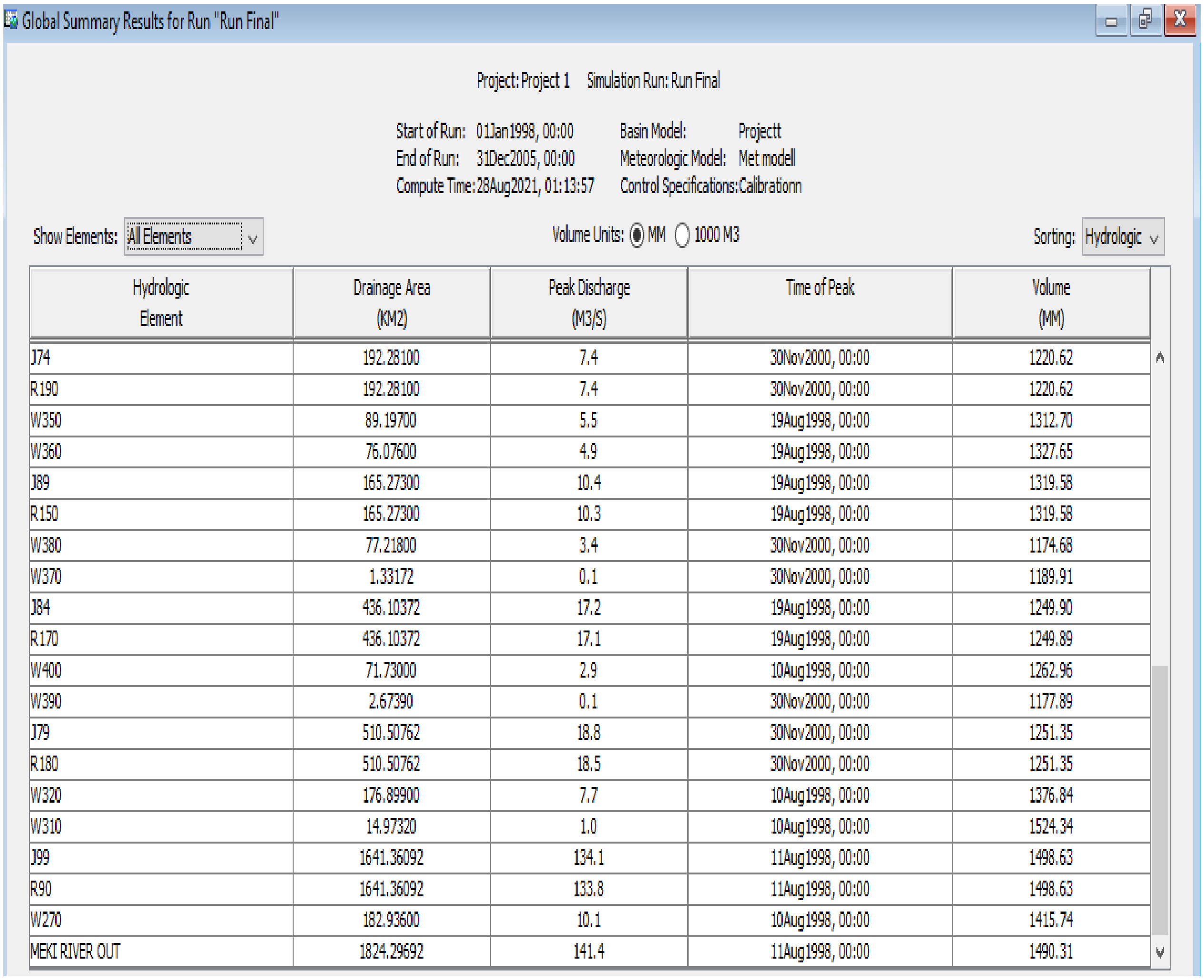
3.3.4 Validation

Simulating the model for the full 11-year period with the adjusted SMA parameters and river reach lag times completed the validation of the HEC-HMS model. Figure 4.2 shows a comparison of model simulated and observed streamflow over an 11-year period (January 1, 1998 to December 31, 2008), demonstrating that the model simulations are adequate.

3.3.5 RAINFALL RUNOFF SIMULATION BY APPLING SOIL MOISTURE ACCOUNTING (SMA) ALGORISM

Since this model is a continuous running model, potentially, both rainy and dry weather conditions may help simulate runoff. Water is collected under the SMA system in different areas, on the canopy, in surface depressions, in the soil profile and in groundwater layers. Data for soil (%), groundwater1(%), maximum infiltration rate (mm/h), impervious (%), soil storage (mm), tension storage (mm), soil percolation (mm/h), groundwater 1 storage (mm), ground water1 percolation (mm/hr.), are included in the SMA model.

table 3. 11 global summaries of peak discharge and volume for the basin



Project: Project 1 Simulation Run: Run Final

Start of Run: 01Jan1998, 00:00 Basin Model: Projectt
End of Run: 31Dec2005, 00:00 Meteorologic Model: Met modell
Compute Time: 28Aug2021, 01:13:57 Control Specifications: Calibrationn

Show Elements: All Elements Volume Units: ● MM ○ 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (MM)
J74	192.28100	7.4	30Nov2000, 00:00	1220.62
R190	192.28100	7.4	30Nov2000, 00:00	1220.62
W350	89.19700	5.5	19Aug1998, 00:00	1312.70
W360	76.07600	4.9	19Aug1998, 00:00	1327.65
J89	165.27300	10.4	19Aug1998, 00:00	1319.58
R150	165.27300	10.3	19Aug1998, 00:00	1319.58
W380	77.21800	3.4	30Nov2000, 00:00	1174.68
W370	1.33172	0.1	30Nov2000, 00:00	1189.91
J84	436.10372	17.2	19Aug1998, 00:00	1249.90
R170	436.10372	17.1	19Aug1998, 00:00	1249.89
W400	71.73000	2.9	10Aug1998, 00:00	1262.96
W390	2.67390	0.1	30Nov2000, 00:00	1177.89
J79	510.50762	18.8	30Nov2000, 00:00	1251.35
R180	510.50762	18.5	30Nov2000, 00:00	1251.35
W320	176.89900	7.7	10Aug1998, 00:00	1376.84
W310	14.97320	1.0	10Aug1998, 00:00	1524.34
J99	1641.36092	134.1	11Aug1998, 00:00	1498.63
R90	1641.36092	133.8	11Aug1998, 00:00	1498.63
W270	182.93600	10.1	10Aug1998, 00:00	1415.74
MEKI RIVER OUT	1824.29692	141.4	11Aug1998, 00:00	1490.31

3.4 GROUND WATER MODEL CONCEPTUALIZATION

A conceptual groundwater model is a diagram or cross-section of the groundwater flow system (Cowin et al., n.d.). The dimensions of the numerical model and the grid design rely on the nature of the conceptual model. Groundwater models try to reflect a genuine groundwater aquifer system with a mathematical counterpart. Groundwater models that are conceptual depict how water enters and moves through an aquifer system. A conceptual model is a simplified version of the underlying aquifer system under investigation. The following are some of the characteristics that are frequently mentioned in conceptual models:-

- ✓ Define boundary locations
- ✓ Define the material properties of aquifers (like, hydraulic conductivity).
- ✓ Systemic stresses (withdrawal wells, infiltration trenches, etc.) (Cowin et al., n.d.).

3.4.1 hydrogeology

3.4.1.1 aquifer hydraulic properties

Existing data, fieldwork, indirect and direct, qualitative and quantitative approaches were utilized to determine the hydraulic parameters of the aquifer used in the conceptual model and for the first run of the numerical model. In order to see the lateral distribution and nature of the aquifer, existing pumping test data, geologic map, hydrogeological map, soil map, lithology obtained from well logs, aquifer thickness, water table depth, structures and surface water features, and so on are used to characterize the hydraulic properties of the aquifer. For the research area, the geographical distribution and magnitude of hydraulic characteristics of the aquifer are unknown. During model calibration, the hydraulic conductivities of the aquifer were modified.

3.4.1.2 hydraulic conductivity distribution in the catchment

The main parameter for conceptual model development is hydraulic conductivity. In this research field, the rocks in the study area have different permeability due to lithology, primary and secondary structure variation, fragment size of pyroclastic sediments, and weathering grades. The catchment is divided into five ranges of permeability due to the absence of comprehensive research and time constraints. According to(Mitiku, 2011a) the first classification ranges from moderate to very high permeability area (K: 10 - 20 m/day). This region consists of recent basalts and heavily eroded ignambrites in the eastern fault Escarpment; and along the main fault, scoria cones east of Butajira. Conductivities in these areas are mainly associated with joints, faults, vesicles and the scale of the scoria fragment. Second, the range (K: 5 - 10 m/day) of the Medium to High Permeability Region. There are less welded ignimbrites, less broken basalts, alluvial and colluvial deposits intercalated with pumice fragments, found at the foot of volcanic mountains. Based on the characteristics of ignimbrite, fracturing and weathering grade, the units possess medium to high permeability. Thirdly, there is a medium permeability zone (K: 1 - 5m/day). Broad areas are protected by this permeability zone around the lake. The lithological groups found in this region are Ignimbrites alternating with lacustrine sediments such as: clay, diatomite, shale beds, and reworked pumice. The group also contains rhyolite, pumice, tuff and ignimbrite of low secondary permeability; and is dominantly covered by silty soil, black cotton soils, and sometimes lacustrine sediments. The fourth permeability zone varies from low to medium (K: 0.1 - 1m/day). It is the largest zone comprising much of the eastern highland mountain regions of Chilallo, Kakka, Galama and Guraghe Mountain. The rocks comprising this area are strongly welded ignimbrites, tuff, rhyolite and trachyte without identifiable large faults. The permeability of the soils and the upper weathered rock. The volcanic sequences that underlie them, however are enormous. Last classification range; very low permeability zone (K: 0.01-0.1m/day). The group consists of acidic volcanic plugs and caldera rims with subordinate obsidian lava flows controlled by silicon pyroclastic including pumice flow and ash.

3.4.2 Occurrence of groundwater

According to (Mitiku, 2011a)The key geologic units for the presence of groundwater in the research region are Quaternary sedimentary deposits and volcanic formations. Except for a minor outcrop near Kela town, Mesozoic sedimentary strata are found at larger depths, potentially exceeding 1000m, as can be calculated from rift displacement in the area. The area has Quaternary sedimentary layers ranging in composition from clay to gravel, as well as depositional environments ranging from lacustrine to fluvial, fan, and tulus deposits. In the Ziway plain, the dominating lacustrine deposit may be found. Clay and silt deposits alternate with reworked pyroclastic deposits such as pumice, ash, and volcanic shards in this sediment. This deposit is often over 200 meters thick. Despite its heterogeneity, this formation represents one of the primary aquifers in the studied area. As a result, the Ziway plain sediment is one of the most important aquifers to consider for groundwater development. The Kuntane-Inseno-Kela plain was the second area of sediment deposition. Sediment deposits consisting of lacustrine, fluvial, pyroclastic, talus, and fan deposits characterize this plain. It has 200-meter-thick sediment deposits. In the study area, there is also a large aquifer zone. Finally, the Butajira Crescent, which has an average thickness of around 80 meters and is characterized by gravel and sand deposits with clay and silt produced from fan, talus (debris flow), and river deposits. Despite its small size, this location is also believed to have a good aquifer.

The study area's principal volcanic formations are Quaternary pyroclastic deposits. The earlier volcanic formations (Tertiary Volcanic Rocks) are found deep beneath the Quaternary strata in escarpment locations. Minor rhyolite and basaltic formations can be found west of Lake Ziway and in the Butajira area. The rift pyroclastic deposits are the primary formations in terms of groundwater. In the studied area, these deposits can be regarded important volcanic aquifers.

In the rift valley area, earlier volcanic rocks made up of rhyolites and basalts are found in the escarpment and deep beneath the Quaternary deposits. In broken locations, these rocks can be major fracture aquifers. As a result, these formations, particularly those in the rift fracture zones, may serve as major aquifers. Under the Tertiary volcanic layers, the Mesozoic sedimentary formations (limestone and sandstone) are located over 1000m below the current ground surface. These are aquifers with a high potential for groundwater. The little exposure near Kela village is located on the escarpment and is not significant as a groundwater source.

3.4.3 Groundwater level and movement

Groundwater flows from recharge zones to discharge zones. Transpiration from plants rooted below the water table can discharge to the atmosphere; streams, lakes, and other surface-water bodies can discharge to the atmosphere; and pumping wells can discharge to the atmosphere. On the basis of the available data table 3.11 below and by using surfer software to draw the contour, groundwater flow directions have been estimated. The study area's groundwater flow is primarily from the western escarpment towards Lake Ziway, indicating that it is the primary recharge source. Except for the Tora-Koshe-Dugda ridge and the Cinder Cone sections, the groundwater level is mainly flat to gradual slope. Because of the structure of the rocks or the fault systems that separate these zones, the groundwater contour shows a steep slope with decreased permeability in these locations(Mitiku, 2011a). The groundwater level in the Butajira Crescent area dips from roughly 2000 m to 1800 m.a.s.l in the Kuntane Inseno area.

The Cinder Cone and basaltic flows that erupted along a regional fault likely function as a barrier or limited permeability zone, resulting in a steep groundwater slope. The Crater Lake Har-Shetan is located in this area. AG Consult, Consulting Hydrogeologists & Engineer had been monitoring groundwater levels at Tora-Koshe-Dugda Ridge, Kuntane-Inseno-Kela plain, Cinder Cones and Basalt, and Butajira Crescent (Anuary, 2008b).The result reveals that when the lake level rises, the water table in the aquifer adjacent to the lake rises, showing that the aquifer close to the lake is replenished by lake water. During the monitoring period, the groundwater in the Tora-Koshe-Dugda ridge did not show any changes in the water table. This indicates that the aquifer either has a high storage value or does not get significant seasonal rainfall recharge. Significant water level changes have been seen near the fault line dividing the Kuntane-Inseno-Kela plain from the Tora-Koshe-Dugda ridge. This shows that the aquifer receives both direct and lateral groundwater recharge. This could imply that the fault zone in this area has a low storage coefficient, causing the groundwater level to fluctuate a lot. The well in the midst of the Kuntane-Inseno-Kela plain also shows a very low seasonal response. This is due to the fact that the aquifer on this plain has a higher storage capacity.The water level in the well in the Cinder Cone location has likewise remained constant. This could indicate that the scoria formation has a high storativity.(Anuary, 2008a) Significant water level variation has been seen at the Butajira Crescent observation location (up to 6 m). This is due to the clayey sediment's low storage parameter at this location.

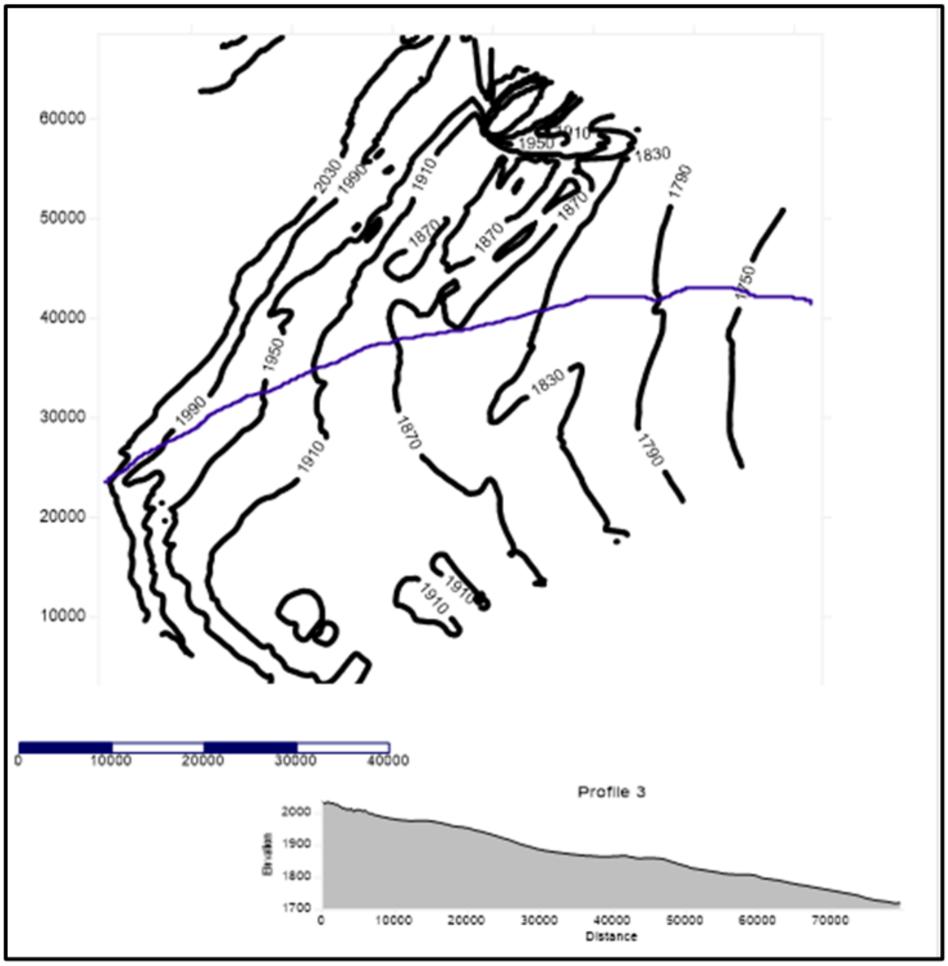
Table 3.12 observed static water level collected for 90 wells,source:RV GW point data base(MOWIE),(Anuary, 2008a,Halcrow,2007,).

Borehole Name/ID/code	UTM-E(M)	UTM-N(M)	SWL(M)
BH-2	453276	901204	1810
BH-16	435517	877276	1820.81
BH-17	439069	878182	1807.67
BH-18	438154	876204	1808.38
BH-22	447247	889418	1810
BH-26	432756	897440	2003.3
BH-30	430941	896250	2048
BH-35	432428	886909	1847.74
S.Shershra	436926	899128	1883.45

Weja	446999	886227	1820.4
Inseno test well	440020	888300	1828.56
DebubYeberaswrha	435517	877276	1788.81
Debub Goto	438154	876204	1703.38
SemenSanbeunfila	439069	878182	1809.67
Kosh test well	448646	885794	1732
BH-41	432501	898201	1973
BH-42	436926	899049	1854
RV2288	429307	897130	1871
RV2365	449039	891512	1837
RV2372	438896	894475	1910
RV2436	445134	895474	1825
RV2566	449214	913780	1923
RV5274	426254	887320	2000
BH-6	441974	890758	1749
BH-12	415084	877224	2094
BH-15	436818	892494	1758
BH-31	435852	869258	1682
BH-32	453015	883724	1524
BH-33	447720	875620	1565
BH-34	446742	872640	1592
SW	441811	891169	1817.5
SW	445587	890527	1812
SW	446858	889032	1817
SW	440559	886885	1823
SW	440854	889603	1821
SW	439032	888026	1822
SW	438206	887054	1820.4
SW	439526	889020	1822.5
SW	439537	889407	1822
SW	439689	889746	1822
SW	447780	886782	1813
SW2-1	443712	908129	1880
SW2-2	442690	908775	1889
SW3-1	441925	908580	1897
SW3-2	443068	907196	1878
SW3-3	444979	905272	1868
SW1	446896	904607	1850
SW1	443288	909887	1818

Jole-1(SW)	440195	905819	1886
C-camp(SW)	440014	905638	1896
(SW)	448520	858400	1776
Jole-3(SW3)	444039	903498	1848
Jole-2(SW2)	442310	904952	1865
Adel(SW2)	448953	900604	1812
Gose(SW)	447562	904659	1833
Inseno(HDW)	442017	891450	1825
Gogeti(HDW)	442293	908704	1897.5
SW-10	440195	905619	1886
SW-11	443712	908129	1880
SW-12	443068	907198	1878
SW-14	444979	905272	1868
SW-15	442310	904952	1865
SW-16	447042	906854	1855
SW-17	446896	904607	1850
SW-18	444039	903498	1848
SW-19	431103	880724	1834.5
SW-20	437645	890366	1833
SW-21	447562	904659	1833
SW-22	438525	892515	1832
SW-23	438398	891339	1828.5
SW-24	434096	877393	1827
SW-26	430723	880064	1825.75
SW-27	440559	886885	1823
SW-28	441913	891311	1822.5
SW-29	439526	889020	1822.5
SW-31	434916	877533	1822
SW-32	441620	889345	1822
SW-33	439032	888026	1822
SW-34	444425	890845	1821
SW-35	440854	889603	1821
SW-37	438206	887054	1820.4
SW-39	445997	892208	1819
SW-41	448674	899951	1818
SW-43	446858	890325	1817
SW-44	431974	879460	1816
SW-45	441090	883120	1816
SW-46	445831	891566	1815

SW-47	441700	884120	1814
SW-48	447780	886782	1813
SW-49	445587	890527	1812



— Cross section line

Figure 3.18 observed ground water contour and its cross-section.

3.4.4 Boundary conditions

The initial step in every groundwater modeling study is to define the research area's boundary conditions. In order to have a comprehensive understanding of a hydrologic system in the investigated area, it is important to appropriately identify and assign system boundaries. The two forms of system boundaries are physical and hydraulic system boundaries (Cowin et al., n.d.) The physical boundaries of groundwater aquifer systems are formed by the existence of an impermeable mass of rock or a large body of surface water. Hydraulic boundaries are invisible and might include groundwater splits and streamlines. They are formed by hydrologic circumstances. In addition to mathematical equations, evidence regarding the physical condition of the process is required to produce a single solution for the difficulties found in the study region during modeling. Constant head boundaries can be seen at the edges of bodies of water such as lakes or reservoirs.

A constant head boundary in a flow net has a line of constant head running along it, and streamlines are perpendicular to it. At the border between the aquifer and materials with much lower hydraulic conductivity, no-flow boundaries form. Constant head lines are perpendicular to a no-flow boundary, which is a streamline (Stream, 2015). Outside of the groundwater model domain, boundary conditions describe how an aquifer interacts with the environment. Heads at surface waters in contact with the aquifer, as well as the position and discharge rate of a pumping well, are examples. At least one separate boundary condition is stated for each distinct solution. Boundary conditions are divided into four categories, each of which is derived from the two most prevalent.

1.Constant Head Boundary: The head is known, and the source of water has a constant water level at the groundwater model border, hence this is a sort of stated head boundary condition. This condition is used to mimic an aquifer in close proximity to a lake, river, or other external aquifer. Groundwater is usually in direct contact with surface water, such as a lake or a river, and drains freely interact with the aquifer. Dirichlet boundary is the mathematical term for it.

2.No flow Boundary (across which no flow occurs): The no-flux, zero-flux, impermeable, reflecting, or barrier flux boundary is a highly particular sort of specified flux boundary. No flow borders are impermeable barriers that allow no flux to pass through. They are physical or hydrological barriers that prevent water from entering or leaving the model domain. When creating the model grid's boundary or declaring grid blocks as inactive (i.e., hydraulic conductivity = 0), no flow boundaries are provided. For this investigation, impermeable floors are used as a no-flow border. No-flow boundaries, specified head boundaries, specified flux boundaries, and leakage boundaries are just a few of the boundary conditions that the finite element method can handle (Stream, 2015).

3.Constant Flux Boundary: The second type of defined flux boundary condition is Neumann's condition, sometimes known as recharge borders. Water flow into and out of the aquifer is regulated. The amount of induced recharge to the aquifer is described by this boundary condition.

3.4.5 Aquifer Geometry and Stratigraphic Units

The following definitions are necessary under the ground water conceptual model: that is, the scale of the modeling domain was taken as close to the magnitude of the watershed of the study. The limits of the model have been calculated in such a way that it encompasses the whole region of interest and coincides with hydrological limits. The simulation domain was divided into 300m by 300 m finite-difference grid cells of equal size. And also, from 30 m by 30 m resolution DEM data, the top surface of the model was collected (Digital Elevation Model). Furthermore, with the MODFLOW setting 'LAYCON=1, unconfined', the unconfined aquifer with the study region boundaries was modeled as one sheet.

In deciding the number of layers regulating groundwater flow within the system, identification of hydro stratigraphic units is crucial. A hydro stratigraphic unit consists of geological units with similar geological hydro characteristics. It is possible to group multiple geological units or subdivide a single formation into various aquifers and aquitards(McDonald & Harbaugh, 1984). The stratigraphic units are discretized in a separate basement from the drilling lithological definition and well logs. The aquifer thickness in this study is very rough, which lies within the (80-265) m interval. But, except for the central part of the Inseno-Kosh-Dugda and cindare cones areas where high elevation ridges are located, in most parts of the watershed(Anuary, 2008b).

3.4.6 Groundwater discharge

The aquifer system not only receives a recharge but also releases its resource back into the system. Abstraction of groundwater from the study area's aquifer system, springs, base flow to surface water bodies, inter basin or aquifer system transfer, and evapotranspiration are all possible sources of groundwater removal. Springs and seeps discharge to streams in the study region, and there are many perennial springs with good discharge that originate from the western escarpment and run to streams before draining to Lake Ziway.

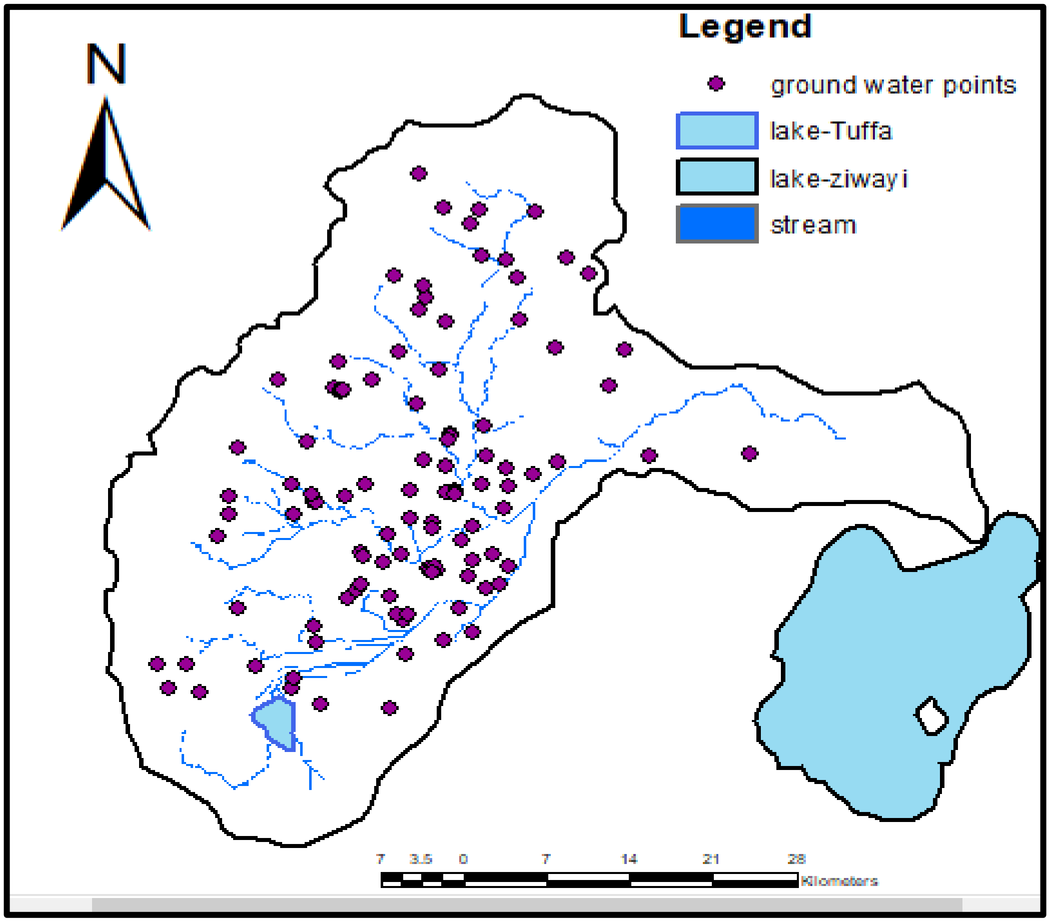


Figure 3.19 Spatial distribution of groundwater abstraction well

3.4.7 ground water recharge

Taking into account the various geomorphological and hydro-geological arrangements in the study region, groundwater recharge in the area can be considered.(Anuary, 2008b)The following are important geomorphological features that regulate the condition of recharge in the region. The western escarpment, Butajira Crescent, cinder cone area, Kuntane-Inseno-Kella Plain, Tora-Kasha-Dugda Ridge. First of all, by groundwater inflow and surface runoff, the western escarpment leads(Anuary, 2008b). From this escarpment, the Big River Meki originates. The recharge flows as ground water to the rift valley region in the western mountains. Recharging from this mountain may not be restricted by the boundaries of the river catchment. Third, as a result of its fracture-oriented flow, the Cinder cone areas slow the flow of groundwater as a result of its low permeability. This area is not necessary to recharge from other sources, except for direct rainfall whose recharge is not substantial. Fourth, there are three major recharge components for the Kuntane-Inseno-Kella Plain. Recharge from direct runoff, flood from the western escarpment and from streams and rivers flowing to this plain to recharge. Third, as a result of its fracture-oriented flow, the Cinder cone areas slow the flow of groundwater as a result of its low permeability. This area is not necessary to recharge from other sources, except for direct rainfall whose recharge is not substantial. Fourth, there are three major recharge components for the Kuntane-Inseno-Kella Plain. Recharge from direct runoff, flood from the western escarpment and from streams and rivers flowing to this plain to recharge. Finally, deep groundwater, with the exception of groundwater inflow, characterizes Tora-Koshe-Dugda Ridge; direct recharge is not necessary in this region. Finally, some of the following methods would be used to estimate recharge for each geomorphological area for the modeling purpose; Water Balance Method, Empirical Relationship, Chloride Method, based on satellite data and Recharge Estimation Using Model Estimation. Therefore, I could pick recharge estimation from the above lists using model estimation .since model predicts the amount of recharge in Meki-river catchment with limited data and time referred in appendix 6.so, hydrological model recharge estimation (rainfall-runoff tool in HEC-HMS known as Soil Moisture Accounting (SMA) was used.

3.4.8 OVER VIEW OF GROUND WATER - SURFACE WATER INTERACTION

Traditionally, surface and groundwater sources are treated separately in water management activities. These sources are tapped for more and more water with the rise in population and water demands that require careful consideration of their quantity and quality. According to (USGS, 2012)Nearly all surface water sources (streams, dams, reservoirs, wetlands, and estuaries) communicate with groundwater in the form of water recharge to the aquifer or groundwater contributes to the bodies of surface water that may have problems with quantity and quality. As a consequence, water drainage from streams may deplete groundwater or, conversely, groundwater pumping may deplete water in streams, reservoirs, or wetlands. Although surface and groundwater systems are in complex contact, a hydraulic head differential is a function of recharging or gaining water into the surface system of the groundwater system. It is called the gaining mechanism in the event of water contributing to the surface system and the water table would be higher relative to the bed of streams. Conversely, groundwater recharge from surface water sources can occur when the groundwater table is lower relative to the bed level of surface water bodies. The baseflow of streams provides groundwater discharge to streams and is also a primary component of the overall streamflow. Surface water contamination can cause depletion of the quality of groundwater and, conversely, groundwater pollution can contaminate the water in surface water bodies. Successful management of land and water therefore requires a clear understanding of the relationship between systems of groundwater and surface water.in addition,The hydrogeology of the catchment is discussed in this section based on the perineal river flow characteristics with regard to geology, groundwater elevation contours, slopes and environment, as well as modeling the regional groundwater flow of the catchment in order to investigate the relationship between surface water and groundwater in general.

3.5 GROUND WATER MODEL

3.5.1 Modeling materials for groundwater

Global Mapper (18), GIS (10.4.1), and surfer (12) were used depending on the purpose and form of data to be simulated to GW-SW interaction and their effect assessment in the research topic. Each software's application during the thesis work is described below, along with the groundwater modeling approach.

3.5.1.1 Use of GIS software

- GIS is critical for this analysis because it is used to analyze climate data, previous groundwater borehole data, topographic data, land use and land cover data, and it is used to coordinate and handle data from the Ministry of Water, Irrigation, and Energy (MoWIE).

- .The stream network is also produced using GIS, indicating that the study area contains a variety of perennial and intermittent rivers. The perennial rivers will be used as a constant head boundary in the groundwater model.

- The boreholes, rainfall gauging stations, and river gauging stations must all be located.

3.5.1.2 Use of Surfer software

Surfer can be used to preprocess groundwater modeling data, and it was (a) used to generate model data that met the groundwater model's requirements. Surfer preprocesses all of the groundwater simulation input parameters, (b) to check the uniform distribution of the terrain profile in the basin, the global mapper path profile documents can be modified to model input and blanked file formats, respectively, to outright the XYZ grid global mapper information, (c) to plot the river basin's topography uniformity map (d) to convert excel files to surfer model input files (e) to construct the study area's model grid.

3.5.1.3 Use of Global mapper

Global mapper software can discretize the groundwater problem in the study area. By discretizing the groundwater issue and delineating the study area, the global mapper can be used. Since the global mapper program is stress-free when it comes to DEM delineation and interpretation. The study area must be described through a series of procedures, (a)The first step is to open the country's digital elevation model (Ethiopian DEM) in the global mapper software working window. The Ethiopian mapping agency provided the digital elevation model (DEM) with a resolution of 30m*30m. (b) after placing the DEM on the global mapper working space, selecting the file menu from the global mapper toolbar and exporting the file in global mapper package format, (c) On the global mapper working space, after exporting the file, a dialogue box appears, from which we can pick export bounds. (d) finally, from the dialogue box, pick the box delineation instruction menu and delineate our study area in box size, saving the values anywhere you want.

3.5.2 OVERVIEW OF THE MODEL

Through the MODFLOW model software processing (version 5.2.0.1), which is based on the finite-difference method, the three-dimensional groundwater flow equations that form the groundwater flow model of this study were solved. As a one-layered and steady-state condition, the groundwater flow model was set up. In general, the purpose of the model was to simulate the groundwater flow of the unconfined aquifer and thus analyze the distribution of water table elevations and groundwater fluxes in order to manage the sustainability of the sub-basin groundwater system in order to create a numerical model, it is necessary to analyze the movement of water within the hydrological units that set up the groundwater system on the basis of the U.S. The flow in the upper-Meki catchment was simulated by a modular three-dimensional finite-difference groundwater flow model geological survey.

The model was carried out to handle the input and output environment in the code supplied using the Processing Modflow Pro interface (Version 5.2.0.1.) (Kinzelbach, 2014). It is also essentially based on the physical theory of groundwater flow, Darcy's law and the equation of continuity. The steady-state groundwater flow is typically simulated in a three-dimensional aerial view based on the following governing differential equation (McDonald & Harbaugh, 1984)

$$\frac{Kx\partial^2 \mathrm{h}}{\partial x^2}+\frac{Ky\partial^2 \mathrm{h}}{\partial y^2}+\frac{Kz\partial^2 \mathrm{h}}{\partial Z^2}=0$$

Where: Ky, Ky and Kz are hydraulic conductivity terms along the three axes and the units are in(l/t) also h indicates the hydraulic head(m).

3.5.3 model characteristics and structure

3.5.3.1 model grid size

There are 240 columns, 230 rows, and one layer for a total of 55,200 cell nodes in the finite difference grid, and each cell size has a uniform grid size of 300 m by 300 m. The size of the model is high, but it serves the purpose of understanding the regional ground water flow mechanism. The model grid, boundary conditions, flow package (rivers and well packages) are shown in Figure 3.19; active, inactive and constant head.

3.5.3.2 Top of layer

It is the top elevation of the confined aquifer layer under consideration and drawn from the ASTER digital elevation model of 30m-by-30m resolution. The aquifer was considered to be a single layer and unconfined in this study. The top layer elevation was therefore deemed to be the ground surface elevation. In this case, the DEM data is interpolated using global mapper 18 as field data to generate a grid file in a format compatible with the Processing Modflow Pro (Version 5.2.0.1.) and imported into the elevation model referenced by its geographical position.

3.5.3.3 Bottom of layer

It is modelled on the bottom elevation of the aquifer layer. The aquifer thickness, which lies within the (80-265)m interval, is very rough in this study. But, except for the central part of the Inseno-Kosh-Dugda and cindare cones areas where high elevation ridges are found, in most parts of the watershed. Because of this, higher altitude zones have been simulated by assigning relatively higher cell depths in order to avoid cell drying during simulations. In most parts of the sub-basin, the bottom layer was therefore removed by subtracting a range of (80-265 m) from the top elevation. The thicknesses of the aquifers are generally very irregular as they have not yet been determined precisely for the aquifers.

3.5.3.4 boundary conditions

In figure 3.19 below the boundary conditions are shown. According to(Anuary, 2008b) The major part of the boundary is flux boundary inflow in western and northern direction as well as at lake-Ziway out let direction and The western and northeaster escarpment areas of Meki catchment which are out of the model boundary the recharge computed as flow rate based on the area covered by them and assigned in the model as flux. But, the remaining part of the boundary taken as no flow boundary. The recharge and well discharge within the actual model boundary in the catchment are provided by **specified flux boundaries** in the model. Ziway lake is at the catchment outlet under the model boundary and is regarded as the internal **specified head boundary**.

The following hydrological process is included within the model boundary: recharge, groundwater flow to and from streams, well withdrawal and groundwater outflow to Lake Ziway. In addition, the surface water simulation outcome of precipitation recharge is represented as a specified-flux boundary condition. **Recharge** to the groundwater system was provided through consideration of groundwater sources from **precipitation infiltration** and is simulated as a specified flux to the top layer of the model.

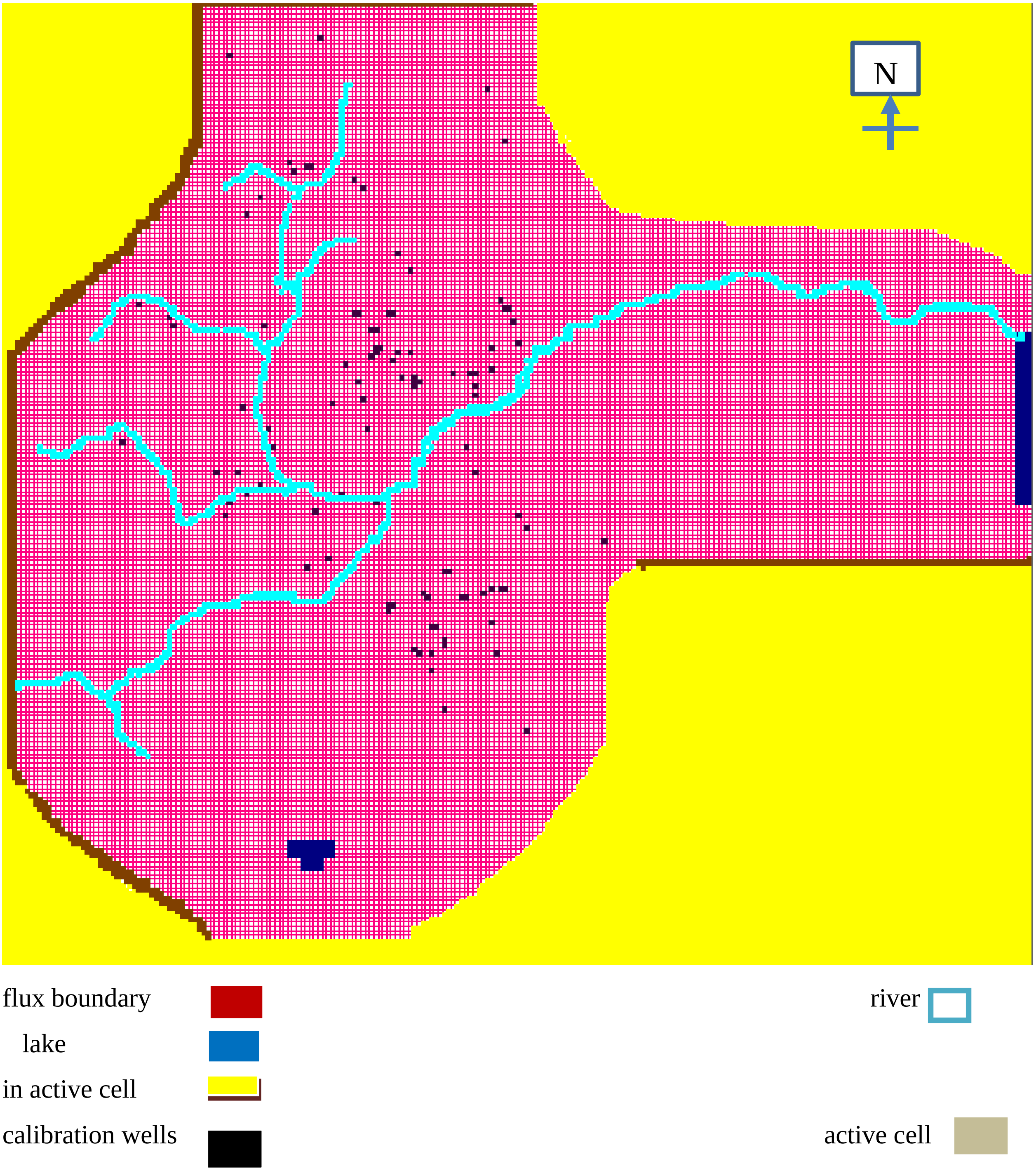


figure 3. 20 the model grid and boundary condition

3.5.3.5.river package

under the consideration of the conceptual model the perennial river is also important boundary condition and used to simulate the flow of water between aquifer and river.as well as, the package of the code described by(Kinzelbach, 2014).therefore, It allows water to flow from the aquifer to river, thereby removing water from the model by seepage to gaining stream reaches. In addition to this, Water can also flow out of the stream into the aquifer. however, the seepage out of the stream is independent of the stream discharge. Thus, a losing reach of stream could recharge the aquifer with higher elevation is being carried in the stream.

The river package takes the river bed conductance by considering the following variables; Length(m), width of river channel(m), river bed sediment thickness (m) and vertical hydraulic conductivity (Kr).That means, Criv=KrLW/M (1b). then, the leakage rate between the aquifer and the river is calculated as follow;

$Q_{riv}=C_{riv}$ (Hriv-h), when $h>R_{bot}$(1c).Whereas, Hriv; the head in source reservoir and h; is the head in aquifer below the source reservoir; at the time the water table decline below the bottom of the stream bed (R_{bot}), leakage stabilizes as well as, Q_{riv} is determined from the following equation: $Q_{riv}=C_{riv}(Hriv-R_{bot}),h<R_{bot}$(1c)

Western Ziway catchment include Meki river, Lebu,Irenzaf,Weja and Akamuja perennial tributaries. The movement of ground water to or from streams is a function of the head in the stream, H_{riv}, also known as stream stage. Stream stages used in this simulation were determined by taking an approximate average stream elevation within the cell based on the observed field value, and ASTER DEM derived from a 30m-by-30m resolution. The rate of water movement to and from a stream in response to a given head gradient is controlled by streambed conductance .

table 3. 13 perineal river package input((Makin et al., 1976)

number	River (main and tributary)	Conductivity(m/day)	Sediment bed thickness(m)	River head(m)	River width(m)
1	Lebu-river	0.12	0.76	1879.66-2164.54	7
2	Meki-river(main-perineal)	0.09-0.12	1	1637.3-2001	7.25-15
3	Akamuja-river	0.12-0.27	0.8	1834.43-2371.59	8.5
4	Irinzaf river	0.076-0.27	0.85	1815.54-2296.69	7-8.5
5	Weja River	0.13	0.84	1808.68-1938	6-10

The final boundary condition is groundwater withdrawal, which is simulated as a specified flux. In the study area there are irrigation, public water supply and individual domestic wells pumping from the aquifer. Specified fluxes are removed from cells corresponding to the geographic locations of the wells

3.5.3.6 Initial and prescribed hydraulic head

MODFLOW processing requires initial heads to begin the simulation. It was then obtained by subtracting a constant value of 30 m from the top elevation of the sheet, based on aquifer topography and conceptual hydrogeological map, over a wide area. After that as initial heads in active cells, the real value of water level elevation was given.

3.5.3.7 Hydraulic conductivity

The number of layers is one in this model since flow inside the layer was considered to be horizontal. Hydraulic conductivity is the amount of water that flows under a unit hydraulic gradient through a unit area calculated at right angles to the flow direction through a porous medium in a unit time. Both the medium and the fluid are a function of hydraulic conductivity. The hydraulic conductivity that determines the flow rate of the groundwater in the aquifer system is the required parameter in the aquifer system. The model used a hydraulic conductivity of 0.0. About 1 m/day and 20 m/day (taken from professor Tenalem ,1998).

3.5.3.8 Groundwater recharge

The groundwater recharge per day is simulated from surface water model of river flow in sub-basin total area of 1824 km^2. Assign the total daily spatial distribution of groundwater recharge to the whole sub basin. That means, Recharge to the model is applied by computed result from HEC-GEO HMS (SMA) In this model Recharge was applied to the active model area as a spatially varying, specified flux to the highest active cell. Generally, precipitation recharge changes spatially with land surface permeability, which is a function of soil characteristics and land use, and spatial distribution and intensity of rainfall. since model predicts the amount of recharge in Meki-river catchment with limited data and time referred in appendix 6. Therefore, from the surface water simulation result the amount of annual recharge to western Ziway-Meki river catchment applied in this model is 64.6 mm/year or (1.769×10^{-4})m/day.

3.5.3.9 Discharge

In the model area, discharge from groundwater systems includes groundwater withdrawal, groundwater outflow to Lake Ziway and discharge to stream and different MODFLOW packages were used to simulate these discharge components.

Discharge to streams were modeled using the river package and was used to simulate the hydraulic connection between groundwater and surface water by allowing streams to gain or lose water, based on the difference between the surrounding hydraulic head and stream stage, through riverbed material of a specified hydraulic conductance (McDonald & Harbaugh, 1984).Estimated riverbed conductance was based on model calibration. Model cells were designated as river cells along major streams and tributaries where the ground water table intersected the land surface.

In the model, pumping wells were simulated with the well package and by assigning the recharge rate of the well negative values are used to assign pumping wells, then positive cell values indicate injection wells. The injection or pumping rate of a well is independent of both the cell area and the hydraulic head in the cell. MODFLOW assumes that a well penetrates the full thickness of the cell.in case of, shortage of well-construction data available, all wells were assumed to be fully penetrating in the layer.

3.5.4 MODEL INTERPRETATION AND CALIBRATION

(McDonald & Harbaugh, 1984) has investigated that calibration clarify the simulation is reproducing field measured heads and flow. The following parameters are basic for the model calibration; boundary condition, hydraulic conductivity, recharge and discharge stress condition. Under this study, Steady-state calibration was made using static water level of 56 wells. In order to get the best match between simulated and observed hydraulic heads and flow-controlled modification of parameter and values were imperative.

The calibration of the model can be done by the hand operated trial and error modification of aquifer parameters or inverse solving method. The later one method approaches a problem to get a set of hydrogeological parameters to meet observed value and the forward solving method use an aquifer system parameter to calculate the head. In spite of this, in this model the calibration target is taken with observed hydraulic head measured on the selected production well.as well as, the model applies the trial-and-error method which gives good results for the steady state calibration and satisfy the objective of the study.

The model is calibrated to steady state condition with observed head measured at the available production well. As well as, the water balance is checked every time corresponding to input values of recharge and outputs from wells. The groundwater level measurement is taken during the construction and inventory time of the borehole. Because, there is lack of monitoring the existing well standing water level and no accessing like an observation pipe installation to easily measure the water level. The model uses 56 wells for calibration targets distributed with in the basin. Prior to calibration assessing simulated result with observed data means that the hydraulic gradient and the simulated head roughly match those of the estimated one.as well as, the calibration process keeps the base flow of upper-Meki catchment. Then after, the Western Ziway- Meki river catchment is calibrated with manual trial and error adjustment as follow:

3.5.4.1 trial and error calibration

This calibration method relies on prior information and expertise about the region from the modeler. In order to determine the response of the aquifer parameter or boundary changes on the simulated head to match the observed head, the modeler uses his expertise. With data on the head distribution over the aquifer system, the model tries to determine the aquifer parameter. It results in a set of parameters of the aquifer system that minimize the difference between the head being simulated and observed.

In trial-and-error calibration, the aquifer parameter will be modified or adjusted until the sequential model run match simulated head to calibration target. Accordingly, the model use adjustment, dominantly, in the hydraulic conductivity and minor adjustment on the recharge and river conductance. In model calibration process, a satisfactory result for the steady state calibration is found which meet the overall goals of the study.

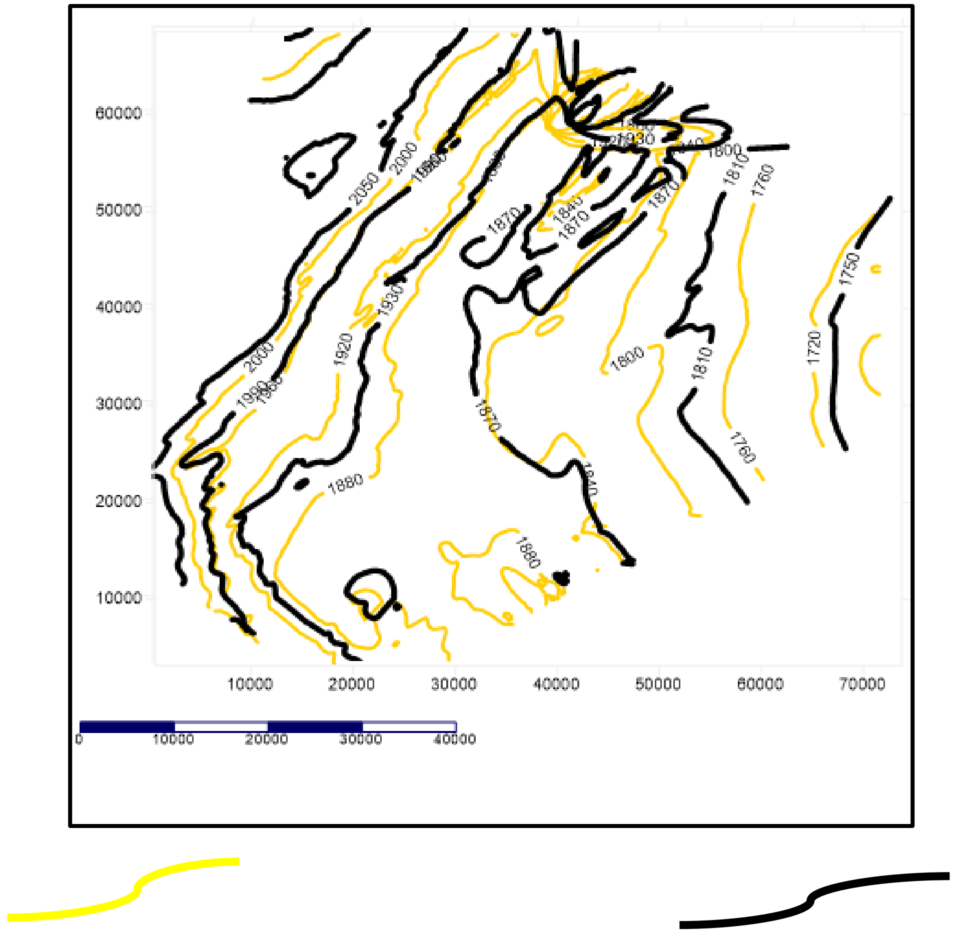
3.5.4.2 Evaluation of the calibration process

The calibration outcome is determined both quantitatively and qualitatively and aims to use the recommendation of the protocol(McDonald & Harbaugh, 1984) to test the calibration that involves matching the contour map of the measured and virtual head, calibration statistics used to evaluate the model outcome.

Two calibration parameters were used in this model: visual correspondence of the simulated contours with those of the observed contours and correspondence of the simulated hydraulic heads at 75% of the points within 25 m of the observed hydraulic heads. After that when the fit between observed and calibrated heads was within this criterion and simulated groundwater contours, the model was presumed to be calibrated.

3.5.4.2.1 Contour map comparison

Visual judgment of the simulated and observed heads of the region is carried out to evaluate the calibration of the model using contour map comparison. Upper-Meki River catchment modeling could be categorized as regional studies and one way to calibrate the model is to match the simulated and measured map trend. Therefore, the simulated contour model of the hydraulic head approaches the measured contour one. It is found that the simulated heads follow almost the same trend as that of the ground water contour observed. That means, with reasonable accuracy, approximating the observed contour. However, in the context of complex aquifers with an inherited nature of head difference in small distances and poor groundwater data management of the country, it will be very unusable to achieve identical simulated and measured contours.



simulated ground water surface ,40m

observed ground water surface ,60m

figure 3. 21 observed vs simulated hydraulic heads overlay contour map

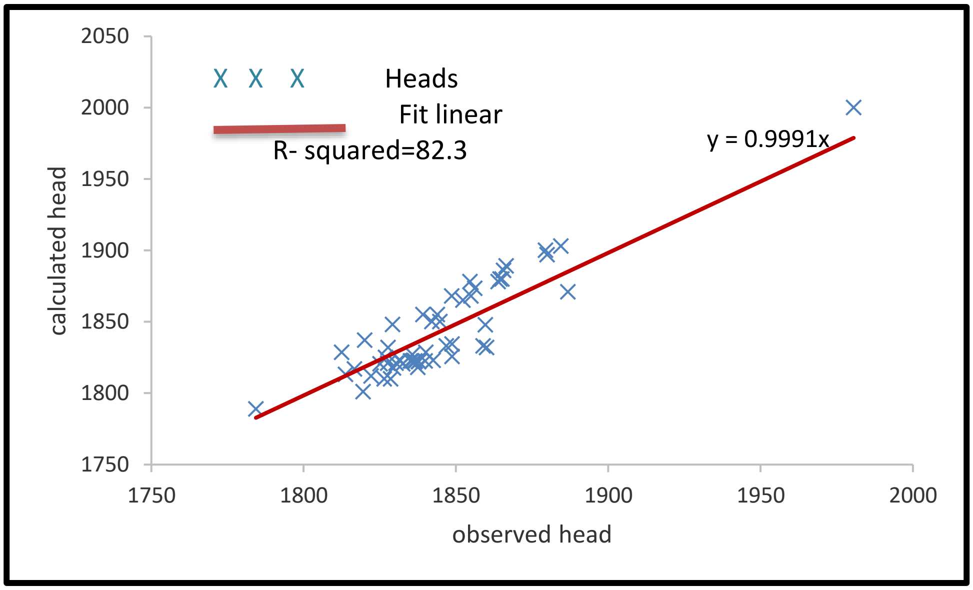


Figure 3.22 Linear regressions of observed and simulated hydraulic heads for 56 wells.

3.5.4.2.2 Root Mean Squared Error (RMSE)

Observed from the field data that is modelled or measured using The Root Mean Square Error to measure the difference between values predicted by a model and the values actually (RMSE). The typical deviation of the residuals (prediction errors). Residuals are a measure of how far data points are from the regression line and RMSE is a measure of how these residuals are spread out. Furthermore, it tells you how focused the data is around the best fit line. In accordance with (McDonald & Harbaugh, 1984). Mean error (ME), mean absolute error (MAE) and root mean squared error are the usual ways to define the average difference between simulated and observed hydraulic heads (RMSE). However, the use of RMSE is very common and makes numerical predictions an excellent general-purpose error metric. RMSE amplifies and severely punishes large errors, as compared to the comparable Mean Absolute Error. The RMSE values can be used to distinguish model performance from that of a validation period during a calibration period, as well as to compare the performance of the individual model with that of other predictive models. A direct relationship with the correlation coefficient exists when standardized observations and forecasts are used as RMSE inputs.

The RMSE of a model prediction is defined with respect to the estimated X_{model} variable
as the square root of the mean squared error:

RMSE=

$$\sqrt{\frac{\sum(Xobs,i\text{-}Xmodel,J)2}{n}}.$$

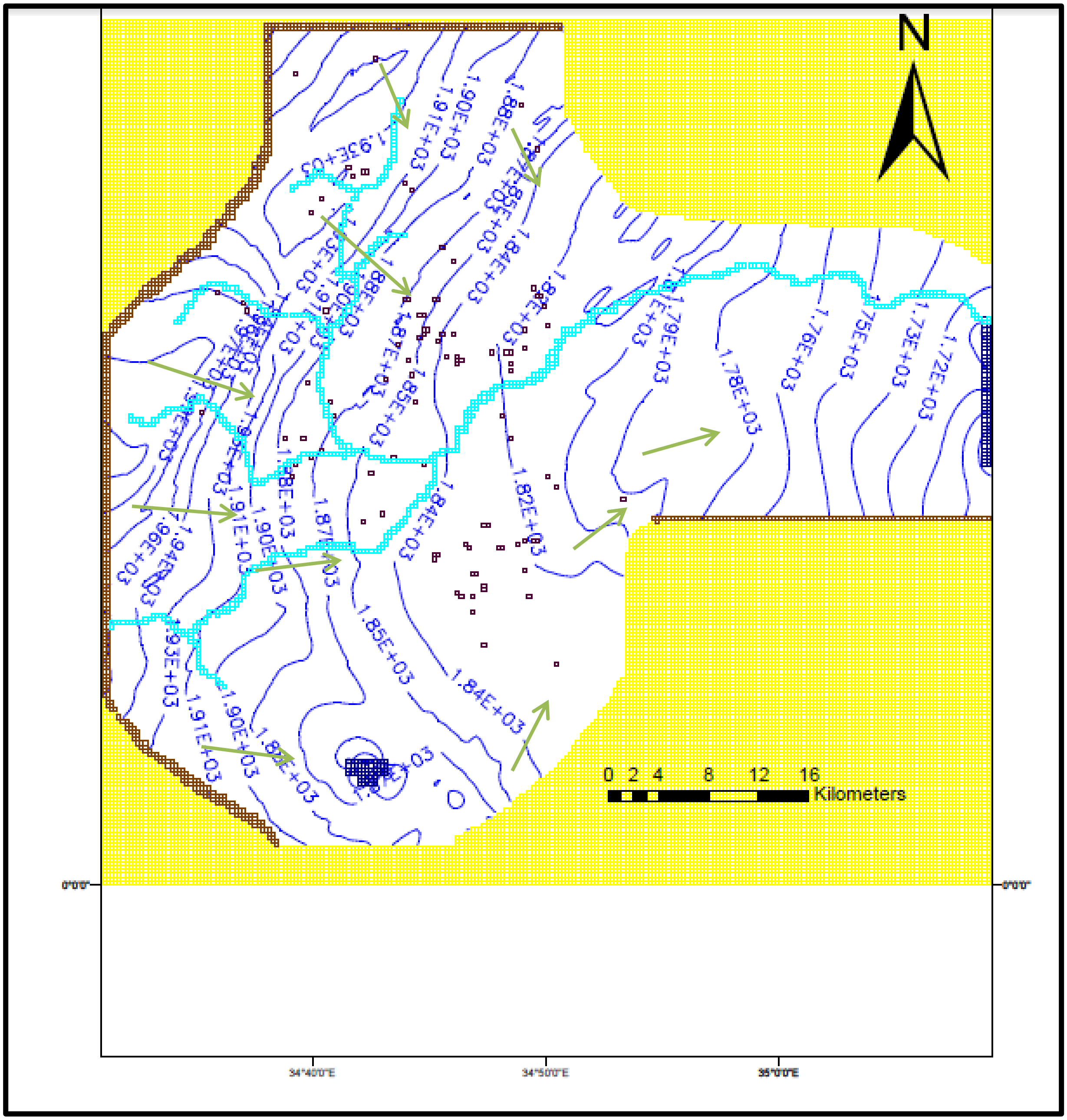
Where $X_{observed}$ is observed values and X_{model} is modeled values at time/place

Correlation coefficient(R^2)was found to be 0.823 after calibration (figure 3.21)

table 3. 14 statistics for the calibrated model

Measures	calibrated
Residual mean(m)	19.079
Root mean square error (RMSE)	20.65
sum of residual squares(M^2)	23902.5264
minimum residual(M)	0.364
Maximum residual(m)	29.475
Range in target value(m)	29.111
Standard deviation	29.98
Standard dev./range of observed values%	14.19

According to this study, in the subsurface of the groundwater reservoirs (Aquifers), the groundwater potential is stored, recharged from rainfall, the internal groundwater flow from one aquifer with a better hydraulic head to another aquifer with a lower hydraulic head.



GW-flow direction →

figure 3.23 calibrated ground water hydraulic head of western Ziway-Meki watershed

CHAPTER FOUR

4. RESULTS & DISCUSSION

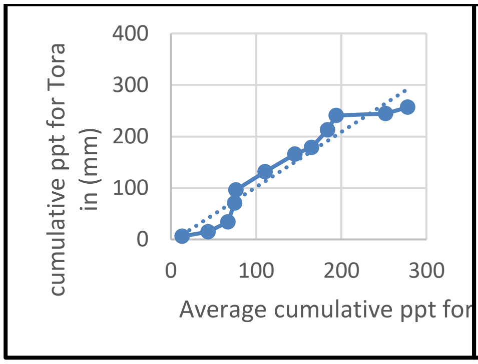
The results of data processing, the simulation of surface water and ground water are presented after calibration in this chapter.

4.1. Data processing calculation results

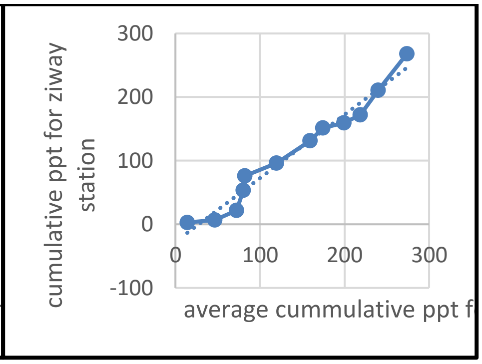
4.1.1.Consistency of the precipitation records.

The double mass curve technique Is described in section 3.2.1.1.3 was carried out to check the quality of the metrological station. For this reason, high quality assessment of the recorded rain fall data for each metrological station was carried out in such a way each year from 1998-2008 was treated independently for consistency check.it was found that four stations that show inconsistency in the data .as the scatter plot shown in figure, the data present a break in slope clearly shown .therefore, the data from the break point were adjusted using equation 3.1.

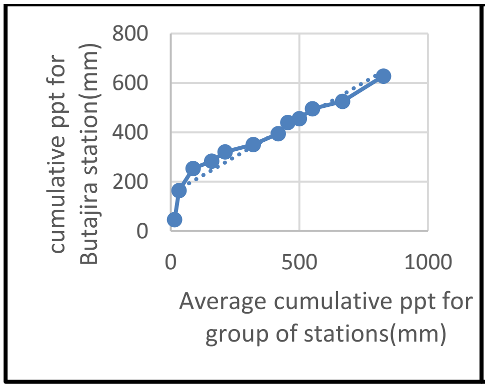
A.Double mass curve for Tora station



B.Double mass curve for Ziway station



C.Double mass curve for Butajira station



D.Double mass curve for Meki- station

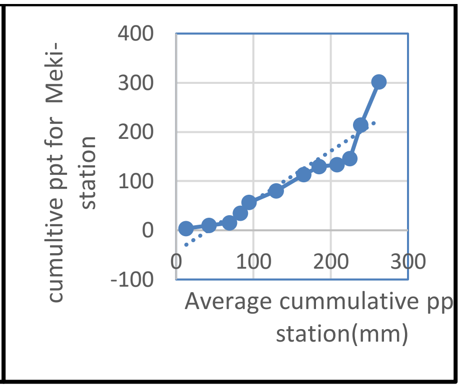


Figure 4.1 Double mass curves of the precipitation gauges(units in mm).the double mass curve in A,B,C and D shows inconsistency in the data.

4.2. EVALUATION OF THE HEC-HMS RESULTS

As the simulated results match the observed data moderately well the HEC-HMS model simulation has been successful. According to the model results figure 4.2 below, both simulated and observed peak and low flows occur at about the same moment. During the rainy winter from 1998 to 2008, the highest flow occurs, while the low flows occur in every dry season because there is no flow for most of the summer months in the Meki-catchment. After that, according to figure 4.2 below, the model parameters discovered by the calibration procedure were determined acceptable to use for the whole simulation period and, based on the validation results, are suitable to use for further analysis.

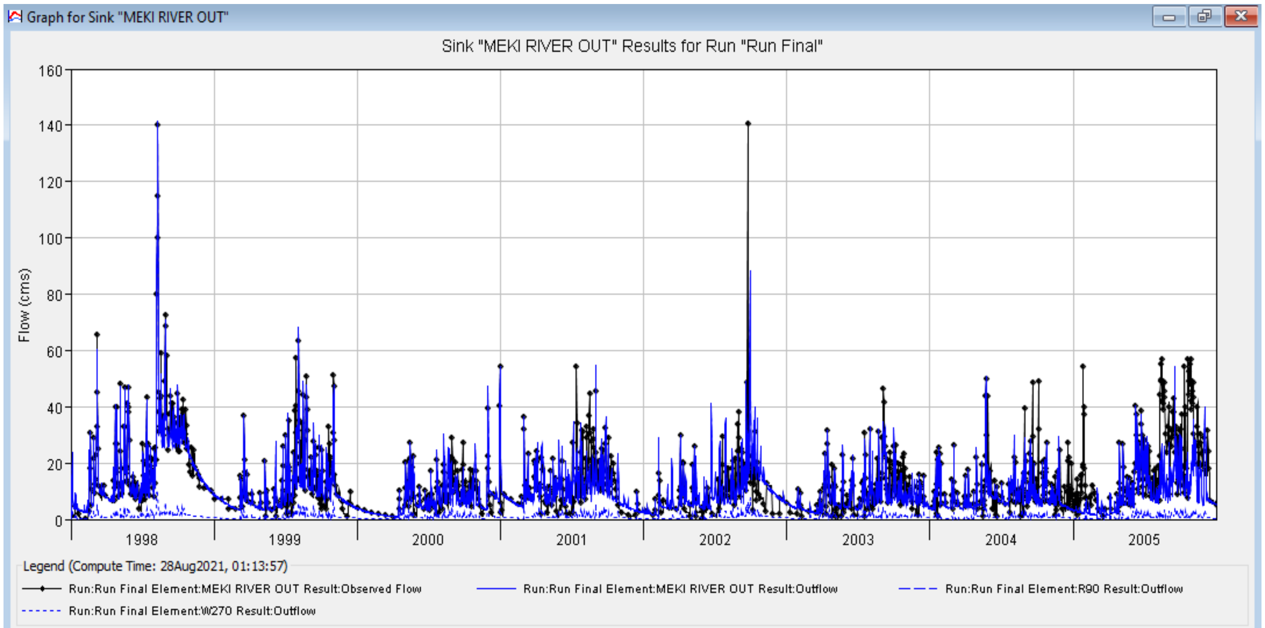


figure 4.2 comparisons of observed and simulated stream flow after the calibration period(i.e.,01 JAN1998.00:-31-DEC,2005,00:00)

the above figure 4.2 indicates SMA model runoff effects the model therefore predicts lower runoff during the peak observation periods; however, during the low observed runoff, the simulated runoff was higher and the SMA approach in the HEC-HMS model can correctly predict the peak runoff timing.

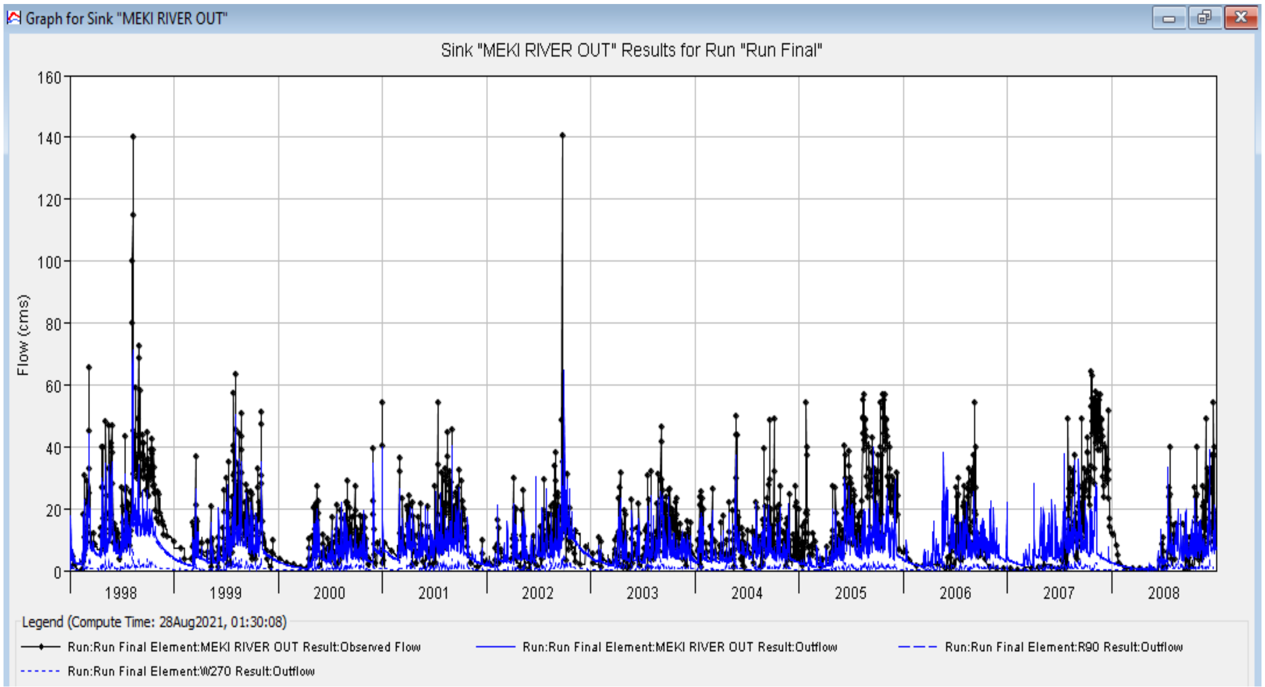


Figure 4.3 Comparison of observed and simulated streamflow for 11-year period.

The SMA method has been able to produce useful knowledge about groundwater percolation. The amount of groundwater percolated was dependent on the type of water year (wet or dry). As expected, wet years produced more groundwater percolation, while dry years produced less percolation. The interesting outcome was the volume of water that was transferred to groundwater. The total amount of groundwater water percolated was just above 64.6 mm per year and the amount of run-off was 162.5 mm per year. The outcome suggests that the rainfall in this area is delivered almost different to the groundwater and surface run off. This is most likely due to the less amount of sub-watershed agricultural, natural areas and the presence of hills and valleys that trap water as percolation and produce more runoff due to erosion and overall impermeable surfaces in the catchment. Therefore, by percolation, the groundwater aquifer receives less percentage of the precipitation each year**.**

4.3 PMWIN MOD FLOW RESULTS EVALUATION

4.3.1 Water budget of the domain of the ground water model

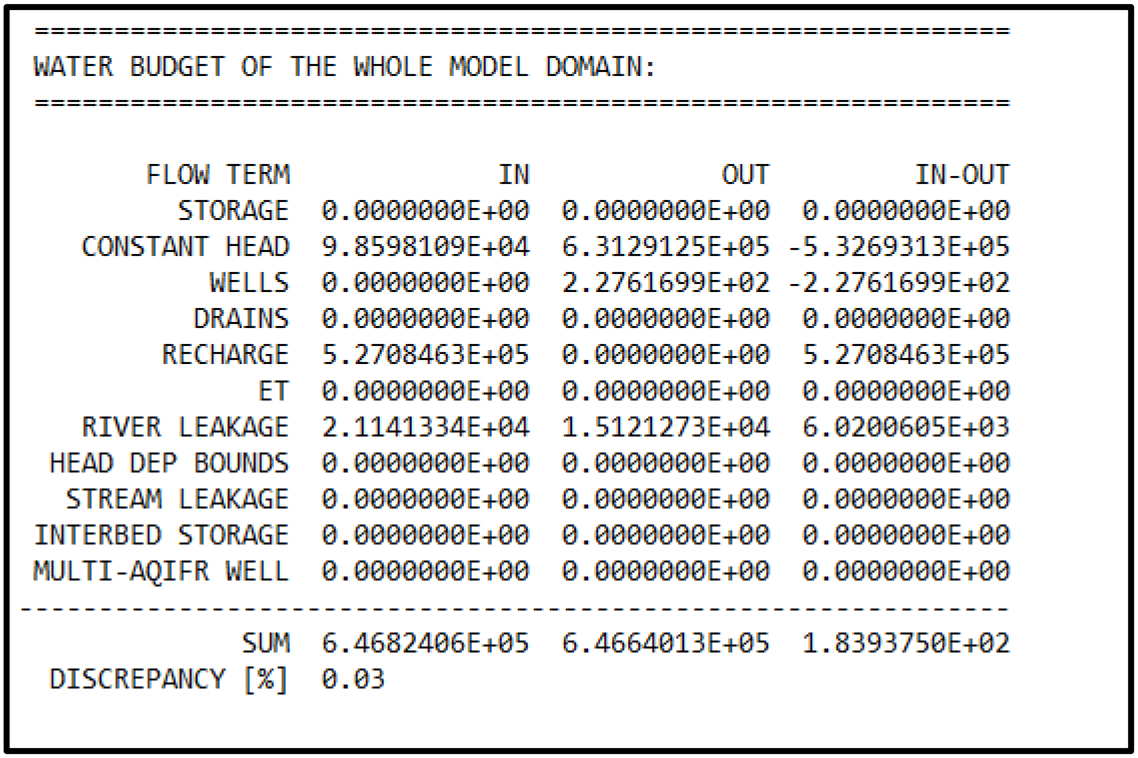
The water budget is balanced with a percentage discrepancy of [percent] 0.03 for steady-state simulation. The model's water budget includes the terms of inflow; the boundary of recharge, river and constant head, and the outflow term; the boundary of wells, river and constant head. Both inflow and outflow are in balance according to the model outcome, which is compatible with the steady-state theory. A strong inflow of groundwater towards the watershed was observed at the foothills of the eastern escarpment/Dega Nurena mountain, in the northwest of the study area based on the modeling results. In fact, the flow directions towards the river varied considerably, primarily affected by stream-aquifer relationships and groundwater withdrawals. Results of the model's water budget, shown in Table 4.1, showed that groundwater recharge represented about 81.48% of the total water input for the entries.as well as, leakage from the river into the subsurface and constant head was 3.28%,15.24% respectively under input water budget. It is also observed that when ground water flow directions are examined in the surrounding area of the river, there is a significant amount of ground water influx towards the river.

To quantify and identify all flows in and out of the aquifer structure, the water budget of the model domain is used. Through an aquifer system, this water budget of the model area quantitatively evaluates the amount of groundwater. Although the in-flow and outflow components of the groundwater system are the most difficult to directly calculate, the model has computed both components. By trial-and-error approach, model calibration was performed until the simulated head matched the observed head values to a satisfactory degree. A reasonable match between simulated and observed heads with an RMSE error of 20.65 m was indicated by the calibration result. Therefore, the calibrated groundwater flow for this study area was able to simulate the measured head, especially the sub-basin. The hydraulic conductivity values were taken from Dr. Tenalem Ayenew (1998) for the Meki aquifer. The main purpose of these hydraulic conductivity calculation values was to determine the properties of the aquifer. The hydraulic conductivity obtained in this model varies from 0.1 to 21 m/d and on the other hand, the calibrated values mostly range from 0.1 to 15m/d.

table 4. 1 water budget of the calibrated model with and without abstraction wells

	water budget without well abstraction(natural condition)			**water budget with well abstraction**		
flow term(l^3/t	**in**	**out**	**in-out**	**in**	**out**	**in-out**
wells	**0.0000000E+00**	**0.0000000E+00**	**0.0000000E+00**	**0.0000000E+00**	**2.2761699E+02**	**-2.27616E+02**
recharge	**5.2708463E+05**	**0.0000000E+00**	**5.2708463E+05**	**5.2708463+05**	**0.0000000E+00**	**5.2708463E+05**
river leakage	**2.1136121E+04**	**1.5122637E+04**	**6.0134844E+03**	**2.1141334E+04**	**1.5121273E+04**	**6.0200605E+03**
constant head	**9.8547891E+04**	**6.3146225E+05**	**-5.3291438E+05**	**9.8598109E+04**	**6.3129125E+05**	**-5.3269313E+05**
sum	**6.4676863E+05**	**6.4658487E+05**	**1.8375000E+02**	**6.4682406E+05**	**6.4664013E+05**	**1.8393750E+02**
discrepancy [%]	**0.03**			**0.03**		

table 4. 2 Simulated water budgets of Western Ziway- Meki river catchment



```
===============================================================
WATER BUDGET OF THE WHOLE MODEL DOMAIN:
===============================================================

       FLOW TERM             IN             OUT          IN-OUT
         STORAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
   CONSTANT HEAD  9.8598109E+04  6.3129125E+05 -5.3269313E+05
           WELLS  0.0000000E+00  2.2761699E+02 -2.2761699E+02
          DRAINS  0.0000000E+00  0.0000000E+00  0.0000000E+00
        RECHARGE  5.2708463E+05  0.0000000E+00  5.2708463E+05
              ET  0.0000000E+00  0.0000000E+00  0.0000000E+00
   RIVER LEAKAGE  2.1141334E+04  1.5121273E+04  6.0200605E+03
 HEAD DEP BOUNDS  0.0000000E+00  0.0000000E+00  0.0000000E+00
  STREAM LEAKAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
INTERBED STORAGE  0.0000000E+00  0.0000000E+00  0.0000000E+00
MULTI-AQIFR WELL  0.0000000E+00  0.0000000E+00  0.0000000E+00
---------------------------------------------------------------
             SUM  6.4682406E+05  6.4664013E+05  1.8393750E+02
 DISCREPANCY [%]  0.03
```

In general, by using the calibrated model with a percentage difference of 0.03, the water budget of the whole model domain was simulated. It includes the following groundwater flow system inflow components: first, constant head boundary recharge, with a value of (9.85981 × 10^4) m^3/day. Second, precipitation groundwater recharge, which is (5.2708463×10^5) m^3/day and river leakage groundwater inflow, with a value equal to (2.1141334×10^4)m^3/day. It includes the simulated outflow of groundwater from the system. Discharge to the constant head boundary, which is (6.3129125×10^5) m^3/day, groundwater outflow with a value equal to (1.5121273×10^4) m^3/day through river leakage and groundwater outflow with well withdrawal a value equal to (2.2708463×10^2) m^3/day. Finally, Table 4.2 shows the inflow and outflow components of the water balance and the steady-state hydrologic budget of the model-calculated study area.

4.3.2 Sensitivity analysis

(Kinzelbach, 1992)To measure the uncertainties in the calibrated model caused by uncertainty in the estimates of aquifer parameters, stresses, and boundary conditions, model sensitivity analysis is performed. To investigate a sensitivity analysis, the response of the calibrated model to a number of values for different input parameters needs to be checked. After that it helps to decide the model parameters that have the greatest influence on a model. The outcome of the study will, therefore, direct future efforts to collect data that will minimize model errors. The sensitivity analysis was performed by adjusting the calibrated values of conditions systematically(Kinzelbach, 1992). In this analysis, for variations in hydraulic conductivity, river leakage and recharge, model sensitivity was simulated. Groundwater models are vulnerable to the variation of different input parameters and parameters of the model that are most sensitive to the model. That means small changes in these parameters can lead to large variations in the simulated heads or fluxes. Therefore, the response of the calibrated numerical model to changes in model parameters such as hydraulic conductivity and recharge was examined. In addition, the other parameters were held to the calibrated steady state value during simulation when the effect of one parameter was being evaluated, and each parameter was adjusted uniformly across the entire region. Whereas the magnitude of head changes or fluxes from the calibrated solution was used as a measure of the model's sensitivity to that specific parameter. The Sensitivity Analysis Test was conducted using recharge and hydraulic conductivities in this model outcome, since the model was most responsive to them. In order to measure the sensitivity of the model to the parameters, the calibrated recharge and hydraulic conductivity values varied between ±10% , ±20% , ±30% . ±40% , ±50% , ±60% ±70% and ±75% at different times. By altering the hydraulic conductivity by the specified percentage and the corresponding root mean squared head changes in % from the calibrated value, a total of eight model runs were made in Table 4.3. In all simulations, Simulated water levels in the model were more sensitive to decreases in recharge values, but more sensitive to decrease in hydraulic conductivity values. However, relative to recharge and hydraulic conductivity, the model is not as sensitive to decreases or increases in pumpage.

Table 4. 3 % shift in the calibrated hydraulic head sensitivity parameter with the corresponding RMSE head change from the calibrated value

Parameter number	Percent change from the calibrated value in the sensitivity parameter	The percentage change of the respective RMSE head from the calibrated value
1	Hydraulic conductivity decreased by 10%,20%,30%,40% ,50%,60%and by 75 %	20.65,20.91,22.15,25.4,26.65, 27.85,30.65,40.65 and 45.66 respectively.
2	Hydraulic conductivity increased by 10%,20%,30%,40% ,50%,60%and by 75 %	21.99,25.01,30.15,35.61 ,40,50.63,55.61and60 respectively.
3	Recharge increased by 10%,20%,30%,40% ,50%,60%and by 75 %	21.61,22.01,23.15,24.65,29,33.76, 35.6 and 39.6 respectively.
4	Recharge decreased by 10%,20%,30%,40% ,50%,60%and by 75 %	27.63,32.15,34.4,42.65,49.65,53.62, 65.8 and 73.17 respectively.

4.3.3. Model limitation

The Meki river catchment's steady-state groundwater flow model provides a regional-scale simulation of groundwater flow. b/s, unconfined/confined aquifer type in the study area's aquifer system. A simplified approximation of actual conditions is a groundwater model. Because the database management of the country's hydrogeology is so inadequate and with few important parameters, the groundwater model results are dependent on the correctness of the input data and have commensurate limitations in model precision. As a result, the model's user should consider the lack of data that the modeler experienced.

A homogeneous grid cell size of 300 meters by 300 meters was used to discretize the model. The conditions within the node, such as groundwater level and flow, are reduced to one average value for the entire node as a result of this discretization. As a result, the approach is ineffective for analyzing site-specific issues or problems. At this scale, the hydrologic characteristics and aquifer unit shape in areas of the model area are unknown. Aquifer thickness and hydraulic conductivity, for example, can change at intervals smaller than the current model resolution, especially in areas with extensive structures. Random error in the field data used for model calibration can also cause model uncertainty, which is converted into uncertainty in the calibrated parameter values through model calibration.

Hydraulic conductivity can vary greatly in severely fractured and active tectonic locations.

As a result, raising the hydraulic conductivity can indirectly replicate groundwater level and flow in these places; nevertheless, the consequences of these structures on the aquifer system may not be adequately addressed using the models. The model's calibration might be improved by finer discretization of some parameters, such as hydraulic conductivity or recharge; but, due to a lack of sufficient field data, finer discretization is not feasible. The geological condition of the area is too complicated; thus, the model is considered to be a single layer, unconfined, and homogeneous aquifer system that ignores the earth's natural heterogeneity, and the user is expected to account for all of the assumptions made on the page. As a result, more data might be used to update the model, improving the accuracy of the model prediction parameter and allowing it to be used for a more detailed study.

4.3.4 Pumping Scenario

Table 4.4 Water Demand of the population and animals within each hydrogeological zone modified from (Ministry of water resources Ethiopian water technology center,2008)

Hydrogeological zone	Population base year(2006)	Water demand of l/s	Population 2010	Water demand m3/s	Population 2015	Water demand M3/s	Population 2020	Water demand m3/s
Butajira crescent	69,361	20	75,758	25	84,590	30	94,452	36
Tora-Koshe-Dugda	200,884	58	102,612	74	244,991	87	273,554	103
Cindare cones and basaltic areas	144,439	42	157,760	53	176,153	63	196,690	74
Kunteno-Inseno-Kela plain	217,377	63	237,425	80	265,106	95	296,013	120
total	632,061	183	690,355	232	770,840	275	860,709	325

Simulations are required to carry out the projected water supply demand for human consumption and cattle within different hydrogeological zones in order to carry out the pumping scenario. The model is running for the years 2010, 2015 and 2020 on the basis of table 4.4 above to see the drawdown resulting from these pumps. The data is therefore inserted as ten pumping wells in each hydrogeological zone.

table 4.5 The drawdown and pumping rate computed for ten wells pumping in each hydrogeological zone to cover the water demand.

year	Butajira Crescent		Kunteno-Inseno-Kela plain		Tora- Koshe-Dugda		cindare cones and basaltic areas	
	Pumping l/s	Draw down m	Pumping l/s	Draw down m	Pumping l/s	Draw down m	Pumping l/s	Draw down m
2010	20	1.13	58	0.3	42	3.907	63	5.1
2015	30	1.695	87	0.65	63	5.8	80	6.476
2020	36	2.034	103	1.003	74	7.183	120	9.714

The highest drawdown is in Cinder cone areas of 9.714 m according to figure 4.1 below and the least drawdown is in Kuntane-Inseno-Kela plain, which is just around 1.003 m for the maximum pumping quantity, which is 325 l/s in 2020. Currently, this is the limit that can be reached at ten wells for each hydrogeological zone location by pumping.

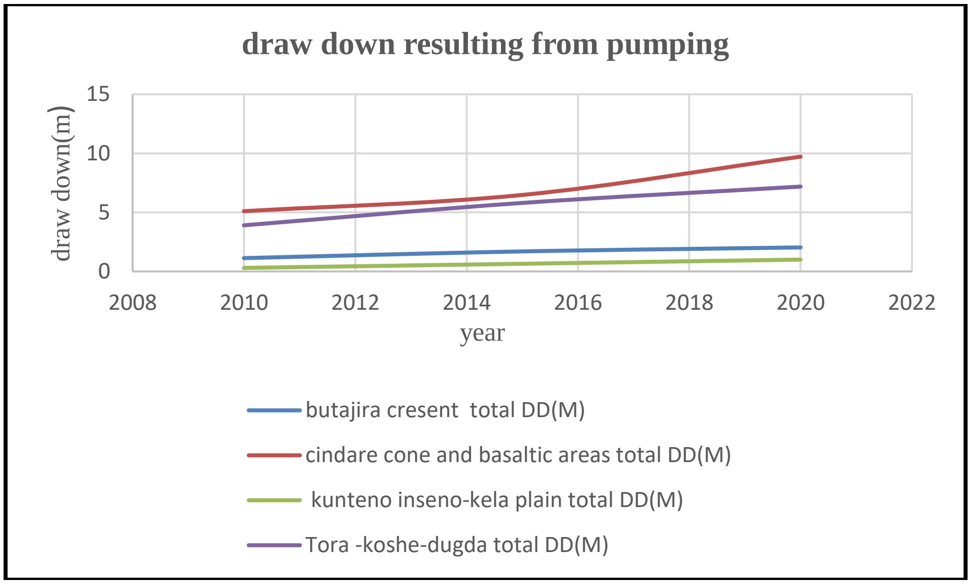


Figure 4.4 Drawdown resulting from pumping based on the water supply demand of the population up to year 2020.

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

this research demonstrates progress in integrating a surface water model with a groundwater model to achieve an analysis of groundwater pumping near & away from a river. In evaluating this result, surface and groundwater models were combined to address the goals.

First, HEC-HMS 4.2.1 simulated the daily runoff and compared to measured daily records and important data for the hydrological simulation methods considered are: catchment area, land use patterns, daily rainfall, daily river discharge, base flow, catchment soil types, and impermeable areal coverage.as well as, for the ground water model: layer top elevation taken from ASTER DEM , layer bottom elevation is based on the aquifer thickness (85 -260), boundary conditions assigned to active cell 1(model area), assigned to inactive cell 0 for north western % south western area and assigned to Lake constant-head cell with a value of -1. The other parametric input is the initial hydraulic head defined for each cell, by subtracting (20-30)m from DEM. The next parameter is horizontal hydraulic conductivity a value of 0.1m/day to 15 m/day is used.in addition, Direct precipitation recharge package is ((1.769×10^{-4})m/day),defined for each cell and 103 abstraction wells are handled in well package. After that, in order to calibrate the hydraulic head, the (SWL) measurements for 56 wells used for steady state model calibration with manual testing and error adjustments. According to statistics the optimized model has an RMSE of 20.65 meters and a correlation coefficient of 0.823 after calibration. With a percentage difference of 0.03, the water budget of the entire model domain was measured. Includes : constant head boundary recharge, with a value of (9.85981×10^4) m^3/day, precipitation groundwater recharge, which is (5.2708463×10^5) m^3/day and river leakage groundwater inflow, with a value (2.1141334×10^4)m^3/day, Discharge to the constant head boundary, which is (6.3129125×10^5) m^3/day, groundwater outflow with a value (1.5121273×10^4) m^3/day through river leakage and groundwater outflow with well withdrawal a value (2.2708463×10^2) m^3/day.Then,respectively,$6.4664013\times10^5$and 6.4682406×10^5 m^3/day of total outflow and inflow . Furthermore, a sensitivity analysis was performed to analyze the response to changes in model parameters including horizontal hydraulic conductivity, recharge rate, and pumping for an increase and decrease of the numerical model adjusted to steady state conditions. Simulated water levels in the model were more sensitive to decreases in recharge values and sensitive to decreases in hydraulic conductivity values. However, relative to recharge and hydraulic conductivity, the model is not as sensitive to decreases or increases in pumpage. Finally, for pumping scenarios, including increased pumping based on water supply demand for the years 2010, 2015 and 2020, the model is also simulated. The result shows that the maximum drawdown is 9.714 m in the Cinder cone areas and the least drawdown is in the Kuntane-Inseno-Kela plain, which is only about 1.003 m for the maximum pumping quantity of 325 l/s in 2020. But this is actually the maximum that can be reached in 10 pumping wells for each hydrological zone. However, the draw down would be less when the number of wells were increased and distributed over the whole area. Finally, the result shows that the community's water supply demand can be covered by fewer declines in Kuntane-Inseno-Kela plain. Whereas, more decline in the Cinder cone areas.

5.2 RECOMMENDATIONS

Future analysis is still recommended for the western Ziway-Meki Sub basin, given the conclusions of this models, and this model had acceptable fits to the observed data, several assumptions were made and there is a lack of available data for the entire Sub basin. First of all, as the population grows and new and larger water supply wells and irrigation wells are installed and brought into operation, this analysis should be repeated every few years as a check on the sustainable status of the Sub Basin. The main issue is that there is a lack of data on coordinates, aquifer information, static water level and test pumping, and so on. It would therefore help to improve the calibration process by finding more monitoring well data, as the model would have a better understanding of the current conditions it is trying to match. In addition, the river simulation would assist with additional stream monitoring by building new stream gages. Having data to calibrate the HEC-HMS generated flows would create more reliability in the generated runoff flows. In general, it is possible to list the following recommendations for future studies:

- Recharge rates used in the model can be modified to accommodate climate change scenarios in order to ultimately evaluate the impact of climate change on water resources in the study area.
- To prepare more monitoring wells to enhance the calibration of the Groundwater Flow Modeling Model for Managed Groundwater System Western Ziway-Meki Sub Basin
- For more precision, model grids and boundary conditions can be refined.
- Re-analysis of the HEC-HMS (SMA) model parameters and formulations for greater model accuracy.
- The aquifer's geological and hydrogeological studies should be further studied in the future by widespread data collection.
- To determine seasonal and annual variations, groundwater abstraction from irrigation as well as from water source boreholes should be regularly documented and registered in the database.

- It is necessary to divide the aquifer system into various layers and estimate their respective hydraulic parameters to represent the system in a more realistic state.

REFERENCE

Abraham, & Nadew. (2018). Impact of Land Use Land Cover Dynamics on Water Balance , Lake Ziway Watershed, Ethiopia. *Hydrology: Current Research*, *9*(4), 309.

Anuary, J. (2008a). Ministry of Water Resources Butajira – Ziway Areas Development Geology. *Instrumentation*.

Anuary, J. (2008b). *MINISTRY OF WATER RESOURCES BUTAJIRA – ZIWAY AREAS DEVELOPMENT STUDY HYDROGEOLOGY AND GROWNDWATER*.

Ayenew, T., Tekleab, S., Goel, N. K., Sciences, C., Sciences, C., Engineering, W. R., & Engineering, I. (2020). Trends and Variability of Precipitation: Implications for Water Resources in Lake Ziway Watershed, Central Ethiopian Rift. *Journal of Environment and Earth Science*, *10*(10), 19–30. https://doi.org/10.7176/jees/10-10-03

Cowin, M. W., Kenner, S., Wilson, E., & Croyle, W. (n.d.). *State of California Edmund G . Brown Jr ., Governor California Natural Resources Agency John Laird , Secretary for Natural Resources Department of Water Resources*.

Donauer, T., Haile, A. T., Goshime, D. W., Siegfried, T., & Ragettli, S. (2020). *Gap and Opportunity Analysis of Hydrological Monitoring in Ziway-Shala Sub-basin*.

Engineering Hydrology_Sabremanya.pdf. (n.d.).

Environment, E., & Ababa, A. (2016). *Socio-Economic Benefit of Wetland Ecosystem (in Case of Lake Ziway)*. *July*, 1–18. https://doi.org/10.20944/preprints201607.0068.v1

Eresso, A. B. U. (2010). *ASSESSMENT OF WATER BALANCE OF LAKE ZIWAY AND ITS TEMPORAL VARIATION DUE TO WATER ABSTRACTION*. *December*.

Fekadu, D. (2016). *School of Graduate Studies Addis Ababa Institute of Technology The Impact of Existing and Proposed Irrigation scheme on Hydrology of lake Ziway*.

Goshime, D. (2019). *IMPACT OF WATER ABSTRACTION ON THE WATER LEVEL OF LAKE ZIWAY , IMPACT OF WATER ABSTRACTION ON THE*. *December*. https://doi.org/10.2495/WS190071

Groundwater Modelling. (2000). *September*.

Groundwater, N., & Modeling, F. (2013). *School of Graduate Studies Collage of Natural Science 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 o*.

Hamilton, P. (2005). Groundwater and surface water: A single resource. *Water Environment and Technology*, *17*(5), 37–41.

HEC. (2000). Hydrologic Modeling System Technical Reference Manual. *Hydrogeology Journal: Hydrologic Modeling System: Technical Reference Manual*, *March*, 145.

Hydrologic, G., & Extension, M. (2000). *HEC-GeoHMS*. *July*.

Kinzelbach, W. (1992). Applied groundwater modeling — Simulation of flow and advective transport. In *Journal of Hydrology* (Vol. 140, Issues 1–4). https://doi.org/10.1016/0022-1694(92)90251-p

Kinzelbach, W. (2014). *A Simulation System for Modeling Groundwater Flow and Pollution*. *May*.

Le, C., Tiercelin, J., Gibert, E., & Travi, Y. (1999). *The Ziway – Shala lake basin system , Main Ethiopian Rift : Influence of volcanism , tectonics , and climatic forcing on basin formation and sedimentation*. *150*, 135–177.

Legesse, D., Abiye, T. A., Vallet-coulomb, C., Abate, H., Legesse, D., Abiye, T. A., Vallet-coulomb, C., & Streamflow, H. A. (2020). *Streamflow sensitivity to climate and land cover changes : Meki River , Ethiopia To cite this version : HAL Id : hal-00799608 Streamflow sensitivity to climate and land cover changes : Meki River , Ethiopia*. https://doi.org/10.5194/hess-14-2277-2010

Lemma, A. (2016). Current Ecological Scenario of some Rift Valley Lakes of Ethiopia: A review. *EC Agriculture*, *1*, 570–580.

Lohani, A. K. (2018). *Rainfall-Runoff Analysis and Modelling*. 1–19.

Makin, M. J., Kingham, T. J., Waddams, A. E., Birchall, C. J., & Eavis, B. W. (1976). Prospects for irrigation development around Lake Zwai, Ethiopia. *Land Resource Study 26*.

McDonald, M. G., & Harbaugh, A. W. (1984). *A modular three-dimensional finite-difference groundwater flow model*. https://doi.org/10.1016/0022-1694(86)90106-x

Mitiku, D. B. (2011a). *Numerical Groundwater Flow Modeling of the Meki River Catchment , Central Ethiopia: A Master thesis submitted to the school of Graduate studies Institute of Technology Addis Ababa University*. 1–111.

Mitiku, D. B. (2011b). *Numerical Groundwater Flow Modeling of the Meki River Catchment , Central Ethiopia Addis Ababa University*.

Of, I., For, P., On, I., & Potential, G. (2015). *By : zekarias Banda*.

Resour, I. J. W., Basin, M. S., Shumet, A. G., & Mengistu, K. T. (2016). *of Waste Resources*

Assessing the Impact of Existing and Future Water Demand on Economic and Environmental Aspects (Case Study from Rift Valley Lake Basin : 6(2). https://doi.org/10.4172/2252-5211.1000223

Scharffenberg, W. (2016). Hydrologic Modeling System HEC-HMS User's Manual. *U.S. Army Corps of Engineers - Hydrologic Engineering Center*, *1*(Agosto), 598. http://www.hec.usace.army.mil/software/hec-hms/documentation/HEC-HMS_Users_Manual_4.0.pdf

Scharffenberg, W. A. (2013). *Hydrologic Modeling System User ' s Manual*. *December*.

Sciences, C. (2017). *College of Natural and Computational Sciences — Application of Geophysical Methods for Delinating Deep and Shallow Ground Water Flow Systems Along Ziway-Butajira and Meki-Midrekebd Traverses , Central Mer , and Their Implication for Fluoride Concentration*.

Stream, H. E. (2015). *SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING HYDRAULICS ENGINEERING STREAM IMPACT ASSESSMENT OF IRRIGATION WATER USE*. *September*.

Submitted, T. (2007). *Effects of Irrigation Practices and Lacustrine Aquifer Development on Water Availability in Ziway-Abijata Corridor SCIENCES*. *February*.

USACE, U. A. C. of E. (2016). Hydrologic Modeling System, HEC-HMS, Quick Start Guide. *U.S. Army Corps of Engineers, Institute for Water Resources, Hydrologic Engineering Center (CEIWR-HEC), August*.

USGS. (2012). NATURAL PROCESSES OF GROUND-WATER AND SURFACE-WATER INTERACTION The Hydrologic Cycle and Interactions of Ground Water and Surface Water. *Aquatic Science*, *15*, 2–32.

Woldesenbet, A. B., Wudmatas, S. D., Denboba, M. A., & Gebremariam, A. G. (2020). Enset-based land use land cover change detection and its impact on soil erosion in Meki river watershed, Western Lake Ziway Sub-Basin, Central Rift Valley of Ethiopia. *Environmental Systems Research*, *9*(1), 1–53. https://doi.org/10.1186/s40068-020-00198-x

Appendix - 1 Meki-river catchment mean monthly precipitation(mm) (1998-2008)

Gauge Station	Jan	Feb	Mar	Apr	May	Ju	Jul	Aug	Sept	Oct	Nov	Dec	yearly men
Meki	26.62	8.35	63.08	67.19	50.5	66.37	166.85	135.12	78.61	29.87	3.71	6.55	702.82
Butajira	45.9	71.6	101.6	132	90.2	126.7	138.4	124.6	137.7	40	107	29.3	1145
Tora	25.7	44.7	79.88	120.97	93.15	85.44	132.89	123.67	119.88	51.66	8.56	6.08	892.58
Ziway	17.8	35.6	55.5	75.8	75.76	83.8	145.8	122.32	88.43	40.55	2.88	3.99	748.23

Appendix- 2 mean monthly discharge (m3/s) after filling the missing data at Meki town (1998-2008).

YEAR	JA	FE	MA	APR	MA	JUN	JUL	AU	SEP	OC	NO	DE	Average
1998	1.599	0.74	12.11	3.272	11.76	5.227	27.62	70.11	29.23	23.11	2.55	0.41	15.64
1999	0.088	0.07	2.841	0.115	0.508	2.835	20.64	22.42	10.15	23.55	4.73	0.27	7.35
2000	0.016	0	0	0.045	0.831	0.643	6.308	14.01	11	8.245	2.96	0.93	3.74
2001	0.009	0.17	3.062	1.908	4.614	10.89	13.79	27.63	39.38	2.554	0.93	0.51	8.78
2002	4.076	3.11	1.581	2.65	3.13	3.46	7.35	12.88	12.46	2.462	1.94	1.63	4.72
2003	0.998	0.58	3.3	2.49	2.197	4.923	3.54	7.9	24.2	3.993	0.36	0.81	4.6
2004	0.928	0.28	0.7	0.16	0.736	2.176	0.33	5.85	20.05	31.69	20.6	12.1	7.96
2005	46.52	8.06	2.11	3.329	12.9	8.06	2.988	12.29	9.09	6.139	2.01	1.53	9.58
2006	1.968	1.8	1.58	1.94	1.58	3.24	11.23	21.11	13.95	5.18	0.66	1.01	5.43
2007	0.769	1.94	0.98	0.74	1.83	0.87	40.9	41.66	23.36	5.545	0.68	0.51	9.98
2008	0.426	0.97	0.58	0.46	0.58	3.172	9.763	20.75	15.24	7.78	13.7	22.7	8.01

Appendix 3 Mean monthly maximum and mean monthly minimum temperature (^{O}c) (1998-2008)

	Mean monthly maximum temperature (^{O}C)												
Year	Jan	Feb	Mar	April	May	Jun	July	August	Sept	Oct	Nov	Dec	Annual
1998	26.4	27.1	25.2	25	27.3	27.3	23.7	23.9	23.7	25.1	25.1	24.6	25.36667
1999	25.7	25.9	26.8	25.9	26.3	26.4	24.4	23.1	24.3	23.5	25.4	24.7	25.2
2000	25.6	26.2	27.7	26.1	25.3	26.4	24.2	26.4	23.4	24.7	25	24.1	25.425
2001	24.2	25	27.5	31	28.6	27.3	27.3	25.9	26.7	27.9	28.3	27.6	27.275
2002	28.1	28.5	27.9	28	28.4	28.8	25.4	24.9	25.6	27.2	27.2	26.4	27.2
2003	26.8	25	29.4	26.2	29.5	26.8	25.6	27.2	27.2	28.7	28.6	27.8	27.4
2004	27	27.8	29.1	29.4	31	28.2	28	27.8	29.1	29.3	27.4	28.4	28.54167
2005	28	29.3	31.5	30.4	31	28.5	24.8	26.2	26.7	27.2	28.3	27	28.24167
2006	26.5	27.6	28.9	26.6	30.6	27.7	25.3	26.3	26.6	27.8	28.6	27.3	27.48333
2007	28.1	27	28.3	29.2	31	28.9	25.9	25.4	27	28.3	28.1	27.4	27.88333
2008	29.2	28.5	28.8	29.3	30.4	29.6	24.5	25.2	27.2	28.5	26.9	27.5	27.96667
average	26.8	27.0	28.2	27.91	29.03	27.80	25.37	25.66	26.136	27.109	27.172	26.618	27.089

year	Mean monthly minimum temperature (^{O}c)												annual
	Jan	Feb	Mar	April	May	Jun	July	August	Sept	Oct	Nov	Dec	
1998	13.6	15.1	16.7	16.9	15.9	15.9	16.2	16	15.2	14	12.7	11.4	14.96667
1999	15.2	16	15	16	16.2	16.2	15.9	16	14.9	14	15	15.6	15.5
2000	14.4	17.67	18.8	18	16	16.02	15.6	16	14.9	12.9	12.2	12.2	15.39083
2001	11.7	11.9	14.2	14.09	14.1	14.1	13.5	13.8	12.7	10.7	10.3	10.8	12.6575
2002	11.3	12.1	13.1	14.2	14.2	14.2	13.4	13.04	12.6	10.9	9.1	8.75	12.24083
2003	8.6	11.9	12.8	13.9	13.01	13.02	12.5	12.1	12.02	10.9	11.9	10.1	11.89583
2004	12.2	12.5	16.4	15.2	15.71	15.7	15.2	15.3	14.3	14.2	10.04	11.9	14.05417
2005	13.4	15.3	15	15.9	16.01	16.02	15.8	15.64	15.2	13.3	12.1	11.4	14.58917

2006	11.7	14.1	15.4	15.6	15.7	15.72	15.63	15.04	14.7	12.1	12.2	14.1	14.3325
2007	12.26	15.87	14.6	15.3	15.51	15.52	14.9	14.9	15.2	12.23	11.24	10.85	14.03167
2008	13.76	15.07	15.7	15.4	16.1	16.1	15.33	15.54	13.72	13.03	11.84	11.85	14.45333
average	12.5	14.31	15.24	15.499	15.312	15.318	14.905	14.850	14.130	12.569	11.692	11.722	14.010

Appendix -5 Mean monthly relative humidity(%) (1998-2008)

	Mean monthly relative humidity(%)												
Year	Jan	Feb	Mar	April	May	Jun	July	August	Sept	Oct	Nov	Dec	Annual
1998	52.23	53.9	69.4	70.22	60.6	58.5	73.2	73.7	75.33	61.13	62.3	62.53	64.42
1999	71.1	74.3	71	76.3	71.2	70.3	76.7	78.7	67.3	71.3	70	85.8	73.66667
2000	84.3	86.9	84.7	86.3	86.8	86.7	86.7	87	89	87.3	86	89.7	86.78333
2001	76.5	84.9	86	0	79.5	80.3	81	82	82	69	46.3	54.63	68.51083
2002	60.5	59.3	69.4	81.7	71.5	57.3	55.7	58	55.7	52.3	51.3	55.71	60.70083
2003	57.3	55.3	43.7	64	51.5	56.3	66.3	61.3	53	56	54.7	68.1	57.29167
2004	56.3	56.9	52.4	52	49.8	56	62.7	60.7	59	52.3	52.4	53.7	55.35
2005	55.7	71.3	69.4	61	60.2	58	64.3	72.3	75	59	49.31	58.1	62.80083
2006	56.6	64.3	66.4	65	58.8	64.3	75.3	76.3	71.3	50.3	61	64.7	64.525
2007	63.7	66.6	53.9	60.9	58.8	63.7	74	76.7	73.7	65	60.7	59.7	64.78333
2008	51.6	57.2	64.4	56.3	62.2	73.3	77.7	76.7	72.6	65	53.7	61.8	64.375
Average	62.34818	66.44545	66.42727	61.24727	64.62727	65.88182	72.14545	73.03636	70.35727	62.60273	58.88273	64.95182	65.74614

Appendix-6 Mean wind speed (in m/s) at 2 m (1998_2008)

station	Mean wind speed (in m/s) at 2 m. a.m.											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ziway	1.69	1.7	1.61	1.57	1.77	2.25	2.13	1.86	1.41			
Buie	2.45	2.53	2.5	2.33	2.38	1.98	1.87	1.79	1.75	2.28	2.42	2.43

Appendix-7 Mean monthly sunshine hours (hours/day) (1998_2008)

station	Mean monthly sunshine hours (hours/day)											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Ziway	10	9.86	8.85	8.85	9.69	8.89	6.92	7.1	7.54	14.38	10.72	10.58
Buie	9.56	9.07	8.93	8.82	8.94	7.47	5.7	6.11	7.48	9.41	10.56	9.65

Appedix-8 western Ziway-Meki sub basin 103 well inventory data

Borehole Name/ID/code	UTM-E(M)	UTM-N(M)	Z-coordinate	SWL(M)	Depth(m)	K(M/DAY)	Q(L/S)
BH-2	453276	901204		1810.00	-		6.5
BH-11	426927	887719		2021.68	174		3.4
BH-16	435517	877276		1820.81	109		5.14
BH-17	439069	878182		1807.67	194		3.1
BH-18	438154	876204		1808.38	187		3.4
BH-22	447247	889418		1810.00	106		6
BH-26	432756	897440		2003.30	154		8
BH-28	432084	897957		2042.60	65		10
BH-30	430941	896250		2048.00	86		6
BH-35	432428	886909		1847.74	90		4
Butajir-town-1	430838	899162	2120	2112.9	80	3.81	7.35
Butajira-town-2	430990	896373	2117	2102.15	87	2.66	6.9
Butajira hospital	431086	898842	2125	2096	77.5	0.96	3.5
Semen Shershra	436926	899128	1932	1883.45	86	0.47	4
Weja	446999	886227	1830	1820.4	9.6	12.8	9.6
Shershera Jole	436158	901900	2115	2081.1	75	9.35	2.9
Inseno test well	440020	888300	1840	1828.56	168		6
Kache ber	424544	894351	2232	2216.35	123.83	0.02	1.5
Butajira Dekuman	432501	898201	2135	2119.8	52	0.67	2.3
DebubYeberaswrha	435517	877276	1828	1788.81	109	0.26	5.14
Debub Goto	438154	876204	1830	1703.38	187	0.45	3.4
SemenSanbeunfila	439069	878182	1942	1809.67	194	0.29	3.1
Kosh test well	448646	885794	1864	1732	244	-	3.1
BH-41	432501	898201	2025	1973	52		7
BH-42	436926	899049	1938	1854	84		3
RV2288	429307	897130	1891	1871	20		1
RV2365	449039	891512	1865	1837	28		1
RV2372	438896	894475	1920	1910	10		1
RV2436	445134	895474	1853	1825	28		0.3
RV2566	449214	913780	1941	1923	18		0.02
RV5274	426254	887320	2119	2000	119		0.277
BH-6	441974	890758	1812	1749	63		6.45
BH-12	415084	877224	2277	2094	183		3.25
BH-15	436818	892494	1824	1758	65		3.25
BH-31	435852	869258	1933	1682	251		3.75
BH-32	453015	883724	1791	1524	267		3.1
BH-33	447720	875620	1865	1565	300		2.5
BH-34	446742	872640	1886	1592	294		3.45
SW				2540	61		0.5
SW				2098	85		0.75
SW				1901	46		2.5
SW				1855	54		2
SW				1822.5	17		3
SW	441811	891169	1832	1817.5	17		3
SW	445587	890527	1835	1812	23		1.56
SW	446858	889032	1832	1817	15		5.5

SW	**440559**	**886885**	**1831**	**1823**	**8**		**2**
SW	**440854**	**889603**	**1839**	**1821**	**18**		**2**
SW	**439032**	**888026**	**1828**	**1822**	**6**		**2**
SW	**438206**	**887054**	**1825**	**1820.4**	**4.6**		**2**
SW	**439526**	**889020**	**1833**	**1822.5**	**12.5**		**2**
SW	**439537**	**889407**	**1833**	**1822**	**11**		**2**
SW	**439689**	**889746**		**1822**	**11**		**2**
SW	**447780**	**886782**	**1829**	**1813**	**16**		**2**
SW2-1	**443712**	**908129**	**1898**	**1880**	**16**		**2.5**
SW2-2	**442690**	**908775**	**1919**	**1889**	**30**		**0.5**
SW3-1	**441925**	**908580**	**1924**	**1897**	**27**		**0.5**
SW3-2	**443068**	**907196**	**1893**	**1878**	**15**		**2**
SW3-3	**444979**	**905272**	**1878**	**1868**	**10**		**3**
SW1	**446896**	**904607**	**1864**	**1850**	**14**		**2**
SW1	**443288**	**909887**	**1855**	**1818**	**37**		**5**
Jole-1(SW)	**440195**	**905819**	**1901**	**1886**			**2**
C-camp(SW)	**440014**	**905638**	**1908**	**1896**			**0.01**
(SW)	**448520**	**858400**	**1794**	**1776**			**1.5**
Jole-3(SW3)	**444039**	**903498**	**1860**	**1848**			**4**
Jole-2(SW2)	**442310**	**904952**	**1873**	**1865**			**2.5**
Adel(SW2)	**448953**	**900604**	**1856**	**1812**			**5**
Gose(SW)	**447562**	**904659**	**1863**	**1833**			**0.75**
Inseno(HDW)	**442017**	**891450**	**1840**	**1825**			**3**
Gogeti(HDW)	**442293**	**908704**	**1924**	**1897.5**			**1.5**
SW-10	**440195**	**905619**		**1886.00**			
SW-11	**443712**	**908129**		**1880.00**			
SW-12	**443068**	**907198**		**1878.00**			
SW-14	**444979**	**905272**		**1868.00**			
SW-15	**442310**	**904952**		**1865.00**			
SW-16	**447042**	**906854**		**1855.00**			
SW-17	**446896**	**904607**		**1850.00**			
SW-18	**444039**	**903498**		**1848.00**			
SW-19	**431103**	**880724**		**1834.50**			
SW-20	**437645**	**890366**		**1833.00**			
SW-21	**447562**	**904659**		**1833.00**			
SW-22	**438525**	**892515**		**1832.00**			
SW-23	**438398**	**891339**		**1828.50**			
SW-24	**434096**	**877393**		**1827.00**			
SW-26	**430723**	**880064**		**1825.75**			
SW-27	**440559**	**886885**		**1823.00**			
SW-28	**441913**	**891311**		**1822.50**			
SW-29	**439526**	**889020**		**1822.50**			
SW-31	**434916**	**877533**		**1822.00**			
SW-32	**441620**	**889345**		**1822.00**			
SW-33	**439032**	**888026**		**1822.00**			
SW-34	**444425**	**890845**		**1821.00**			
SW-35	**440854**	**889603**		**1821.00**			
SW-37	**438206**	**887054**		**1820.40**			
SW-39	**445997**	**892208**		**1819.00**			
SW-41	**448674**	**899951**		**1818.00**			
SW-43	**446858**	**890325**		**1817.00**			
SW-44	**431974**	**879460**		**1816.00**			
SW-45	**441090**	**883120**		**1816.00**			
SW-46	**445831**	**891566**		**1815.00**			

SW-47	**441700**	**884120**		**1814.00**			
SW-48	**447780**	**886782**		**1813.00**			
SW-49	**445587**	**890527**		**1812.00**			

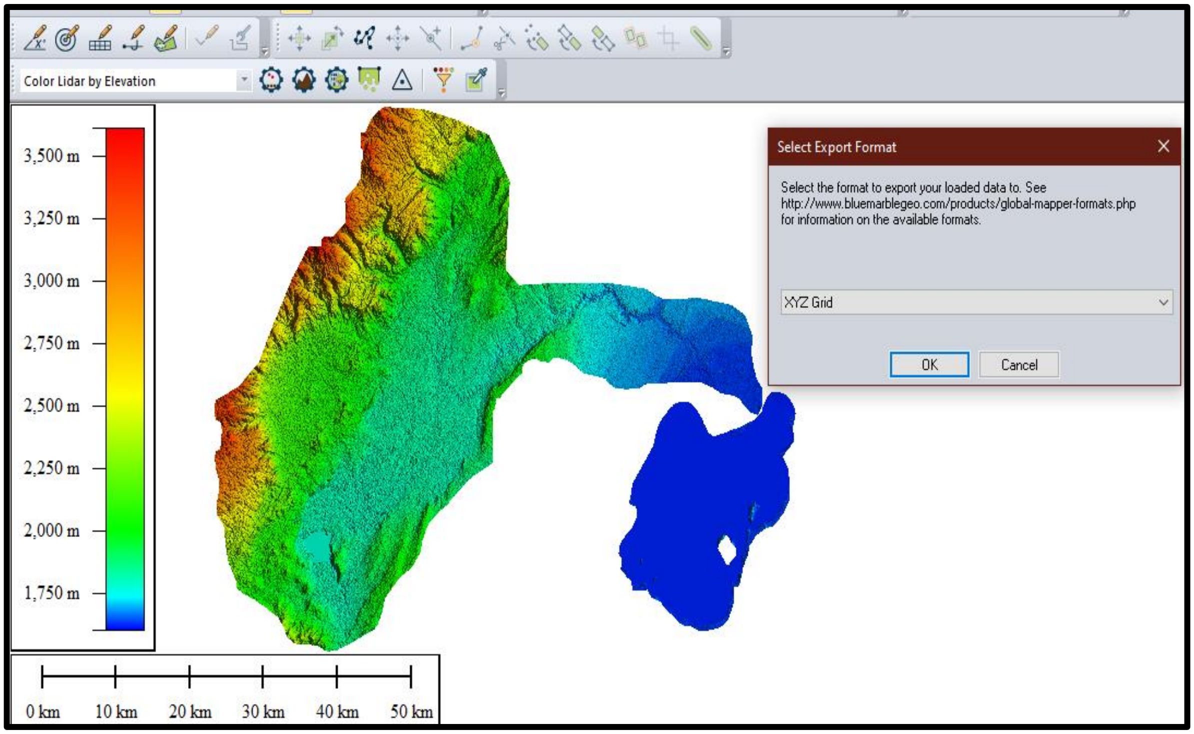
Appendix- 9 simulated steady state and observed static water level for 56 wells.

Borehole Name/ID/code	**calculated value(hs)**	**OBSERVED value(ho)**	**residual**	**absolute residual**	**(Ho-hs)^2**
BH(semen-shershra)	**1851.204**	**1873.45**	**22.246**	**22.246**	**494.884**
BZDP/TW3/Weja)	**1825.035**	**1820.4**	**-4.635**	**4.635**	**21.4832**
BHBZDP/TW4/insen	**1812.404**	**1828.56**	**16.156**	**16.156**	**261.016**
BH/yebrserye	**1784.33**	**1788.81**	**4.48**	**4.48**	**20.0704**
RV2288	**1886.749**	**1871**	**-15.7**	**15.749**	**248.031**
RV2365	**1810.006**	**1837**	**26.994**	**26.994**	**728.676**
RV2372	**1879.417**	**1900**	**20.583**	**20.583**	**423.659**
RV2436	**1826.832**	**1825**	**-1.832**	**1.832**	**3.35622**
RV2566	**1874.457**	**1903**	**28.543**	**28.543**	**814.702**
RV5274	**1970.525**	**2000**	**29.475**	**29.475**	**868.775**
BH-2	**1826.41**	**1810**	**-16.41**	**16.41**	**269.288**
BH-22	**1828.504**	**1810**	**-18.50**	**18.504**	**342.398**
BH-35	**1859.603**	**1847.74**	**-11.86**	**11.863**	**140.730**
SW	**1829.487**	**1801**	**-28.4**	**28.487**	**811.509**
SW	**1839.113**	**1855**	**15.887**	**15.887**	**252.396**
SW	**1835.512**	**1822.5**	**-13.0**	**13.012**	**169.312**
SW	**1839.489**	**1817.5**	**-21.9**	**21.989**	**483.516**
SW	**1822.129**	**1812**	**-10.1**	**10.129**	**102.596**
SW	**1816.636**	**1817**	**0.364**	**0.364**	**0.13249**
SW	**1841.708**	**1823**	**-18.7**	**18.708**	**349.989**
SW	**1840.334**	**1821**	**-19.3**	**19.334**	**373.803**
SW	**1847.76**	**1822**	**-25.76**	**25.76**	**663.577**
SW	**1842.537**	**1820.4**	**-22.1**	**22.137**	**490.046**
SW	**1846.504**	**1822.5**	**-24.0**	**24.004**	**576.192**
SW	**1846.502**	**1822**	**-24.**	**24.502**	**600.348**
SW	**1847.653**	**1822**	**-25.6**	**25.653**	**658.076**
SW	**1813.688**	**1813**	**-0.688**	**0.688**	**0.47334**
SW-10	**1865.648**	**1886**	**20.352**	**20.352**	**414.203**
SW-11	**1855.046**	**1880**	**24.954**	**24.954**	**622.702**
SW-12	**1853.796**	**1878**	**24.204**	**24.204**	**585.833**
SW-14	**1854.886**	**1868**	**13.114**	**13.114**	**171.976**
SW-15	**1842.293**	**1865**	**22.707**	**22.707**	**515.607**
SW-16	**1843.879**	**1855**	**11.121**	**11.121**	**123.676**
SW-17	**1832.065**	**1850**	**17.935**	**17.935**	**321.664**
SW-18	**1829.167**	**1848**	**18.833**	**18.833**	**354.681**

SW-19	**1848.725**	**1834.5**	**-14.**	**14.225**	**202.350**
SW-20	**1858.867**	**1833**	**-25.8**	**25.867**	**669.101**
SW-21	**1856.765**	**1833**	**-23.7**	**23.765**	**564.775**
SW-22	**1827.702**	**1832**	**4.298**	**4.298**	**18.4728**
SW-23	**1850.124**	**1828.5**	**-21.6**	**21.624**	**467.597**
SW-24	**1845.72**	**1827**	**-18.72**	**18.72**	**350.438**
SW-26	**1848.71**	**1825.75**	**-22.96**	**22.96**	**527.161**
SW-27	**1852.55**	**1823**	**-29.55**	**29.55**	**873.202**
SW-28	**1835.035**	**1822.5**	**-12.5**	**12.535**	**157.126**
SW-29	**1849.875**	**1822.5**	**-27.3**	**27.375**	**749.390**
SW-31	**1860.041**	**1832**	**-28.0**	**28.041**	**786.297**
SW-32	**1836.279**	**1822**	**-14.2**	**14.279**	**203.889**
SW-33	**1846.513**	**1822**	**-24.5**	**24.513**	**600.887**
SW-34	**1827.565**	**1821**	**-6.565**	**6.565**	**43.0992**
SW2-1	**1854.452**	**1880**	**25.548**	**25.548**	**652.700**
SW2-2	**1866.452**	**1889**	**22.548**	**22.548**	**508.412**
SW3-1	**1869.851**	**1897**	**27.149**	**27.149**	**737.068**
SW3-2	**1854.573**	**1878**	**23.427**	**23.427**	**548.824**
SW3-3	**1838.639**	**1868**	**29.361**	**29.361**	**862.068**
SW1	**1834.702**	**1850**	**15.298**	**15.298**	**234.028**
SW2	**1847.432**	**1818**	**-29.43**	**29.432**	**866.24**

Appendex-10 study area model grid design procedures

The model grid of the study area is used to check the exactness of delineated study area and better to check the fair distribution model calibration well.in this case, Different procedures are used for this research to design the model grid for the study area. firstly, open the defined study area on global mapper software working window secondly, picking the study area by the digitizing tools. Thirdly, exporting the chosen defined study area in the form of elevation grid format XYZ.



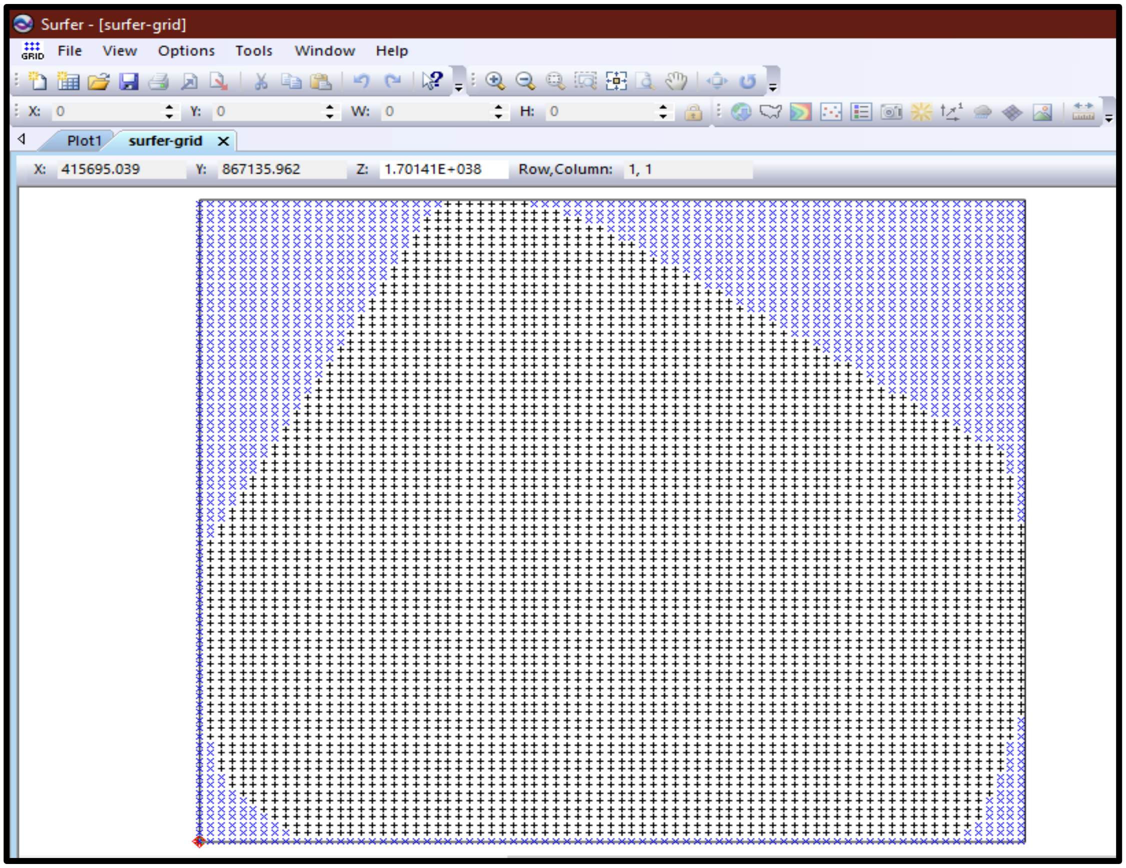
Select Export Format

Select the format to export your loaded data to. See http://www.bluemarblegeo.com/products/global-mapper-formats.php for information on the available formats.

XYZ Grid

Map- 1 dem exporting to elevation grid format (xyz)

The exported elevation grid of the study area continues to check the exact delineated study area. then, rearrange the dialogue box window and obtain the XYZ data. After that, the elevation grid data are arranged in the form of Txt.dat files. Next, generate the path profile for study area and after generating the path profile the data must be in the form of blanked files data. Finally, the elevation grid data is blanked by the border profile blanked files.in order to check the correctness of the defined study area, there is inner and outer blank of the region. Firstly, the outer blank is performed by blanking the dot.dat elevation grid files with the blanked files of the border profile element twelve thousand and six hundred seven (12,607) with zero (1) value. Look the figure below which shows the outer blanked section of the study area with the cross hatch.

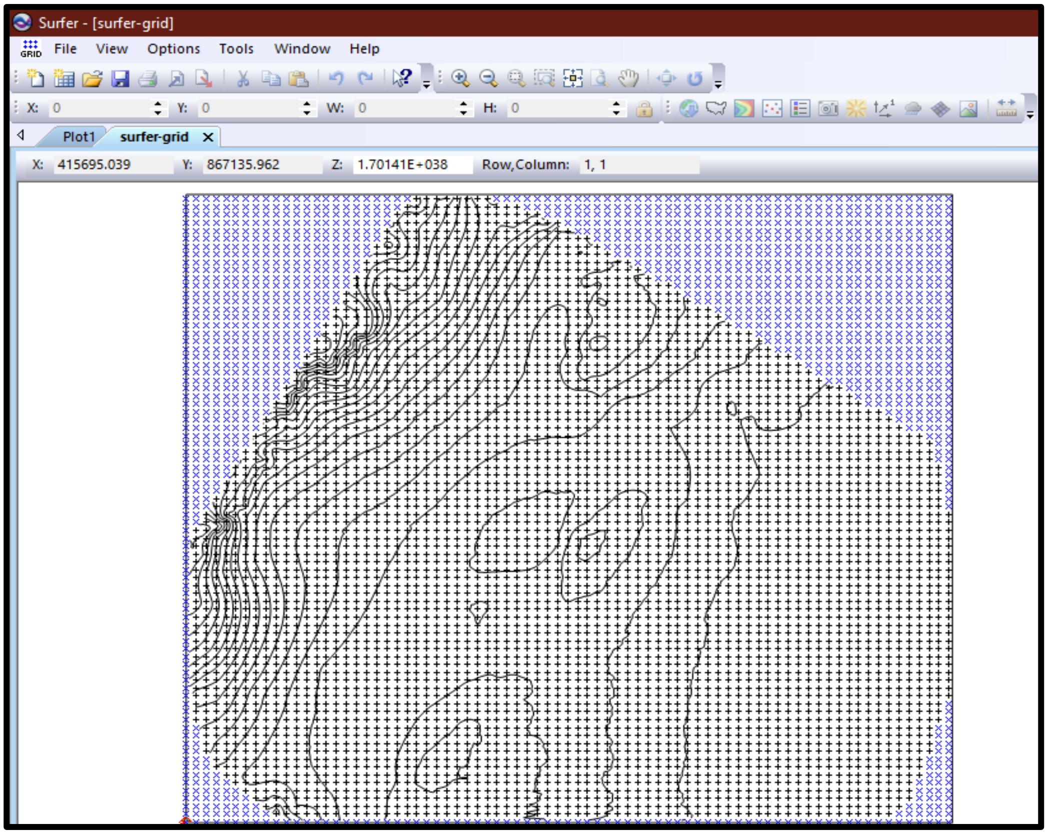


X: 0 Y: 0 W: 0 H: 0

X: 415695.039 Y: 867135.962 Z: 1.70141E+038 Row,Column: 1, 1

Map -2 outer blank of the study area in surfer plot

According to figure below the inner blank is performed by blanking the dot.dat elevation grid files with the blanked files of the border profile element twelve thousand and six hundred seven (12,607) with zero (0) value.

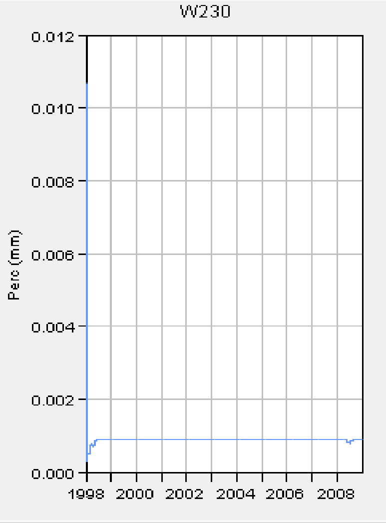


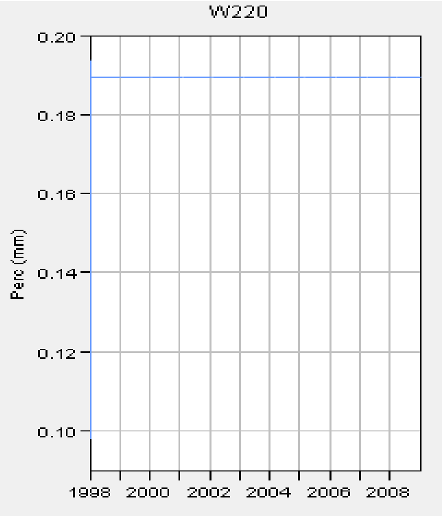
X: 0 Y: 0 W: 0 H: 0

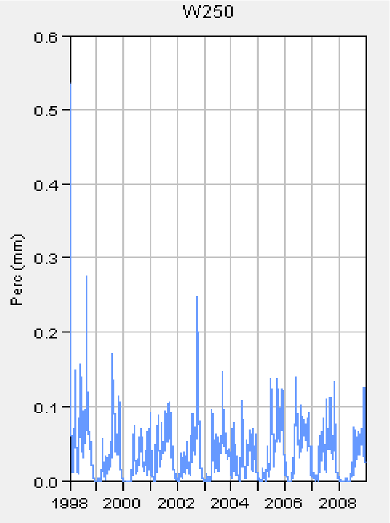
X: 415695.039 Y: 867135.962 Z: 1.70141E+038 Row,Column: 1, 1

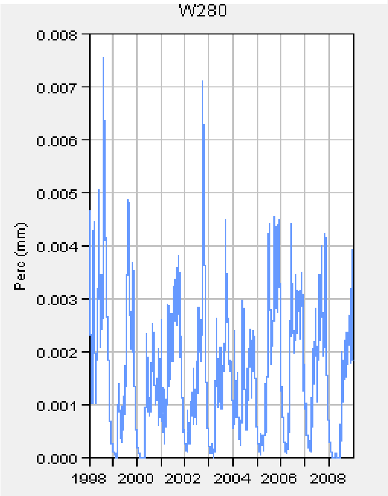
Map -3 inner blank of the study area in surfer plot

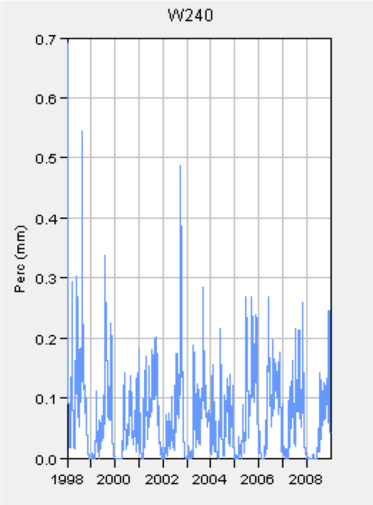
Appendex-11 recharge/ground water percolation graphs of each sub basin of the model .

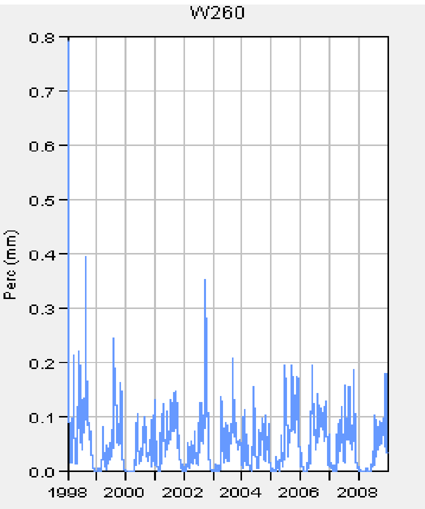


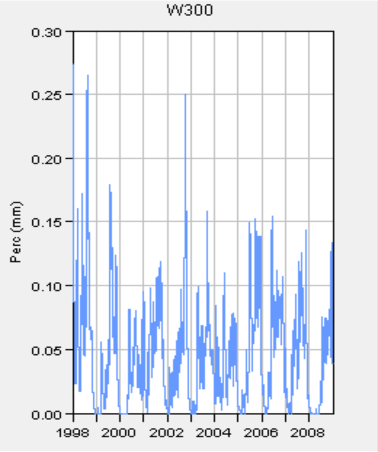


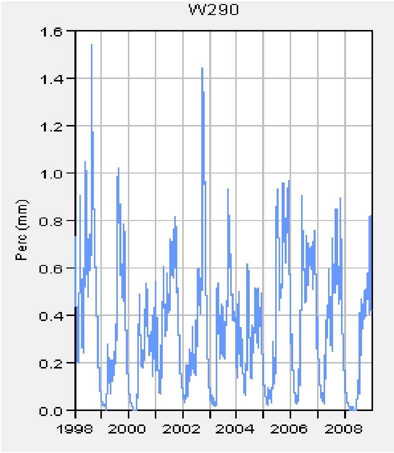


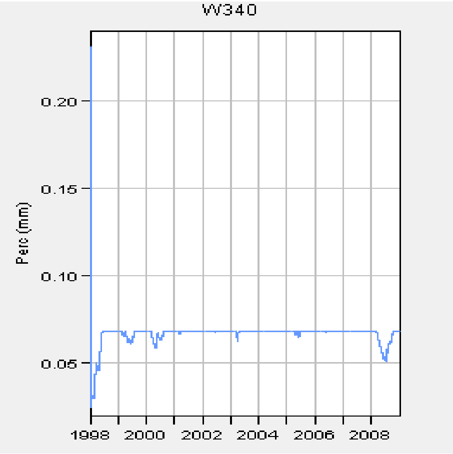


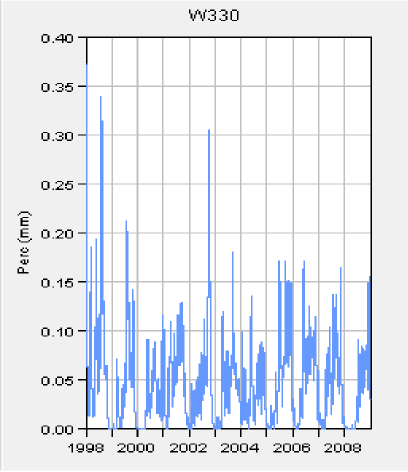


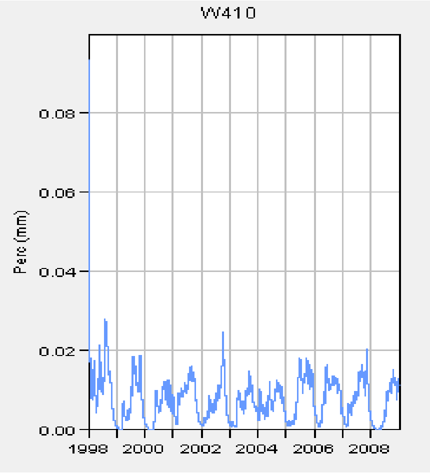


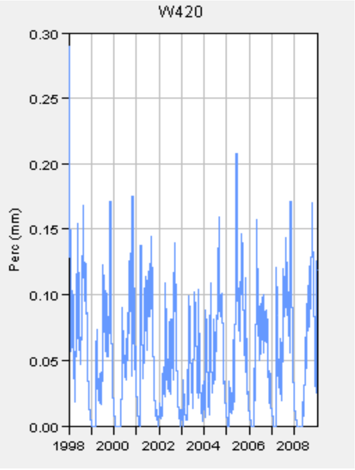


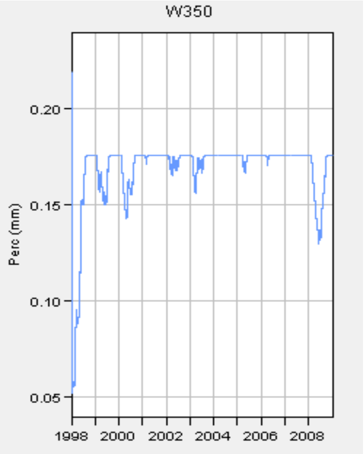


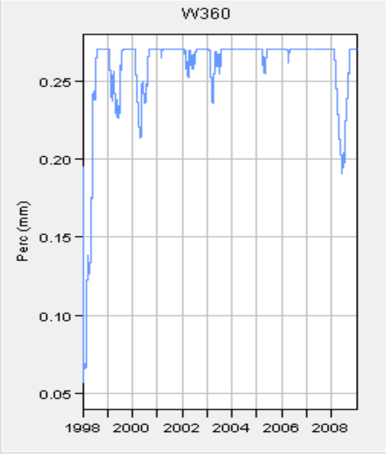


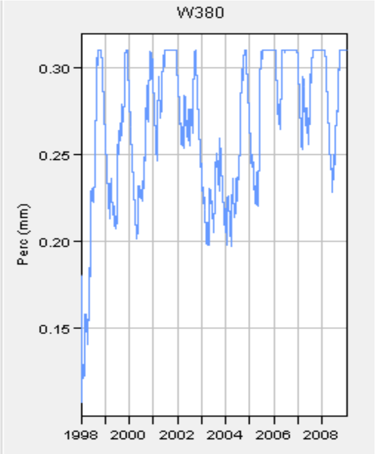

W330
Perc (mm)
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1998
2000
2002
2004
2006
2008

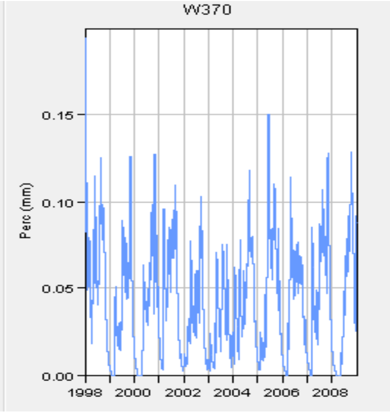

W410
Perc (mm)
0.08
0.06
0.04
0.02
0.00
1998
2000
2002
2004
2006
2008

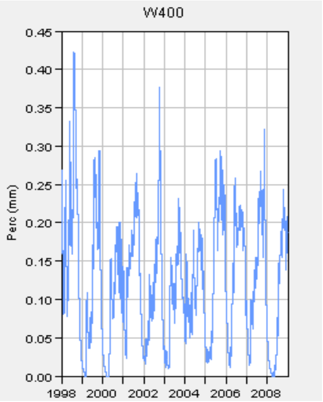

W420
Perc (mm)
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1998
2000
2002
2004
2006
2008

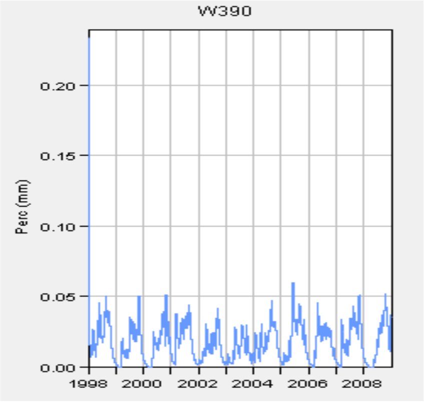

W350
Perc (mm)
0.20
0.15
0.10
0.05
1998
2000
2002
2004
2006
2008

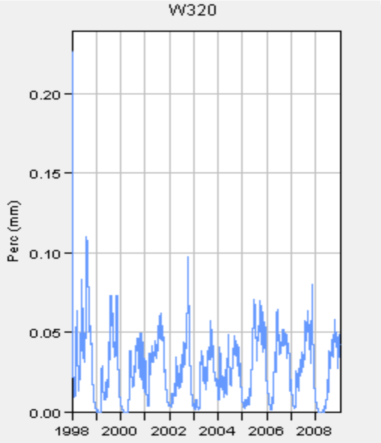

W360
Perc (mm)
0.25
0.20
0.15
0.10
0.05
1998
2000
2002
2004
2006
2008

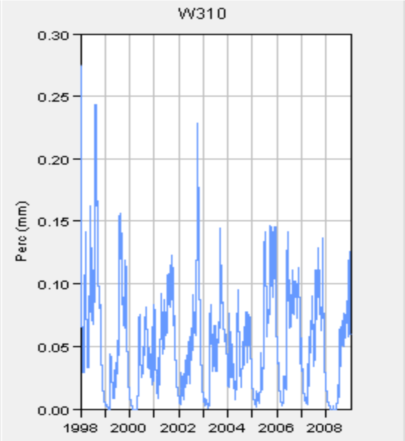

W380
Perc (mm)
0.30
0.25
0.20
0.15
1998
2000
2002
2004
2006
2008

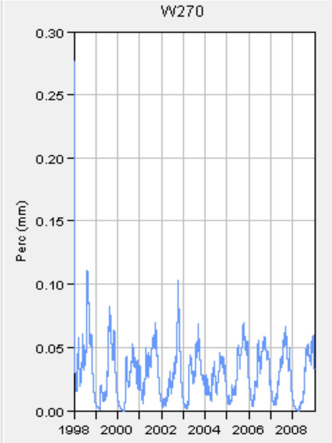

W370
Perc (mm)
0.15
0.10
0.05
0.00
1998
2000
2002
2004
2006
2008


W400
Perc (mm)
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
1998
2000
2002
2004
2006
2008


W390
Perc (mm)
0.20
0.15
0.10
0.05
0.00
1998
2000
2002
2004
2006
2008


W320
Perc (mm)
0.00
0.05
0.10
0.15
0.20
1998
2000
2002
2004
2006
2008


W310
Perc (mm)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1998
2000
2002
2004
2006
2008


W270
Perc (mm)
0.00
0.05
0.10
0.15
0.20
0.25
0.30
1998
2000
2002
2004
2006
2008