



# **Modelling Surface and Ground Water Interactions of Borkena River Catchment, Ethiopia**

WALLE JINIE GOBEZIE

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This is to certify that the thesis prepared by Walle Jinie, entitled: *Modeling Surface water-Groundwater Interactions of Borkena River Catchment* and submitted in partial fulfillment of the requirements of the degree of Master of Science (Water Resource Management) complies with the regulations of the university and meet the accepted standards with respect to originality and quality.

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Advisor \_\_\_\_\_ Signature \_\_\_\_\_ Date \_\_\_\_\_

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## Abstract

Inadequate water resources supply among different water users can be viewed both from social and economic dimension. The Borkena Catchment is affected by recurrent draught due to climate change in every eight to ten years. To sustain the water security of the catchment understanding the groundwater surface water interaction and management is necessary. The general objective of this study is to analyze the surface and groundwater interactions; specifically to estimate the recharge, to identify the regional and local ground water in the system and to assess if the Borkena river is gaining or losing river. ArcSWAT was applied to understand the water balance components of the study. The SWAT model result was calibrated by using SWAT CUP SUFI2 algorithm with daily stream flow data ranging from 2000-2007 and validated with stream flow data ranging from 2008-2014. The groundwater and management parameters are more sensitive (groundwater revap coefficient, groundwater delay, threshold depth of water in the shallow aquifer vital for return flow to occur (GWQMN), deep aquifer percolation fraction (RCHRG\_DP)). The model goodness of fit was evaluated with coefficient of determination and the Nash-Sutcliffe Coefficient on a monthly basis for both calibration and validation periods and resulted 0.68 and 0.66 for calibration period and 0.64 and 0.63 for validation periods respectively. After calibration the ArcSWAT model was conducted and the result was good. From the SWAT model the annual rainfall of the whole catchment is 1017.5mm. The recharge calculated is found 12% of annual rainfall, surface runoff is 62% of the annual rainfall and evapotranspiration is 58% of the annual rainfall. Based on the produced hydrogeological cross sections, hydrogeological map, and groundwater level map from deep boreholes water level and physico-chemical analysis water types data, there is groundwater transfer from Abay basin (Gerado) to Awash basin (Combolcha-Kemisse). The water types at Gerado/Abay basin (KCTVW-01-19) are Na-HCO<sub>3</sub>-CO<sub>3</sub>, water type at Combolcha/ Awash basin (KCVTW-02-19) is Ca-Na-Ca-Mg-HCO<sub>3</sub> and water type at Kemisse/Awash basin (KCVTW-03-19) is Na-Ca-HCO<sub>3</sub>-SO<sub>4</sub> which are similar but due to geo-chemical processes evolution of compounds is identified. This indicated that there is regional groundwater flow (transfer) from Abay (Gerado) to Awash (Combolcha-Kemisse) and from the NW-N-S or Kutaber-Desse to Combolcha and Kemisse locally. The surface water and groundwater exchange is analyzed based on the boreholes groundwater elevation and Borkena river elevation data the positive values in each river and borehole data indicated that there is river water seepage to aquifers and negative values indicated groundwater flows from aquifer to river. The analysis result indicated that 41.66 % is effluent or gaining river, 36.11 % is influent or losing and 22.22% is effluent or Influent River. This also confirmed with the SWAT-MODFLOW model result for 7448 river cells. A further study to identify Regional groundwater flow from Gerado/Abay to Combolcha/Awash basin and Surface water and groundwater interaction using Isotope analysis method is recommended.

**Key words:** Groundwater-Surface water Interactions, ArcSWAT, SWAT-MODFLOW, Borkena Catchment.

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## Acronyms and Abbreviations

ADSE	Amahara Design and Supervision Enterprise
ArcGIS	Geographic Information System work with Maps & Geographic Information
ArcSWAT	ArcGIS extension software for Soil & Water Analysis
ArcView	GIS Software application and Extension from ESRI
BCM	Billion Cubic Meter
$C_{riv}$	River Conductance
D	Aquifer thickness
DEM	Digital Elevation Model
E	East
EC	Electrical Conductivity
ECDSWC	Ethiopian Construction Design & Supervision Corporation
ESRI	Environmental Systems Research Institute
ET	Evapotranspiration
e.g	Example
ITCZ	Inter Tropical Convergence Zone
GPS	Global Position System
GSE	Geological Survey of Ethiopia
GW	Groundwater
GW-SW	Groundwater-Surface Water
HEC-HMS	Hydrologic Engineering Center's Hydraulic Modeling System
HRU	Hydrologic Response Unit
Hrs	Hours
DHRU	Disaggregated Hydrologic Response Unit
i.e	that is
ITCZ	Inter tropical Convergence Zone
K	Hydraulic Conductivity
Kh or Kx	Horizontal Hydraulic Conductivity
Km <sup>2</sup>	Square Kilometer
Kv or Kz	Vertical Hydraulic Conductivity
KW Models	Kinematic Wave theory Models
L <sup>3</sup>	To indicate in cubic meters
L/T	Length/Time to indicate meter per day
M <sup>3</sup>	Cubic Meter
M <sup>3</sup> /s	Cubic meter per second
m.a.s.l	Meters above sea level
m.b.g.l	Meters below ground level
M/L <sup>3</sup>	Mass per Length to indicate Killogram per Cubic meter

MODFLOW	Modular Three Dimensional Finite Difference Groundwater Flow Model
MoWIE	Ministry of Water, Irrigation and Energy
M sec <sup>2</sup> /kg	Meter second square per killogram
N	North
NGO	Non-Governmental Organizations
NMA	National Meteorological Agency
NNW-SSE	North North West-South South East
NSE	Nash-Suctliffe efficiency
OAT	One at a time for sensitivity analysis
P	Precipitation
PD models	Probability distributed models
PH	Potential of Hydrogen
QGIS	Quantum Geographic Information System
R <sup>2</sup>	Coefficient of Determination
RCMRD	Regional Center for Mapping of Resources for Development
SCS-CN	Soil Conservation Service Curve Number
SEI	Stockholm Environment Institute
SPOT image	High resolution Earth Observation Satellite system operating from Space.
SRTM	Shuttle Radar Topography
S <sub>s</sub>	Specific Storage
SUFI	Sequential Uncertainty Fitting
SW	Surface Water
SWAT	Soil and Water Assessment Tool
S <sub>y</sub>	Specific Yield
T	Transmissivity
USA	United States of America
USDA	United States Development of Agriculture
USDA-ARS	United States Development of Agriculture-Agriculture Research Service
USGS	United States Geological Survey
UTM	Universal Transvers Mercator
V <sub>v</sub>	Volume of Void
V <sub>t</sub>	Total Volume
WATBAL	Water Balance Model
WEDSWS	Water and Energy Design & Supervision Works Sector
WMO	World Meteorological Organization
X-Section	Cross-Section

## **1. Introduction**

### **1.1. Background**

One of the serious challenges to human being in the 21<sup>st</sup> century is highly linked with the increasing population, water insecurity, food insecurity, environmental degradation and fastest energy consumptions with limited resources. Water resources are subject to change over space and time due to precipitation and temperature cycles, which are becoming increasingly unpredictable due to the effects of climate change (Petersen-Perlman et al., 2017). Environmental and land degradation worsen the food production, global warming and poverty situations globally and in developing countries in particular to in Borkena River Catchment area or Southern Wollo area.

Conflicts over water use seem to increase in recent years globally. This situation aggravates in a country where irrigation is becoming the dominant use of water. Although conflicts will always occur between different water rights holders in a prior appropriation system, traditional mechanisms of sharing and delivery of water management practices have been unable to meet the needs of consumptive and irrigation uses. In addition, increases in ground-water withdrawal, and changes in climate aggravates the situations (Zektser & Loaiciga, 1993). Moreover, rapid population growth, is adding another significant challenge to water management through increased demand for water, conversion of irrigated land to suburban, exurban, and resort development, and alteration of traditional water management practices. The challenge of providing enough water for the overwhelming majority of the population puts major pressure on the supply of water satisfying the ever increasing demand. The increasing population compounded with climate change and variability amplified the pressure (Larned et al., 2015).

For proper utilization of groundwater and surface water resources, understanding the hydrology and hydrogeological systems and the study of their vulnerability to natural and anthropogenic stress conditions is very essential (Masetti et al., 2009). Interaction between groundwater and surface water play a crucial role in hydrological cycle (Li et al., 2020). Although groundwater and surface water are usually evaluated as separate water masses, they are hydrologic-ally connected transition zone in a

hydrologic continuum. The term “ground-water/surface-water transition zone” is more or less equivalent to ground-water/surface water interface zone, which refers to the interface between ground water and moving surface waters (Larned et al., 2015).

Therefore separate management of groundwater and surface-water resources is rapidly giving way to integrated GW-SW management. Meeting the flow requirements of both surface and groundwater systems are a primary aim of integrated management. To achieve this aim, managers need information about two issues: the effects of groundwater input on surface water systems and the effects of surface-water input on groundwater systems (Larned et al., 2015).

Models are used to help establish locations and characteristics of aquifer boundaries and assess the quantity of water within the system and the amount of recharge to the aquifer and the surface water ground water interactions (Anderson & Woessner, 1992). These models are used to calculate the rate and direction of movement of groundwater through aquifers and confining units in the subsurface, and the exchange of surface and groundwater between aquifers and sources and sinks, where groundwater is added or removed from the aquifer.

However, one of the key challenges in modeling GW-SW interactions is the significant time scale differences between surface water and ground water processes (Lewandowski J. et al., 2020). Because groundwater movements or flows can be orders of magnitude slower than surface water movement, the responses of groundwater systems to hydrological and management drivers such as climate variability, land use change, and groundwater extraction can be very damped and lagged. Hence a key requirement in modeling GW-SW interactions is to account for these time lags. Borkena alluvial aquifers origin is considered to be local tectonic development forming intermountain troughs. The main axis of the trough nearly runs in N-S and NNW-SSE direction. The dominant geological formations found in the valley are poorly compacted sedimentary basin fill deposits (alluvial) underlain by tertiary volcanic rocks. The frame is composed of Tertiary volcanic rocks.

The total river catchment of Borkena, valley alluvial aquifer is 1606.13 km<sup>2</sup>. The western volcanic escarpments and the eastern ridge bound the alluvial valley aquifers are highly dissected by stream networks often with rugged topography. The valley

plains alluvial aquifers have often gently rolling to the south with isolated hills as observed in southern extreme part of the area. Elevation reaches 3500m on the escarpment, whereas the wide Borkena graben lies at an average elevation of 1400 m.a.s.l. Borkena alluvial aquifers are three distinct isolated aquifers separated by tertiary volcanic ridges which are a) near each other and may be hydraulically interconnected valley plains of Kutaber (AlashaMeda) - Boru Meda - Dessie, b) Combolcha, and c) Harbu-Chefa- Kemissie.

For a sustainable development of groundwater in the proposed study area it is essential to estimate the recharge mechanism, the ground water flow condition, the groundwater surface water interaction of the catchment and potential available groundwater resource through systematic studies in order to evaluate the exploitable groundwater resources for the economical use of the available scarce resources without affecting the environment.

### **1.2. Statement of the Problem**

Inadequate water resources supply among different water users can be viewed both from social and economic dimension. First of all, the country must be safe guard its nation against water supply quantitatively as well as qualitatively, otherwise it arises water use conflict between its nations when seen from its social perspective. The Borkena Catchment is affected by recurrent draught due to climate change in every eight to ten years.

Identification of ground water movement along flow paths of varying lengths from areas of recharge to discharge area is essential for a study area. The source of water to the water table (ground-water recharge) is infiltration of precipitation through the unsaturated zone. Ground-water flow systems can be of greatly different sizes and depths, and they can overlie one another. Local flow systems can be underlain by intermediate and regional flow systems. Water in these deeper flow systems have longer flow paths, but they also eventually discharge to surface water. Surface water bodies that receive discharge from more than one flow system receive that water through different parts of their bed. Because of the different lengths and travel times of water within flow paths, the chemistry of water discharging into the surface water

from different flow paths can be substantially different (Wondzell, 2015). The water resources potential of the study area is dependent not only on the surface water but also on the groundwater. When deduced from the physiographic and structural setting of the catchment, the catchment may get significant deeper recharge from the Western escarpment or adjacent basin (Abay basin). This research tried to show that there is regional flow that contributed to the flow from Abay basin in to the Borkena catchment. The land of the study area, therefore, be dependent not only the surface water but also largely on the groundwater.

Despite the Catchments key importance, little is known about the details of the water resources in an integrated manner. Engida (2015) has conducted Steady state groundwater modeling only on the alluvial aquifers by excluding Desse, Borumeda and Kutaber alluvial aquifers and all Tertiary volcanic aquifers in the study area. Besides this the aquifer thickness he calculated during his study considered only the alluvial aquifers which are less than 210m thick but by now there is also another volcanic aquifer found below the alluvial aquifer as of the boreholes data drilled up to nearly 600 (six hundred) and 512 meters below the surface at Combolcha and Kemmisse towns. Therefore, there is knowledge gap to be filled for better understanding, utilization and management of the water resources of the Catchment by using both SWAT and SWAT-MODFLOW Model Techniques. Getachew (2016) has also conducted Numerical Groundwater flow modeling on the part of the Borkena river catchment using Modflow Model with the objective of identifying the most sensitive parameter of the hydrogeological system with limited water point data. He used very limited borehole data as well as the aquifer thicknesses considered were less than 200m. Here, there is also a gap with limitation of data and the area coverage to be modeled. So, this study used more data sets and also extended the model area from 1212 km<sup>2</sup> in the previous studies to 1606 km<sup>2</sup>. Understanding the interaction between surface water and ground water, identifying the groundwater flow system, evaluation of the inter-basin groundwater flow and recharge mechanism is essential for the management and utilization of the water resources.

### **1.3. Objective of the study work**

#### **1.3.1. General Objective of the study work**

The general objective of the study was to analyze the surface water-groundwater interactions of Borkena River catchment.

#### **1.3.2. Specific Objectives**

The specific objectives of this research were:

- To estimate the groundwater recharge of the Borkena River catchment.
- To identify the local and regional groundwater flow system.
- To assess the surface and groundwater dynamics (effluent or influent) river.

### **1.4. Research Questions**

1. What is the recharge mechanism of the study area?
2. How could be the groundwater flow system defined?
3. Is the river effluent or influent (How the river and groundwater interaction looks like)?

### **1.5. Significance of the Study**

Rapid population growth, water use conflict among users and water scarcity are common throughout the globe, more in developing countries, rendering it sensitive to climate change. Water resources are increasingly under pressure from population growth, economic activity and intensifying competition for the water among users. The study area is one of the drought prone area which is confronted by recurrent drought. Ethiopia has planned to minimize the scarcity of water resource throughout the country in the growth and transformation plan 2 (GTP II) plan period.

Therefore, understanding the interaction of the surface and groundwater system and characterization of aquifers and the groundwater flow system is crucial for sustainable and effective use of surface and groundwater resources of the study area. This thesis work presents a framework for implementing and applying integrated surface water-groundwater models to address water management questions in the catchment of the Borkena River. Model construction is facilitated through the development of a graphical user interface SWAT-MODFLOW (GUI) tool, ArcSWAT capable of generating required input files, configuring simulation settings, and visualizing and interpreting results. A methodology to optimize a SWAT model is presented with

automatic and manual calibration process and sensitivity analysis using SWAT CUP SUFI2 algorithm. The proposed modeling framework and an ArcSWAT based graphical user interface for the SWAT-MODFLOW model can facilitate the use of integrated models worldwide to assist with finding technical solutions to water issues. Results can help enhance understanding regarding the spatio-temporal patterns of hydraulic head elevation, recharge, surface-subsurface water interaction and the water resource availability and the ground water flow systems in the catchment.

## **2. Literature Review**

### **2.1. Surface Water**

According to WMO (2012) surface water, generally, lakes, dams, streams and rivers, is water that is open to the atmosphere and feeds by runoff from the surface. Hydrology is the geoscience that describes and predicts the occurrence and circulation or movement of the earth's water. According to Laat and Savenije (1992), the development of hydrology as a science based on physical and mathematical principles is of more recent date (since 1930). The hydrology is restricted to the terrestrial occurrence of water, excluding oceanography and meteorology and it studies the flow of water overland, in rivers and lakes, but also through soil, plant and atmosphere. It includes quantifying the effects of human interventions on the natural system at watershed, river basin, regional, country and continent scales. Studies conducted by hydrologists were traditionally concerned with the supply of water for domestic and agricultural use and the prevention of flood disasters but their field of interest also includes hydropower generation, navigation, water quality control, thermal pollution, recreation and the protection and conservation of nature (Laat and Savenije, 1992). The hydrologic cycles as shown in Figure 2.1-1 below the circulation of water evaporated from the sea and land surfaces, its transport through the atmosphere to the land and its return to the sea via surface, subsurface percolated in to the ground and seep to the lake and atmospheric routes. The water balance is mainly applied to a river catchment area contributing to the discharge at a particular cross-section.

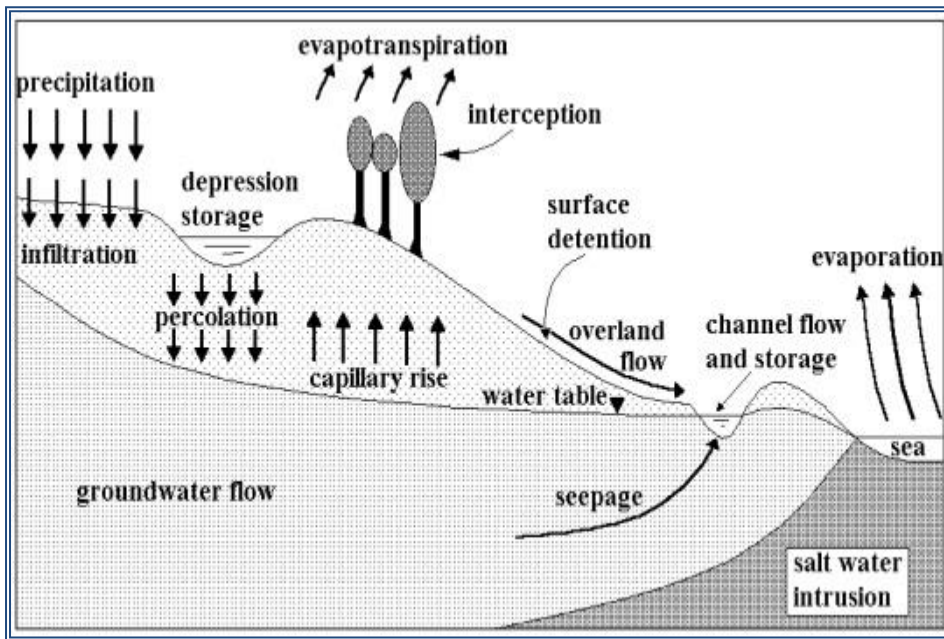


Figure 2.1-1 Hydrologic Cycle representation adopted from (Laat and Savenijie, 1992)

### 2.1.1. Runoff Mechanisms

The two principal theories describing tools of runoff (overland flow) generation are infiltration excess, or Hortonian overland flow, and saturation excess. Infiltration excess is based on the concept that runoff begins when rain fall rates exceed soil infiltration capacities (Horton 1933, 1940) assuming runoff amounts are directly controlled by factors that determines soil infiltration rate, such as land use and soil type. Hortonian overland flow is important in arid regions, where soil crusting and/or surface sealing occurs during rain storms, and also in urban areas, where impervious surfaces cause surface runoff. It also occurs in extremely heavy intensity storms in nearly all regions. Therefore, a management perspective based on the infiltration excess concept can identify on the basis of land use and possibly, soil type.

The second concept of runoff generation is the saturation excess theory, which assumes that runoff is generated by direct precipitation on or from saturated areas in the landscape (Dunne and Black, 1970), and that once the soils in these areas become saturated to the surface, all additional rain that falls (regardless of intensity) becomes overland flow. The extent of these saturated areas can vary with season and from

storm to storm; thus the saturation excess theory has been extended to encompass variable source area hydrology, attributed primarily to Dunne and Black (1970).

The most common approach to predicting runoff model, such as SWAT (Arnold et al., 1993), is through the soil conservation service curve number (SCS-CN) (USDA, 1972) method. The SCS-CN method is theoretically consistent with the infiltration excess theory (e.g., Hjelmfelt, 1980) as well as the saturation excess theory, but is most commonly used in a way that implicitly assumes infiltration excess as the primary runoff mechanism by using land use and soil class to assign runoff potential. In contrast, methods that assume saturation excess theory use landscape and topographical factors rarely used in the SCS-CN method as indicators of runoff potential.

Models based on either the infiltration-excess or the saturation-excess theory can be calibrated to correctly simulate flow at the watershed outlet at a wide range of temporal scales, regardless of the true runoff generation process. Accurate characterization of runoff generation is essential in biogeochemical models to correctly estimate flow and nutrient flux. The widespread commitment to models based on the SCS-CN method creates an urgent need to incorporate saturation excess theory for use in watersheds where saturation excess hydrology dominates (Lyon et al., 2006).

### **2.1.2. Hydrological models**

Modeling is defined as the process of forming, combining and integrating component parts in to a realistic representation of the prototype. United States Development of Agriculture (USDA, 1972) lists the following benefits of modeling: Models that help sharpen the definition of hypotheses, define and categorize the state of knowledge, provide an analytical mechanism for studying the system of interest, and can be used to simulate experiments instead of conducting the experiments on the watershed itself.

Hydrological models are characterization of the real world system. Modeling of the rainfall runoff process of hydrology is needed for many different causes and the main reasons being limited range of hydrological measurement techniques and limited

range of measurements in space and time (Beven, 1989). Therefore, it is necessary to develop a means of extrapolating from those available measurements in space and time to un-gauged catchments and in to the future to assess the likely impact of future hydrological changes (Beven, 1989). A wide range of hydrological models are used by the researchers, however, the applications of those models are highly dependent on the purposes of which the modeling is made (Beven, 1989).

### 2.1.3. Types of Hydrological Models

Hydrological models are characterization of the real world system. Modeling of the rainfall runoff process of hydrology is needed for many different causes and the main reasons being limited range of hydrological measurement techniques and limited range of measurements in space and time. There are three types of models:

**Lumped Models:** parameters of lumped hydrologic models do not vary spatially within the basin and thus basin response is evaluated only at the outlet, without explicit accounting for the response of individual sub basins. Parameters of lumped models often do not represent physical features of hydrologic processes and usually involve certain degree of practicality. The impact of spatial variability of model parameters is evaluated by using certain procedures for calculating effective values for the entire basin. The most commonly employed procedure is an area weighted average (Haan et al., 1994). Lumped models are not usually applicable to event-scale processes. If the interest is primarily in the discharge prediction only, then these models can provide just as good simulations as complex physically based models (Beven, 1989).

**Semi-distributed models:** parameters of semi-distributed models (simplified distributed) are partially allowed to vary in space by dividing the basin in to a number of smaller sub basins. There are two main types of semi-distributed models: a) Kinematic wave theory models (KW models, such as HEC-HMS), and b) Probability distributed models (PD models, such as TOPMODEL). The Kinematics wave theory models are simplified versions of the surface and/or subsurface flow equations of physically based hydrologic models (Beven, 1989). In the probability distributed models spatial resolution is accounted for by using probability distributions of input parameters across the basin.

**Distributed Models:** parameters of distributed models are fully allowed to vary in space at a resolution usually chosen by the user. Distributed model approach attempts to incorporate data concerning the spatial distribution of parameter variations together with computational algorithms to evaluate the influence of this distribution on simulated precipitation-runoff behavior. Distributed models generally require large amounts of data for parameterization in each grid cell.

#### **2.1.4. Selection of the Model**

There are various criteria which can be used for choosing the right hydrological model for a specific problem. These criteria are always research dependent, since every project has its own specific requirements and needs. Further, some criteria are also user dependent (and therefore subjective). Among the various research dependent selection criteria, there are four common, fundamental ones that must be always answered (Cunderlik, 2003).

- Required model outputs important to the research and therefore to be estimated by the model (Does the model predict the variables required by the research such as long-term sequence of flow?)
- Hydrologic/Hydrogeologic processes that need to be modeled to estimate the desired outputs adequately (is the model capable of simulating single-event or continuous processes?)
- Availability of input data (Can all the inputs required by the model be provided within the time and cost constraints of the research?)
- Price (does the investment appear to be worthwhile for the objectives of the research?)

#### **Reasons for Selecting SWAT and SWAT-MODFLOW Model**

The reasons behind for selecting SWAT, SWAT-MODFLOW model for this study are:

- The model was applied for land use land cover change and hydrogeological models for the groundwater flow system assessment in different parts of the world.

- The Model simulates the major hydrological/hydrogeological processes in the catchment.
- It is relatively less demanding on input data, and
- It is readily and freely available.

## **2.2. Groundwater**

The development and efficient management of groundwater resources requires a good understanding of the hydrogeological properties of the rocks that form the major aquifers. Hydrogeological parameters such as piezometric head, transmissivity, hydraulic conductivity, storage coefficient, aquifer thickness, etc. are all functions of space. These variables are not purely random, but there is some kind of correlation in the spatial distribution of their magnitudes. In this study attempts will be made to investigate the spatial distribution and correlation of aquifer parameters of the study area. Managing surface water and groundwater as a unified system is important for water resource exploitation and aquatic ecosystem conservation. The unified approach to water management needs accurate characterization of surface water and groundwater interactions (Liu et al., 2015).

## **2.3. Surface water-Groundwater Interactions**

Surface water and groundwater interaction is a natural process and it is a complex phenomenon. It is classified as connected and disconnected systems. It could take place in three types as a) Water flux entering from aquifer to river (gaining), b) Water flux leaving river (loosing) and c) combination of the two loosing or gaining river (Winter et al., 1998)

Globally, groundwater and surface water have been historically managed as isolated components of the hydrologic cycle as they have different behaviors both in temporal and spatial scales (Sophocleous, 2002). Surface water commonly is hydraulically connected to ground water, but the interactions are difficult to observe and measure and commonly have been ignored in water-management considerations and policies. However, these interactions can have significant implications for both water quantity and quality management. The interaction between groundwater and surface water is

an important aspect of the water cycle, and the management or use of one often impacts the availability and temporal patterns of the other (Sophocleous, 2002).

For example, the base flow in streams and rivers is mostly contributed from groundwater, while pumping water from wells near reservoirs or rivers is most likely recharged from surface water. Land use conditions also play an important role in the interaction of surface water and groundwater. These physical interaction processes also transport contaminants and thus integrate the biogeochemical interchanges between surface water and ground water components (Szczucin'ska, 2014). Therefore, water balance modeling needs to include both the contributions from groundwater resources and free surface water resources in a watershed.

The basic problem of water balance interactions between groundwater and surface water is stream-flow depletion, i.e., water withdrawals from aquifers can cause adverse impacts on nearby streams, such as stream-flow reduction. Hence, effective management of water quantity and quality issues requires an understanding of these surface water-groundwater interactions (Brodie et al., 2007).

Many analytical models have been developed for various aquifer and stream conditions. Analytical models are easy to use, require minimum data input, offer instantaneous solutions, and are usually assumed to provide conservative estimates. However, for complicated hydro-geologic conditions, numerical models are preferred (Sophocleous et al., 1995). The present research work focuses on the groundwater-Surface water interaction and is useful for the following main reasons: locating areas of surface-water recharge to groundwater, improving understanding of processes at the interface between surface water and groundwater, and determining the relation of water exchange between surface water and groundwater. Learning the hydrological system as never-ending processes- raining, flowing, evaporation, transpiration, dilution, and cooling, coupled with our activities and governance of these interactions is quite complex and immensely challenging (Reta, 2018).

#### **2.4. SWAT-MODFLOW Model Structure**

The interaction between groundwater and surface water is an important aspect of the water cycle and the management or use of water resource. This study is conducted a coupled groundwater-surface water investigation with SWAT-MODFLOW softwares

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to investigate the hydrological and hydrogeological conditions and the impacts of groundwater withdrawals on groundwater and surface water interactions at a river basin scale in Borkena river catchment.

SWAT-MODFLOW is a coupled hydro (geo) logical model that employs both the soil and Water Assessment Tool (SWAT) and MODFLOW SW-GW Models respectively to yield an integrated output. The SWAT-MODFLOW code developed by (Bailey et al., 2016) couples SWAT with the MODFLOW code, which improves the solution of groundwater flow problems in the system.

SWAT and MODFLOW are divided in to two components which are the input component and the computation components for the purpose of including MODFLOW in to the groundwater component for SWAT (Kim et al., 2008). For the purpose of SWAT-MODFLOW division SWAT is divided in to two units (components), before and after the subroutine 'simulate' which contains the loops governing the modeling of processes in the catchment and MODFLOW is embedded as a subroutine. That is subroutine 'gwmod' is associated with groundwater flow, which is computed based on recharge from each HRU in SWAT. As MODFLOW does not have any division of sub-basins or HRU, an alternative method is required in order to use the HRU based groundwater recharge in SWAT as the input for MODFLOW.

In other words the main program of SWAT-MODFLOW model is simply a modified version of the main program of SWAT (Kim et al., 2008). The SWAT-MODFLOW model begins by initiating SWAT and then reads the input data which are required to initiate SWAT. When MODFLOW is employed, the groundwater recharge of the cell from HRU and the river stage of the cell are used for input in MODFLOW. After applying MODFLOW, the output of the cells (cell-based recharge, aquifer evapotranspiration, and exchange rate between river and aquifer) are added via the HRU and channel, and sent to SWAT. In the SWAT-MODFLOW integrated model, the recharge rate of the cell and river stage is used as input data for MODFLOW from SWAT.

According to Neitsch et al. (2011) SWAT was developed to predict the impact of land management practices on water, sediment and agricultural chemical yields in large complex watersheds varying soils, land use and management conditions over long periods of time. It is a GIS interface (ArcGIS) software and the input parameters are digital elevation model (DEM), Land use, Soils maps and Climate data. The basic structures of SWAT are Basin, Sub-basins, Routing (Flow direction, flow line generation and flow accumulation) and Hydrological response unit (HRU).

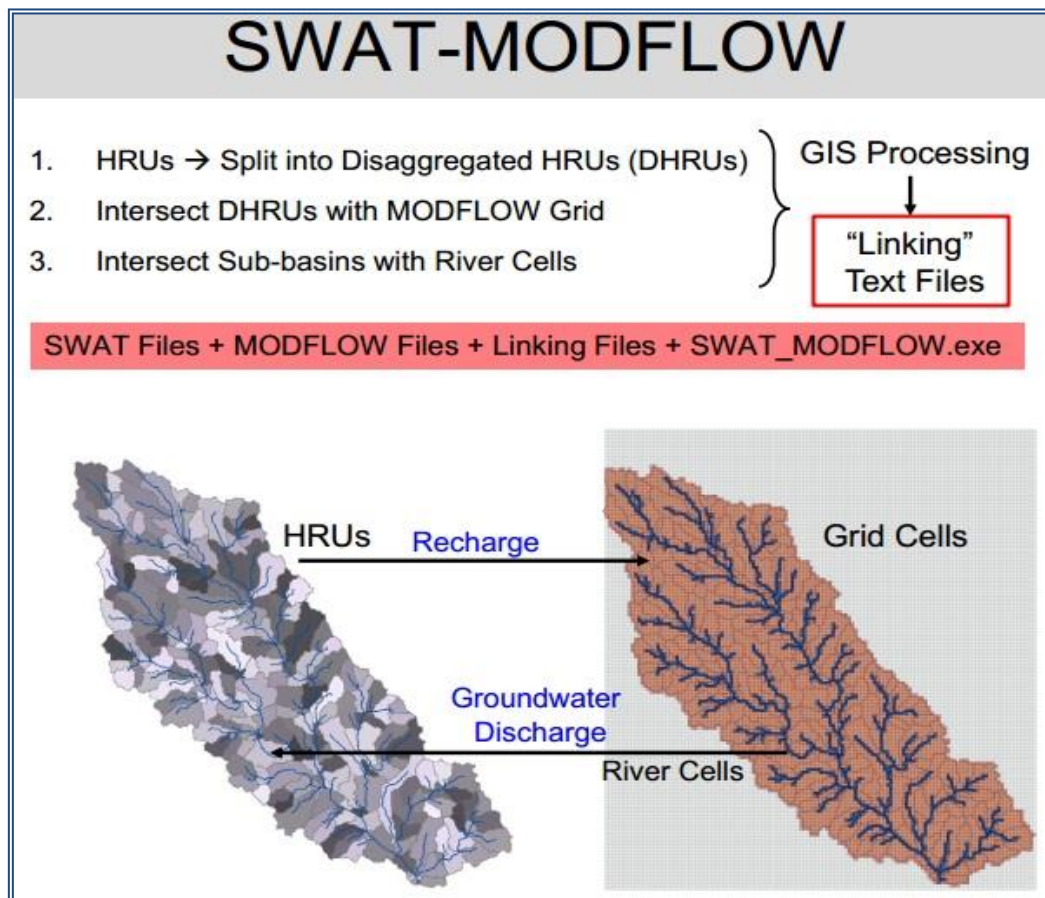


Figure 2.4-1 SWAT-MODFLOW LINKAGE (Source: Bailey et al., 2016)

## 2.5. Theoretical development of SWAT and MODFLOW

The soil and water assessment tool (SWAT) model is a continuous time semi-distributed, processed based river basin model and it was developed to evaluate the effects of alternative management decisions on water resources and nonpoint-source pollution in large river basin. The first version of SWAT was developed in the early 1990s and released as version 94.2. Srinivasan and Arnold (1994) and Arnold et al,

(1998) later published the first peer-reviewed description of a geographic information system (GIS) interface for SWAT and overview describing the key components of SWAT, respectively. The researchers pronounced the expanding global use of SWAT as well as several successive releases of the model: like versions 96.1, 98.2, 99.2 and 2000. Gassman et al. (2007) provided further description of SWAT, including SWAT version 2005. Krysanova and Arnold (2008), Douglas-Mankin et al. 2010, and Tupad et al., (2010) provide further updates on SWAT application and development trends and provide the description of SWAT version 2009. The development of SWAT software is a continuation of USDA Agricultural Research Service (ARS) modeling experience that spans over a period of 30 years (Gassman et al, 2007). The current SWAT model includes key components contributed from USDA-ARS models.

According to McDonald and Harbaugh (1998), MODFLOW is a well-known and widely used modular three dimensional block centered finite difference code used in layered aquifer systems. MODFLOW is physically based since it combines Darcy's law and the mass balance for sub surface flow. MODFLOW is able to represent a number of aquifer conditions, including confined, unconfined, leaky, delayed yield and variable confined/unconfined conditions. Both steady state and transient conditions can be simulated. The options for deactivating regions within the territory permit the modeler to design complex irregular systems with ease. The model can account for all the common boundary conditions generally encountered. These boundary conditions include fixed or pressured heads, variable or constant fluxes, groundwater recharge/discharge, point withdrawals, and drains.

Due to its lumped characteristics, the SWAT model is limited in terms of allocating with groundwater flow. On the other hand, MODFLOW has difficulty in computing the distributed groundwater recharge, which is a major input for groundwater modeling. Therefore, by sustaining the advantages of the SWAT and MODFLOW models, it is possible for the hydrological constituents to be reasonably quantified. If an HRU-based groundwater recharge is used for input data in MODFLOW, and the groundwater flow between the aquifer and the stream is computed and exchanged to



model is developed to provide a consistent basis for estimating the amounts of runoff under varying land use and soil types SCS (soil conservation service) curve number method calculating as follows:

$$Q_{surf} = \left( \frac{R_{day} - I_a}{R - I_a + S} \right)^2 \dots \dots \dots 2.5.2$$

Where :  $Q_{surf}$  is accumulated runoff or rainfall excess (mm H<sub>2</sub>O), R is day rainfall depth for the day (mm H<sub>2</sub>O),  $I_a$  is an initial abstraction which includes surface storage, interception and infiltration prior to runoff (mm H<sub>2</sub>O) and S is retention parameter (mm H<sub>2</sub>O) and is calculated as:

$$S = 25.4 \left( \frac{100}{CN - 10} \right) \dots \dots \dots 2.5.3$$

Where CN is the curve number for the day and it is a function of land use, soil permeability and antecedent soil water condition. Commonly  $I_a$  is approximated by 0.2S and equation 2.5.2 can be rewrite as;

$$Q_{surf} = \left( \frac{R_{day} - 0.2 S}{R + 0.8 S} \right)^2 \dots \dots \dots 2.5.4$$

**Peak runoff rate**

The peak runoff rate is a signal of the erosive command of a storm and is used to forecast sediment loss of a catchment. SWAT calculates the peak runoff rate with modified rational method for each HRU as;

$$Q_{peak} = \frac{Q_{surf} \alpha_{tc} A}{t_{conc}} \dots \dots \dots 2.5.5$$

Where,  $Q_{peak}$  is peak runoff rate Cubic meter per second (m<sup>3</sup>/s),  $\alpha_{tc}$  the fraction of daily rainfall that occurs during the time of concentration,  $Q_{surf}$  is the surface runoff (mm), A is the Sub-basin area Square Kilo-meter (km<sup>2</sup>),  $t_{conc}$  is time concentration (hr) and 3.6 is conversion factor.

SWAT estimates the value of  $\alpha_{tc}$  by using:

$$\alpha_{tc} = 1 - \exp(2 * t_{conc} * \ln(\alpha + \beta)) \dots \dots \dots 2.5.6$$

where;  $\alpha_{0.5}$  is the fraction of daily rain falling in the half-hour highest intensity rain fall,  $t_{conc}$  is the time of concentration for the sub basin (hrs).

**2.6. Model Efficiency Evaluation**

The performance of SWAT and MODFLOW and/or SWAT-MODFLOW is evaluated using statistical measures to determine the quality and reliability of predictions when compared to observed values. Coefficient of determination ( $R^2$ ) and Nash-Sutcliffe simulation efficiency (NSE) are the goodness of fit measures used to evaluate model prediction.

**The coefficient of determination  $R^2$**  value is an indicator of strength of relationship between the observed and predicted values. It specifies how well the distribution of the measured data is.

$$R^2 = \frac{[(Obs-Sim)(Sim-Obs)]^2}{\sum_{i=1}^n (Obs-Sim)^2 \sum_{i=1}^n (Obs-Sim)^2} \dots \dots \dots 2.5.7$$

**The Nash-Sutcliffe simulation efficiency (NSE)** indicates how well the plot of observed versus simulated value fits. If the measured value is the same as all simulated values, NSE is 1. If the NSE is between 0 and 1, it indicates deviations between measured and simulated values. If NSE is negative, simulations are very poor, and the average value of output is a better estimate than the model simulation (Nash & Sutcliffe, 1970). This coefficient is calculated by the equation:

$$NSE = \frac{\sum_{t=1}^T (Q_m^t - Q_0^t)^2}{\sum_{t=1}^T (Q_0^t - \overline{Q_0})^2} \dots \dots \dots 2.5.8$$

Where,  $Q_0$  is the mean of observed discharge,  $Q_0^t$  is observed discharge at time t and  $Q_m^t$  is modeled discharge.

**Percent Bias (PBIAS):** measures the average trend of the predicted data to be larger or smaller than their observed counterparts. The optimal value of PBIAS is Zero, with

low magnitude values indicating accurate model simulation. Positive values indicate model underestimation bias, and negative values indicate model overestimation bias.

$$PBIAS = 100 * \left[ \frac{\sum (Sim-Obs)}{\sum Obs} \right] \dots\dots\dots 2.5.9$$

### 2.7. Model Limitations

A major limitation to large area hydrologic modeling of SWAT is the spatial detail required to correctly simulate environmental processes. For example, it is difficult to capture the spatial variability associated with precipitation within a catchment. Another limitation is data files can be difficult to manipulate and can contain several missing records. SWAT-MODFLOW has a limitation for a spatial distribution on the output of model result in groundwater head and flow line.

### 2.8. Previous Studies Conducted in the Study area

Many published and unpublished researches have been done so far on the Borkena river catchment and surrounding area partially on Hydrology, hydrogeology, watershed, irrigation, water supply etc. and very few groundwater models have been conducted on the upper Catchment of the river basin and at different alluvial deposit areas for the fulfillment of thesis by Getachew 2016 and by Engida 2015 for Amahara water bearaux purpose at selected areas only. But there is no integrated work on the whole river catchment especially there is no Model Conducted using SWAT-MODFLOW softwares in the whole catchment to see the surface water groundwater interaction. The studies conducted in the study area before did not address the problems identified and have not sufficiently defined the interactions of surface water-groundwater system and the local and regional groundwater flow condition of the study area. In this research work evaluating the interaction of surface and groundwater resource using SWAT-MODFLOW Model techniques in the whole Borkena river catchment for the first time is conducted. And some suggestions for the catchment groundwater potential and flow systems and the groundwater is used as a mitigation for recurrent drought since the study area is drought susceptible.

Getachew (2016) has conducted Numerical Groundwater flow modeling on the upper part of the Borkena river catchment using Modflow Model with the objective of

identifying the most sensitive parameter of the hydrogeologic system with limited water point data and he recommended the groundwater management for the decision makers. But for this research the SWAT-MODFLOW Model technique is incorporated both surface water and ground water inputs to simulate the recharge, the SW-GW interaction and the groundwater flow system. The ArcSWAT model was applied to see the water balance system of the study area and to calculate the recharge covering the whole catchment area boundary. Recent water point data has been incorporated for this model purpose.

Mesfin (2001) has conducted hydrogeological investigation of the upper and middle Borkena river catchment to investigate and understand the different lithologic unit and to characterize and group them into hydrostratigraphic unit and map them, to analyze the water balance and to study the water quality of the study area. At the end the study recognized four hydrostratigraphic units namely: Alluvial & River channel deposits, alluvial deposits, Scoria & Basaltic lava flow, and Massive basalt, welded tuff and rhyolite. His study doesn't show the surface water groundwater interactions and he didn't cover the whole catchment. But this study has covered the whole catchment of the Borkena River and conducted surface water-groundwater model to see the flow and interaction of the system. The above findings by the researcher are essential to correlate the aquifer characteristics in the study area and have been used for this research for the development of conceptual model.

Muluken (2015) has also Conducted Assessment of Groundwater Potential and Its quality for Irrigation purpose in Sub Catchment of Borkena River, Kombolcha, Ethiopia. This study concentrates on the potential and quality of water for irrigation for partial fulfillment of the requirement for his Master of Science in Soil and Water conservation engineering for Haramaya University. Even if his study has not covered the whole catchment of Borkena River catchment, some useful ideas on land use and land cover has been considered for this research work.

Amhara Design and Supervision Works Enterprise (ADSE, 2013) has conducted detail hydrogeological study in the study area. This study applied the WATBAL method for Recharge estimation and identified the annual recharge value of 115mm at

Kombolcha and 134mm at Chefa Swamp. They found that the annual recharge from the total rainfall is 9.94% at Kombolcha and 11.58% at the Chefa Swamp where the total annual rainfall is 1157mm. The detailed account of the hydrostratigraphy from well logs has been addressed in previous hydrogeological study by Amhara Design and Supervision Works Enterprise. On this research the total annual rainfall was found to be 1017.5mm in the catchment when calculated based on the 39 years weather data using ArcSWAT Model. The recharge condition and the flow system of the groundwater was conducted with this research and correlated with Amhara design and supervision's study result. This result is used exhaustively for the conceptual model development and later for SWAT and SWAT-MODFLOW modeling.

Tenalem (2015) has conducted Steady State Groundwater Flow Modeling on the part of the eastern Amhara Development Corridor in Chacha, Deneba and Kesem Sub-basin as a freelancer for Amhara Design and Supervision Works Enterprise. On the study the author classified the important aquifers at regional scale as fractured and weathered volcanic (volcanic aquifers) and unconsolidated aquifers which is an extension of the study area conducted on this research. This result is applied for the conceptual model of the study for this research work.

Engida (2015) conducted Steady State Groundwater Flow Modeling on Borkena, Jara, Gerado, Ataye, Karakore rivers valley alluvial aquifers by **excluding** the Desse, Kutaber and Borumeda alluvial aquifers and the volcanic aquifers when he was assigned as a freelance consultant for Amhara Design and Supervision Works Enterprise. According to his study in Borkena catchment, the Tertiary Volcanic rock covers 1214.5km<sup>2</sup> and the alluvial deposit at Kutaber-Borumeda-Desse covers 13.8km<sup>2</sup>, Kombolcha alluvial covers 38.1 square kilo-meter (km<sup>2</sup>), Chefe-Harbu-Kemisse alluvial covers 410.7 km<sup>2</sup>. From this only 27.6% of the area is covered by alluvial deposit from a total area of 1677 km<sup>2</sup> and only 462.6km<sup>2</sup> or only the alluvial deposit was modeled to see their independency in aquifer system. But for this study the whole catchment was modeled including the tertiary volcanic rocks (1214.5km<sup>2</sup>) and the Desse, Kutaber and Borumeda area alluvial aquifers(13.8km<sup>2</sup>) which were not included in Engida's model are included in this model.

### **3. Methods and Materials**

#### **3.1. Description of the study area**

##### **3.1.1. Location**

The study area Borkena River Catchment is situated in the Eastern Amhara National Regional State, which comprises South Wollo, North Shoa and Oromo Special Zone as shown in the figure 3.1.1-1 below. The Borkena River Catchment is elongated from North to South direction and covered a total area of 1606.13 Square Kilometers (Km<sup>2</sup>). It is approximately bounded between Coordinates (UTM Zone 37, Addindan): E= 550000m to E=581000m and N=1143000m to N=1243000m. The location and drainage map of the study area is located in the Figure 3.1.1-1.

Modeling Surface water-groundwater Interactions of Borkena river Catchment

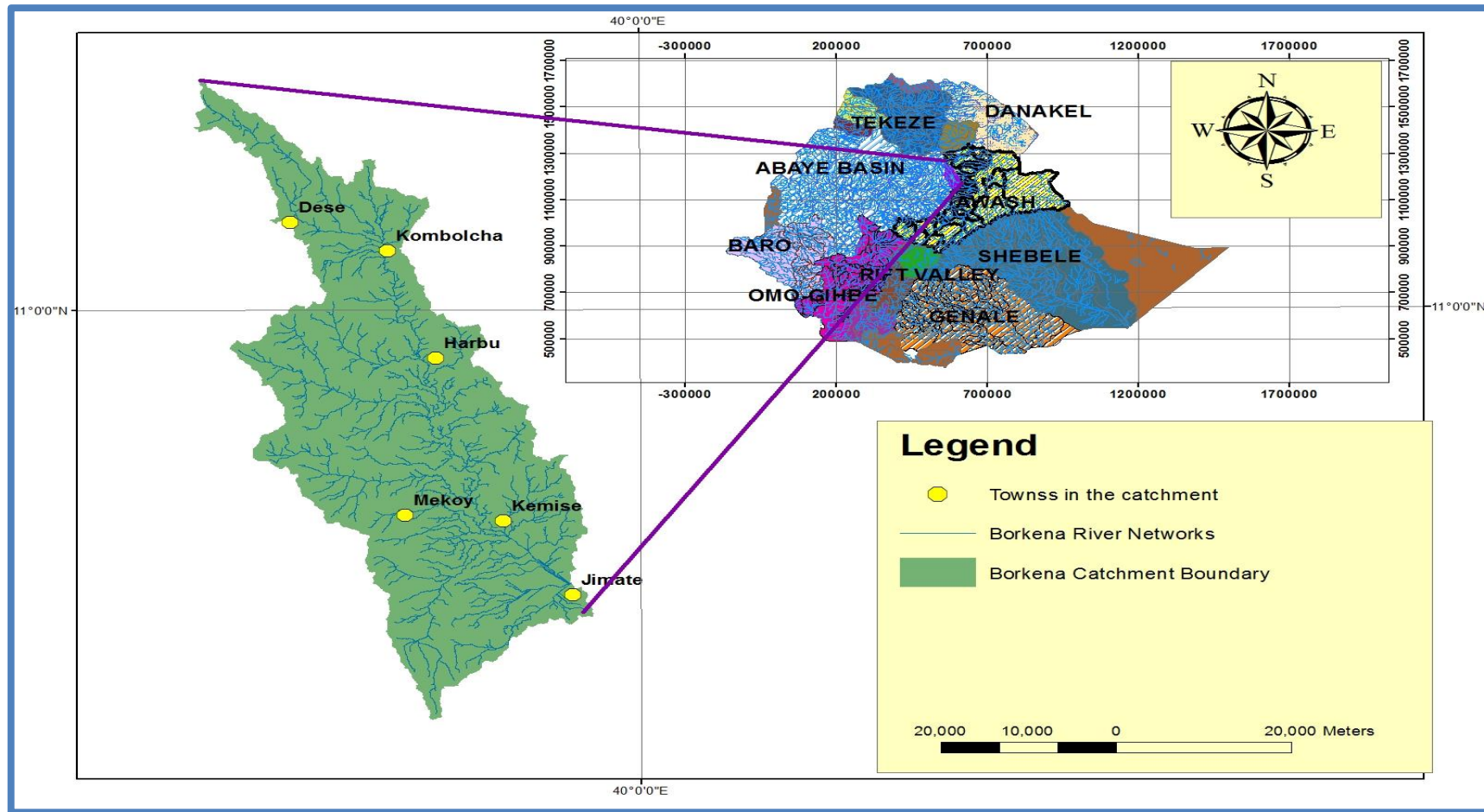


Figure 3.1.1-1 Location and Drainage density of the study area prepared using ArcGIS software (Source: Ethio-GIS data)

### **3.1.2. Topography/Physiography**

The Topography of the Borkena River Catchment is Mountainous to plateau, and its elevation ranges from 1400 up to 3500 m.a.s.l as shown in Figure 3.1.2-1. The geomorphology of the study area depends on the geology, tectonic distortion and climatic condition of that particular area. The landscape morphology of the study area reflects the various major tectonic deformations that affected the region since the Cretaceous time to present. Consequently, there are four geomorphologic units that forms the Physiography and climate of the study area (Engida , 2015): They are: Faulted block highlands, Dissected highland plateaus, ridges and terraces, Elevated plains and Marginal graben catchments.

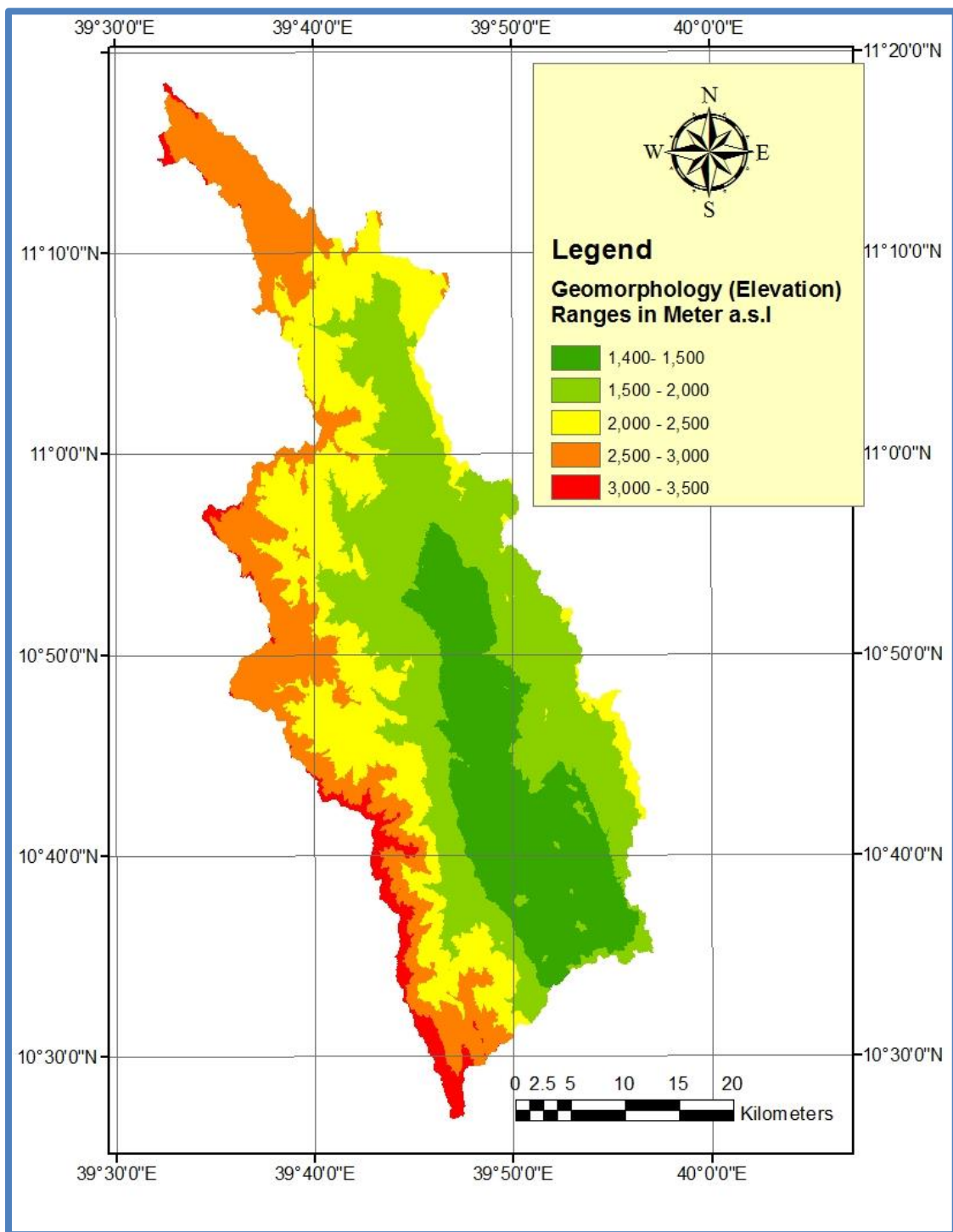


Figure 3.1.2-1 Geomorphology of the study area processed from DEM 30m using ArcGIS

### 3.1.3. Climate Characteristics

The Ethiopian climate system is under the influence of the Indian and Atlantic Ocean monsoons (Gemechu, 1977). The seasonal migration of the Inter Tropical Convergence Zone (ITCZ) controls rainfall patterns in most parts of the country. During the summer, the ITCZ is located in northern Ethiopia, and the region is under the influence of moisture from the Atlantic and Indian Ocean. During the months of October to February, the ITCZ migrates to the south of Ethiopia, and most of the country is characterized by dry air. The northward movement of the ITCZ from March to April brings moisture from the Indian Ocean, which results in small spring rain. Rainfall in the western-most sector of Ethiopia is mainly in summer (July - September), while in the eastern part of the country it is in spring (March – May) and in October. The central part of the country is characterized by a bimodal rainfall pattern, with both summer and spring rainfall. The study area is located in the center of Ethiopia, is influenced by two moisture sources, and characterized by two rainy seasons in summer (July - September) and spring (March - April). Based on the classification on the altitude (elevation) and temperature zonation; the study area is lying in the range of:

- a) Warm to cool, semi humid covers the temperate highlands b/n 1500-2500 m.a.s.l, temperature b/n 16-20 degree centigrade & annual rainfall of around 1100mm
- b) Cold to cold humid with temperate high land of 2500m-3200m a s l, temperature b/n 10-16 degree centigrade with an annual rainfall of around 1300 mm.
- c) Cold moist temperate zone with the highest plateaus of 3200-3500 m a s l, average temperature below 10 degree centigrade.

The main synoptic features that affect the Ethiopian rainfall including the project area are presented by Table 3.1.3-1. The project area receives its main rainfall from February-April less rain fall during *Bulg (Bega)* Season and from June-September high rain fall during *Kiremet* (summer) season. The Orographic influence on rain fall depth values is also marked in the mountainous area that prevails in the area under study.

**Table 3.1.3-1 Main synoptic features affecting Ethiopian rainfall (Gemechu, 1977)**

<b>Major Synoptic features affecting rainfall cover of Ethiopia</b>				
<b>Season</b>	<b>ITCZ (South Atlantic Ocean effect/ El Nino, SOI)</b>	<b>North Indian Ocean Effect</b>	<b>Low level Jet &amp; Tropical easterly jet</b>	<b>Remarks</b>
June-Sept (Main rainy Season)	ITCZ Moves Northwards To Red Sea. Most parts of Ethiopia Receives Rain.	Sea Surface Temperature Condition influences the main Rain.	Active and Moves northwards.	South & Southeastern Ethiopia do not receive rain.
Feb-May (Small rainy Season).	ITCZ is in the south Ethiopia bringing rains to south and southwestern Ethiopia.	Moisture source for eastern, southeastern and some central highland parts of Ethiopia receive useful rain.	Moves Northwards	As important as the main rain season for eastern and north eastern Ethiopia
Oct-Jan (Dry Season)	ITCZ is located further south and brings rain for south and southeastern Ethiopia	Occasionally Causes some untimely rainfall in most parts of Ethiopia.	Weak and Migrate southwards	Crop Harvesting time in most parts of Ethiopia

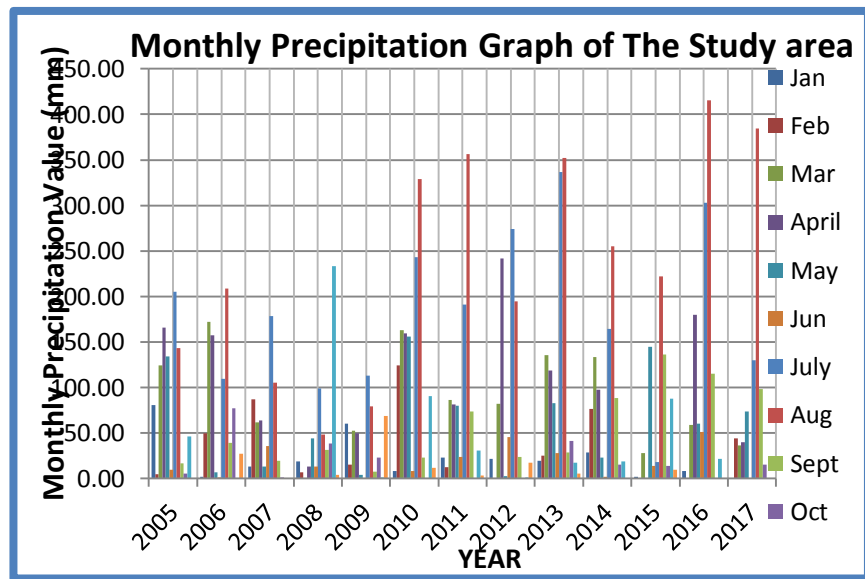
### 3.1.3.1. Rainfall

Precipitation Variability, Climatically, rainfall variability and intensity in the catchment follows a humid to semi-arid tropical bimodal distributed precipitation pattern. Variability is caused by alternating dry and rainy seasons, as well as long-term influences, which is overlapping with regional orographic effects. The mean annual precipitation in the study area which is calculated with arithmetic mean method is 875.16-1176 mm/year.

More, Climate data has been collected from National Meteorological Agency (NMA) since it is a major input for the analysis of SWAT model from the stationed mentioned in Table: 3.1.3.1-1 but only the two stations (Combolcha and Kemisse) data were found to be suitable for the SWAT input. The rainfall on the Borkena river catchment is bimodal.

**Table 3.1.3.1-1 Rainfall (Climate) data stations in and around the study area**

No.	Station Name	East	North	Altitude	Class	Record period	Remark
1	Boru Meda	566852	1240528	2629	4		
2	Chefa Robit	602298	1166340	1400	3		
3	Combolcha	548056.4	1223755	1903	1	1979-2017	
4	Dessie	541504.5	1222640	2500	3		
5	Harbu	585780	1207140	1450	4		
6	Kemissie	554724.8	1152999	1450	4	1979-2017	



**Figure 3.1.3.1-1 Rainfall (Climate) data stations in and around the study area**

Rain fall is generally higher in the western Ethiopian high lands and on the volcanoes than in the rift valley or in the Borkena depression. However, there are no significant rain fall gradients across the catchment. Throughout the available record from 1979-2017 annual rainfall ranges 738 mm to 1317 mm.

### 3.1.3.2. Temperature

One of the factors affecting evaporation is temperature of the evaporating surface. The rate of evaporation is dependent on the temperature at the evaporating surface and that of atmospheric air. The amount of water vapor in the atmosphere is directly related to the temperature. At a given temperature air can hold a maximum amount of moisture, saturation, humidity. Mean annual temperature of the study area ranges

from 5.91 degree centigrade 30.79 degree centigrade. The temperature data has been compiled from meteorological stations listed in Appendix 2.

### **3.1.3.3. Relative Humidity**

Relative humidity is the relative amount of the quantity of moisture in the air to the amount needed to saturate the air at the same temperature. It indirectly governs the rate of evaporation; higher values of relative humidity indicate that the air is nearer to saturation point, and lower values that the air consists fewer water vapor in the atmosphere. As relative humidity approaches to 100% evaporation ceases.

The relative humidity record has also been collected from meteorological stations located in and in the vicinity of the study area (Appendix: 3).

### **3.1.3.4. Sunshine Hours**

Evaporation take place almost without interruption during both day and night, however the process is almost active under direct radiation from the sun. Sunshine hours have been collected from meteorological stations located inside the study area (Appendix 4).

### **3.1.3.5. Wind speed**

Wind speed data is also an essential weather parameter for the input of SWAT model and it has been collected from the meteorological stations as of other parameters (Appendix: 4). As evaporation proceed, the air above the evaporating surface gradually becomes more and more saturated and, if it is unable to take up any more evaporation ceases. The emergency of saturated air by drier air would enable evaporation to remain. Thus this association of air and moisture allocation is directly proportional to wind speed and turbulence. The wind speed is a significant factor in governing the rate of evaporation and it is collected and organized in text format for the SWAT input data.

## **3.1.4. Hydrology**

The Borkena catchment is located in the Eastern Amhara corridor under Awash basin covering an area of 1606 square kilo-meter (Km<sup>2</sup>). Calculation of the catchment area is not equal for all evaluations because various base maps were used. The watershed area is delineated by using QSWAT and/or ArcSWAT software version 2012.

Borkena River is one of the principal river of the Awash basin largest tributaries.

#### **3.1.4.1. Surface Water Network Development**

The drainage pattern of the Borkena river catchment is asymmetric and in some parts dendritic with a moderate to high drainage density. Small rivers rise on the slopes or foothills along the west and north to north east side. Rivers flow from the western plateau to the east and south east. Rivers flow at the beginning in shallow valleys but then they start to erode moderate gorges and dissect the plateau into deep river canyons and in the low land it becomes gentler.

In the center of the catchment the rivers tend to turn towards the southeast following the direction of the canyon of the Borkena River. The Borkena River itself originates by a confluence of the Rift valley, faulting and due to the tectonic action, flowing from the north-south and North West to south east. The confluence is due to the East-west fault system of the rift. The action of this fault of NNW-SSE, E-W directions makes the drainage system of the catchment asymmetric with longer river courses flowing from the north to the south (left tributaries of the Borkena River) and right courses from the north-east (right tributaries of the Borkena River).

#### **3.1.4.2. Surface water regime of Borkena Catchment**

River discharge is monitored by three gauging stations in Borkena River. Borkena at Dessie, Borkena at Combolcha and Borkena at Chefa area. The maximum elevation at the headwater area is 3350 m.a.s.l and the minimum elevation at the Borkena outlet (at gauging station i.e. Borkena at Dewe-Chefa of Swamp) is 1400 m.a.s.l. Borkena river catchment borders with Abay basin at the western part of it, with Robit-Tis-Abalima catchment on the northern part and Jara river catchment on the southern part.

#### **3.1.4.3. Base flow**

Base flow is groundwater seepage in to a stream. When groundwater table is higher than a stream bed, the water seeps in to a stream. Base flow represents one of the most important types of information on groundwater resources in the catchment. The base flow TIMESPLOT has been described by Nathan and McMahon (1990). It was found that by means of a correlation analysis the appropriate base flow values can be determined on the basis of daily river discharge data. The base flow can be identified

Modeling Surface water-groundwater Interactions of Borkena river Catchment

from a series of observed monthly low-water runoff values with the discharge values to use Time Plot as the simplest assessment method. It has been shown that a short-term average of discharge measurement data of a 1-3 years period is a good approximation for groundwater recharge areas. The Time plot hydrograph separation method for calculation of base flow was used in this study for a one-year observed flow data and one year precipitation data and the result is tabulated below.

The measured discharge (runoff) of the Borkena River catchment at the Chefa Swamp outlet station shows an average value of 6.314 m<sup>3</sup>/s which has very significant difference with the field measured discharge value. Total flow from the catchment is not directly measured so a balance model is used to calculate the discharge and the total flow is equal to 12.09 m<sup>3</sup>/s. Therefore from the above expression the base flow value is 5.097 m<sup>3</sup>/s.

	Total flow	Base flow	Runoff	Total Rain	
m <sup>3</sup> /s	12.09	5.097	6.993	mm	903.595
hm <sup>3</sup>	380.21	160.3	219.92		

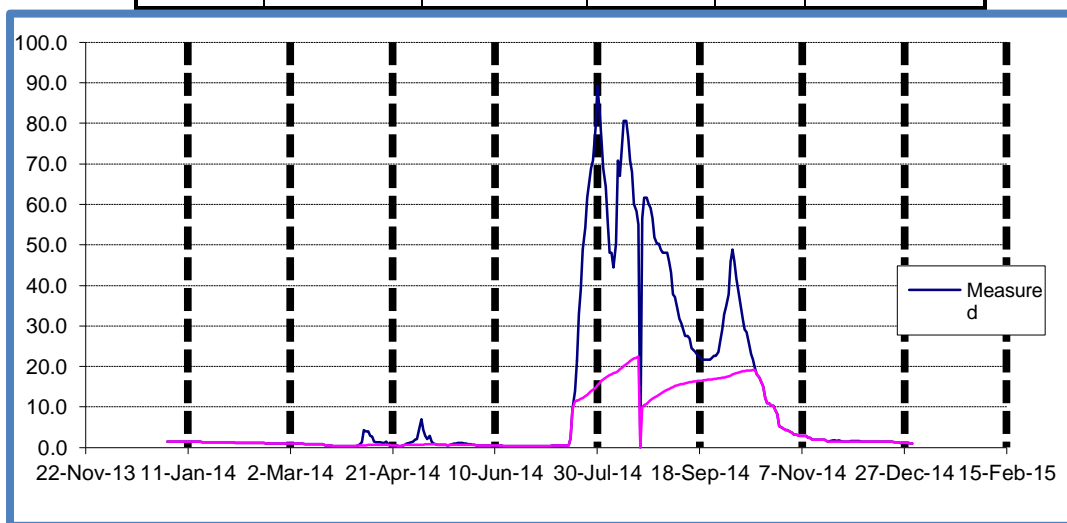


Figure 3.1.4.3-1 Base flow graph of Borkena river 2014 data

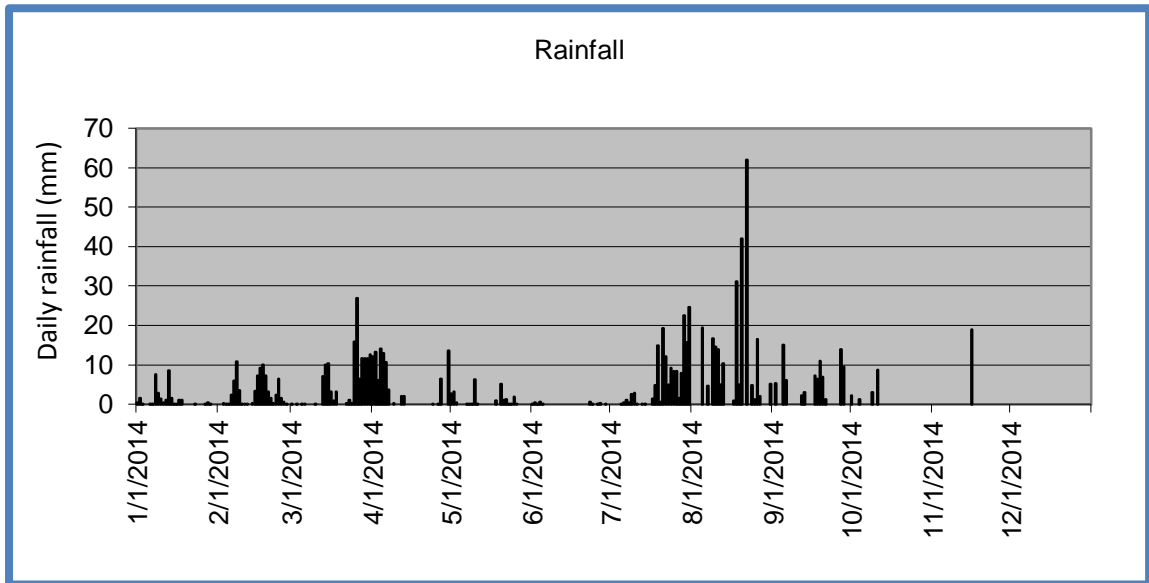


Figure 3.1.4.3-2 Rainfall distribution of Borkena catchment calculated in TIMEPLOT

### 3.2. Approach and Methods (Data Collection, analysis and Verification)

The methodology of this study has the components of data collection, data processing running the SWAT Model and SWAT-MODFLOW Model, Sensitivity Analysis, Calibration, Validation and Model Interpretation. The SWAT Model was calibrated with sensitive parameters and validated with the observed flow data. Since SWAT-MODFLOW is the updated form of SWAT Model it was not calibrated. The calibrated TextInout result of SWAT output was imported to SWAT-MODFLOW model. The basic activities to be accomplished to meet the objectives of this research are basically based on extensive field works and tests. Secondary and primary data collection and analysis from concerned offices (water sectors) were the major activities. The study started by reviewing different literatures related to the research work.

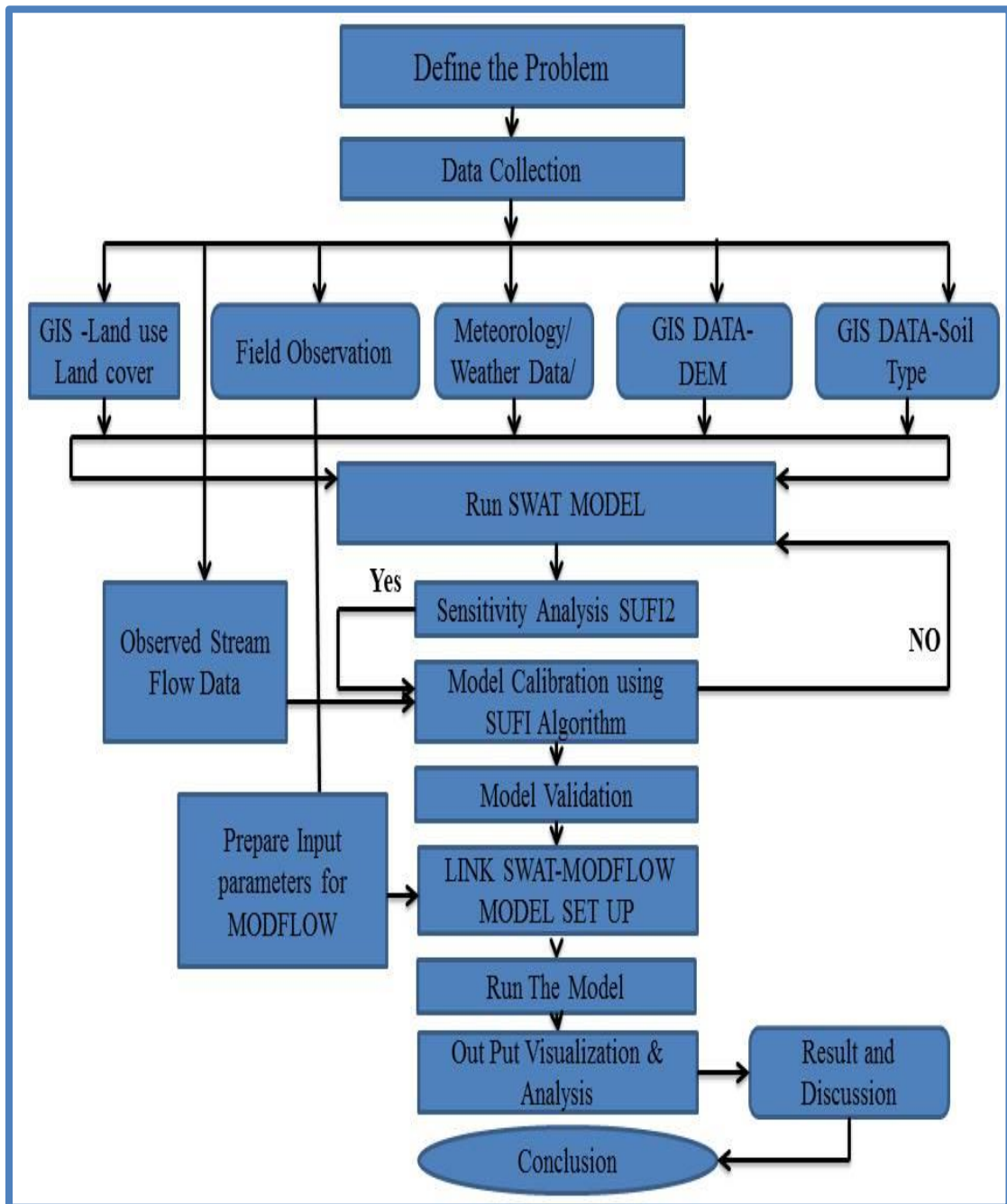


Figure 3.2-1 Frame Work (Flow-Chart) of the Research

Table 3.2-1 Input and Measured data and used Softwares for the Model

Data Type	Source	Scale/Periods	Data Description / properties
Terrain/Topography	MoWIE Open source (USGS: <a href="https://earthexplorer.usgs.gov/">https://earthexplorer.usgs.gov/</a> )	30 m	Digital Elevation Model (DEM), Slope Map, Drainage map, Watershed Delineation was prepared etc using ArcGIS Software
Soil-1998	MoWIE (FAO, 1998)		Soil raster map was extracted and prepared with soil types in FAO Classification with Soil look up table as an input for SWAT
Land use/Land use, 2015	MoWIE (RCMRD-SERVIR-AFRICA)		Land use raster map was prepared with land use types using ArcGIS software with look up table as an input for SWAT
Flow	MoWIE	2000-2014	Observed Flow from 2000-2007 for Calibration and Observed flow 2008-2014 for Validation was set to SWAT CUP SUFI 2

<b>Data Type</b>	<b>Source</b>	<b>Scale/Periods</b>	<b>Data Description / properties</b>
Weather	NMA	1979-2017	Daily precipitation, Minimum and Maximum Temperature, Wind Speed, Relative humidity were prepared in excell with location and set in WGEN calclater for the SWAT reference databse. And put as Txt format for SWAT input.
Bore holes	ECDSWC, WEDSWS		Input parameters like Hk, Ss, Sy, Initial hydraulic head, Aquifer thickness, Depth to water level. Used as a base for the production of Hydrogeological map
Ethio GIS 2007 Data	MoWIE		Location Map of the Study area with Basins was produced using ArcGIS software
Geologic Map	MoWIE	1/2000 000	Geological Map was Produced using this map as a base map and from this Hydrogeological map was developed based on exsisting water point data like

lithologic and boreholes data

## Softwares

ArcGIS 10.3	ECDSWC, WEDSWS	Used to Prepare Location Maps, Land Use/Land Cover Maps, Soil Maps, Slope Maps for SWAT input, DHRUs, MODFLOW Grids and DHRUs intersection, Identifying River cells, Preparing Hydrogeological Maps, X-Sections, Groundwater level maps etc.
Autocad 2007	ECDSWC, WEDSWS	Used to prepare Cross-Section Maps
Global Mapper 18	ECDSWC, WEDSWS/Open Source	Used to Export GeoTif files and To Georeference Maps

ArcSWAT 2012, SWAT 2012, QGIS 2.6.1, SWAT CUP SUF2	Opensource( <a href="http://www.brc.tamus.edu/swat/arcswat.html">http://www.brc.tamus.edu/swat/arcswat.html</a> ), <a href="http://swat.tamu.edu/software/arcswat/swat-editor/">http://swat.tamu.edu/software/arcswat/swat-editor/</a> , <a href="http://qgis.org/downloads/QGIS-OSGeo4W-2.6.1-1-setup-x86.exe">http://qgis.org/downloads/QGIS-OSGeo4W-2.6.1-1-setup-x86.exe</a>	Watershed Delineation, Water balance or recharge estimation, Drainage Map preparation, Surface runoff estimation, Selection of Sensitive parameters, Calibration and Uncertainty analysis
SWAT-MODFLOW	Open Source ( <a href="http://swat.tamu.edu/software/swat-modflow/">http://swat.tamu.edu/software/swat-modflow/</a> )	Model GW-SW Interactions

### **3.2.1. Data Collection**

The necessary data that was collected and used for the study can be stated as spatial and time series data. Spatial data used are DEM 30m resolution, Land use land cover data and Soil map data which are collected from MoWIE. The time series data are Meteorological data and hydrological data which were collected from NMA and MoWIE respectively. The Borehole data were collected from ECDSWC-WEDSWS to analyze and prepare input parameters for Modflow. Beside these, Water level measurements of the boreholes have been conducted using Deep meter.

- Meteorological data and hydrogeological data was collected from NMA & MoWIE.
- Hydrogeological data like Pumping test records, Geophysical survey data; well log data were collected from WEDSWS and analyzed.
- Geo-referencing of different maps, images and water points of the area (Boreholes, dug wells, springs) using GPS for different map preparation purpose.
- Topographic map of the project area (scale 1:50,000 sheets or 1:250,000)
- Geological and Hydro geological map of Ethiopia (scale of 1:2,000,000), and/or Hydro geological map of the area (scale of 1:250,000) and others, were collected and mapped for conceptual model to see the flow system and GW-SW interaction in the study area.
- Thematic maps like soil map, land use-land cover map, geological map, hydrogeological map, structural maps and imageries were collected from MoWIE.

### **3.2.2. Meteorological Data**

The meteorological data required were: daily precipitation, daily maximum and minimum air temperature, daily solar radiation, daily wind speed and daily relative humidity. These data were prepared for SWAT from 1979-2017 year period of two meteorological stations.

- Precipitation: the daily precipitation of Combolcha and Kemisse Stations were prepared in text format.

- Temperature: the daily minimum and maximum temperature of Combolcha and Kemisse Stations were prepared in text format.
- Solar radiation: the daily solar radiation of Combolcha and Kemisse stations were prepared in text format.
- Relative humidity: the daily relative humidity of Combolcha and Kemisse stations were prepared in text format.
- Wind speed: the daily wind speed of Combolcha and Kemisse stations were prepared in text format.
- All the above data were collected from National Meteorological agency for the period from (1979-2017 G.C).

### **3.2.3. Hydrological Data**

Daily flow data is required for SWAT Model Calibration and Validation. This data was obtained from MoWIE hydrology department office from 2000-2014 G.C. The selected site was Borkena at Chefa Swamp Outlet. This site was selected as it has long term and reliable stream flow data. This site is found at the final outlet of the Borkena Catchment.

### **3.2.4. Digital Elevation Model (DEM) Data**

The digital elevation model (DEM) is a digital representation of a topographic surface and it is specifically made available in the form of raster or regular grid of spot heights. It is the basic input of SWAT hydrological model. The Borkena River Catchment was delineated and river networks were generated from DEM. The DEM obtained has a resolution of 30m x 30m. Elevation of the study area ranges from 1400-3500 masl.

### **3.2.5. Soil Map Data**

The soil textural and physicochemical properties required by the SWAT model include soil texture, accessible water content, hydraulic conductivity, bulk density and organic carbon content for each soil type. These soil map data were obtained from FAO (1998, 2002, 2005) from MoWIE. It was observed that Lithic Leptosols (Lpq), Eutric Vertisols (VRe), Eutric Leptosols (Lpe) and alluvial deposits in Swamp area (SWA) are the most dominant soils in the catchment (Figure 3-2-5).

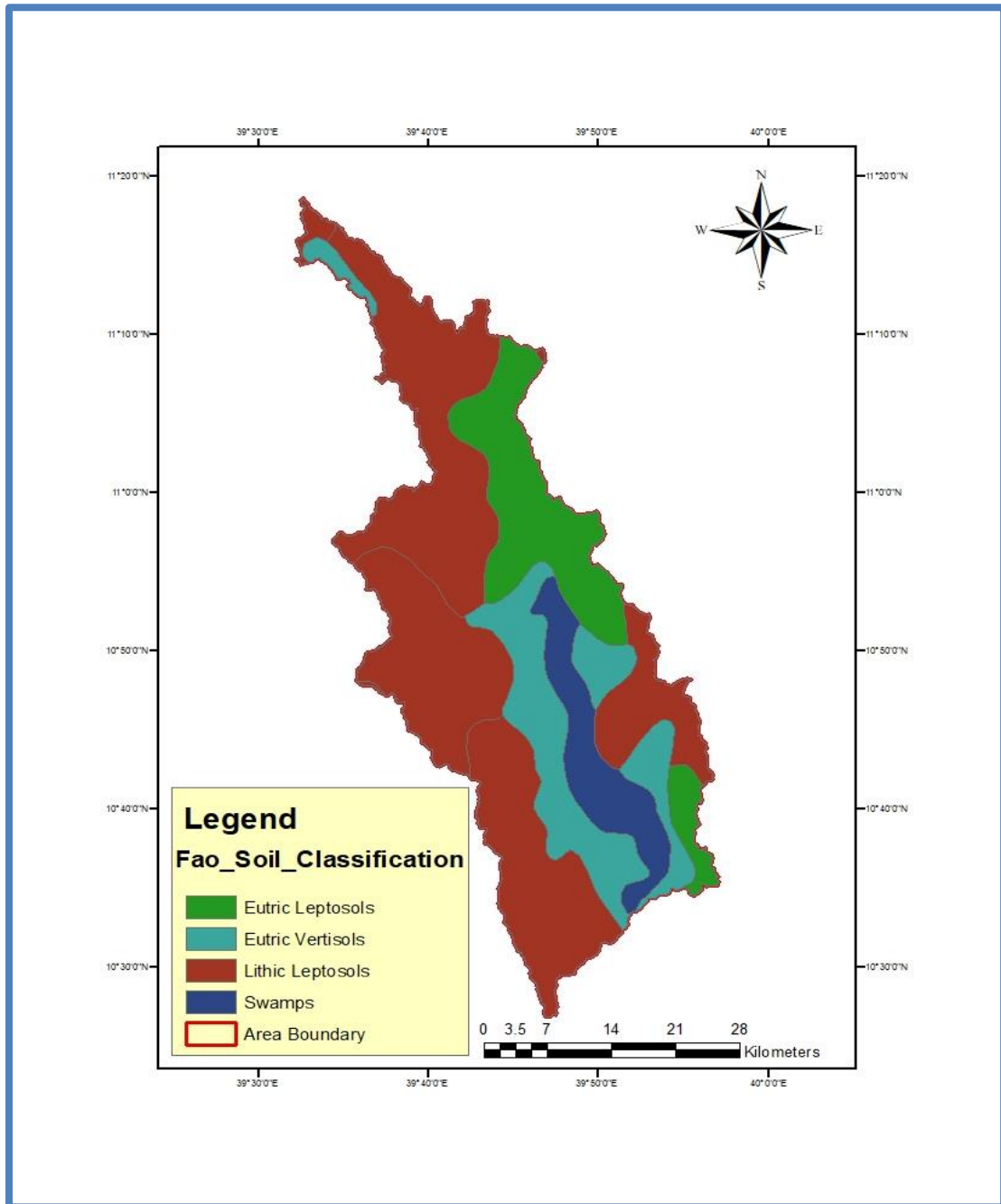


Figure 3.2.5-1 Soil Classification map of Borkena Catchment modified from (FAO, 2005)

### 3.2.6. Land use/ land cover map

Spatial distribution and specific land use parameters were required for modeling. SWAT has predefined land uses identified by codes to link land use maps to SWAT land use databases in the GIS interface. Hence, while preparing the look up table, the land use types were made compatible with the input needs of the model. The classified land use map and its attribute were adjusted to the SWAT model requirement format and databases. Agricultural land use (AGRL) /796.04 Km<sup>2</sup> or 49.6 % coverage is the dominant land use in the Borkena catchment and the catchment is the most cultivated land, wet land and with some patch of grass land, shrub land, bare land and natural forest land. The wet land area covers the low lying areas, around Chefa area along the river banks. The land use land cover map was obtained from MoWIE (Figure 3-2-6).

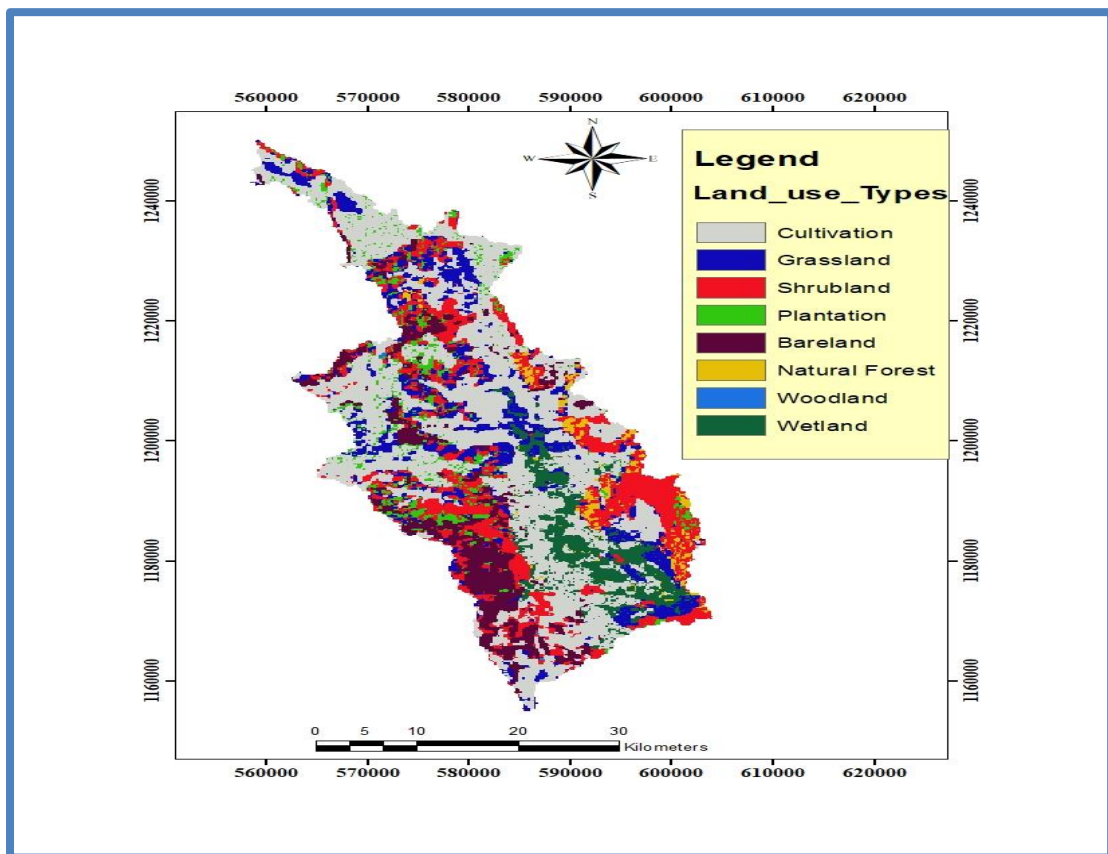


Figure 3.2.6-1 Land use/ land cover of Borkena Catchment extracted from RCMRD-SERVIR Africa, 2015 (MoWIE).

### 3.2.7. Slope of the study area

The study area is bounded by mountains in the west and eastern part of the catchment. As shown in the slope map of the study area the majority of the catchment is covered with very steep slope. As indicated in the slope map produced from DEM using ArcGIS software the slope classes are classified as Gentle slope (0-8%), Slightly steep slope (8-15%), Moderately steep slope (15-20%) and very steep slope (20-35%) (Figure: 3-2-7). But for the SWAT input the slope was classified in three classes; class 1 (0-8%), Class 2 (8-15%) and Class 3 (>15%).

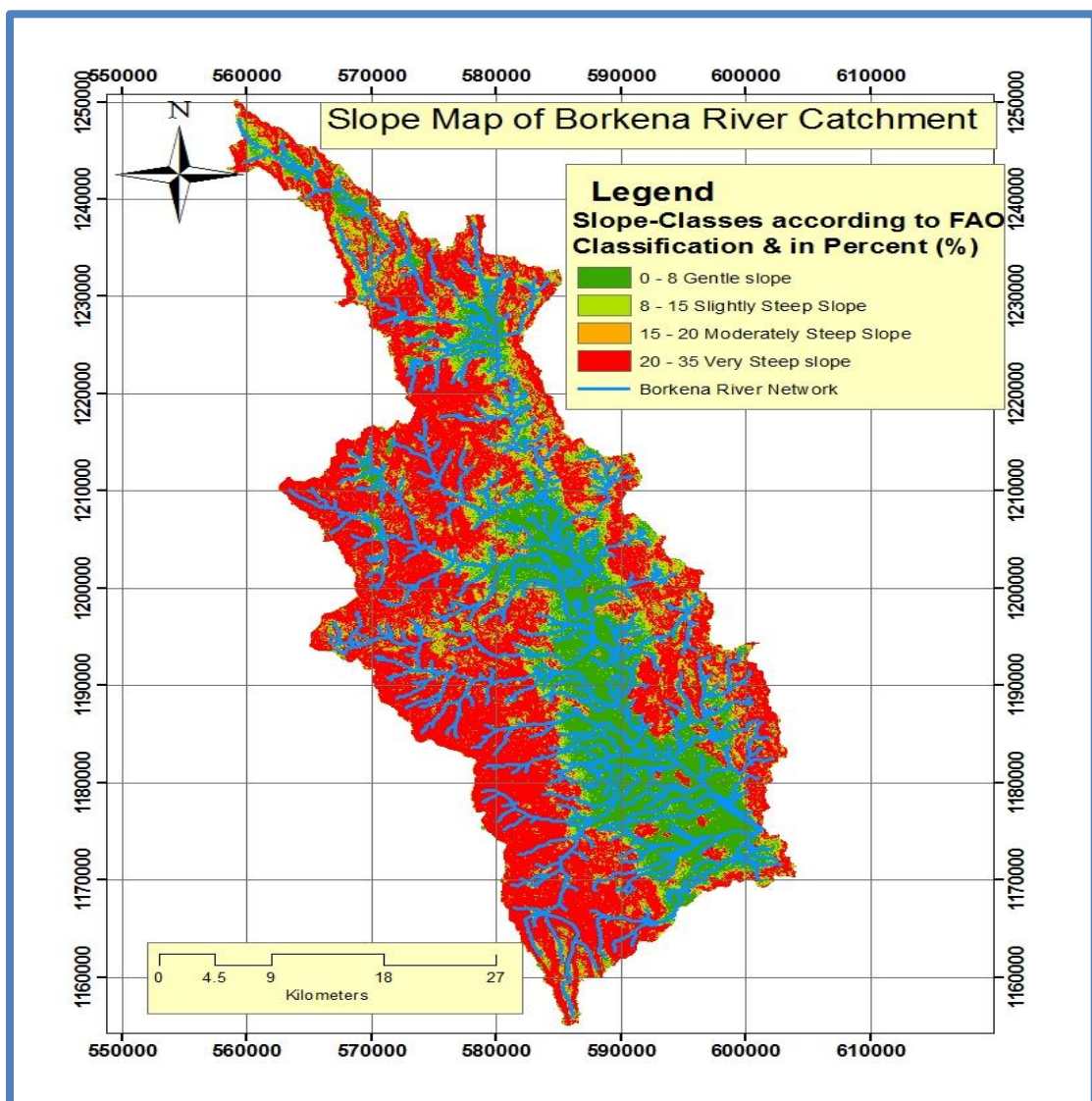


Figure 3.2.7-1 Slope Map of Borkena Catchment processed from DEM 30m using ArcGIS software.

### **3.2.8. Data Analysis**

Hydrological studies of water resources development and management depend heavily on meteorological and hydrological data analysis.

#### **3.2.8.1. Meteorological data analysis**

Daily precipitation, daily temperature (maximum and minimum), sunshine hours, relative humidity and wind speed were collected from meteorological stations within and around the catchment. Weather generator WGEN analysis was conducted to prepare the WGEN\_Borkena weather data for reference database for SWAT input data.

#### **3.2.8.2. Filling Missing Rainfall data**

The linear and multiple regression methods were applied to fill the missing rainfall data. The meteorological stations used for daily precipitation were Combolcha and Kemisse stations and these stations were selected to be principal stations for the weather generator. For the missing data filling these stations were added to WGEN with their statistical values. SWAT took data of each climatic variable for each sub-basin from those climate stations.

### **3.2.9. Hydrogeological Data**

#### **3.2.9.1. Borehole Data**

Hydrogeological data of boreholes were collected from different government, non-government organizations and private drilling contractors and water point's inventory during field visits. The objective of data collection was to review the groundwater data availability, distribution and data quality in the project area.

From the water points inventory a total of more than 144 boreholes data are collected from the above organizations so far. These water points are distributed in and around the project area. As indicated in the hydrogeological boreholes are distributed in and around the study area. The objective of collecting these borehole data is to identify the input parameters for SWAT-MODFLOW model like Hydraulic Conductivity (K), Aquifer thickness, Specific storage, Specific Yield, Hydraulic conductivity of River bed material, initial hydraulic head.

### 3.2.10. Geology

The study area is located on the northwestern plateau and escarpments and covered the whole area of Borkena marginal graben. The Borkena graben is bounded by the mountain chains of the northwestern plateau to the west which is the most important structural feature in the block with Borkena River flowing along the axis of the graben for most of its length. The main rock formations that outcrop in the block is the highly weathered, jointed aphanitic basalt of the Ashange Basalt (E3as) that crops out along deep cut river gorges on the western side of the block and along the foothills of the border faults of Borkena graben. The Ashange basalts are overlain by a succession of basaltic flows of the Aiba formation (E2ai) and rhyolitic flows and ignimbrites mapped as Alaje Molale Rhyolites (E2ajs/m).

Along most of the length of the graben a succession of rhyolite flow domes and ignimbrites mapped as Alaje Rhyolites (NIar) make the graben margins. A related rhyolite flows domes and ignimbrites are also found exposed along the margins of the Kombocha half-graben where Borkena graben narrows out in to the plateau and are bordered with a related succession of rhyolite flow domes and ignimbrites mapped Albuko Rhyolites (Figure: 3-2-10).

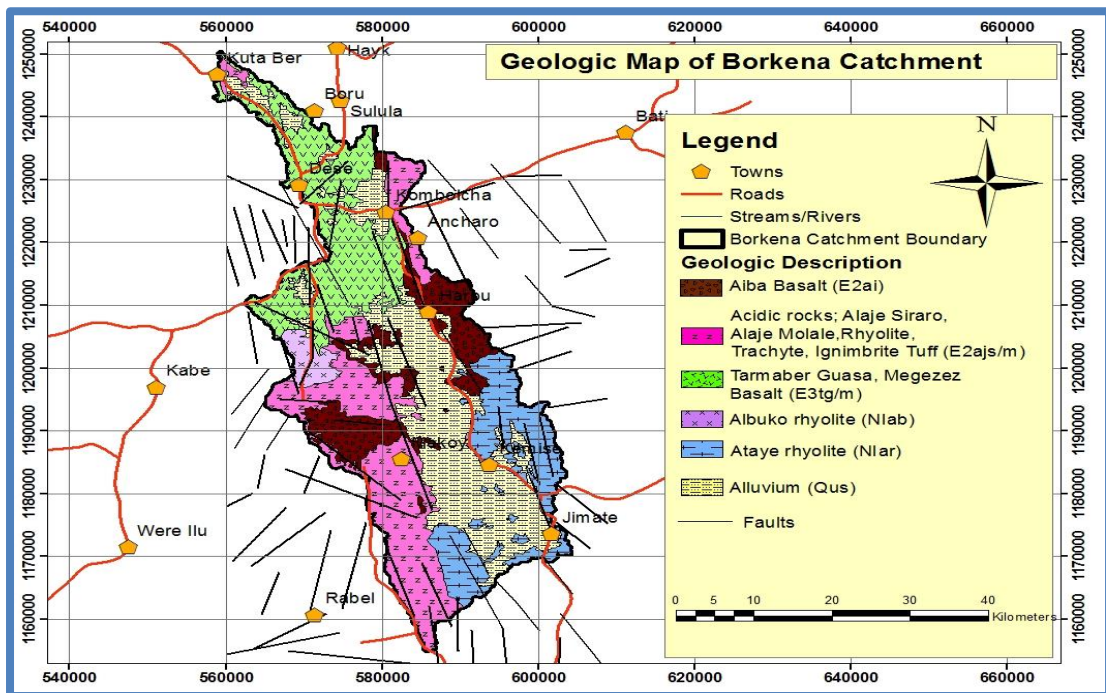


Figure 3.2.10-1 Geologic Map of Borkena Catchment

### **3.3. Determination of Groundwater-Surface water Interaction**

Determining groundwater-surface water interaction is one of the objectives of this study. Preceding steps were major inputs to this stage. The geological and structural setting of the basin and its surroundings, hydrogeological conceptual models and hydrogeomorphic and hydrogeological landscape units generated in the previous steps have been utilized as major inputs at this stage. Under this major task, different sub-stage activities were employed. The interactions between groundwater and surface water are complex. To understand these interactions in relation to climate, landform, geology and biotic factors (Sophocleous, 2002).

### **3.4. Modeling**

Semi-distributed SWAT model and the recently developed SWAT-MODFLOW model has been applied, which allows full distribution of the groundwater domain, to the Borkena river catchment. MODFLOW is a physically-based, fully-distributed, and three-dimensional (3D) finite-difference groundwater model, and it is considered a state-of-the-art international standard for simulating and predicting groundwater conditions (Anderson and Woessner, 1992). It is used to simulate both steady state and transient conditions. MODFLOW outputs include groundwater hydraulic head or drawdown at the center of each grid cell as well as groundwater flow rates to/from each stream segment if the River (RIV) package is used.

#### **3.4.1. SWAT Model Set up and Input of the Model**

SWAT allows a number of different physical processes to be simulated in a catchment. A catchment will be partitioned in to a number of sub catchments. The input information for each sub catchment or sub-basin has been organized in to the categories of Climate; HRUs; groundwater and the main channel or reaches draining the sub basin. HRUs are the lumped land areas within the sub-basin or sub-catchment that are comprised of unique land cover, Soil and management combinations (Neitsch et al., 2011).

### **3.4.1.1. Model Parameterization**

#### **a) Watershed and Channel Delineation**

The DEM 30m x 30m resolution is used to drive the watershed boundary, channel network, and sub-basin size and distribution. The Borkena River catchment was delineated with an outlet point at the out let of the catchment. The overall catchment was further broken down in to sub-basins based on the algorithms provided by the ArcSWAT model. As a consequence these sub-basins influence the level of spatial complexity that is represented in the SWAT model. A sub-basin in SWAT is defined as the hydrologic area contributing to only one stream channel. Stream channels were defined as DEM cells having at least 3000 hectare contributing area. The contributing area resulted delineating 12 sub-basins by using 12 manually added outlet points and by selecting one outlet point to delineate the sub basins using the ArcSWAT software.

The first step in initializing a catchment simulation in SWAT model is to delineate the catchment and partition in to sub-basins. ArcSWAT allows the user to delineate the catchment and sub-basins using the Digital Elevation Model (DEM). DEM is a grid of square cells where each cell represents the elevation value at that location and the elevation value for each cell is an average of overall elevations inside the cell.

The catchment delineation tool uses and expands the ArcGIS, spatial analyst functions to perform catchment delineation (Neitsch et al., 2005) and stream network was defined for the whole DEM by the model using the concept of flow direction and flow accumulation. To define the origin of streams a threshold area was determined by the user and this threshold area defines the minimum drainage area required to form the origin of the stream. The catchment outlet is manually added and selected for finalizing the catchment delineation. With this information the model automatically delineated the catchment area of 1606.13 Km<sup>2</sup> with 12 sub-basins (Figure: 3-4-1).

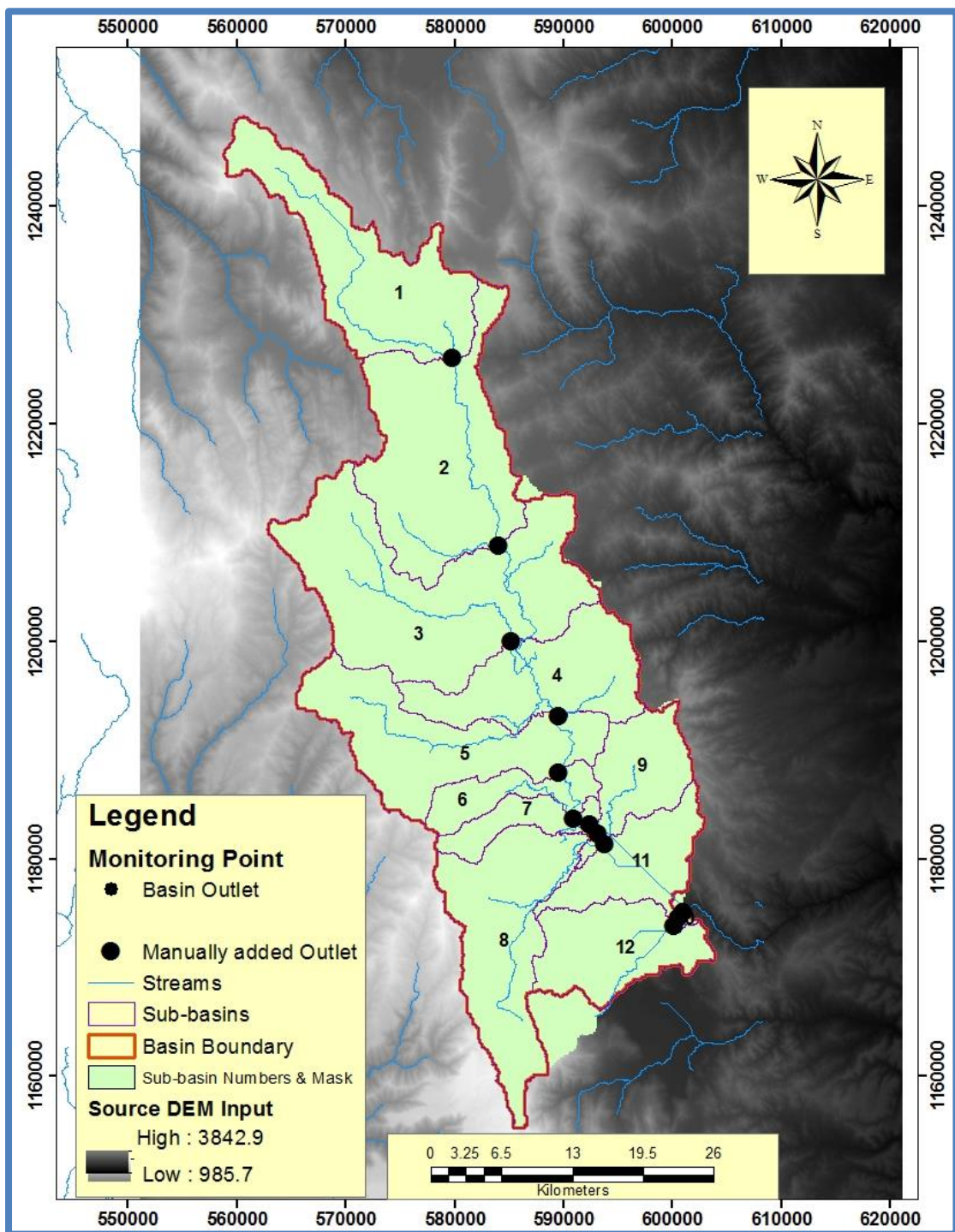


Figure 3.4.1.1-1 Delineated Catchment and Sub-basins during ArcSWAT Modeling Process

### **b) Hydrologic Response Unit (HRU) Analysis**

Hydrologic response units (HRUs) are lumped land areas within the sub-basin that comprised of unique land cover, soil and management combinations. HRUs enable the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers and soils. The runoff is estimated separately for each HRU and routed to obtain the total runoff for the catchment. This increases the accuracy in flow prediction and provides a much better physical description of the water balance. The land use and the soil data in a projected shape file format were loaded in to the SWAT interface to determine the area and hydrologic parameters of each land soil category simulated within each sub-basin. The land cover classes were defined using the look up table. A look up table that identifies the 4-letter SWAT code for the different categories of land use/ land cover classes. After the land use SWAT code is assigned to all map categories, calculation of the area covered by each land use and reclassification were done. As for the land use, the soil layer in the map was linked to the user soil data base information by loading the soil look-up table and reclassification applied. The DEM data used during the catchment delineation was also used for slope classification. After the reclassification of the land use, soil and slope then the overlay operation was performed.

The other step in the HRU analysis was defining HRUs,. The Distribution of HRU in this study was determined by assigning numerous HRU to each sub-basin. In multiple HRU definition, a threshold level was used to eliminate minor land uses, soils and/or slope classes in each sub-basin. Land uses, or soils which cover less than the threshold level are eliminated. The threshold level set is a function of the project goal and amount of detail required. In the SWAT user manual it is suggested that number of HRUs are better to be smaller and HRUs in each sub-basin are also better to be smaller in number, hence taking the recommendations in to consideration, 10% for land use and 10% for soil threshold levels were assigned so as to encompass most of spatial details.

The next step in HRU definition was selection of slope classification option (single or multiple) and if multiple slopes are selected then it would define the range of slope.

For this study multiple slope option (an option for considering slope classes for HRU definition) was selected and the slope classes were classified to three as level to gently undulating (0-8%), rolling to hilly (8-15%) and steeply dissected to mountainous (above 15%).

Finally defining the HRUs within a sub-basin complete the HRU setup. For this study the option of multiple HRU was selected as 10% threshold for land use, soil, and slope in each HRU from the sub-basin values respectively. The reason for taking these threshold values were in order to keep the HRUs to a reasonable and manageable number. Even though, application of these thresholds eliminates the land uses and soils that covered relatively small areas in the sub-basin it created a total of 187 HRUs for 12 sub-basins.

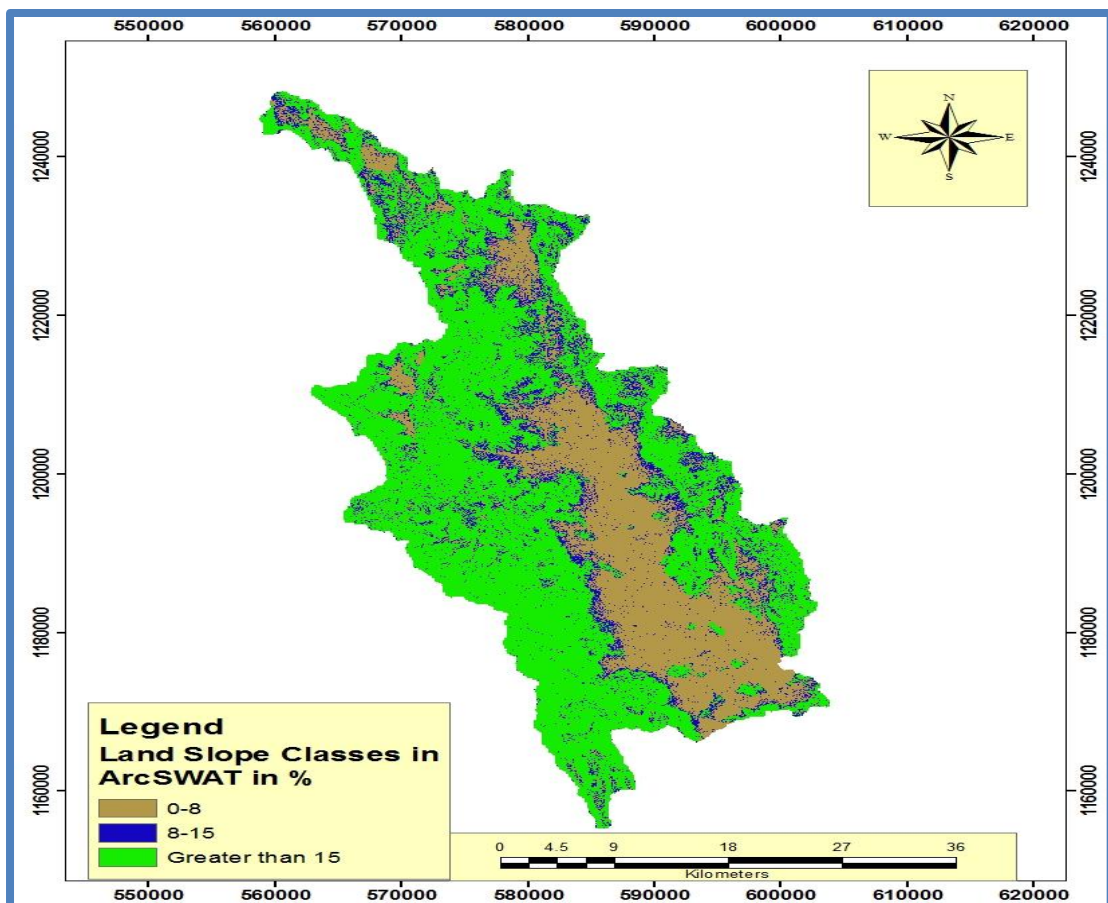


Figure 3.4.1.1-2 Slope map processed and reclassified during ArcSWAT model process

### **3.4.1.2. SWAT Model Input**

Inputs for SWAT including catchment area and main channel length were determined by ArcSWAT-GIS interface from 30m x 30m resolution DEM of the study area. ArcSWAT processes mapped land uses and soils data as well as the Digital Elevation Model (DEM) to create a set of default model input files.

SWAT requires specific statistics about watershed characteristics such as topography, land use/ land cover, soil types, weather data and management practices. The model uses a two level schemes: first catchment and sub-catchment delineation is performed based on topographic information, followed by further disintegrating in to HRUs using land use and soil type consideration in order to represent heterogeneous watershed properties. Climate inputs are required since they control water balance that derives all the processes simulated in the catchment.

Digital Elevation Model (DEM), Soil data, Land use and stream network layers and also weather and river discharge were input data for ArcGIS ArcSWAT interface used for prediction of stream flow and calibration purpose.

#### **a. Spatial data Digital Elevation Model (DEM)**

Topography is defined by a DEM which describes the elevation of any point in a given area at a definite spatial resolution. A 30m resolution digital elevation model data was taken from the Ministry of Water, Irrigation and Energy (MoWIE). The DEM was used to delineate the Catchment and to analyze the drainage patterns of the land surface terrain, sub-basin parameters such as slope gradient, slope length of the terrain and the stream network characteristics.

#### **b. Soil data**

The requirements of SWAT includes different soil textural and physico-chemical properties such as soil texture, available water content, soil hydraulic conductivity, bulk density and organic carbon content or different layers of each soil type. The raster map of the soil map and look up table for SWAT database was prepared. These soil data was obtained from MoWIE (FAO, 2005) and processed in ArcGIS with the

soil types. The major soil types in the study catchment are Lithic leptosol (Lpq) covered 55.21%, Eutric Vertisols (VRe) covered 18.81%, Eutric Leptosols (Lpe) covered 16.33% and Swamps covered 9.65% of the study area. The soil look up table was changed in to Soil database file and imported in to the ArcSWAT database and the user soil was also prepared and imported in to the ArcSWAT reference database (Figure: 3-4-1-2).

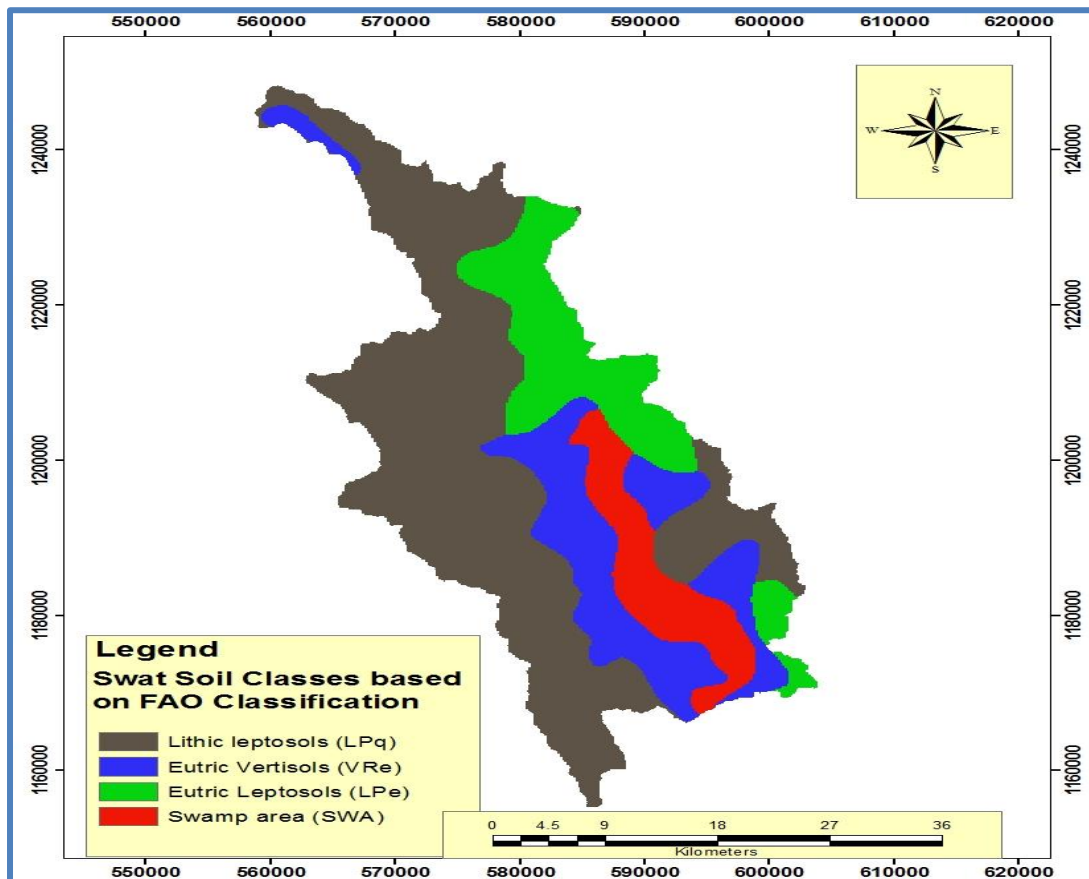


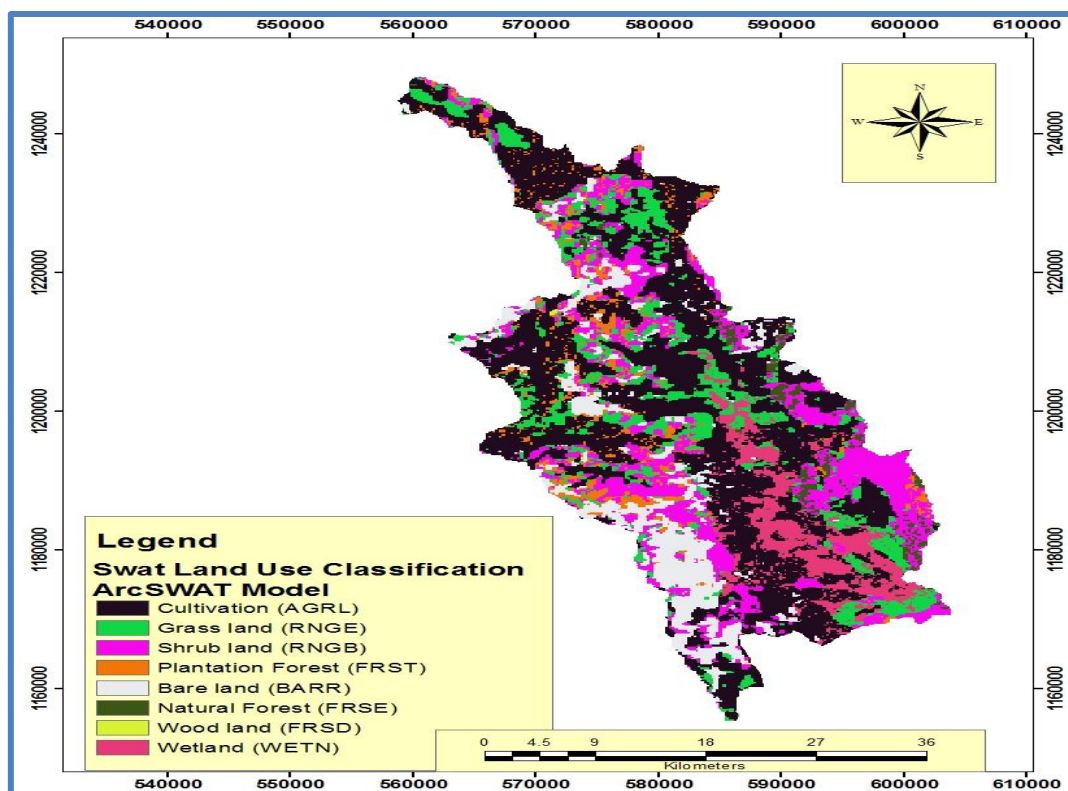
Figure 3.4.1.2-1 Soil map processed and reclassified during ArcSWAT model process

Table 3.4.1.2-1 Soil types processed in ArcSWAT showing the area coverage in the catchment

Value	SOIL_ID	Area (Km2)	Area (%)
1	Lpq	886.67	55.21
2	Vre	302.09	18.81
3	Lpe	262.26	16.33
4	SWA	154.98	9.65
Total		1606.00	100

**c. Land Use**

Land use is one of the most significant elements that affect runoff, evapotranspiration and surface erosion a catchment. The land use data of the study area was found from MoWIE. The land use map of the study area was reclassified after the raster map and look up table was used as an input for ArcSWAT. The land use map was reclassified to represent the land use rendering to the definite land cover types such as Cultivation land (AGRL), Grass land or pasture land (RNGE), Shrub land or brush land (RNGB), Plantation forest land (FRST), Bare land or Barren (BARR), Natural forest land (FRSE), Wood land or deciduous forest land (FRSD), and Wetland or marsh land (WETN) (Figure: 3-4-1-3). The land use look up table was changed in to land use land cover database format and imported in to in the ArcSWAT database file.



**Figure 3.4.1.2-2 Soil types processed in ArcSWAT showing the area coverage in the catchment**

**Table 3.4.1.2-2 Land use/ land cover of the study area after processed in ArcSWAT**

<b>Land use/Cover</b>	<b>Area (Km2)</b>	<b>% Area (Km2)</b>
Agricultural (AGRL)	796.04	49.57
Range land (RNGE)	237.34	14.78
Brush land (RNGB)	297.00	18.49
Plantation forest (FRST)	19.90	1.24
Bare land/Barren (BARR)	160.31	9.98
Natural Forest (FRSE)	0.17	0.01
Deciduous forest/wood (FRSD)	0.01	0.00
Wetland (WETN)	95.23	5.93
Total	1606.00	100.00

**d. Weather Data preparation (Weather Generator)**

The WGNMaker Macro is applied to prepare .wgn files for SWAT based on daily weather data. The 39 years weather data (precipitation, Temperature, Relative humidity, Solar radiation and Wind Speed) data were put in one folder and processed to a directory of WGNMaker Macro and after that the WGNMaker was started to prepare .wgn files of the two stations weather data (Combolcha and Kemise Stations) for ArcMap interface for ArcSWAT input. The climate data was prepared with the year covering from 1979-2017 in daily bases. After the WGEN is prepared it was changed in to database file and put in ArcSWAT reference database. WGEN file helps to how to simulate weather variables (Precipitation, Temperature, Solar radiation, Relative humidity and Wind speed).

**Table 3.4.1.2-3 Station Locations Put in reference database of ArcSWAT after preared in Weather Generator**

<b>ID</b>	<b>STATION NAME</b>	<b>LAT</b>	<b>LONG</b>	<b>ELEVATION</b>
24	OutKemisse	39.6875	10.7719	1450
25	OutCombolcha	39.7176	11.0839	1857

**e. River Discharge Data**

Hydrology department of the MoWIE provided the daily river discharge of the Borkena river. This data was prepared appropriate for SWAT CUP input and used for

model calibration and Validation. The river flow data obtained was covering the period from 2000 G C up to 2014 G C daily river flow. The flow data is found from the Borkena river outlet at Chefa Swamp Outlet river discharge station.

### **3.4.2. SWAT Model Simulation, Sensitivity Analysis, Calibration and Validation**

After the model was set up the next step is to run the model and the result the simulation cannot be directly used for further analysis. Instead, the ability of the model to sufficiently predict the consistent stream flow should be evaluated through sensitivity analysis, model calibration and model validation (White & Chaubey, 2005).

#### **3.4.2.1. Sensitivity Analysis**

There are several parameters which affect a complex hydrological modeling. Most of the values of these parameters are not exactly known. This can be for many reasons. Spatial variability, measurement error, incompleteness in the description of both the elements and processes present in the system are some of the reasons (Holvoet et al., 2004). Therefore optimizing internal parameters of a model is an important task in order to achieve a well representative hydrological model. This kind of task is called model calibration which is usually supported by sensitivity analysis. Determination of sensitive parameters by comparing the output variance due to input variability is conducted with the help of sensitivity analysis. It also facilitates selecting important and influential parameters for a model calibration by indicating the parameter that shows higher sensitivity to the output due to the input variability.

Sensitivity analysis was performed to determine the influence of a set of parameters had on predicting total flow. The analysis was carried out to identify the SWAT's hydrologic sensitive parameters by comparing their relative sensitiveness. It was performed on nine different SWAT parameters (Figure 3.4.2-1). An observed stream flow data of 8 years from 01 January 2000 up to 31 December 2007, of Borkena River at Chefa Swamp outlet station was used for calibration and flow data of 7 years from 2008 up to 2014 was for validation. Using ArcSWAT interface, the position of the sub

basin that contains the analysis of stream flow was selected and the method of the algorithm for the analysis was defined. From this project, one factor At a Time (One-at-a-Time/OAT) Sensitivity analysis method was applied.

By applying the P-Value and t-stat values identification method as shown in Figure 3-4-2-1, the sensitive parameters used in this model are (the curve number) CN2, V\_ALPHA\_BF.gw, ESCO, GW\_REVAP, GW\_DELAY, GWQMN, RCHRG\_DP, and SOL\_AWC. According to Hyung-Kyung et al. (2011) In SUFI-2, parameter uncertainty accounts for all sources of uncertainties such as uncertainty driving variables, conceptual model, parameters, and measured data. The degree to which all uncertainties are accounted for is quantified by a measure referred to as the P-factor, which is the percentage of measured data bracketed by 95% prediction uncertainty (95PPU). P-value determined the significance of the sensitivity and a P-value close to zero has more significance or sensitive. Another measure quantifying the strength of a calibration/ uncertainty analysis is the R-factor, which is the average thickness of the 95PPU band divided by the standard deviation of the measured data. The other quantifying measure is the t-stat, which provides the measure of sensitivity. The larger absolute values of t-stat are more sensitive parameters. According to Hyung-Kyung et al. (2011) the value of the P factor ranges between 0 and 1, while that of R-factor ranges between 0 and infinity. A P-factor of 1 and R-factor of zero is a simulation that exactly corresponds to measured data.

## Modeling Surface water-groundwater Interactions of Borkena river Catchment



**Figure 3.4.2.1-1 Sensitivity graph showing the most sensitive parameters based on P-value and t-stat values of each parameter**

**Table 3.4.2.1-1 Table showing the P-value and t-stat value to see the most sensitive parameters put in rank**

Parameter Name	t-Stat	Abs (t-stat)	P-Value	Sensitivity Category
8:A_REVAPMN.gw	0.11	0.11	0.92	Medium
3:V_GW_DELAY.gw	0.19	0.19	0.86	Highly Sensitive
6:V_ESCO.hru	0.39	0.39	0.72	Medium
5:A_GW_REVAP.gw	1.04	1.04	0.34	Medium
7:R_SOL_AWC(..).sol	1.19	1.19	0.29	Medium
9:R_RCHRG_DP.gw	-1.27	1.27	0.26	Medium
4:V_GWQMN.gw	1.52	1.52	0.19	Highly Sensitive
2:V_ALPHA_BF.gw	-1.93	1.93	0.11	Highly Sensitive
1:R_CN2.mgt	-4.16	4.16	0.01	Very Highly Sensitive

### 3.4.2.2. Model calibration and Verification

#### i) SWAT CUP for Simulated SWAT Calibration

SWAT-CUP is a calibration, validation and sensitivity analysis tool for SWAT model. SWAT Calibration and Uncertainty Program (SWAT-CUP) is a computer program which provides the calibration, validation and sensitivity analysis of SWAT models (Vervoort, 2017). It involves several methods such as SUFI2, PSO, GLUE, Parasol, and MCMC which can be chosen for the purpose of calibration and uncertainty

analysis. These accesses the SWAT input files and runs the SWAT simulations by modifying the given parameters. The storage of the value of the objective function and the modification of parameters are the basis for comparison. SWAT-CUP requires a specific format in all the observed data to allow the calibration.

SUFI 2(Sequential Uncertainty Fitting) algorithm developed by Abbaspour et al. (2007) has been used for this study. The Uncertainty is an interface of calibration, validation and sensitivity analysis of SWAT model and it converges with relatively smaller number of iterations and provides possibility of restarting an unfinished iteration.

## **ii) Model Calibration**

Model inputs and values of parameters are associated with a number of uncertainties. Therefore model calibration is an important task to improve the result of model simulation. It is a process in which parameter adjustment are made in order to simulate as closely as possible the hydrological behavior of the catchment. A proper model calibration is necessary to consider a good fit between simulated and observed catchment runoff volume, the shape of the hydrograph, the peak flow and the base flow. All these objectives are considered during model calibration because a single objective function cannot establish a reasonable match between simulated and observed data. Most calibrations are supported by sensitivity analysis which avoids performing calibration on non-effective parameters.

Calibration can be performed in two ways: either manually or automated. In ArcSWAT 2012 manual calibration helper used for making adjustment to parameters across a user defined group of HRUs or sub-basins. Auto calibration and uncertainty of ArcSWAT 2012 is used for automated calibration. It has two dialogue boxes namely Auto calibration input and Auto calibration output. The earlier allows performing the automatic model calibration by selecting a simulated model and a sub-basin which a discharge outlet located at. The latter provides option to refine to the out parameters.

Model calibration is a means of adjusting or fine tuning model parameters to match with the observed data as much as possible, with limited range of deviation accepted. Similarly, model validation is testing of calibrated model results with independent data set without any further adjustment (Neitsch et al., 2005) at different spatial and temporal scales.

Parameter estimation for model calibration is a various techniques designed to reduce the uncertainty in the estimates of the process parameters. A typical approach is to first select an initial estimate for the parameters, somewhere inside the ranges previously specified. The parameter values are then adjusted to more closely match the model behavior to that of the catchment.

Calibration of stream flow carried out at the outlet of sub-basin 10 (at Chefa Swamp outlet point) Borkena catchment. This site was selected because of it is the final outlet point of Borkena catchment having available measured flow data. The stream flow was collected in daily time step and organized for monthly time step for calibration.

Based on the available model input data parameters the time periods of modeling are:

- ✚ Flow Calibration period (2000 G C-2007 G C)
- ✚ Flow Validation Period (2008 G C-2014 G C)

The first three years of each period used is applied as a model warm up period and is not used for model evaluation.

### **3.4.2.3. Model Validation**

Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. For estimating the effectiveness of future possible management practices the model must be first calibrated to measured data and should then be tested (without further parameter adjustment) against an independent set of measured data to utilize any predictive catchment model . This analysis of a model on an independent data set is commonly referred to as model validation. Model calibration determines the best or at least a reasonable, parameter set while validation ensures that the calibrated parameters set achieves

reasonably well under an independent data set. Provided the model predictive capacity is demonstrated as being somehow reasonable in the calibration and validation phase, the model can be used with some confidence for future predictions under some different management scenarios. The flow validation was carried out at a station similar to the calibration. The statistical criteria used for the calibration procedure for ( $R^2$ , NSE and PBIAS) were used during the validation to make sure that the simulated values is still within the accuracy limits  $R^2 > 0.6$ ,  $NSE > 0.5$ , and  $PBIAS < \pm 15\%$  (Santhi et al., 2001).

### **3.4.3. Hydrogeological Setting and analysis of the study area**

Prior to construction of any numerical groundwater model, it is important to properly conceptualize the flow system in question. A conceptual model is a detailed description of the groundwater flow system to be modeled and should identify the hydrologic and hydrogeologic conditions and all-important features and drivers of the groundwater system, including sources, sinks, boundary conditions, geophysical features that convey water or interrupt flow, recharge, site stratigraphy, material properties, etc. in order to understand the groundwater flow system conceptual hydrogeological X-section is prepared.

A conceptual model designed for most groundwater flow modeling, at a minimum, includes information on boundaries; hydrostratigraphy and hydrogeologic properties; flow directions and sources and sinks; and a field-based estimate of components of the groundwater budget (Sophocleous, 2002).

The SWAT-MODFLOW model begins by initiating SWAT and then reads the input data which are required to initiate SWAT. When MODFLOW is employed, the groundwater recharge of the cell from HRU and the river stage of the cell are used for input in MODFLOW. After applying MODFLOW, the output of the cells (cell-based recharge, aquifer evapotranspiration, and exchange rate between river and aquifer) are added via the HRU and channel, and sent to SWAT. In the SWAT-MODFLOW integrated model, the recharge rate of the cell and river stage is used as input data for MODFLOW from SWAT.

The geological and structural setting of the area is the basis in understanding the hydrological and hydrogeological processes that happened in the past, and happening at present and in the future. A hydrogeological map and x-section is prepared to conceptualize the alluvial aquifer and tertiary volcanic aquifers are interconnected. Groundwater flow in the alluvial aquifer is governed by the configuration of the low to moderate permeable tertiary volcanic rocks which underlay the alluvial formation and surrounds it in all directions, the hydraulic properties of the aquifer material, the areal extent and thickness of the aquifer, recharge and groundwater discharge. This information are used to construct the conceptual model of groundwater flow that describes the internal and external boundaries of the groundwater flow system, the inflow and outflow of water at these boundaries, and effect each boundary that has on the groundwater flow in the aquifer. The groundwater flow in Borkena catchment alluvial aquifer is towards the central and southern Parts of Borkena River and it is largely defined by the configuration of low to moderate permeability of tertiary volcanic rock which surrounds it in all direction. Borkena River drains the excess groundwater inflow to the alluvial aquifer after filling the subsurface reservoir of alluvial aquifers in the catchment. This condition is used to construct the conceptual model.

Borkena catchment alluvial aquifer is a natural subsurface reservoir filled by runoff infiltration of large numbers of rivers mainly at the western and northern periphery of the alluvial aquifer (where very coarse gravel, pebbles and boulders dominate) and dammed by the low to moderate permeable tertiary volcanic formation in all direction and spills the excess water as distributed discharge along the central and lower parts (lower elevation areas) of Borkena River through the confining thin layer of clay. The alluvial aquifer is totally saturated and confined by thin layer of clay less than 10m along the main river channel and its flood plain. According to Well accomplishment report of KCVTW-02-19 and KCVTW-03-19 drilled at Combolcha and Kemisse towns which are 600m and 512m deep, the alluvial aquifer thickness reached 248m to 300m and below 300m thickness high potential tertiary volcanic aquifer is found. Based on these data the two aquifers are hydraulically interconnected with low to medium permeability. The reason for this argument is that the depth to the

groundwater level in the alluvial aquifer and the volcanic aquifer is found to be confined in some places and similarly unconfined in other places.

According to ADSE (2013) study result the hydrogeological setting of Borkena catchment is alluvial aquifer. Based on this research the researcher identified that there are two potential aquifers found in the catchment based on the test wells well accomplishment report in Gerado, Combolcha and Kemisse towns mentioned above. The hydrogeological map of the catchment is also prepared based on the hydrogeological data from Amahara Design and Supervision Enterprise as a base map.

#### **3.4.3.1. Conceptual Model and Input parameters for MODFLOW**

As shown from the developed Hydrogeologic map and the cross section maps of the study area alluvial aquifers are isolated each surrounded by low to moderate productive volcanic aquifers. The alluvial aquifers are recharged from the low to moderate productive extensive volcanic aquifers and the deep volcanic aquifers are recharged from regional groundwater flow and from Borkena river flow. The regional groundwater flow is indicated in the conceptual cross-section from the Gerado to Combolcha or From Abay basin to Awash basin.

Based on the boreholes data observation the aquifers especially at the middle center and southern center (along the Borkena River) are found to be artesian or overflowing and there is a distributed discharge of the groundwater to the river. The reasons considering the groundwater discharges from the aquifer along Borkena River are:

- i) The base flow of Borkena River increases after passing through the alluvial aquifers when it flows through the volcanic rock channel. This is formulated from hydrological analysis using SWAT hydrograph analysis.
- ii) The boreholes drilled along the lowest elevation areas are artesian or overflowing.

- iii) A large Swamp is developed at the southern part of Borkena catchment and boreholes drilled near the swamp are artesian indicating the main discharge of this is along Borkena and its flood.

Therefore the alluvial and volcanic aquifers are conceptualized in similar way since they are high productive the one overlain the other and SWAT-MODFLOW Model is developed to see the SW-GW interaction, and the groundwater flow system.

#### **3.4.3.2. Aquifer Parameters**

Hydrogeological map and cross-sections are prepared to conceptualize the aquifers. Groundwater flow is governed by the configuration of low to moderate permeable tertiary volcanic which underlay the alluvial formation and surrounds it in all directions, the hydraulic properties of the aquifer material, the areal extent and thickness of the aquifer, recharge and groundwater discharge. This information are used to construct the conceptual model of groundwater flow that describes the internal and external boundaries of the groundwater flow system, the inflow and outflow of water at these boundaries, and effect each boundary that has on the groundwater flow in the aquifer. The groundwater flow in alluvial aquifer is towards the central and southern Parts of Borkena River and it is largely defined by the configuration of moderate permeability of tertiary volcanic rock which surrounds it in all direction. Borkena River drains the excess groundwater inflow to the alluvial aquifer after filling the subsurface reservoir of alluvial. This condition is used to construct the conceptual model.

##### **a) Hydraulic properties and Input parameters**

Most drilled wells are found within the central part of the alluvial aquifers and are flowing (artesian) wells. A test well drilled in Combolcha town 600m depth has fully penetrated the alluvial aquifer at a depth of 248 meters with a static water level of 10.24m yielding 75.5 l/s but to see the two aquifers separately the alluvial aquifer was sealed or grouted up to 300m depth and the resulted yield is as described above. This study argued that the two aquifers are hydraulically interconnected.

### **Horizontal Hydraulic Conductivity (K)**

Hydraulic conductivity is the volume of water that will move through a porous medium in unit time under a unit hydraulic gradient through a unit area measured at right angles to the direction of flow (Kruseman and Ridder, 1994). It determines the ease by which water can move through aquifers. Therefore it can determine the productivity of the aquifer. The hydraulic conductivity of fractured rocks depends largely on the density of fractures and the width of their apertures. Fractures are not evenly distributed spatially because rocks of different properties respond differently to applied stresses. Fracturing is common at the escarpment and central part of the study area because of rifting and active tectonic activity.

Hydraulic conductivity of the area is highly variable due to the presence of different geologic structures and it is demonstrated on the results of the analysis of pumping test data. Acidic rocks have the least in the area which is 0.01 m/day at Desse area and goes up to 36.6 m/day in the tertiary fractured volcanic aquifers and in the alluvial area at Combolcha, Kemisse, Chefa, which has wide range of values. For this study the average hydraulic conductivity value is taken for the MODFLOW input. The existing boreholes data and pumping test result data is collected and averaged as **3.38** m/day.

### **Vertical Hydraulic Conductivity (K<sub>v</sub>) anisotropy ratio (K<sub>H</sub>) (K<sub>z</sub>/K<sub>r</sub>)**

An anisotropy ratio relates hydraulic conductivities in different directions. For example, vertical-to-horizontal hydraulic conductivity anisotropy ratio is given by  $K_z/K_r$ .

Where,  $K_z$  is vertical hydraulic conductivity [L/T] and  $K_r$  is radial (horizontal) hydraulic conductivity [L/T]. Anisotropy in a horizontal plane is given by  $K_x/K_y$  where  $K_x$  and  $K_y$  are horizontal hydraulic conductivities in the x and y directions, respectively [L/T]. Todd (1980) reported values of  $K_z/K_r$  ranging between 0.1 and 0.5 for alluvial and possibly as low as 0.01 when clay layers are present.

### **Streambed Hydraulic Conductivity**

The hydraulic properties of a streambed are major control in the hydrologic connection between a stream and an aquifer. Streambed characteristics such as thickness, width, bed material, and vertical hydraulic conductivity ( $K_v$ ) have a great influence on streambed hydraulic properties and water movement. The vertical hydraulic conductivity ( $K_v$ ) of streambed plays an important role in river water and groundwater interaction. Determination of the vertical hydraulic conductivity ( $K_v$ ) of the entire riverbed has significant importance for the study of groundwater recharge (Unnikrishnan and Sarada, 2016).

### **Aquifer thickness (b)**

The saturated aquifer thickness of the aquifer may be determined from published reference boring/well logs or field data. The saturated thickness of the aquifer has the dimensions of length. For confined units, the saturated thickness will correspond to the thickness of the aquifer. For unconfined aquifer, the saturated thickness represents the vertical distance from the mean annual static water level elevation to the base of the aquifer.

For this study the aquifer thickness of the Borkena catchment is determined from the pumping test result of existing boreholes static water level and the elevation difference with the borehole depth. The aquifer thickness estimated for this study is about 280m covering both the alluvial and tertiary volcanic aquifers.

### **Transmissivity (KD or T)**

Transmissivity is the product of the average hydraulic conductivity  $K$  and the saturated thickness ( $D$ ). It is the rate of flow under a unit hydraulic gradient through a cross-section of unit width over the whole saturated thickness of the aquifer (Kruseman and Ridder, 1994). The analysis result of pumping test data for some wells is presented. Transmissivity ranges from 4.3 m<sup>2</sup>/day to 1895.6 m<sup>2</sup>/day and average transmissivity value in the catchment is 255.36.

$$T = Kb \dots\dots\dots 3.5.3.3$$

Where T is Transmissivity [ $L^2/T$ ], K is Hydraulic conductivity [ $L/T$ ] and b is aquifer thickness [L].

### Porosity

The porosity of the alluvial aquifers which is used as an input for SWAT-MODFLOW is 40 to 70 percent for clays, 35 to 50 percent for silts, 25 to 50 percent for sands, and 25 to 40 percent for gravels (Freeze and Cherry, 1979). They also determined categorized the porosity of the fractured basalt rock as from 5-50 percent. The alluvial aquifer in the study catchment is dominantly sand and gravel and the saturated average porosity is estimated to be 20 percent and on average 0.3 was considered in SWAT-MODFLOW model. The combolcha area and Kemississe unconfined/confined alluvial and volcanic aquifer is a natural reservoir filled by runoff infiltration of large numbers of streams mainly at the western and north western periphery of the alluvial aquifer (where the very coarse gravel, pebbles and boulders dominates) and dammed by the low to moderate permeable tertiary volcanic formation in all direction and spills the excess water as distributed discharge along the central part or lower elevation areas of the catchment. Heath (1983), defined porosity as the void space of a rock or unconsolidated material;

$$n = \frac{V_v}{V_t} \dots\dots\dots 3.5.3.4$$

Where, n is porosity [dimensionless],  $V_v$  is void volume [ $L^3$ ] and  $V_t$  is total volume of the catchment aquifer [ $L^3$ ].

### Specific Yield

The specific yield determines the ratio of the volume of water that will drain because of gravity to the total volume of the saturated aquifer. The specific yield of the alluvial aquifer is usually varies from 0.15 to 0.2. For the Borkena catchment the alluvial aquifer is estimated to be around 0.15. Morris and Johnson (1967) indicated the specific yield values for various geologic materials; Coarse, Medium, and Fine Gravel as 21%, 24% and 28% and Coarse, Medium, and Fine Sand as 30%, 32% and 33%. On average 0.15 was considered as an input.

$$S_y = \frac{\text{Volume of Water an unconfined aquifer will yield by gravity}}{\text{Unit Volume of the unconfined aquifer}} \dots 3.5.3.5$$

**Specific storage**

According to Todd (1980) the specific storage of a saturated aquifer is defined as the volume of water that is stored or released from the aquifer by the expansion of water and compression of the soil or rock or the volume of water that a unit volume of aquifer releases from storage under a unit decline in hydraulic head. On average 0.00015 was considered for the model.

$$S_s = \rho g \alpha + n\beta \dots 3-5-3-6$$

Where,  $\rho$  is mass density of water (=1000 kg/m<sup>3</sup>) [M/L<sup>3</sup>],  $g$  is gravitational acceleration (=9.8 m/sec<sup>2</sup>) [L/T<sup>2</sup>],  $\alpha$  is aquifer compressibility [T<sup>2</sup>L/M],  $n$  is total porosity [dimensionless], and  $\beta$  is compressibility of water (=4.4 \* 10<sup>-10</sup> m sec<sup>2</sup>/kg or Pa<sup>-1</sup>) [T<sup>2</sup>L/M].

**Storativity or Coefficient of Storage**

Storativity is defined as the volume of water that a permeable unit will release from storage per area of aquifer per unit change in head drop and the storativity values ranges from 5 \* 10<sup>-5</sup> to 5\* 10<sup>-3</sup> (Todd, 1980).

$$S = S_y + S_s b \dots 3-5-3-7$$

Where,  $S$  is Storativity,  $b$  is aquifer thickness,  $S_y$  is Specific yield, and using substitution method substituting equation 3-5-3-6 in to 3-5-3-7.

$$S = S_s b = S_y + (\rho g \alpha + n\beta) b \dots 3-5-3-8$$

**River Packages**

The movement of ground water to and from perennial rivers is another important boundary condition. The flux of water between the ground-water system and rivers is, in part, dependent on the hydraulic head in the ground-water system and is simulated as a head-dependent flux boundary. Streams were simulated using river

package, which is used to simulate the flow of water between an aquifer and an overlying source reservoir which is usually a river or a lake. In a model cell containing river parameters, the rate of leakage between the river and the aquifer ( $Q_{riv}$ ) is calculated from;

$$Q_{riv} = C_{riv} * (h_{riv} - h) \quad h > B_{riv} \dots\dots\dots 3-5-9$$

Where,

$h_{riv}$  is head in the river (taking river elevation from each river cell)

$h$  is the head in the aquifer directly below the river

$B_{riv}$  bottom of the streambed

$C_{riv}$  is the streambed conductance which accounts for the length (L) and width ( $W_{riv}$ ) of the river channel within the cell, the thickness of the riverbed sediments ( $M_{riv}$ ), and their vertical hydraulic conductivity (K<sub>riv</sub>), where,

$$C_{riv} = \frac{K_{riv} * L * W_{riv}}{M_{riv}} \dots\dots\dots 3-5-10$$

When the water table falls below the bottom of the streambed ( $B_{riv}$ ), leakage stabilizes and the leakage rate through the riverbed ( $Q_{RIV}$ ) is given by

$$Q_{riv} = C_{riv} * (h_{riv} - B_{riv} ) \quad h \leq B_{riv} \dots\dots\dots 3-5-11$$

Cells in the model representing stream-aquifer relations (river cells) are shown in the annex. 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 stage is the elevation of the water surface in the stream, and a single value must be chosen to represent the stream across the entire cell. Stream stages used in this simulation were determined by picking an approximate median stream elevation within the cell based on the observed field value, Digital Elevation Model (DEM) derived from a 30m-resolution Shuttle Radar Terrain Model (SRTM) image taken as topographic maps (elevation of stream cells).

The streambed conductance,  $C_{riv}$ , controls the rate at which water moves to or from a stream in response to a given head gradient. Direct measurements of streambed conductance are rare and these terms are usually derived empirically during model

calibration. Streambed conductance terms were initially calculated for Borkena river using a streambed thickness of 0.5-3 m in the low lands, stream widths of 30-100 m, and a vertical hydraulic conductivity of Horizontal hydraulic conductivity (K) times 0.5 (some constant) for the river. The hydraulic conductivity value was then adjusted during model calibration. Therefore the river package file was prepared to enable groundwater-surface water exchange between MODFLOW grid cells and SWAT sub-basin channels with the file name (modflow\_LRW.riv).

### **Well Package**

Most of the boreholes are drilled for water supply consumption for water supply system of different Kebeles and woreda towns at different places in the study area. In this model, the abstraction amount of the boreholes analyzed based on the yield of the boreholes and average pumping eight hours for towns and rural villages. The abstraction of groundwater was simulated using well package. In this model pumping wells was defined using Cell-by-Cell input method. The injection or pumping of the rate of a well is independent of both the cell area and the hydraulic head cell. MODFLOW assumes that a well penetrates the full thickness of the cell. To simulate withdrawal of water from aquifers through well package, negative value of the rate of daily abstraction (m<sup>3</sup>/d) was assigned to the entry recharge in well Package MODFLOW and the prepared well data is annexed in this paper. Around 27 wells were collected and prepared as well package input files in to SWAT-MODFLOW.

### **3.4.3.3. Groundwater Levels and Movements**

In general precipitation, evapotranspiration, and pumpage affect groundwater levels. In the study area water levels are generally highest in July, August and September when precipitation is greatest, evapotranspiration is lowest, and irrigation withdrawals are minimal; from November till February water levels are lowest when evapotranspiration and pumpage are greatest. The important parameter for the consideration of the groundwater flow is the static water level of the existing borehole. Based on the existing boreholes groundwater elevation data groundwater level and flow map is produced.

Average groundwater head distributions along with the direction of flow were estimated for the catchment from water level data of boreholes found in different parts of the catchment. The general direction of groundwater movement throughout most of the catchment was from the margin of the Mountain Ridge (recharge area towards Chefa or discharge area).

#### **3.4.3.4. Groundwater Occurrence**

Due to the difference in mineralogy, texture and structure of volcanic rocks water bearing potential also varies. Groundwater circulation and storage in the volcanic rocks depend on the type of porosity and permeability formed during and after the rock formation (Tamiru, 2006).

The catchment has highly permeable alluvial sediment, low permeable acidic volcanic and fractured and weathered (rhyolites, tuffs, pumice), and moderate to high permeable tertiary volcanic rocks. High spatial variability in the permeability of volcanic rocks of the area is due to differences in the degree of fracturing.

According to this study the high potential aquifers encloses around the Combolcha, Harbu, Kemisse, and Chefa alluvial and tertiary volcanic aquifers, where there is an artesian deep well found at Kemisse. It is recharged mainly by overland flow from part of the Western Ethiopian Plateau high lands, and partly from direct precipitation, perennial streams and springs from the western highland and from inter-basin transfer of groundwater from Abay to Awash basin. To see the aquifer characteristics of the Kutaber and Borumeda area there should be deep boreholes drilled in the area.

The majority of Moderate Potential Aquifers constitute deeply buried fractured tertiary volcanic aquifer with plentiful good quality perennial springs supplying drinking water for surrounding villages and towns. Mainly the alluvial aquifers are the potential units of this group.

Low Potential Aquifers are those with thin layer of top clay soil and acidic units, it has very low permeability, very low recharge amount. In the study area acidic volcanic rocks such as Rhyolite, Trachyte and Ignimbrite are grouped under low

potential aquifers and are found in areas with hilly topography and poorly developed joints and fissures, which increase runoff instead of infiltration.

### 3.4.3.5. Groundwater Recharge

Because an elevation of groundwater availability is largely dependent up on recharge, it is a crucial model parameter warranting careful examination and meaningful implementation (Freeze, 1971). Groundwater recharge refers to the process by which the volume of water is percolated and crosses the water table to become part of groundwater flow system.

The major sources of groundwater recharge for the unconsolidated sediment aquifer are subsurface seepage from the fracture openings of the volcanic rocks of the western mountainous area, seepage from runoff generated from precipitation in the highlands and infiltration from precipitation that takes place in the valley plains and contribution from fractured basalt along faults and may be contribution from the volcanic rocks underlying through faults.

The groundwater recharge of the area can be calculated using the following Darcy equation. The Darcy equation for groundwater systems is

$$Q = T \times I \times L \times 365 \dots\dots\dots 3.5.3.7.1$$

Where, Q= Average annual groundwater recharge in Mm<sup>3</sup>

I= Hydraulic gradient

T= Transmissivity of the catchment in m<sup>2</sup>/day

L= Width of flow at right angle to the direction of flows in meter

According to this study the recharge of the Borkena catchment is estimated by using SWAT model and the average annual rain fall is 1017.5mm. the average annual run off was found to be 23.7% of average annual rainfall (241.54mm), the evapotranspiration loss 58.4% of the average annual rainfall (594.5mm) and the total average annual recharge is found to be 12% of the average annual rainfall which is (114.75mm). Except the recharge and rainfall amount which have a slight difference

with the previous study estimations, the surface run off and evapotranspiration values are found to be similar.

Groundwater recharge in the basin typically occurs:

- as direct rainfall to permeable ground, generally greatest in the basin margins where rainfall is relatively high.
- as recharge from rivers systems (often via alluvial materials).
- from overlying or adjacent groundwater bodies and recharge from regional flows.

Recharge, which is water contributing to groundwater passing through water table, could be direct, indirect or localized based on the source and mechanism by which water reaches the water table. The amount and type of recharge depends on land use/land cover, topography, climate, drainage, geographic location, vegetation, structure, soil condition and other.

Generally the north western and western part of the catchment gets better recharge than the southern as a result of its higher rainfall amount and perennial streams from the north western escarpment, in addition to these faults facilitate recharge to the aquifer. The floor of the catchment gets recharge from precipitation as direct recharge and as indirect from perennial rivers (Stream networks in Borkena catchment) and recharge from regional flows.

Escarpment and highland volcanic mountains of the western margin of the catchment gets large amount of recharge. This is due to the characteristic features of the area, which are joint and fracture zones affecting this area, its high drainage density, high amount of rainfall and elevated altitude with flat topped hills, which favors infiltration over surface runoff.

The second group is the foot of escarpment and the area at the northern mountain which has very impermeable rocks and it has lower recharge relative to the highland due to reduced infiltration by the steep slope and undulating topography. It has fast and shallow circulating groundwater coming from direct recharge of this area and the highland. In this part of the catchment recharge is

mainly contributed from direct precipitation and perennial streams draining the western escarpment, faults of this area facilitate the recharge process. The eastern part gets higher amount of recharge than the western hills, which is characterized by intermediate direct recharge from depressions.

Volcanic domes and volcanic necks of the floor is another group of receiving localized recharge from precipitation through joints and depressions formed by faulted volcanic hill in the area. The absence of soil cover and the less permeable volcanic products of these group are the reason for lower amount of recharge compared to the other three recharge zones.

The last zone is the floor of the catchment with relatively lower amount of rainfall and characteristic evapotranspiration. Presence of swamp and shallow groundwater table are clear manifestation of discharge areas. It gets direct recharge from precipitation indirect recharge from Borkena River and associated open channels and deep regional flows.

#### **3.4.3.6. Groundwater Discharge**

Discharge from the study area mainly occurs through well withdrawals and discharge to stream and springs. Discharge by evapotranspiration generally occurs in topographically low areas where groundwater table is intersected or close to the surface like the swamp around Chefa Swamp, at Combolcha in some places and at Kemisse in some places. In the study area discharge to streams occurs as springs and seeps, there are several perennial springs with good discharge originating from the western highlands of the catchment and flowing to streams draining this part of the catchment. Well withdrawals are from domestic, typical wells and industrial as well as irrigation in small amount, which is the dominant development activity in the study area.

Generally Groundwater discharge occurs as a result of:

- discharge from springs
- discharge into surface waters (supporting base flow)
- discharge to the surface (wetlands)
- discharge to adjacent (or overlying) groundwater bodies

In the study area there are several fault controlled cold springs in the northern, northwestern and central parts of the catchment, these springs are fast, shallow circulating groundwater where the faults causes the westward flowing groundwater to emerge as spring flow. On the north western highland near the watershed boundary, there are so many low to moderate discharge cold springs in low depressions and open channels resulting when groundwater table and the surface coincide.

In general discharge areas of the catchment are manifested as swamps, depressions, and springs, which are controlled by faults, are found largely in the western and central part of the study area. The swampy area around Chefa is a typical discharge area in the catchment.

#### **3.4.3.7. SWAT-MODFLOW Model**

SWAT-MODFLOW interface is a graphical user interface developed to create a fully linked SWAT-MODFLOW model based on an existing SWAT (version 2012) model that has been created with the QSWAT(QGIS) and ArcSWAT interface (Bailey et al., 2016). SWAT-MODFLOW is a hydrologic model that combines the land surface and stream hydrologic processes of SWAT and the groundwater hydrologic processes of MODFLOW to provide a comprehensive coupled hydrologic model for watersheds (Bailey and Park, 2019). The user defines a finite difference grid for a MODFLOW model, which is then linked with HRUs & Sub-basins of the SWAT model through geo-processing routines. In running a coupled SWAT-MODFLOW model requires values of variables (Mapped) from the SWAT model to the MODFLOW model and from the MODFLOW model back to the SWAT model as follows:

- Recharge to the water table (SWAT HRUs-MODFLOW grid cells)
- Water table elevation (from MODFLOW grid cells to SWAT HRUs)
- Sub-basin Channel/stream Stage (SWAT Sub-basin channels-MODFLOW river cells)
- Groundwater-Stream exchange rates (MODFLOW River cells to SWAT sub-basin).

Running a coupled SWAT-MODFLOW model requires that values of state variables be passed (mapped) from the SWAT model to the MODFLOW model and from the MODFLOW model to the SWAT model.

As SWAT HRUs do not have a designated geographic location, HRUs are disaggregated in preprocessing GIS routines. Disaggregation splits apart an HRU into individual polygons that have a specific geographic location. These Disaggregated HRUs (DHRUs) are then intersected with MODFLOW grid cells in order to pass variables between SWAT and MODFLOW. Although MODFLOW river cells, for which volumetric flow exchange rates between the aquifer and the stream are estimated, they are intersected with SWAT sub-basins for transferring groundwater return flow rates to the correct sub-basin streams.

In MODFLOW, the aquifer system is divided into a rectangular mesh of blocks which are organized by rows, columns, and layers. Each block is known as a “cell” and the center of the cell corresponds to a “node”, where the head is calculated. Taking topography, size and hydrogeology of the Borkena catchment and available data into consideration, the model area was discretized into 47 rows and 23 columns with a grid size of 2000m\*2000m. In designing the grid, the length to width ratio (aspect ratio) of the cells should be kept as close to one as much as possible to avoid numerical instabilities or errors (Konikow and Reilly, 1998). The MODFLOW grid for the current project has 47 rows and 23 Columns which has a total of 1081 grid cells. Since MODFLOW needs the ground surface elevation for the grid cell (used as to of the layer), the DEM that has been used during the initial ArcSWAT set up model is used and a 280m aquifer thickness for the entire catchment is applied.

The Most parts of Western and Eastern escarpments for a pertinent physical boundary of the catchment were established as no-flow boundary. The general head boundary package used to simulate head dependent flow conditions, where groundwater flows in to or out of a cell from an external source is provided in proportion to the difference between the head in the cell and the head assigned to the external source. Thus some part of the north western and the southern parts of the catchment are assigned as general head boundary.

The already produced DHRUs then are intersected with the MODFLOW grid, with the resulting weighted areas used to pass information between SWAT and MODFLOW. The number of DHRUs produced for the current project is 38431.

The next procedure was creating the SWAT-MODFLOW LINKAGE. The information required to link HRUs, DHRUs, SWAT Sub-basins, and MODFLOW grid cells are required in four text files. Those text files are:

- ✚ Swatmf\_dhru2hru.text (relates HRUs to DHRUs)
- ✚ Swatmf\_dhru2grid.text (relates DHRUs to GRID CELLS)
- ✚ Swatmf\_grid2dhru.text (relates GRID CELLS to DHRUs)
- ✚ Swatmf\_river2grid.text (relates RIVER CELLS to SUB-BASINS)

The linkage information is stored in memory during the simulation and used when variables are passed between the two models.

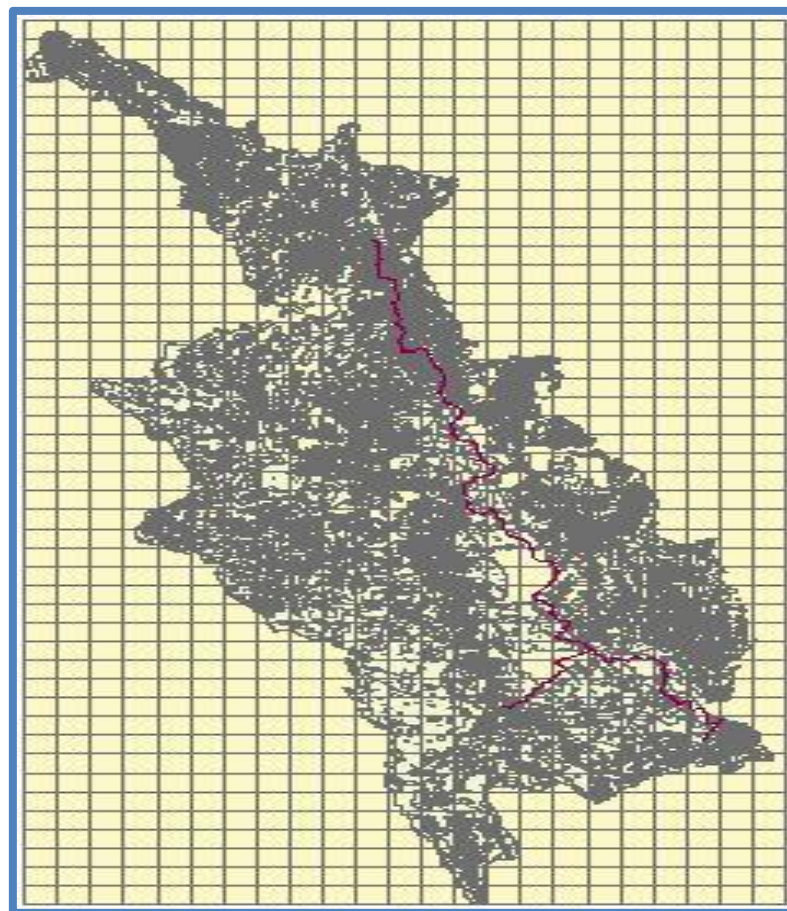


Figure 3.4.3.7-1 The MODFLOW mesh (grid) area and DHRUs

## **4. Result and Discussion**

### **4.1. SWAT Model**

A SWAT model was calibrated and validated on a monthly basis to estimate the flow and recharge of the study with ground water flow system using a time series dataset of 39 years from 1979-2017. During modeling the data prepared and used for the model covers the period from 1979 G C to 2017 G C. The catchment was sub-divided in to 12 sub-basins based on a chosen out let and threshold area of 1606.13 km<sup>2</sup>. The overlay of land use, soil and slope maps resulted in the definition of 187 HRUs.

#### **Flow Simulation**

The simulated flows at the outlet of the catchment gauging station were compared with the observed flow. About, 270 simulations has been done by SWAT CUP, SUFI2 algorithm sensitivity analysis at the catchment of sub-basin number 10, where the outlet of the catchment found for flow calibration with the output of nine parameters were reported as sensitive in different degree of sensitivity for flow. These 9 parameters have effect on the simulation when changed.

#### **Flow Calibration**

Before calibration is conducted, the performance of the model was evaluated from the initial simulation runs with model default parameter values. From this the monthly simulation coefficient of determination ( $R^2$ ) of 0.33, Nash Sutcliffe model efficiency (NSE) of 0.33, and mean deviation of -3.9% were obtained from the initial model run. The result shows the performance indicator was not with the acceptable range (limit), i.e.  $R^2 > 0.6$ ,  $NSE > 0.5$  and  $PBIAS < \pm 15\%$  (Santhi et al., 2001), but the model flow parameters were required adjustment and this adjustment was based on the sensitivity analysis result of flow parameters.

Model calibration was carried out automatically and manually by importing the parameters automatically after each iteration and adjusting manually with the acceptable range. The calibration processes considered the sensitive parameters and their values were varied iteratively within the allowable ranges until satisfactory

agreement between observed and predicted stream flow was achieved. The final calibration or last iteration Fitted result shown in Table: 4.1-1.

**Table 4.1-1 Fitted values of Calibrated flow parameters with the absolute t-stat and P-value**

Parameter Name	Range	Fitted Values	t-Stat	Abs(t-stat)	P-Value
7:R__SOL_AWC(..).sol	±25%	0.07083	0.02	0.02	0.98
1:R__CN2.mgt	±25%	33.824554	0.54	0.54	0.61
4:R__GWQMN.gw	0-5000	-29.23986	-0.55	0.55	0.61
3:A__GW_DELAY.gw	0-500	28.845243	-0.65	0.65	0.55
6:V__ESCO.hru	0.5-0.1	13.561003	0.88	0.88	0.42
2:V__ALPHA_BF.gw	0-1	0.601967	-1.24	1.24	0.27
8:A__REVAPMN.gw	0-500	62.291344	1.65	1.65	0.16
5:A__GW_REVAP.gw	0.02-0.2	-0.056756	-1.82	1.82	0.13
9:R__RCHRG_DP.gw	0-500	0.205622	-2.35	2.35	0.07

The model goodness of fit was evaluated and the model presentation after adjusting all the above parameters. Calibration resulted after simulation and/or calibrated was found to be coefficient of determination ( $R^2$ ) of 0.68 (Figure: 4.1-1), Nash-Sutcliffe efficiency (NSE) of 0.66 and mean deviation of -2.7% showing a good agreement between measured and simulated monthly flows (Table: 4.1-2).

**Table 4.1-2 Calibration result statistic for monthly measured and simulated stream flow**

Monthly Time Step	Mean Annual Stream flow (m3/s)		R2	NSE	Deviation
	Observed	Simulated			
<b>Calibration</b>					
2000-2007	7.17	8.60	0.68	0.66	-2.70%

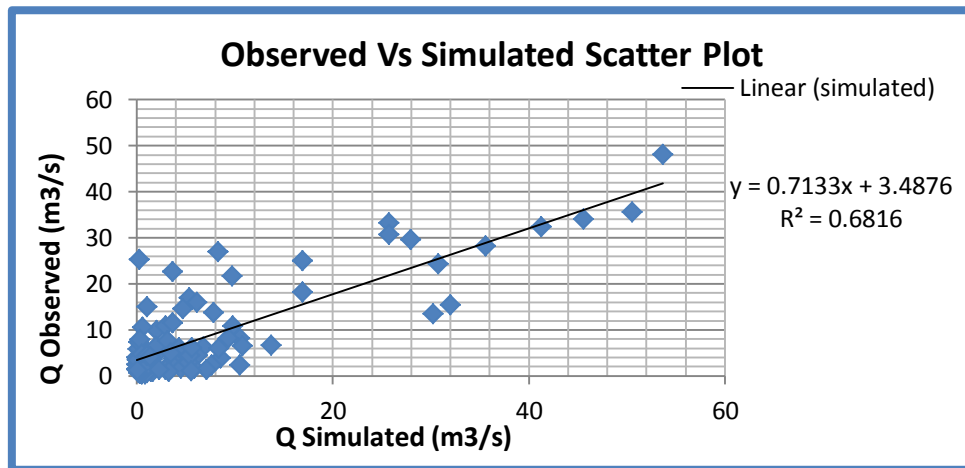


Figure 4.1-1 Observed Vs Simulated linear graph to show the coefficient of determination  $R^2$

## Stream Flow

During the calibration period (2000-2007), the simulated monthly flows were more or less matched in the same trends with the measured monthly flows ( $R^2=0.68$  and  $NSE=0.66$ ) as shown in Figure: 4.1-2. The trends of seasonal variability and monthly average discharge were well captured. The average or mean annual Base flow conducted for 2014 year rainfall and observed data with TIMESPLOT graph resulted is 5.097 m<sup>3</sup>/s and the eight year simulated mean flow result after calibration is 8.6 m<sup>3</sup>/s which is closer to the base flow result in TIMESPLOT graph. The model slightly over estimates the peak monthly flow in most of the simulation periods of April to May and July to September. This is due to the seasonal high rain fall variability.

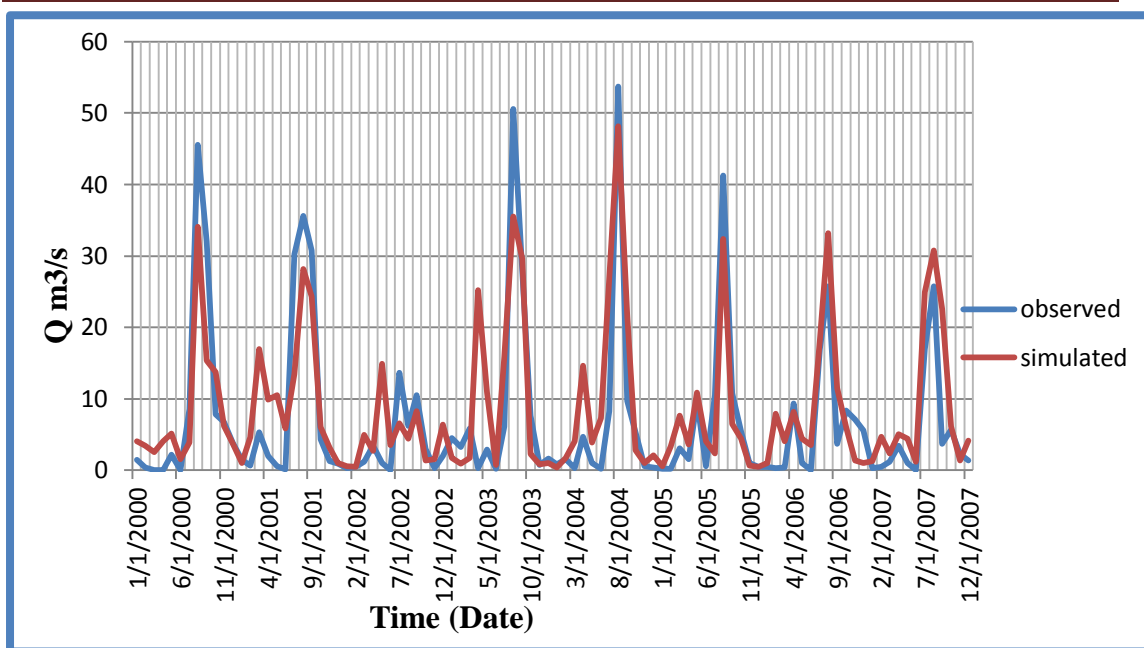


Figure 4.1-2 Calibration results of average monthly observed and simulated flow hydrograph (2000-2007)

### Flow Validation

The model performance in validation was carried out from 2008 to 2014, without further adjustment. Accordingly good match between monthly measured and simulated flows in the validation period were demonstrated by the correlation coefficient  $R^2=0.64$  (Figure: 4.1-3), Nash-Sutcliffe simulation efficiency  $NSE=0.61$  and mean deviation of measured and simulated flows for the monthly flow was found to be 2.48% (Table: 4.1-3).

Table 4.1-3 Default, Calibration, and Validation statistic for monthly observed and simulated stream flow

Parameters	Default Value	Calibrated (2000-2007)	Validated (2008-2014)
R2	0.33	0.68	0.64
NSE	0.33	0.66	0.63
D%	-3.90%	-2.70%	2.48%

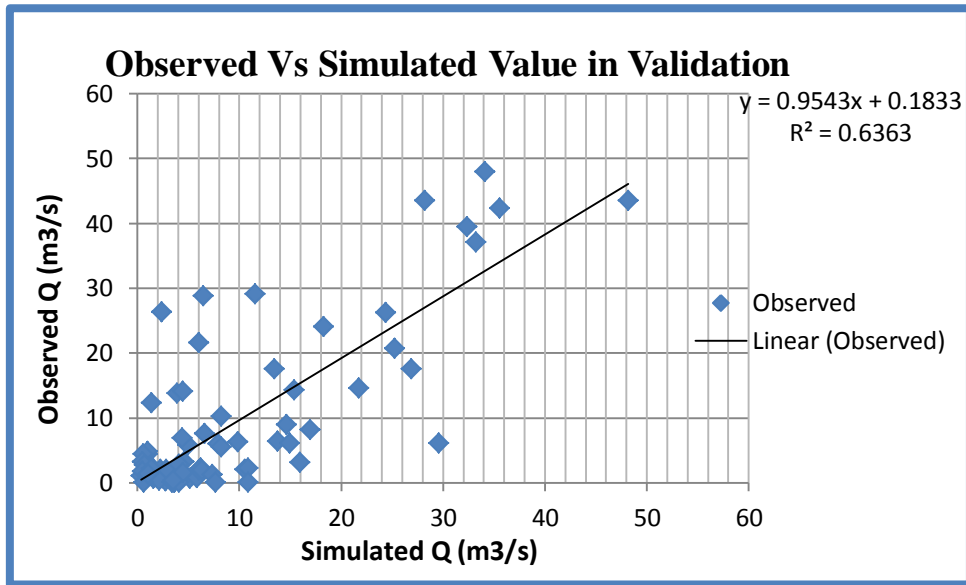


Figure 4.1-3 Observed Vs Simulated linear graph to show the R2 in Validation

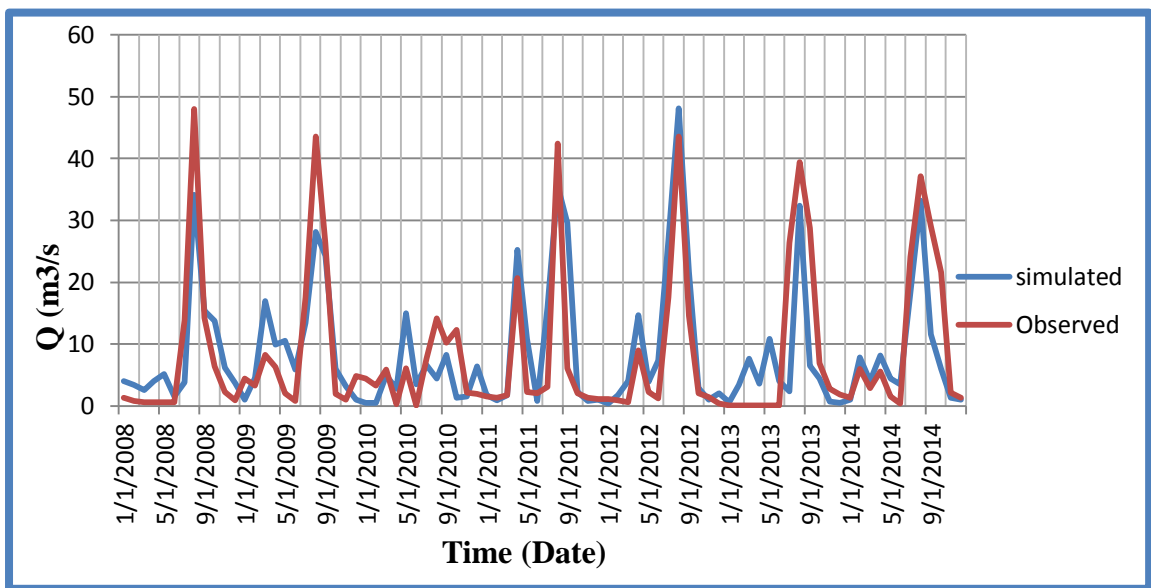


Figure 4.1-4 Validation result of average monthly Observed and Simulated flow hydrograph (2008-2014)

The hydrograph result of the validation period of the observed and simulated flow in monthly estimation, the model slightly over estimates some of the peak flows of the months, like in the 1<sup>st</sup> to 5<sup>th</sup>, 15<sup>th</sup> to 17<sup>th</sup>, 63<sup>rd</sup> to 65<sup>th</sup> months of the simulation periods and some of the months peak flows were also under estimated by the model like: 25<sup>th</sup>, 31<sup>st</sup> to 35<sup>th</sup> and 83<sup>rd</sup> months of the simulation periods (Figure: 4.1-4). This may be

resulted from the quality of weather or flow data used as an input for the model and seasonal variations in summer and winter.

#### **4.1.1. Recharge Estimation of the study area**

After the ArcSWAT Model is conducted the SWAT output should be checked using a SWAT CHECK. As a first check it is important to understand something about the quality of the data. This involves running a script to calculate potential ET/rough actual ET using a crop factor and to do a water balance:  $P-ET=Q$  and to plot the water balance. This can help to get an understanding of the data quality.

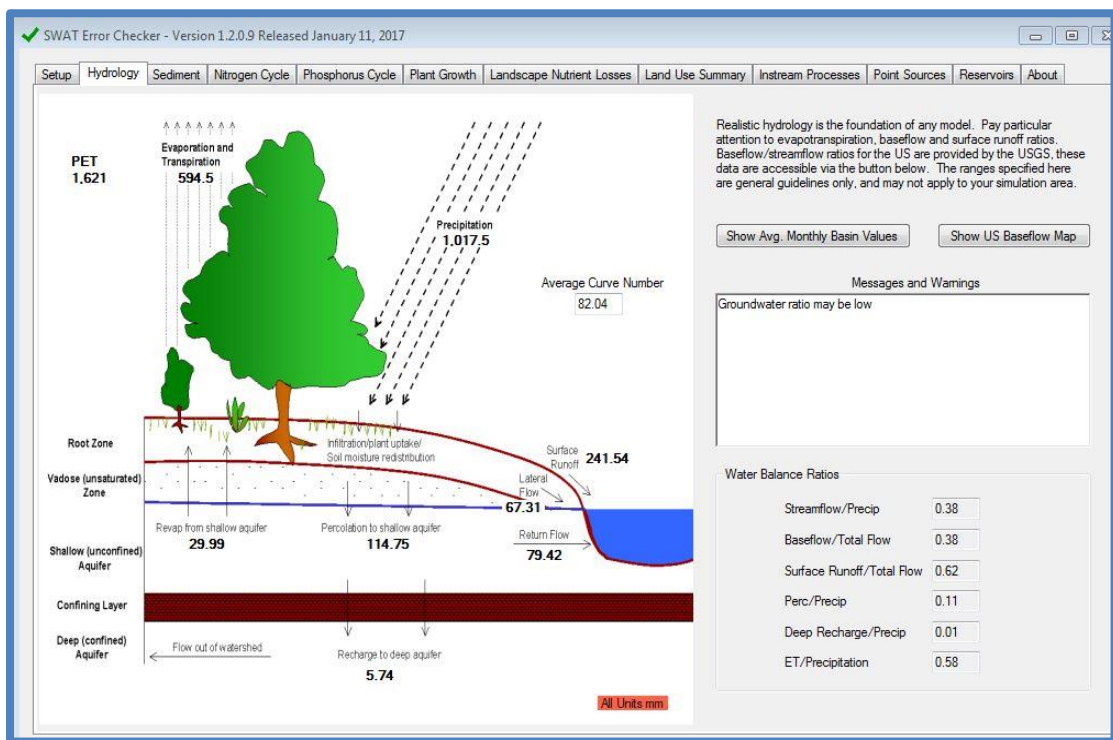
For this study with the first run of the SWAT model the SWAT output was checked with run Swat check and the deep groundwater ratio has been found very low and lateral flow is found greater than ground water flow. Therefore, to correct these problems the simulated result was calibrated using sensitive parameters so many times and the problem was solved by running the model and checking the SWAT output with swat-check (Figure:- 4.1.1-1).

Tesfaye (1988) has developed the groundwater map of Ethiopia in a small scale (1:6 000 000) and he estimated the mean annual recharge of Ethiopia to be varied between 0 up to 400mm per year using base flow separation method. From this map the study area Borkena catchment is categorized on the range from 50-150mm per year. Seifu (2013) has also conducted a study on groundwater of Ethiopia. He estimated the total annual groundwater groundwater recharge for the entire Ethiopia ( $1.2 * 10^6$  km<sup>2</sup> of land area) to be 36 Billion m<sup>3</sup> per year. From this he estimated 4, 074 Mm<sup>3</sup> / year recharge for Awash basin. Since this study is in Awash basin at Borkena catchment therefore the annual recharge given for the entire basin is nearly 370 mm/year.

One of the objectives of this study is estimating the recharge of the study area. During the first simulation of SWAT before calibration, the total annual aquifer recharge was 9.98 % of the total annual rainfall in the catchment. Different literatures stated that the annual average recharge of the alluvial aquifers can take from 10% up to 22% of annual total rainfall. Due to this soil evaporation compensation factor (ESCO), and available water capacity of the soil layer (SOL\_AWC), groundwater delay

(GW\_DELAY), threshold depth of water in the shallow aquifer vital for return flow to occur (GWQMN), deep aquifer percolation fraction (RCHRG\_DP) has to be considered and calibrated. Since the objective of running the SWAT model is to estimate the recharge of the total catchment area in order to link the SWAT output with MODFLOW for the simulation of groundwater head and groundwater-surface water interaction, reasonable amount of recharge should be identified in the catchment. In order to get good recharge value for the total catchment area, calibrating the Simulated SWAT output result with SWAT CUP SUFI2 algorithm was mandatory. After calibration the ArcSWAT model by adjusting manually and automatically the sensitive parameters like the Curve number (CN), groundwater revap coefficient (GW\_REVAP), groundwater delay (GW\_DELAY), threshold depth of water in the shallow aquifer vital for return flow to occur (GWQMN), deep aquifer percolation fraction (RCHRG\_DP), the base flow alpha factor (ALPHA\_BF) in days, threshold depth of water in the shallow aquifer for revap or percolation to the deep aquifer to occur (REVAPMN), soil evaporation compensation factor (ESCO), and available water capacity of the soil layer (SOL\_AWC) in mm/mm of soil depth in SWAT CUP and the values of the sensitive parameters are determined and confirmed with coefficient of determination then those results are manually adjusted in in ArcSWAT and the SWAT model was processed after calibration (Khalid et al., 2016). The SWAT model result run after calibration indicated that the groundwater recharge was found to be 12 % of the total annual rainfall in the catchment (Figure: 4.1.1-1). This result is good result for the total catchment and it possible to link it with the MODFLOW for the groundwater-surface water interaction simulation. In the SWAT check result before calibration, the lateral flow was greater than groundwater flow and due to that it was assumed that there was a problem in the model but when the model is simulated after calibration the problem is resolved and the groundwater recharge is around 12% of the annual rainfall (Figure: 4.1.1-1).

## Modeling Surface water-groundwater Interactions of Borkena river Catchment



**Figure 4.1.1-1 Water balance ratio of SWAT output after Calibration**

**Table 4.1.1-1 Average annual Basin/catchment values (Water Balance) calculated using SWAT after calibration.**

Parameters	Values (mm)
Precipitation	1017.50
Surface Runoff Discharge	241.54
Lateral flow Soil Discharge	67.31
Groundwater (Shallow aquifer) Discharge	79.42
Groundwater (Deep aquifer) Discharge	5.71
REVAP (Shallow aquifer=soil/plants)	29.99
Deep aquifer recharge	5.74
Total aquifer recharge	114.75
Total water yield	393.99
Percolation out of soil	114.76
Actual Evapotranspiration	594.50
Potential Evapotranspiration	1621.00
Total Sediment Loading (T/HA)	349.47 T/HA

**Table 4.1.1-2 Average Monthly Catchment values in Borkena Catchment**

MONTH	RAIN (mm)	WATER				SED- YIELD (T/HA)	PET (mm)
		SURF Q (mm)	LAT Q (mm)	YIELD (mm)	ET (mm)		
1	22.24	3.04	1.2	5.46	17.56	5.54	114.66
2	25.38	4.04	1.39	6.28	18.74	4.66	115.22
3	66.69	11.84	3.37	16.63	39.84	14.6	136.58
4	96.78	19.14	5.76	27.16	62.81	24.28	139.78
5	61.63	10.21	4.7	17.97	70.56	17.69	169.87
6	35.9	2.86	2.05	6.92	50.81	9.28	173.81
7	267.98	68.17	14.87	84.58	88.28	101.72	136.2
8	254.84	81.5	18.51	111.93	96.83	103.08	145.89
9	104.21	22.99	9.07	56.13	67.99	41.65	134.89
10	43.31	11.35	3.65	36.98	37.62	14.21	126.1
11	22.04	4.32	1.56	17.4	23.86	8.71	113.28
12	16.24	2.04	1.17	6.5	19.47	4.02	113.72

The annual precipitation averaged about 1017.5 mm over the entire basin (Table: 4.1.1-3 and Figure 4.1.1-2). It is observed from the result that small percentage changes in ET can reflect large percentage changes in runoff and percolation because ET is usually large compared with runoff and percolation; hence, the importance of managing ET in the control of runoff and percolation. Reduced runoff can dramatically reduce erosion and the potential for increased recharge. From the total annual precipitation, 241.54mm goes to as surface runoff/total flow; 114.75mm went for recharge to the aquifer, and 594.5 mm to the evaporation. The percentage contributions of these components are therefore, 62%, 12% and 58% for the runoff, recharge and evapotranspiration (ET). This result is very similar to recharge estimated by Amhara Design and supervision Enterprise in 2013 using WATBAL method and felt in the category of the recharge map produced by Tesfaye (1988) which is 50-150 mm per year. The Amhara Design and Supervision Enterprise estimated the recharge that 13% of the annual rain fall which is 152.75 mm of (1175mm rainfall) in 2013. Due to climate change and different reasons the rainfall and the recharge is decreased even if it is closed to my result. Whereas this recharge study result is by far different from recharge estimated by Seifu (2013) for the Awash basin in regional scale.

#### **4.1.2. Groundwater Flow**

The second objective of this study is to identify the groundwater flow system of the Borkena Catchment locally and regionally. On this study one of the arguments for the recharge mechanism of the deep potential (alluvial and volcanic) aquifers in Combolcha, Harbu, Kemisse and Chefa is assumed to be from the inter-basin transfer or groundwater flow from Abay to Awash basin and local recharge from the escarpments of Kutaber, Borumeda Desse and suburbs. The reason for the regional flow is the three deep boreholes drilled at Gerado/Abay basin (500m) KCTVW-01-19, Combolcha/ Awash basin (600m) KCTVW-02-19) and Kemisse/ Awash basin (512m) KCTVW-03-19 indicated that big amount of water is stored in lower tertiary volcanic aquifers discharging up to 75.5 l/s. The Gerado catchment is found at higher gradient and the Combolcha, Kemisse aquifers are found at lower gradient and this indicated that there may be an inter-basin transfer of groundwater from Abay to Awash basin as of the water type in the two basins and the transmissivity of the tertiary volcanic aquifers. To justify this, the physico-chemical analysis result of the three deep boreholes indicated that they have similar water types except that changes in chemical composition by evolution during the inter-basin transfer process. The water type at Gerado/Abaye basin KCVTW-01-19 is Na-HCO<sub>3</sub>-CO<sub>3</sub>, the water type of Combolcha/Awash basin KCVTW-02-19 is Ca-Na-Mg-HCO<sub>3</sub> and that of Kemisse/Awash basin is Na-Ca-HCO<sub>3</sub>-SO<sub>4</sub> and from this we can see the evolution of the water type. Due to the geo-chemical process in the groundwater flow the Na-HCO<sub>3</sub>-CO<sub>3</sub> type of water in Gerado catchment change to Ca-Na-Mg-HCO<sub>3</sub> type of water in Combolcha and this changed to Na-Ca-HCO<sub>3</sub>-SO<sub>4</sub> type of water when it reached to Kemisse low land because of evolution process.

This indicated that the HCO<sub>3</sub> is giving way to the SO<sub>4</sub> ion along the flow path from Gerado to Combolcha to Kemisse. Having longer residence time and larger distances covered by a moving groundwater causes the groundwater to enrich in Cl ion at last if we see the physico-chemical results of the low land areas. Moreover, it needs further investigations using isotopic analysis.

The second justification for the groundwater regional flow is that the cross section developed for this study from Gerado to Combolcha (West-East) direction based on

the boreholes data (lithology, depth and static water level) indicated that there is deep regional groundwater flow from Gerado to Combolcha. This argument is done from the perspectives of the permeability (hydraulic conductivity) and Transmissivity results found from the three deep boreholes at Gerado, at Combolcha and Kemisse lower tertiary volcanic rocks lithology data.

Figure: 4.1.2.1-2 represents the cross-section of Inter-basin flow from West (Gerado) direction to the East (Combolcha) direction of groundwater flow based on KCVTW-01-19 and KCVTW-02-19 static water level data and water types result from their physico-chemical analysis data. Figure: 4.1.2.1-3 represents the direction of groundwater flow from North (Kutaber) where Borkena river is started to South directions (Kemisse-chefa) through Combolcha based on Kutaber borehole, Desse Zuria borehole, KCVTW-02-19 borehole at Combolcha and KCVTW-03-19 borehole at Kemisse static water level data respectively.

#### **4.1.2.1. Hydrogeology**

Hydrogeological map is produced to identify the potential aquifer extents in the study area and to characterize the stratigraphic conditions. Based on this research the researcher identified that there are two potential aquifers found in the catchment based on the test wells well accomplishment report in Gerado, Combolcha and Kemisse towns mentioned above. The hydrogeological map of the catchment is also prepared based on the hydrogeological data and existing boreholes (Figure: 4.1.2.1-1). Engida (2015) has determined that the tertiary volcanic aquifers and alluvial aquifers are not hydraulically interconnected. He considered that for example Gerado alluvial aquifer is dammed by low permeability volcanic rocks. But this research argued that there is inter-basin groundwater flow from Gerado/Abay to Combolcha/Awash basin regionally as discussed above (Figure: 4.1.2.1-2). The evidence for this is by considering the geo-chemical (physico-chemical) result of the deep boreholes drilled at Gerado and Combolcha and the Groundwater level and gradient. Besides this the high permeability, high hydraulic conductivity and high Transmissivity results of the tertiary volcanic aquifers indicated that there is inter-basin groundwater transfer.

Modeling Surface water-groundwater Interactions of Borkena river Catchment

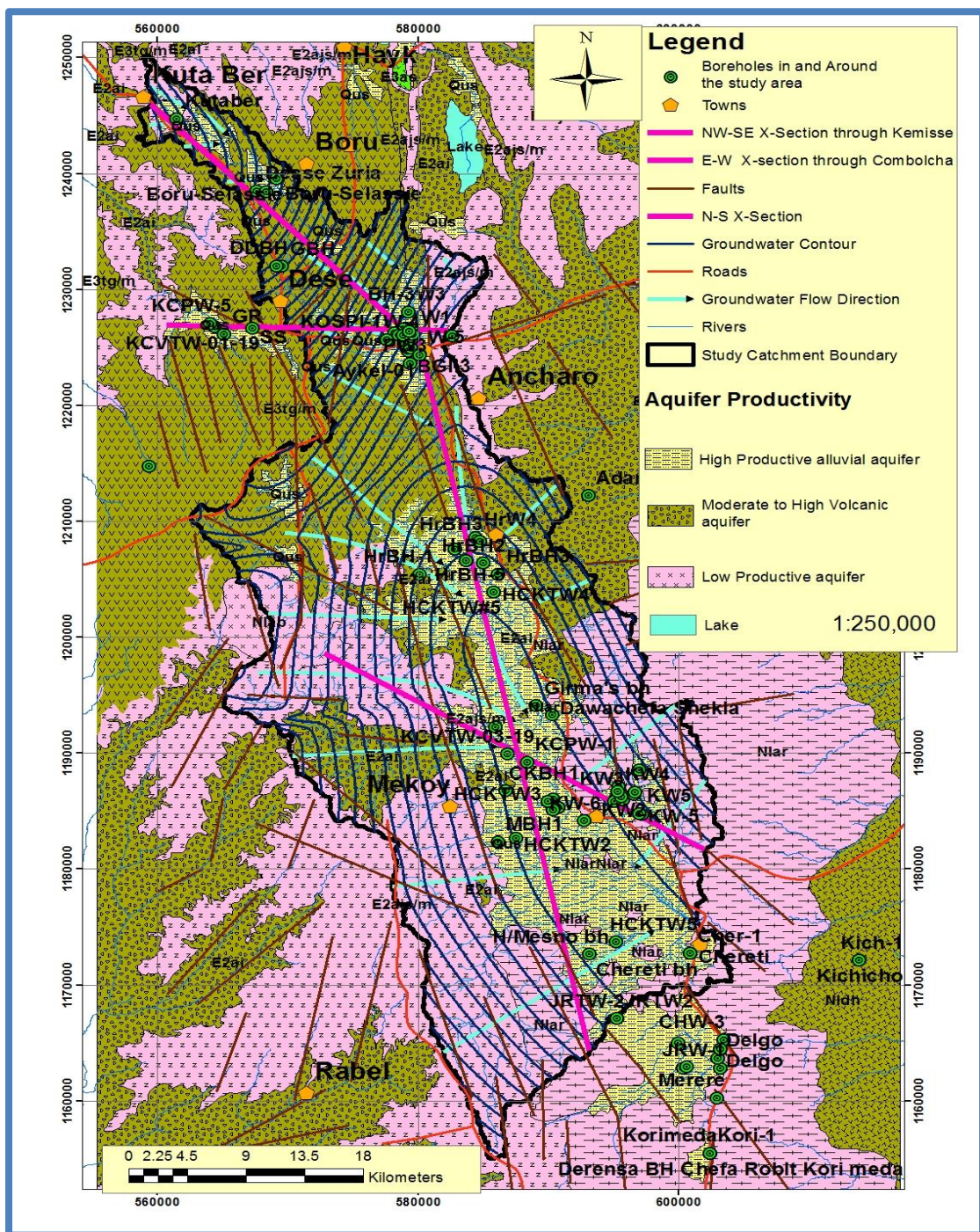


Figure 4.1.2.1-1 Hydrogeological map of the study area (Modified from ADSE, 2013)

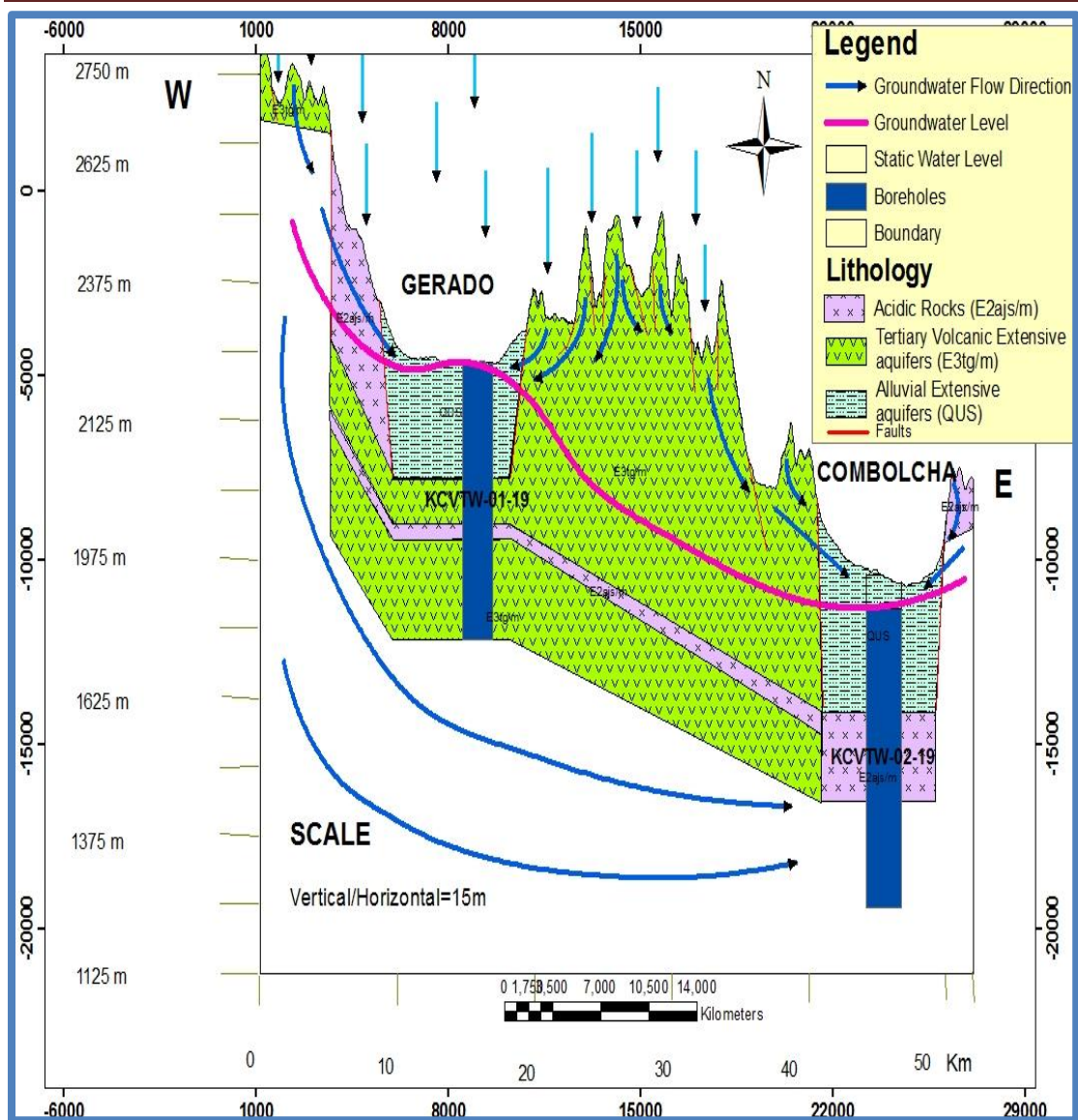


Figure 4.1.2.1-2 Gerado-Combolcha Cross section showing regional and local groundwater flow from Abay to Awash

### Hydrostratigraphy

Borkena catchment can be classified in to three aquifer system. They are a) Low productive Ataye and Albuko rhyolite and slightly weathered and fractured basalt, b) Intergranular weathered and fractured aquifer with medium to high productivity and c) High productive alluvial aquifer of the marginal graben (Figure: 4.1.2.1-1).

**a) Low Productive Aquifers**

These are mostly the acidic rocks of Ataye and Albuko rhyolite, slightly weathered and fractured Aiba, Tarmaber and Alaje geological formations which occupies faulted blocks and escarpments, dissected plateau, domes and shield volcanic centers morphological features. Due to tectonic activities the above mentioned formations are found within highly fractured and weathered geomorphological features. The weathering and fracturing makes the volcanics highly permeable and favor for groundwater recharge but due to steep slopes and rugged topographic terrains the recharged ground water could not be stored, instead it flows to low land marginal graben plain areas. Within narrow intermountain valleys, there are wells having 5-30 l/s yields recharged from local and/or regional inter basin groundwater storage. The transmissivity of the volcanic aquifers are found to be low.

**b) Medium Productivity aquifers**

There are a number of intermountain valley plain areas located on the tertiary volcanic areas within marginal grabens which have 20 to 60 m depth alluvial deposits and underlain by weathered and fractured tertiary volcanic rocks. These intermountain valley plain areas yield from medium to high amount of groundwater from the underlain weathered and fractured volcanic aquifers. On the other hand the alluvial aquifers of the Borkena catchment area reaches up to 306 m depth and the underlain volcanic aquifer is found to be high productive yielding up to 75 l/s independently (Well accomplishment report of KCVTW-02-19, KCVTW-03-19).

**c) High Productive aquifer**

The alluvial aquifers in Borkena catchment are found to be extensive alluvial deposits with alternative layers of gravels and sand that intercalate with thin confining clay layer and silt and underlain by weathered and highly fractured volcanic rocks (alluvial 300m thick and tertiary volcanic 200m thick) having 20 up to 75.5 l/s yields with 20 to 76m draw down and transmissivity from 4.30 to 1895.6 m<sup>2</sup>/day is classified to high productive aquifer.

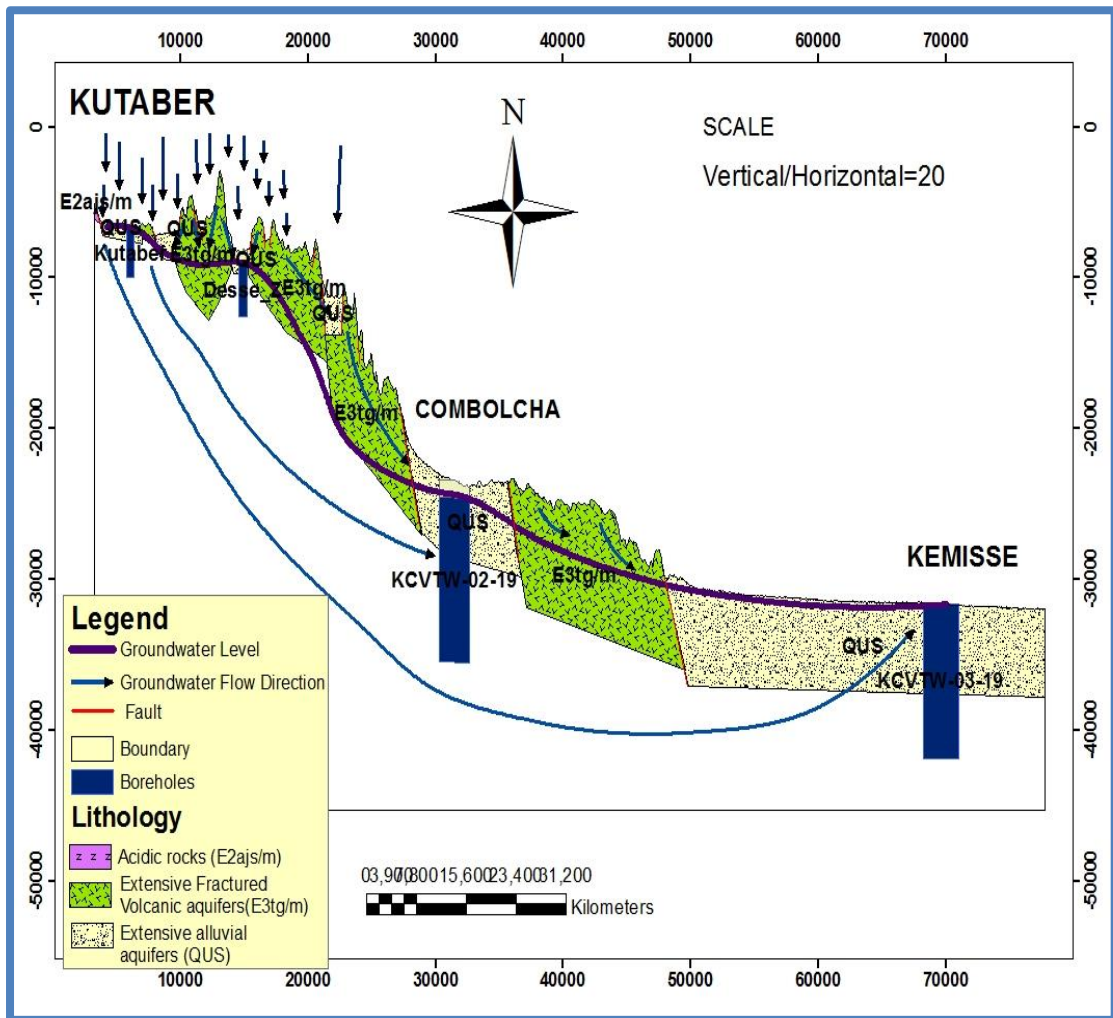


Figure 4.1.2.1-3 Cross-sectional line of Borkena catchment developed along the river profile to show local and regional groundwater flow

### Structure

Structurally three different orientations (NNW-SSE, N-S, NW-SE) and (NE-SW) and (E-W) corresponding respectively with the Red Sea Rift, Main Ethiopian Rift, and Gulf of Aden Rift trend (Engida, 2015). The main geological structures that form Brkena graben are NNW-SSE, N-S, and E-W trending faults. NNW-SSE and N-S created Borkena graben which is elongated nearly in north-south direction and forms the alluvial aquifers.

The NW-SE and E-W faults control the surface and groundwater flow from the volcanic outcrops (West and East) side of elevated catchment of Borkena river catchment to the graben alluvial aquifers.

#### **4.1.3. Surface water-Groundwater Interactions**

The third objective of this study is indicating if the river is effluent or influent or if the river is gaining river or losing river. Effluent rivers are streams which get their water from groundwater whereas influent rivers are streams which do not get water from groundwater but loss their water in to the ground (adding water to the groundwater system). The source of all rivers or streams is water from precipitation and groundwater. The ocean, land and atmosphere play a vital role in the hydrologic cycle by ensuring continued sustenance of drainage systems by directly feeding streams. Streams interact with the ground by exchanging water.

Effluent river systems are found mainly in tropical and temperate climates, while influent streams are found in arid areas.

For this research existing boreholes very closer to Borkena stream (found starting 2m to 150 m distance from the river) are collected and their groundwater elevation was correlated with the river elevation nearest to each borehole. For example the borehole in Kutaber has a ground elevation of 2666.8 m.b.g.l and the surface elevation of the river very closer to it is 2680 m.a.s.l, therefore this river is a gaining river an effluent river since it is located at the start Point of Borkena River where springs are commonly found. Similarly, the borehole in Boru Silasse Kebele02 has a groundwater elevation of 2568 m.b.g.l and the surface elevation of the river closer to it is 2602 m.a.s.l and this river is also a gaining or an effluent river. Around 36 wells found very closer to Borkena river from the start point at Kutaber up to the outlet at Chefa area are selected and analyzed (Appendix: 5). By subtracting the groundwater elevation in m.b.g.l of the selected wells to the surface water elevation in m.a.s.l of the Borkena river existed closer to that well it is determined that if their difference is negative then the river is gaining or effluent river and if their difference is positive value the river is losing or influent river (Appendix: 5). Based on this the river which is found in the

highlands of the study area is found to be Effluent river while the river which is found in the lowlands of the study area like Kombolcha, Harbu and Chefa area is found to be influent river. This result indicated that around 41.66% of the river is found to be Effluent and 36.11% of the river part is found to be losing or Influent River. Around 22.22% of the river and existing wells are found at equal pizometric level either they are losing or gaining river. The tropical area starting from the tip of the river up to the hill foot of the Combolcha area the river is found to be gaining (Effluent) river in between the foot of the hill around combolcha and Harbu area the wells groundwater elevation and the river elevation are found to be in equal level or are combination of the two (losing or gaining river), then around Harbu area and the corresponding high lands are losing or Influent rivers then after the lowland area up to Chefa through Kemisse the river is found to be gaining or effluent river. The measured discharge (runoff) of the Borkena River catchment at the Chefa Swamp outlet station shows higher base flow in the highlands as plotted in the base flow graph conducted using TIMEPLOT (Figure: 3-1-8) indicated that the river is effluent on the lowlands.

#### **4.1.3.1. Groundwater Levels and Movements**

The existing groundwater flow information comes from water discharge points including; springs, shallow and deep wells and hand dug wells. More than 95% of the water discharge points are used in order to generate the groundwater level maps which are found to be shallow and deep wells. The piezometric-surface map has been drawn using the geostatistical method of, kriging using Arc GIS software (Figure: 4.1.3.1-1).

As shown in the (Figure: 4.1.3.1-1) below generally, the groundwater flow from the Tertiary volcanic aquifer toward the alluvial aquifer and the groundwater level found within the range of 1440 at Chefa Swamp outlet area up to 2720 m a.s.l at the start point of the Borkena river near Kutaber. The groundwater level is highly controlled by the topographic set up, the geology set up, and amount of rainfall in the study area. Therefore, the groundwater level is higher in the tertiary volcanic aquifer relative to the alluvial aquifer. The groundwater movement is strongly controlled by geological structures and mainly faults. Figures: 4.1.2.1-2, 4.1.2.1-3 and 4.1.3.1-1 illustrate the

movement and occurrence of groundwater across and along the Borkena catchment in selected areas.

In the study area depth to the water table is highly variable; it ranges averagely from 0m (artesian) well in the alluvial Sediment to more than 41.6m in the alluvial and tertiary fractured aquifers. Water level altitudes are highest in the Northern part of the catchment, which is about 2720m above sea level.

The lowest water level altitude in the study area is around the southern part of the catchment and it is about 1440m above sea level. In the alluvial sediments the water level gradient is fairly flat, where discharge occurs as base flow to streams or evapotranspiration from swampy areas around Chefa, where groundwater is close to the surface or even above in some places (Figures: 4.1.2.1-2 and 4.1.2.1-3). In fact if the water is to move through rock, the pores must be connected to one another and if the pore spaces are connected and large enough that water can move freely through them, the rock is said to be permeable. Permeability and hydraulic conductivity are the measure of an aquifer's ability to transmit water. Permeability and hydraulic gradient determine the rate of flow of water. The hydraulic gradient is the change in head (decrease in water level) per unit distance as shown in Figure: 4.1.3.1-1 and the flow system is controlled by the permeability, hydraulic conductivity, hydraulic head and faults and fractures as stated before.

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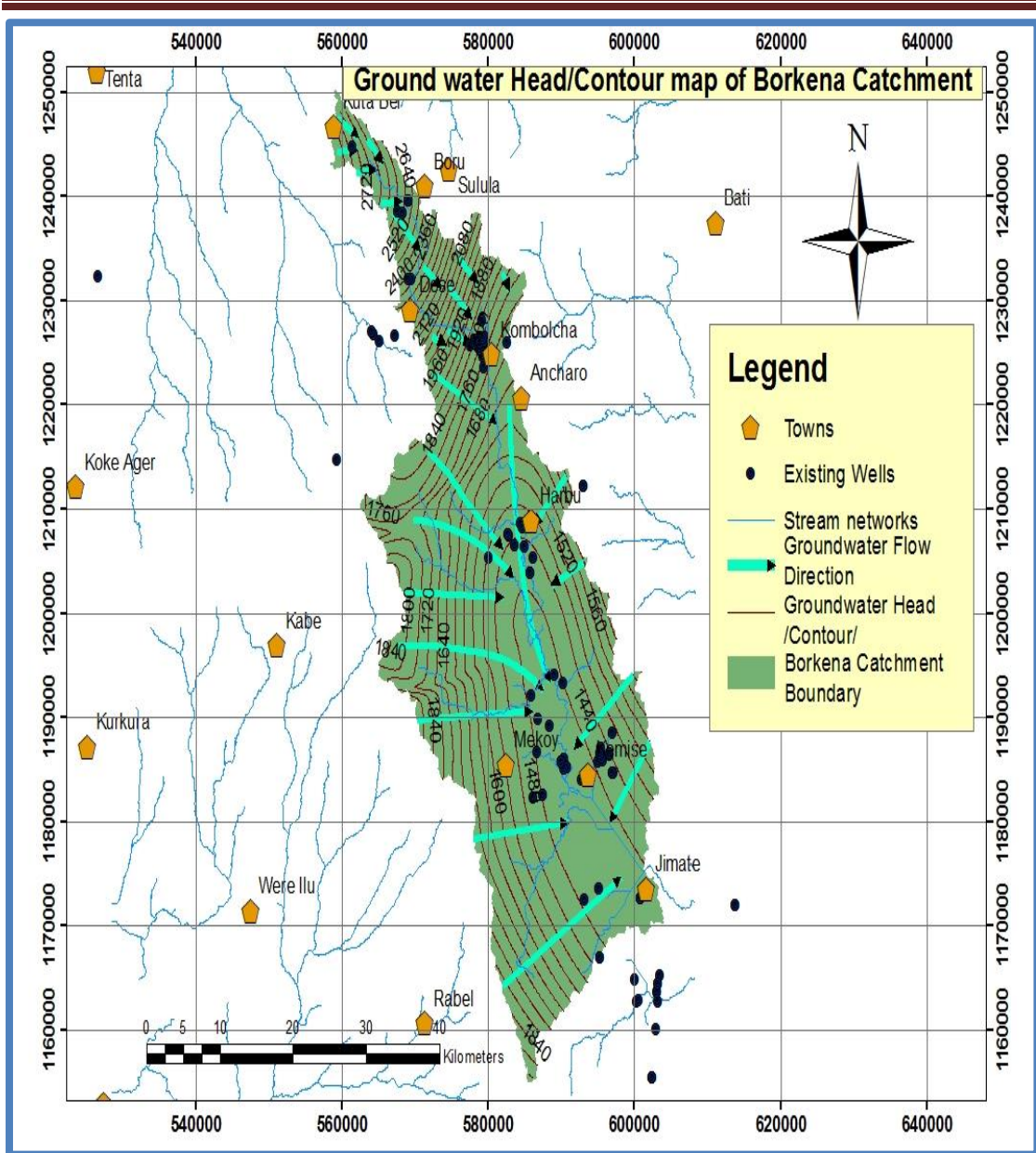


Figure 4.1.3.1-1 Groundwater contour and flow map of Borkena Catchment developed using ArcGIS Software based on Boreholes data

#### 4.2. SWAT-MODFLOW Model

The SWAT-MODFLOW model has many similar features to that of the ArcSWAT model. For standard SWAT/QSWAT model simulations, the *output.std* file contains daily-averaged depths for the principal water balance variables in the catchment (e.g. rainfall, surface runoff, groundwater flow to streams, etc.). The *output.std* file for the SWAT-MODFLOW simulations has the same general format as the original SWAT model, but with several key additions that provide more information regarding groundwater and groundwater-surface water interactions.

The differences between the two are summarized as follows:

Variables common to the original QSWAT/SWAT simulations and the SWAT-MODFLOW simulations are: PREC(Rainfall in the watershed), SURQ(Surface runoff to streams), LATQ(Lateral flow to streams), GWQ(Groundwater flow to streams), PERCOLATE(Deep percolation (recharge) to groundwater), TILE Q(Tile drain flow to streams), SW(Total soil water contained in the watershed) and WATER YIELD(Total water added to streams ( = SURQ + LATQ + GWQ + TILE Q ) )

The additional new Variables which are found in SWAT-MODFLOW simulations are the following: GWQ (Groundwater flow to streams), SWGW (Seepage from streams to the aquifer), GW(Total groundwater contained in the watershed), WATER YIELD(Total water added to streams = SURQ + LATQ + GWQ – SWGW + TILE Q). This takes into account the water that leaves the stream and seeps into the aquifer. The SWAT-MODFLOW simulation outputs are exchange between the SWAT and MODFLOW systems. These outputs are mainly groundwater-surface water interactions, recharge and river stage (Bailey and Park, 2019).

The main objective of simulating SWAT-MODFLOW is that to analyze the groundwater-surface water interaction of the Borkena river catchment and confirm the analysis conducted based on the existing boreholes ground elevation below ground level and the nearby river surface elevation above sea level. For this model around 16 observation wells, 27 abstraction wells and 49 river cells were selected and their corresponding river conductance were calculated as

$(C_{riv} = \frac{Conductivity\ K * Length\ L * Width\ W}{Thickness\ M})$  and given for each cell and the river elevation with each river stage was applied then the data was used as an input for the SWAT-MODFLOW river package as mudflow\_LRW.riv file to be run in MODFLOW-NWT.exe. After the simulation of SWAT-MODFLOW model, the groundwater-surface water exchange result was checked from swatmf\_out\_MF\_gwsw file. The result indicated that the river cells were found projected above 7448 cells rather than 49 river cells. Similar to the previous analysis based on the existing boreholes and nearby rivers data, the SWAT-MODFLOW simulation identified the groundwater-surface water exchange for each MODFLOW river cell. The model resulted the groundwater-surface water exchange in m<sup>3</sup>/day with zero for both losing or Inffluent and gaining or effluent River, positive value for losing or inffluent River and negative value for gaining or effluent River. As discussed using the existing borehole and river elevations analysis part, the model result is also indicated that in the discharge area around Kemisse-Chefa the groundwater flows from the aquifer to the river and the values are negative in this area, where as in combolcha and surrounding area the values are zero that means the rivers either gaining or losing river. The areas surrounding the Harbu, Desse surrounding areas the model result values are positive and the river is losing (inffluent) river. Whereas the highlands of Kutaber where the Borken river starts, the river is found to be gaining (effluent) river. The interaction of groundwater-surface water in the catchment can also be determined using physico-chemical analysis and Isotope analysis methods but due to budget deficit problem it was not possible to conduct this analysis.

## 5. Conclusion and Recommendation

### 5.1. Conclusion

The ArcSWAT model was performed so as to understand the different water balance components of the study area and to estimate the groundwater recharge. Parameters for sensitivity analysis were selected by reviewing previously used calibration parameters and documentation from the SWAT manuals and by checking the SWAT CUP SUFI2 Sensitivity analysis result to identify the most sensitive parameters with the t-stat which provides the a measure of sensitivity and P-values which determine the significance of the sensitivity. Parameters having with larger t-stat absolute values are more sensitive and having close to zero P-values are more sensitive. The parameters used for sensitivity analysis are Curve number (CN), groundwater revap coefficient (GW\_REVAP), groundwater delay (GW\_DELAY), threshold depth of water in the shallow aquifer required for return flow to occur (GWQMN), deep aquifer percolation fraction (RCHRG\_DP), the base flow alpha factor (ALPHA\_BF) in days, threshold depth of water in the shallow aquifer for revap or percolation to the deep aquifer to occur (REVAPMN), soil evaporation compensation factor (ESCO), and available water capacity of the soil layer (SOL\_AWC) in mm/mm.

The SWAT model was calibrated with monthly flow data ranging from 2000 to 2007 and validated with monthly stream flow data ranging from 2008 to 2014. The initial run of the un-calibrated data indicated a tendency to over-predict the lateral flow and underestimated the groundwater recharge below 10% of annual rainfall. However, automatic and manual calibration of the flow parameters such as CN values, GW\_REVAP, ALPHA\_BF and REVAPMN parameters improved the flow prediction accuracy and the recharge of the catchment when the SWAT model was simulated after calibration became 12% of the annual rainfall.

Finally, after calibrating the parameters using SWAT CUP SUFI2 algorithm, the ArcSWAT model was simulated again and showed better model performance for the calibration period.

The model goodness of fit was evaluated using the coefficient of determination ( $R^2$ ) and the Nash-Sutcliffe (NSE) on monthly basis both for calibration and validation and

resulted 0.68 and 0.66 for the calibration period and 0.64 and 0.63 for the validation period respectively. The calibration has 96 monthly flow variables and validation period have 84 monthly flow variables.

From the ArcSWAT model result the annual precipitation of the whole of the study catchment was averaged 1017.5mm which is closer to the study result conducted by Amahara Design and Supervision Enterprise using WATBAL method which is 1170mm annually (ADSE, 2013).

Among 1017.55mm annual rainfall 241.54mm goes to as surface runoff/total flow; 114.75mm went for recharge to the aquifer, and 594.5 mm to the evaporation. The percentage contributions of these components are therefore, 62%, 12% and 58% for the runoff, recharge and evapotranspiration respectively. The surface runoff is high due to the steep slope of the catchment area. And it is observed from the result that small percentage change in ET can reflect large percentages in runoff because ET is large compared with runoff. Reduced runoff can dramatically reduce erosion and the potential for increased recharge.

The regional and local groundwater flow system was determined by producing two cross-sections and analyzing the existing boreholes physico-chemical result water types in and around the study catchment area.

The X-section developed from West (Gerado) direction to the East (Combolcha) direction indicated that there is Inter-basin flow or regional groundwater flow from Abay basin to Awash basin based on KCVTW-01-19 and KCVTW-02-19 static water level data and water types result from their physico-chemical analysis data.

The water type at Gerado/Abaye basin KCVTW-01-19 is Na-HCO<sub>3</sub>-CO<sub>3</sub>, the water type of Combolcha/Awash basin KCVTW-02-19 is Ca-Na-Mg-HCO<sub>3</sub> and that of Kemmisse/Awash basin is Na-Ca-HCO<sub>3</sub>-SO<sub>4</sub> and from this we can see the evolution of the water type. Due to the geo-chemical process in the groundwater flow the Na-HCO<sub>3</sub>-CO<sub>3</sub> type of water in Gerado catchment change to Ca-Na-Mg-HCO<sub>3</sub> type of water in Combolcha and this changed to Na-Ca-HCO<sub>3</sub>-SO<sub>4</sub> type of water when it reached to Kemisse low land because of evolution process.

The X-section developed from North (Kutaber) to South (Kemisse) represents the direction of local groundwater flow from North (Kutaber) where Borkena river is started to South directions (Kemisse-chefa) through Combolcha based on Kutaber borehole, Desse Zuria borehole, KCVTW-02-19 borehole at Combolcha and KCVTW-03-19 borehole at Kemisse static water level data respectively.

The interaction of groundwater surface water is determined based on the existing boreholes which are very close to the Borkena River's ground water elevation in m.b.g.l and Borkena River's surface elevation data and by applying SWAT-MODFLOW model simulation and by making analysis of the SWAT-MODFLOW result (swatmf\_out\_MF\_gsw).

The surface water and groundwater interactions of the Borkena river is identified by subtracting the existing boreholes groundwater level m.b.g.l from the river surface elevation m.a.s.l. Based on this analysis the temperate highland area starting from Kutaber up to Combolcha (including eastern and western parts of the catchment area) is found to be effluent river and the lowland area starting from Kemisse up to Chefa semi-arid area is mostly found to be influent river where as the Combolcha area is found to be both losing and gaining river. In general around 41.66% of the area is Effluent River, 36.11% of the area is Influent River, and 22.22% of the area is both effluent and Influent River (Appendix: 5). This result is confirmed by running a coupledSWAT-MODFLOW simulation and observing SWATMF\_OUT\_MF\_GWSW output (Appendix: 6).

For this model SWAT-MODFLOW model the model area was discretized in to 47 rows and 23 columns with a grid size of 2000m\*2000m. In designing the grid, the length to width ratio (aspect ratio) of the cells should be kept as close to one as much as possible to avoid numerical instabilities or errors. The MODFLOW grid for the current project has 47 rows and 23 Columns which has a total of 1081 grid cells (Figure: 3.4.3.7-1).

49 river cells were assigned with the river elevation and river conductance data and the output of the SWAT-MODFLOW model projected the river cells above 7448 and

the result of each river cell was with positive, negative and zero values to indicate that the river is losing or influent, gaining or effluent and both gaining and Losing River respectively (Appendix: 6).

## **5.2. Recommendations**

The general objective of this study is assessment of groundwater-surface water interactions in Borkena river catchment to evaluate the response of hydrologic-hydrogeologic system so as the resulting consequence on the system can be projected. The following recommendations are forwarded for groundwater-surface water management and further study.

- ❖ As it has been seen the decreasing of recharge has adverse effect on the groundwater table and stream leakage. So, solutions should be forwarded to tackle such environmental unfriendly problem. The most important measures that should be taken are decreasing the expansion of afforestation, constructing soil and water conservation structures etc.
- ❖ Adequate and evenly disseminated groundwater level monitoring wells should be placed in the whole catchment in order to comprehend the overall head structure and fluxes in groundwater levels. This helps to carry out better steady and transient groundwater flow modeling, so that system response can be predicted with better confidence.
- ❖ Detailed recharge evaluations has to be carried out by joining different methodology like WetSpass, again Soil water budget model and catchment water balance method to conduct detail model simulation. Because recharge is the most significant model input parameter.
- ❖ The model still needs appropriate hydraulic conductivity values, recharge values for each cells with better accuracy, because the prepared hydraulic conductivity values were produced based on the collected pumping test data from regional water bearaux.

To represent the system in a more realistic condition, it is important to divide the aquifer system in to different layers and estimates their respective hydraulic conductivity parameters.

- ❖ Although numerous boreholes were constructed by different bodies (governmental, nongovernmental organizations, individuals, firms, etc.), a central groundwater database, either in a national and/or regional level is not established in the region to organize the records generated during the construction of these wells. Data are collected in a non-standardized and nonsystematic manner.
- ❖ Meteorological data and Hydrological data is not properly registered and data quality was the main challenge for this study, therefore proper data registration and good database development on the sectors is recommended.
- ❖ This research uses hydrogeological analysis, existing deep boreholes data and physco-chemical analysis of the existing boreholes data to show there is regional groundwater flow from the adjacent Abay basin to Awash basin or Borkena catchment but in order to be sure further Isotope analysis method of investigation should be carried out. This method should also be applied for groundwater and surface water interaction for the whole catchment for further confirmation.

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## Modeling Surface water-groundwater Interactions of Borkena River Catchment

### Appendices

#### Appendix: 1 Monthly precipitation values of the study catchment (2005-2017)

Year	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual
2005	80.59	4.33	124.23	165.41	134.37	9.48	205.44	143.10	16.27	5.14	46.33	0.00	934.68
2006	2.14	49.76	171.98	157.25	6.51	1.42	109.45	208.73	38.96	77.35	0.27	27.42	851.24
2007	13.34	86.68	61.78	63.47	13.16	35.61	178.73	104.89	19.48	1.44	0.60	0.00	579.17
2008	19.04	6.64	0.00	12.84	44.22	12.79	98.78	47.98	31.64	38.73	233.56	4.06	550.28
2009	60.27	15.10	52.38	49.32	4.20	0.40	112.97	79.14	7.58	22.84	1.39	68.65	474.25
2010	7.85	124.18	163.10	159.29	156.04	8.47	242.88	329.21	23.25	0.64	90.22	11.87	1317.00
2011	23.00	12.29	86.09	81.60	80.11	23.78	191.04	356.11	73.32	0.13	30.77	3.02	961.26
2012	21.52	0.00	82.23	241.98	2.24	45.17	273.94	194.35	23.38	0.03	0.99	17.14	902.97
2013	19.16	24.99	135.44	118.76	82.61	28.02	336.83	352.24	28.80	40.89	17.53	5.53	1190.79
2014	28.73	76.73	133.25	97.61	23.27	1.80	164.29	255.30	88.30	15.30	19.00	0.00	903.59
2015	2.00	0.00	27.60	0.00	144.90	13.60	17.70	222.30	136.30	14.00	87.60	9.90	675.90
2016	8.30	0.00	58.50	179.70	60.50	51.20	302.80	415.10	115.30	0.10	21.80	0.00	1213.30
2017	0.00	44.20	36.50	40.10	73.70	0.00	129.80	384.40	98.50	15.50	0.00	0.00	822.70

#### Appendix: 2 Mean maximum and Minimum Temperature of the study area (2005-2017)

Year	Temp (oC)	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual Av
2005	Max	19.12	23.01	22.68	22.05	22.48	25.08	23.12	22.79	22.50	21.25	20.57	19.98	22.05
	Min	5.91	3.92	8.63	7.58	9.11	9.50	10.93	9.24	8.13	3.46	1.09	-0.76	6.40
2006	Max	21.23	22.36	21.12	21.54	24.60	25.50	22.29	21.35	22.18	21.61	20.29	20.12	22.02
	Min	3.38	5.80	7.89	8.26	7.47	10.21	11.07	9.90	7.64	4.25	2.87	6.07	7.07
2007	Max	20.44	21.18	23.15	22.88	25.05	24.62	20.94	22.50	23.26	21.47	20.30	20.07	22.16
	Min	5.74	8.64	6.20	8.14	7.50	10.62	10.20	9.20	8.04	1.44	2.02	-0.67	6.42
2008	Max	21.18	21.27	23.75	22.03	24.00	24.72	23.14	22.93	23.00	21.13	18.88	19.68	22.14
	Min	4.67	3.50	2.00	5.79	7.71	9.43	11.36	9.11	6.66	4.91	3.61	2.17	5.91
2009	Max	19.95	21.51	22.84	23.13	24.67	26.28	22.08	23.27	23.51	20.66	20.76	18.42	22.26
	Min	5.68	5.41	7.49	6.61	6.55	8.41	11.06	9.25	6.54	4.10	1.62	7.04	6.65
2010	Max	19.93	20.70	20.42	21.29	22.24	25.29	21.26	19.87	21.74	21.74	19.23	19.20	21.08
	Min	4.88	8.84	7.75	9.23	10.16	9.68	11.53	9.80	6.99	3.09	2.49	2.44	7.24
2011	Max	18.73	21.71	19.13	21.81	20.89	23.76	21.89	19.02	20.45	20.25	19.01	19.23	20.49
	Min	4.91	3.03	5.50	6.00	6.94	8.15	9.53	8.91	6.30	1.22	4.02	1.56	5.51
2012	Max	19.96	21.69	21.24	19.13	23.03	23.80	20.69	19.80	21.00	20.73	20.72	20.03	20.99
	Min	2.69	0.28	3.66	7.77	5.75	8.02	10.08	7.92	5.55	0.54	1.02	1.69	4.58
2013	Max	20.55	20.85	21.28	22.11	21.72	22.86	20.56	17.58	20.57	19.50	19.33	19.26	20.51
	Min	3.34	3.88	7.65	7.17	7.16	8.23	10.18	8.23	6.07	3.31	2.31	0.78	5.69
2014	Max	18.37	19.30	19.61	19.39	21.30	23.91	21.92	30.80	31.61	31.58	31.99	31.06	25.07
	Min	5.06	7.40	6.61	7.26	7.01	7.68	9.84	10.98	15.05	14.68	13.50	14.16	9.94
2015	Max	29.93	32.55	34.11	35.09	33.91	35.57	36.45	31.67	30.87	32.97	30.93	29.88	32.83

## Modeling Surface water-groundwater Interactions of Borkena River Catchment

Year	Temp (oC)	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual Av
	Min	9.08	8.62	8.86	8.10	13.71	11.65	11.68	16.62	14.66	11.68	12.77	13.08	11.71
	Max	29.05	32.16	34.67	31.13	33.12	35.70	31.66	31.05	31.71	30.16	30.20	30.85	31.79
2016	Min	13.90	12.48	16.10	17.71	15.43	16.00	16.86	16.52	15.91	8.80	9.84	13.08	14.39
	Max	30.85	31.35	32.52	33.93	32.25	36.52	33.08	30.97	30.73	30.86	30.50	29.75	31.94
2017	Min	6.58	14.25	14.43	15.03	16.97	16.38	16.59	16.37	15.80	13.22	9.84	6.61	13.51

### Appendix: 3 mean monthly relative humidity of the study area (2005-2017)

Year	Jan	Feb	Mar	April	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Ann Average
2005	72.96	51.34	66.10	65.04	63.13	35.37	59.27	58.69	54.86	59.39	60.96	56.83	58.66
2006	66.54	65.49	68.36	63.95	43.27	31.26	58.32	71.01	58.59	65.26	65.06	73.39	60.88
2007	70.66	64.85	55.66	59.48	43.15	46.53	67.41	61.71	51.04	57.50	62.32	60.80	58.43
2008	63.26	52.97	34.38	49.43	47.97	38.87	50.41	57.14	56.56	61.82	70.99	63.04	53.90
2009	65.98	59.36	55.85	59.02	40.67	31.34	60.00	57.22	50.59	64.60	59.65	76.97	56.77
2010	65.24	69.72	69.08	72.39	66.38	35.79	66.47	80.65	63.60	61.11	66.75	59.72	64.74
2011	72.40	53.41	65.70	61.82	65.54	40.80	63.32	83.74	71.54	62.56	72.91	61.52	64.60
2012	63.82	49.12	55.59	79.11	52.44	41.20	70.19	78.42	64.01	59.71	61.74	62.82	61.51
2013	62.19	57.02	67.72	70.19	59.48	42.61	74.75	86.94	67.36	71.43	69.75	63.66	66.09
2014	70.34	75.67	71.07	70.71	66.41	39.79	56.44	75.90	91.13	62.68	89.90	88.87	71.58
2015	85.00	71.11	50.77	46.27	54.48	78.77	56.03	56.03	40.83	48.45	64.27	62.58	59.55
2016	91.26	81.93	81.84	78.23	82.26	73.87	85.35	91.19	90.47	49.58	86.43	85.94	81.53
2017	75.97	88.93	55.00	89.40	61.39	78.07	53.71	76.10	54.63	61.48	44.97	42.32	65.16

### Appendix: 4 Mean monthly wind speed (U2) of the study area 2m above the ground level (m/s)

Year	Jan	Feb	Mar	April	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Annual Av
2005	2.31	2.67	2.65	2.37	2.58	3.01	2.09	2.38	2.71	2.71	2.64	2.53	2.55
2006	2.61	2.62	2.27	2.50	3.19	2.94	2.11	2.06	2.52	2.85	2.52	2.56	2.56
2007	2.50	2.55	2.77	2.68	2.94	2.65	1.94	2.34	2.56	2.90	2.78	2.51	2.59
2008	2.55	2.80	2.76	3.28	3.10	2.60	2.34	2.42	2.74	2.70	2.24	2.44	2.67
2009	2.47	2.70	2.85	2.78	3.26	3.22	2.08	2.36	2.84	2.54	2.59	2.23	2.66
2010	2.54	2.16	2.45	2.23	2.29	2.81	2.13	2.02	2.43	2.81	2.40	2.22	2.38
2011	1.74	2.18	1.83	2.08	2.22	2.39	1.86	1.55	2.13	2.46	1.98	2.11	2.04
2012	2.13	2.26	2.04	1.74	2.92	2.55	1.85	1.63	2.31	2.50	2.11	1.97	2.17
2013	1.93	2.15	1.81	2.00	2.31	2.27	1.77	1.50	2.20	2.11	2.11	1.87	2.00
2014	1.76	1.73	2.00	2.33	2.56	2.72	2.05	2.96	2.90	1.97	2.26	2.46	2.31
2015	2.86	2.86	2.54	2.51	2.65	2.83	3.00	3.24	2.68	2.61	2.17	2.69	2.72
2016	2.98	2.15	2.43	2.49	2.57	2.86	2.66	3.21	3.26	2.42	2.32	2.62	2.66
2017	2.65	2.56	2.45	2.22	2.44	2.41	2.28	2.10	2.85	2.35	1.98	2.29	2.38

Modeling Surface water-groundwater Interactions of Borkena River Catchment

Appendix: 5 Table showing the groundwater elevation of existing wells and surface water elevation of the river to indicate the SW-GW interactions in the Borkena river catchment.

Well_ID	X	Y	SWL (m)	GW_Elevation mbgl	Riv_Elevation masl	Difference	River_Type
Kutaber	561487	244816	3.2	2666.8	2680.2	-13.4	Effluent
Boru Sillasse Kb02	569164	1239609	41.5	2568	2602.6	-34.6	Effluent
Wollo University	568373	1238516	42.7	2561.3	2603.6	-42.3	Effluent
GBH	569589	1232065	18.87	2472.1	2487.8	-15.7	Effluent
DDBH	569138	1232098	26.1	2470.9	2489.6	-18.7	Effluent
PW3	579565	1226611	0	1848	1833.6	14.4	Influent
KCVTW-02-19	578915	1226614	0	1839.8	1841	-1.2	Effluent
KCPW-2	579066	1226301	6.96	1831	1833.4	-2.4	Effluent
Well One	579376	1226205	1.66	1832.9	1831.4	1.5	Influent
BH-1	579647	1226175	0	1832.7	1831.4	1.3	Influent
BGI-3	579337	1224720	0	1827	1826.2	0.8	Influent
HrW4	584466	1208649	0	1485.8	1485.8	0	
HrBH-3	584806	1208276	0	1485	1481.5	3.5	Influent
HCKTW1	582859	1207575	5	1499.4	1495	4.4	Influent
Harbu Kut	583712	1206639	0	1475	1470	5	Influent
HrBH2	585040	1206425	6	1469	1469	0	
HrBH3	586180	1205450	0	1471	1464	7	Influent
HCKTW#5	585874	1203916	0	1459	1459	0	
TUCHE	585983	1192236	0	1460	1458	2	Influent
Girma's bh	589091	1194110	0	1436	1435	1	Influent

Modeling Surface water-groundwater Interactions of Borkena River Catchment

Well_ID	X	Y	SWL (m)	GW_Elevation mbgl	Riv_Elevation masl	Difference	River_Type
Dewachefa Shekla	590348	1193360	5.4	1440	1440	0	
KCVTW-03-19	586891	1189916	0	1444	1444	0	
KCPW-1	588411	1189219	4.7	1423.3	1430	-6.7	Effluent
CKBH1	586795	1186734	14.5	1442.5	1447.4	-4.9	Effluent
HCKPW07	590430	1186027	0	1422.7	1422.9	-0.2	Effluent
HCKPW-14	590446	1185131	0	1428	1420	8	Influent
HCKTW2	587545	1182629	8.3	1438.7	1436.9	1.8	Influent
Bilacha	595434	1187099	4.1	1477.9	1473	4.9	Influent
KW-4	595464	1186863	5.8	1470.2	1470.2	0	
KW-3	595586	1186261	5.97	1470.16	1471	-0.84	Effluent
KW-1	595093	1185847	11.13	1437	1447	-10	Effluent
KW5	597030	1184798	9.3	1447	1456	-9	Effluent
Chereti bh	600932	1172716	6	1415.6	1416	-0.4	Effluent
H/Mesno bh	593218	1172644	0	1423	1420	3	Influent

## Modeling Surface water-groundwater Interactions of Borkena River Catchment

### Appendix: 6 Default value of SWAT-MODFLOW river cell GW-SW exchange

Groundwater/Surface Water exchange (m3/day)  
for each MODFLOW River Cell

	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	0.00E+00	2356.099	2269.9	2269.9	2269.9	2269.9	2269.9	2269.9	2269.9	2269.9	2269.9	2269.9	2269.9	-32233.7
2	0.00E+00	2501.14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-66870.1	-163341	-285405	-334857	-355245
3	0.00E+00	942.4194	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	0.00E+00	2319.863	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-21320.1	-95903.4	-208275	-284655	-316269
5	0.00E+00	2537.375	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-53915.5	-189504	-346878	-409740	-435131	-445908	-451308
6	0.00E+00	2682.417	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-12608.3	-90375.2	-167146	-256319
7	0.00E+00	4204.802	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-71902.9	-175122	-275204	-340208	-359720
8	0.00E+00	435.0244	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
9	0.00E+00	2573.611	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-59133.8	-112114
10	0.00E+00	2464.905	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-42336.3	-133879	-287303	-349398	-374597	-384840
11	0.00E+00	2827.358	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	0.00E+00	326.2183	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
13	0.00E+00	978.7549	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
14	0.00E+00	1486.15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	0.00E+00	1921.174	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
16	0.00E+00	1848.704	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
17	0.00E+00	3153.577	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
18	0.00E+00	108.7061	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-1703.18	-5319.65
19	0.00E+00	2356.199	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
20	0.00E+00	1159.932	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
21	0.00E+00	2464.905	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606	2314.606
22	0.00E+00	2718.652	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Modeling Surface water-groundwater Interactions of Borkena River Catchment

23	0.00E+00	1848.704	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
24	0.00E+00	2972.4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
25	0.00E+00	217.5122	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
26	0.00E+00	2573.611	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576	1349.576
27	0.00E+00	3008.635	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
28	0.00E+00	398.689	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
29	0.00E+00	3081.106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
30	0.00E+00	3371.089	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978	3329.978
31	0.00E+00	507.4951	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
32	0.00E+00	3117.341	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
33	0.00E+00	326.2183	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
34	0.00E+00	3661.072	1964.478	1964.478	1964.478	1964.478	1964.478	1964.478	5268.372	8616.913	13617.4	18617.89	21966.43	23618.38
35	0.00E+00	1232.402	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426	586.1426
36	0.00E+00	3588.601	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
37	0.00E+00	2646.082	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272	1710.272
38	0.00E+00	2827.358	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
39	0.00E+00	1739.897	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
40	0.00E+00	3443.66	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
41	0.00E+00	253.7476	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
42	0.00E+00	2501.14	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
43	0.00E+00	1812.468	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	-16838.1
44	0.00E+00	1522.485	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
45	0.00E+00	3081.106	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
46	0.00E+00	2138.687	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
47	0.00E+00	3733.542	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108	3096.108
48	0.00E+00	72.4707	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Modeling Surface water-groundwater Interactions of Borkena River Catchment

49	0.00E+00	1413.679	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559	1189.559
50	-83032.2	-130829	-198600	-228534	-241813	-248178	-251672	-242128	-259402	-264391	-267444	-281259	-277611	-291506
51	-362949	-367568	-368976	-371219	-372658	-373628	-374321	-368751	-377817	-382794	-388018	-398920	-398370	-402206
52	942.4194	-19158.2	-40533.9	-94831.6	-139929	-168729	-187227	-195562	-207724	-215549	-222721	-232816	-236576	-241351
53	-328193	-333830	-334866	-336184	-336567	-336447	-336034	-329516	-337116	-338222	-341320	-350209	-349816	-353444
54	-453316	-455879	-456566	-458520	-459922	-461084	-462105	-456901	-466528	-470942	-476583	-487857	-487548	-491557
55	-289514	-303334	-307639	-310393	-311520	-312024	-312306	-306213	-316024	-319978	-325891	-337573	-337606	-342219
56	-365298	-369603	-371049	-374074	-376291	-378230	-380055	-374428	-387370	-391428	-397702	-410589	-410295	-416267
57	435.0244	435.0244	870.0488	870.0488	870.0488	870.0488	870.0488	3474.89	1305.073	1305.073	2175.122	2175.122	3909.915	2610.146
58	-182864	-234350	-253176	-261242	-264051	-264788	-264722	-258140	-266412	-267660	-271286	-280882	-280013	-283568
59	-388054	-390326	-390078	-390745	-390817	-390601	-390223	-383672	-391762	-394740	-398963	-408793	-407237	-409931
60	2827.358	-40447.2	-86925	-123006	-167887	-201441	-214171	-212872	-224249	-229888	-234928	-245504	-244897	-249021
61	326.2183	326.2183	652.4365	652.4365	652.4365	652.4365	652.4365	2605.768	978.6548	978.6548	1631.091	1631.091	2931.986	1957.31
62	978.7549	978.7549	1957.51	1957.51	1957.51	1957.51	1957.51	7818.103	2936.265	2936.265	4893.774	4893.774	8796.857	5872.529
63	1486.15	1486.15	2972.3	2972.3	2972.3	2972.3	2972.3	11871.08	4458.45	4458.45	7430.75	7430.75	9440.218	-17471
64	1921.174	1921.174	3842.349	3842.349	3842.349	3842.349	3842.349	15345.97	5763.523	5763.523	9605.871	9605.871	17267.14	11527.05
65	1848.704	1848.704	3697.407	3697.407	3697.407	3697.407	3697.407	14767.08	5546.111	5546.111	9243.518	9243.518	16615.79	11092.22
66	3153.577	3153.577	6307.153	6307.153	6307.153	6307.153	6307.153	25190.15	9460.73	9460.73	15767.88	15767.88	28343.73	18921.46
67	-19974.9	-33827.6	-46390.4	-57975.4	-68568.2	-78254.9	-87164.6	-94766.6	-102881	-110281	-117201	-124183	-130476	-136921
68	2356.199	2356.199	4712.397	4712.397	4712.397	4712.397	4712.397	18820.86	7068.596	7068.596	11780.99	11780.99	21177.05	14137.19
69	1159.932	1159.932	2319.863	2319.863	2319.863	2319.863	2319.863	9265.308	-14683.3	-33718	-48395.2	-86773	-117257	-141692
70	2464.905	4779.511	7244.415	7244.415	7244.415	7244.415	7244.415	35921.48	14338.53	14338.53	-11278.3	-40403.7	-48062	-85932.9
71	2718.652	2718.652	5437.305	5437.305	5437.305	5437.305	5437.305	-14772.7	-61886	-86766.8	-101224	-116029	-136770	-161532
72	1848.704	1848.704	3697.407	3697.407	3697.407	3697.407	3697.407	14767.08	5546.111	5546.111	9243.518	9243.518	16615.79	11092.22
73	2972.4	2972.4	5944.8	5944.8	5944.8	5944.8	5944.8	23742.95	8917.199	8917.199	14862	14862	26715.35	17834.4

Modeling Surface water-groundwater Interactions of Borkena River Catchment

74	217.5122	217.5122	435.0244	435.0244	435.0244	435.0244	435.0244	1737.445	652.5366	652.5366	1087.561	1087.561	1954.957	1305.073
75	2573.611	3923.187	6496.798	6496.798	6496.798	6496.798	6496.798	29941.77	11738.18	11738.18	20902.74	20902.74	39231.87	17287.67
76	3008.635	-15794.3	-69039.1	-109473	-138565	-179002	-200815	-202152	-214676	-213910	-211561	-213002	-209283	-215679
77	398.689	398.689	797.3779	797.3779	797.3779	797.3779	797.3779	3184.65	1196.067	1196.067	1993.445	1993.445	3583.339	2392.134
78	3081.106	-53738	-97032.3	-129901	-159969	-192504	-203452	-200118	-210406	-208020	-204374	-204694	-201113	-208052
79	3371.089	6701.067	10072.16	10072.16	10072.16	-36575.9	-75917.9	-75116.1	-123484	-136065	-134913	-154417	-157268	-181478
80	507.4951	507.4951	1014.99	1014.99	1014.99	1014.99	1014.99	4053.772	1522.485	1522.485	2537.476	2537.476	4561.267	3044.971
81	3117.341	3117.341	6234.683	6234.683	6234.683	6234.683	6234.683	24900.71	9352.023	9352.023	15586.71	15586.71	28018.05	18704.05
82	326.2183	326.2183	652.4365	652.4365	652.4365	652.4365	652.4365	2605.768	978.6548	978.6548	1631.091	1631.091	2931.986	1957.31
83	25314.97	28931.4	32592.47	32592.47	34244.41	34244.41	35941.01	66256.47	41834.44	41834.44	55005.37	55005.37	81391.88	60630.92
84	1232.402	1803.516	3035.918	3035.918	3035.918	3035.918	3035.918	13902.1	5425.576	5425.576	9633.779	9633.779	18035.16	11437.29
85	3588.601	3588.601	7177.202	7177.202	7177.202	7177.202	7177.202	28665.04	10765.8	10765.8	17943.01	17943.01	32253.65	21531.61
86	2646.082	4356.354	7002.436	7002.436	7002.436	7002.436	7002.436	33076.02	13036.79	13036.79	23427.5	23427.5	44208.92	27783.86
87	2827.358	2827.358	5654.717	5654.717	5654.717	5654.717	5654.717	22584.39	8482.075	8482.075	14136.79	14136.79	25411.75	16964.15
88	1739.897	1739.897	3479.795	3479.795	-1665.6	-34140.7	-60653.1	-75416.3	-131810	-156499	-167436	-175451	-176850	-183366
89	3443.66	3443.66	6887.319	6887.319	6887.319	6887.319	6887.319	27507.28	10330.98	10330.98	17218.3	17218.3	30950.94	20661.96
90	253.7476	253.7476	507.4951	507.4951	507.4951	507.4951	507.4951	2026.886	761.2427	761.2427	1268.738	1268.738	2280.634	1522.485
91	2501.14	2501.14	5002.28	5002.28	5002.28	5002.28	5002.28	19978.62	7503.42	7503.42	-9829.34	-41727.3	-59906.5	-87172.3
92	-62095	-121676	-197037	-236658	-258666	-272249	-281786	-284019	-297715	-302896	-306539	-312910	-315285	-325385
93	1522.485	1522.485	3044.971	3044.971	3044.971	3044.971	3044.971	12161.32	4567.456	4567.456	7612.427	7612.427	13683.8	9134.912
94	3081.106	3081.106	6162.212	6162.212	6162.212	6162.212	6162.212	24611.27	9243.318	9243.318	15405.53	15405.53	27692.38	18486.64
95	2138.687	-22752.3	-62305.6	-94857	-148000	-183278	-198775	-200123	-211221	-213970	-215407	-220589	-220341	-226942
96	3733.542	6829.651	10563.19	10563.19	10563.19	10563.19	10563.19	51632.16	20534.48	20333.48	-19232	-57624.3	-60784.2	-103463
97	72.4707	72.4707	144.9414	144.9414	144.9414	144.9414	144.9414	578.8818	217.4121	217.4121	362.3535	362.3535	651.3525	434.8242
98	1413.679	2603.239	4016.918	4016.918	-9810.24	-36086.1	-58278.7	-88477.1	-135845	-155197	-162309	-169800	-166958	-178172

Modeling Surface water-groundwater Interactions of Borkena River Catchment

99	-285811	-279652	-277175	-276244	-277949	-278854	-281244	-282367	-283892	-286537	-287728	-289289	-291875	-293008
100	-393862	-388074	-384240	-383127	-383143	-384646	-384698	-385173	-385799	-386486	-387180	-388914	-389001	-389435
101	-238892	-235543	-232313	-230364	-229303	-229420	-229066	-229003	-229116	-229337	-229617	-230543	-230655	-230850
102	-345928	-338794	-332935	-329668	-327725	-327387	-325766	-324586	-323585	-322656	-321774	-321875	-320458	-319362
103	-483347	-477602	-473687	-472425	-472236	-473486	-473266	-473439	-473769	-474147	-474524	-475909	-475654	-475744
104	-334462	-329208	-325842	-325167	-325547	-327386	-327685	-328417	-329303	-330243	-331198	-333183	-333502	-334177
105	-408193	-403249	-400565	-400924	-402324	-405253	-406121	-407583	-409186	-410784	-412348	-415114	-415734	-416923
106	2175.122	1740.098	1740.098	1740.098	1740.098	1305.073	1305.073	1305.073	1305.073	1305.073	1305.073	870.0488	870.0488	870.0488
107	-275824	-269474	-264763	-262726	-261879	-262552	-261750	-261381	-261161	-260991	-260823	-261687	-260903	-260468
108	-400680	-393759	-388715	-386331	-385081	-385299	-384103	-383349	-382757	-382253	-381776	-382328	-381297	-380610
109	-240603	-234429	-230489	-229537	-229853	-231742	-232041	-232784	-233690	-234631	-235569	-237676	-238024	-238728
110	1631.091	1304.873	1304.873	1304.873	1304.873	978.6548	978.6548	978.6548	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365
111	4893.774	3915.02	3915.02	3915.02	3915.02	-2780.14	-13549	-23092.2	-31549.3	-39050.1	-45705.4	-64886.2	-76833.1	-84379.7
112	-36910.3	-53025.5	-65337.1	-89974.3	-109044	-120463	-126285	-129910	-132357	-134161	-135612	-137728	-138563	-139465
113	9605.871	7684.697	7684.697	7684.697	7684.697	5763.523	5763.523	5763.523	5763.523	5763.523	5763.523	3842.349	3842.349	3842.349
114	9243.518	7394.814	7394.814	7394.814	7394.814	5546.111	5546.111	-10866.5	-29502	-44693.7	-57123.2	-68830	-76965	-83720.3
115	15767.88	12614.31	12614.31	12614.31	12614.31	9460.73	9460.73	9460.73	9460.73	9460.73	9460.73	6307.153	6307.153	6307.153
116	-142135	-146582	-150390	-153823	-156963	-159957	-162621	-165086	-167371	-169489	-171455	-173383	-175073	-176644
117	11780.99	9424.795	9424.795	9424.795	9424.795	7068.596	7068.596	7068.596	7068.596	7068.596	7068.596	4712.397	4712.397	4712.397
118	-153822	-160201	-162849	-164212	-164975	-166191	-166348	-166611	-166965	-167384	-167852	-169039	-169279	-169642
119	-107964	-123025	-129251	-131003	-132826	-132781	-133773	-133316	-133223	-134237	-133816	-133810	-134798	-134388
120	-163708	-162886	-161285	-160796	-160971	-162751	-163042	-163793	-164699	-165667	-166640	-168667	-168986	-169683
121	9243.518	7394.814	7394.814	7394.814	7394.814	5546.111	5546.111	5546.111	5546.111	5546.111	5546.111	3697.407	3697.407	-2552.98
122	14862	11889.6	11889.6	11889.6	11889.6	8917.199	8917.199	8917.199	8917.199	8917.199	8917.199	5944.8	5944.8	5944.8
123	1087.561	870.0488	870.0488	870.0488	-1190.99	-4579.32	-7682.34	-12293.1	-24227.5	-34688	-43873.3	-52150.4	-59258.4	-65545.6
124	-22976.9	-51023	-71264.3	-85660.8	-97712.7	-106985	-114296	-122307	-129959	-134463	-136590	-138759	-140471	-141378

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125	-215936	-216109	-215135	-214803	-214697	-215760	-215061	-214814	-214737	-214686	-214657	-215725	-215008	-214739
126	1993.445	1594.756	1594.756	1594.756	1594.756	1196.067	1196.067	1196.067	1196.067	1196.067	1196.067	797.3779	797.3779	797.3779
127	-207547	-206489	-204190	-202587	-201267	-201167	-199347	-198033	-196914	-195877	-194887	-195060	-193436	-192293
128	-175016	-168813	-166522	-164536	-164934	-163891	-164580	-163631	-163244	-164186	-163325	-162976	-163923	-163071
129	2537.476	2029.98	2029.98	2029.98	2029.98	1522.485	1522.485	1522.485	1522.485	1522.485	1522.485	1014.99	1014.99	1014.99
130	11309	-23527.1	-45855.6	-61658.1	-72864.1	-83033.5	-88038.8	-91589.1	-94102.4	-95886.3	-97141.7	-100269	-100258	-100246
131	1631.091	1304.873	1304.873	1304.873	1304.873	978.6548	978.6548	978.6548	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365
132	54737.49	51076.41	49111.94	49111.94	47147.46	47102.81	45138.34	45138.34	45138.34	43218.51	43218.51	43173.86	41209.38	41209.38
133	9047.637	7815.234	7244.121	7244.121	6657.979	6011.719	5425.576	5425.576	5425.576	4854.463	4854.463	4193.174	3622.061	3622.061
134	17943.01	14354.4	14354.4	14354.4	14354.4	10765.8	10765.8	10765.8	10765.8	10765.8	10765.8	7177.202	7177.202	7177.202
135	21717.23	19071.15	17393.15	17393.15	15682.87	14747.06	13036.79	13036.79	13036.79	11326.52	11326.52	10390.71	8680.438	8680.438
136	14136.79	11309.43	11309.43	11309.43	11309.43	8482.075	8482.075	8482.075	8482.075	8482.075	8482.075	5654.717	5654.717	5654.717
137	-183638	-183630	-183341	-183714	-184524	-186319	-186814	-187493	-188257	-189067	-189911	-191626	-192056	-192711
138	17218.3	13774.64	13774.64	13774.64	13774.64	10330.98	10330.98	10330.98	10330.98	10330.98	10330.98	6887.319	6887.319	6887.319
139	1268.738	1014.99	1014.99	1014.99	1014.99	761.2427	761.2427	761.2427	761.2427	761.2427	761.2427	507.4951	507.4951	507.4951
140	-102733	-114513	-131747	-139833	-143636	-146699	-147361	-148055	-148747	-149423	-150094	-151778	-151846	-152254
141	-331346	-337000	-341636	-346611	-351714	-357745	-362419	-367298	-372236	-377190	-382115	-387886	-392252	-396795
142	7612.427	6089.941	6089.941	6089.941	6089.941	4567.456	4567.456	4567.456	4567.456	4567.456	4567.456	-1505.07	-19793.2	-33938.1
143	15405.53	12324.42	12324.42	12324.42	12324.42	9243.318	9243.318	9243.318	9243.318	9243.318	9243.318	6162.212	6162.212	6162.212
144	-226485	-224920	-222514	-221126	-220422	-221092	-220503	-220331	-220337	-220423	-220554	-221657	-221278	-221183
145	-120371	-127367	-131793	-132825	-135728	-136094	-138022	-137270	-136774	-138556	-137690	-137567	-139183	-138227
146	362.3535	289.8828	289.8828	289.8828	289.8828	217.4121	217.4121	217.4121	217.4121	217.4121	217.4121	144.9414	144.9414	144.9414
147	-180982	-181499	-182479	-183035	-184495	-185177	-186434	-186767	-187237	-188447	-188757	-189343	-190523	-190818
148	-288547	-319890	-265925	-337716	-340532	-332556	-319002	-312965	-312314	-311988	-313705	-314374	-316440	-317210
149	-386935	-414846	-395547	-429379	-421630	-412450	-403540	-398954	-397408	-397079	-397248	-398625	-398457	-398678

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150	-229265	-244805	-236997	-256814	-257021	-252938	-246897	-242275	-239379	-237607	-236547	-236542	-235989	-235688
151	-315434	-334499	-315113	-348671	-343837	-334279	-323743	-317252	-313889	-311946	-310630	-310566	-309056	-307926
152	-472878	-498422	-478107	-512075	-504531	-495471	-486508	-481759	-479953	-479296	-479099	-480100	-479527	-479341
153	-331855	-357464	-336981	-372717	-365700	-357191	-348835	-344811	-343730	-343777	-344255	-345926	-345969	-346419
154	-414559	-442971	-418110	-463443	-453558	-443295	-434144	-430569	-430225	-430855	-431734	-433901	-433976	-434632
155	2175.122	1305.073	14339.89	7390.11	4344.939	2175.122	1740.098	1740.098	1740.098	1740.098	1740.098	1305.073	1305.073	1305.073
156	-257056	-278919	-258528	-293757	-287778	-278361	-268578	-263095	-260665	-259489	-258794	-259335	-258294	-257630
157	-377032	-401559	-380905	-413577	-405637	-395995	-386412	-381035	-378621	-377416	-376700	-377195	-376178	-375541
158	-236327	-261986	-241945	-279613	-272723	-263283	-254074	-249573	-248296	-248270	-248723	-250422	-250432	-250889
159	1631.091	978.6548	10753.27	5541.732	3258.204	1631.091	1304.873	1304.873	1304.873	1304.873	1304.873	978.6548	978.6548	978.6548
160	-87331.1	-97593.4	-86330.7	-107640	-113221	-114435	-112404	-110518	-109431	-108846	-108571	-109114	-108953	-108983
161	-137985	-147518	-129475	-156274	-160869	-160815	-157450	-154978	-153814	-153313	-153169	-154002	-153810	-153868
162	9605.871	3912.027	33619.32	-13807.3	-38200.6	-54747.4	-61823.6	-65867.3	-68990.7	-71362.5	-73134.1	-75976.6	-76619.1	-77064.7
163	-87963.3	-110262	-97926.8	-134338	-141029	-140243	-134962	-130723	-128232	-126816	-126090	-126664	-126195	-126141
164	15767.88	9460.73	103952.7	53572.34	28771.3	-12116	-31063.4	-41817.6	-49300.5	-54581.8	-58345.2	-63285.9	-64612.8	-65600.7
165	-177800	-180732	-180868	-185582	-188244	-189956	-190845	-191432	-191923	-192360	-192759	-193231	-193570	-193887
166	11780.99	7068.596	77668.36	40026.64	23533.25	6123.555	-14596.8	-28211.2	-38384.5	-46052.9	-51883.1	-58174.1	-61215.9	-63609
167	-168091	-177520	-165835	-191878	-198412	-198750	-194812	-190955	-188205	-186345	-185183	-185260	-184819	-184810
168	-128545	-158399	-101676	-170796	-170762	-163919	-151843	-146227	-145116	-143908	-144553	-144078	-144965	-144543
169	-167335	-189327	-169521	-206294	-200585	-192996	-185423	-181634	-180458	-180319	-180567	-182017	-181838	-182071
170	-12464.1	-32262.9	-2115.09	-45647.6	-64887.7	-76525.2	-79798.7	-80987.9	-82020.7	-82927	-83734.8	-85953.8	-86320.9	-86698.4
171	14862	8917.199	97980.45	50494.55	29687.75	14862	11889.6	11889.6	-8909.71	-25561.4	-37757.3	-48902	-54982.8	-59560
172	-70546.8	-77012.2	-76904	-85600.3	-91140.8	-95670.9	-98955.5	-101697	-104134	-106300	-108224	-110136	-111662	-113047
173	-137738	-151703	-106580	-165609	-173051	-170946	-162722	-158611	-157746	-157086	-157563	-157942	-158351	-158211
174	-211351	-215609	-182473	-220803	-225335	-225190	-221141	-218854	-218216	-218099	-218123	-219251	-218546	-218249
175	1993.445	1196.067	13142.15	6772.851	3982.028	1993.445	1594.756	1594.756	1594.756	1594.756	1594.756	1196.067	1196.067	1196.067

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176	-188022	-194958	-165391	-206663	-210634	-208855	-202966	-198986	-196832	-195388	-194265	-194413	-192863	-191852
177	-155882	-190229	-125077	-208510	-200523	-188261	-173117	-167327	-166953	-166108	-167356	-167078	-168505	-168277
178	2537.476	1522.485	16728.77	8621.229	5068.762	2537.476	2029.98	2029.98	2029.98	2029.98	2029.98	1522.485	1522.485	1522.485
179	-93540.1	-105332	-45552	-106209	-121522	-128264	-123639	-117782	-113380	-110066	-107569	-107900	-105952	-104608
180	1631.091	978.6548	10753.27	5541.732	3258.204	1631.091	1304.873	1304.873	1304.873	1304.873	1304.873	978.6548	978.6548	978.6548
181	56389.43	43218.51	223593.3	116820.2	37876.14	-3783.5	-13371.4	-18294.1	-22932.1	-24787.6	-27397.2	-29087.4	-30464.6	-30135.5
182	9047.637	4854.463	56249.46	9680.982	-15136.9	-31694.7	-38510.5	-43322.5	-48014.7	-51615.2	-56081.4	-64373	-69444.9	-72394.7
183	17943.01	10765.8	118292.5	60962.45	35842.25	17943.01	14354.4	14354.4	14354.4	14354.4	14354.4	10765.8	10765.8	10765.8
184	21717.23	11326.52	153601.8	80673.22	45144.73	21717.23	19071.15	19071.15	17393.15	17393.15	15682.87	14747.06	13036.79	13036.79
185	14136.79	8482.075	93199.39	48030.61	28239.1	14136.79	11309.43	11309.43	11309.43	11309.43	11309.43	8482.075	8482.075	8482.075
186	-190883	-200306	-179291	-209003	-214845	-216290	-214026	-212486	-212108	-212251	-212631	-214012	-214193	-214682
187	17218.3	10330.98	64438	-24504.3	-64695	-87883.1	-94631.7	-97164.7	-99126.1	-100677	-101929	-105360	-105529	-105841
188	1268.738	761.2427	8364.386	4310.614	2534.381	1268.738	1014.99	1014.99	1014.99	1014.99	1014.99	761.2427	761.2427	761.2427
189	-149715	-164956	-140936	-175919	-175637	-173264	-168500	-165654	-164505	-164019	-163767	-164644	-163934	-163645
190	-398713	-406681	-385688	-419535	-431261	-437913	-439963	-442168	-445175	-448479	-451886	-456211	-459226	-462506
191	-52251	-64510.5	-51261.1	-95428.2	-111941	-119613	-120867	-120993	-121238	-121498	-121755	-122825	-122757	-122917
192	15405.53	9243.318	101563.8	52341.23	30773.48	15405.53	12324.42	12324.42	12324.42	12324.42	-2833.32	-17767.1	-26158.1	-32105.8
193	-218353	-227694	-205189	-240051	-245292	-243882	-238063	-233602	-230971	-229315	-228178	-228271	-227038	-226205
194	-123744	-141218	-41868.9	-150387	-165663	-163997	-154393	-151437	-151381	-149031	-149341	-147699	-148072	-146114
195	362.3535	217.4121	2388.882	1231.118	723.8232	362.3535	289.8828	289.8828	289.8828	289.8828	289.8828	217.4121	217.4121	217.4121
196	-186964	-193922	-148298	-196411	-211597	-216353	-212211	-209219	-208166	-206833	-206617	-205856	-205897	-205232
197	-318375	-320654	-321494	-322695	-324925	-325716	-326833	-328085	-329390	-330699	-332980	-333740	-334814	-336000
198	-399042	-399458	-399896	-401366	-401190	-401379	-401697	-402059	-402441	-402830	-403198	-403576	-403937	-404294
199	-235542	-235487	-235494	-236135	-235973	-235896	-235867	-235864	-235879	-235906	-235930	-235951	-235969	-235977
200	-306951	-306035	-305156	-305272	-303859	-302766	-301805	-300904	-300027	-299162	-298310	-297459	-296607	-295745

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201	-479294	-479289	-479300	-480327	-479731	-479486	-479369	-479295	-479239	-479177	-479108	-479034	-478941	-478842
202	-346999	-347633	-348283	-349950	-349952	-350324	-350839	-351382	-351943	-352495	-353040	-353575	-354091	-354598
203	-435444	-436280	-437098	-439132	-439063	-439562	-440221	-440907	-441577	-442232	-442871	-443481	-444077	-444658
204	1305.073	1305.073	1305.073	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488
205	-257122	-256670	-256237	-256831	-255782	-255100	-254549	-254057	-253572	-253084	-252605	-252122	-251624	-251122
206	-375064	-374651	-374265	-374906	-373964	-373365	-372914	-372527	-372166	-371820	-371487	-371157	-370829	-370504
207	-251496	-252165	-252844	-254600	-254628	-255064	-255638	-256272	-256916	-257570	-258220	-258867	-259510	-260137
208	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365
209	-109139	-109391	-109712	-110717	-110902	-111206	-111582	-112014	-112480	-112972	-113480	-114005	-114539	-115073
210	-154077	-154386	-154753	-155956	-156020	-156281	-156640	-157059	-157507	-157974	-158450	-158925	-159397	-159868
211	-77370.9	-77582.5	-77733.1	-79384.6	-79259.9	-79267.1	-79382.7	-79667.4	-80094.8	-80637.1	-81272	-81981.4	-82753.3	-83572
212	-126325	-126639	-127033	-128365	-128378	-128651	-129043	-129489	-129966	-130452	-130946	-131426	-131913	-132386
213	-66354	-66935.8	-67404.5	-70040.4	-69833.5	-69872.5	-70080.2	-70402.1	-70802.1	-71260.2	-71753.7	-72264.1	-72793.3	-73324.3
214	-194184	-194462	-194723	-195070	-195291	-195498	-195691	-195871	-196039	-196194	-196338	-196472	-196595	-196709
215	-65523	-67072	-68352.3	-71250.3	-71754.5	-72246.9	-72729.6	-73207.9	-73679.5	-74152.3	-74619.5	-75084.2	-75552.3	-76017.4
216	-185082	-185525	-186074	-187382	-187765	-188276	-188858	-189474	-190110	-190747	-191378	-192003	-192612	-193207
217	-144554	-145709	-145428	-145574	-146724	-146447	-146536	-146770	-147065	-147382	-148668	-148437	-148544	-148770
218	-182493	-182967	-183486	-185069	-184972	-185270	-185723	-186241	-186771	-187313	-187863	-188401	-188939	-189487
219	-87600.8	-88395.8	-89005	-90422.1	-90461	-90726.7	-91252.4	-91923.7	-92663.5	-93418.4	-94188	-94950.8	-95706.6	-96444.9
220	-63050.6	-65762.4	-67902.9	-71788.2	-72630.6	-73428.7	-74190	-74924.5	-75637.5	-76337.5	-77023.7	-77701.1	-78372.7	-79034.3
221	-114316	-115487	-116580	-117800	-118748	-119654	-120556	-121462	-122371	-123283	-124192	-125101	-126008	-126912
222	-158412	-159297	-159406	-160221	-160904	-160952	-161289	-161730	-162224	-162744	-163820	-164032	-164439	-164920
223	-218077	-217930	-217787	-218751	-217914	-217513	-217271	-217097	-216940	-216801	-216664	-216533	-216408	-216302
224	1196.067	1196.067	1196.067	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779
225	-191068	-190396	-189800	-190391	-189196	-188491	-187979	-187552	-187180	-186836	-186512	-186202	-185917	-185654
226	-168596	-170240	-170074	-170413	-172026	-171844	-172149	-172627	-173253	-173930	-175711	-175594	-175948	-176424

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227	1522.485	-2043.67	-6088.21	-10399.8	-14015.8	-17453.5	-20726.1	-23843	-33515.4	-42333	-49210.7	-54627	-58944.2	-62436.5
228	-103707	-103132	-102792	-104859	-104162	-103728	-103472	-103348	-103352	-103444	-103585	-103749	-103915	-104075
229	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365
230	-29960.9	-31243.8	-30824.7	-30605.7	-31838	-31376.5	-31108.9	-30977.5	-30945.4	-30972.9	-32345.7	-32028.8	-31867.4	-31808
231	-74467.7	-76383.9	-77545.8	-78999.5	-80191	-80942	-81769.3	-82638.2	-83531	-84430.2	-85680.6	-86444.2	-87256.4	-88099.8
232	10765.8	10765.8	10765.8	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202
233	13036.79	11326.52	11326.52	10390.71	8680.438	8680.438	8680.438	8680.438	8680.438	8680.438	7002.436	7002.436	7002.436	7002.436
234	8482.075	8482.075	8482.075	5654.717	5654.717	5654.717	5654.717	5654.717	5654.717	5654.717	5654.717	5654.717	5654.717	5654.717
235	-215348	-216122	-216979	-218752	-219273	-220032	-220922	-221880	-222872	-223886	-224901	-225926	-226960	-227981
236	-106264	-106780	-107377	-110408	-110388	-110639	-111081	-111657	-112333	-113079	-113878	-114712	-115573	-116448
237	761.2427	761.2427	761.2427	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951
238	-163551	-163550	-163603	-164702	-164215	-164103	-164156	-164275	-164410	-164572	-164734	-164909	-165070	-165243
239	-465938	-469446	-473002	-477476	-480612	-483988	-487476	-491009	-494555	-498092	-501617	-505131	-508622	-512089
240	-123232	-123648	-124131	-125484	-125684	-126097	-126624	-127214	-127847	-128502	-129178	-129855	-130531	-131216
241	-36320.6	-39307.9	-41429.8	-45132.9	-45580.7	-45901.3	-46136.6	-46309.3	-46437.4	-46542.2	-46629.6	-46702.6	-46768.4	-46831.1
242	-225571	-225050	-224595	-225141	-224245	-223668	-223236	-222869	-222541	-222239	-221938	-221640	-221355	-221070
243	-144689	-145748	-144309	-143730	-144977	-143708	-142845	-142266	-141883	-141702	-143790	-143174	-142850	-142711
244	217.4121	-67.5303	-551.745	-1099.91	-1569.04	-2031.2	-2486.77	-2935.97	-3378.76	-4961.26	-6768.26	-8465.8	-10061.1	-11560.1
245	-204868	-205368	-205049	-205081	-205764	-205597	-205637	-205799	-206044	-206333	-207310	-207368	-207568	-207854
246	-337228	-338472	-339710	-340942	-332299	-346956	-353483	-322481	-363862	-365641	-343347	-364372	-358693	-355983
247	-404635	-404983	-405314	-405641	-399860	-408816	-415619	-397691	-417174	-422732	-408049	-417051	-413158	-410733
248	-235983	-235986	-235979	-235962	-232305	-236589	-240595	-231409	-241240	-245244	-238556	-242891	-240919	-238972
249	-294895	-294046	-293197	-292349	-285577	-293012	-296038	-279050	-297338	-299389	-286285	-294531	-289830	-286201
250	-478737	-478627	-478499	-478366	-472082	-480666	-486041	-467679	-487146	-491820	-476736	-485618	-481408	-478599
251	-355085	-355564	-356035	-356486	-350651	-360097	-365539	-347439	-368267	-373115	-358386	-368285	-364551	-362275

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252	-445211	-445751	-446278	-446778	-439895	-451600	-456722	-435557	-461755	-464431	-447574	-460564	-455224	-452615
253	870.0488	870.0488	870.0488	870.0488	3474.89	1305.073	870.0488	7390.11	1740.098	1305.073	5214.988	1740.098	1305.073	1305.073
254	-250617	-250109	-249599	-249085	-242364	-250638	-254169	-236273	-256001	-258775	-244733	-253755	-249172	-245910
255	-370181	-369861	-369555	-369251	-362871	-371162	-376326	-358152	-377170	-381658	-366796	-375405	-371181	-368312
256	-260774	-261394	-262011	-262625	-256814	-266690	-272725	-254842	-276314	-280630	-266511	-276853	-272870	-270576
257	652.4365	652.4365	652.4365	652.4365	2605.768	978.6548	652.4365	5541.732	1304.873	978.6548	3910.641	1304.873	978.6548	978.6548
258	-115615	-116165	-116715	-117264	-114082	-119078	-121546	-112727	-124202	-126405	-120746	-127157	-126804	-126072
259	-160337	-160802	-161265	-161715	-157385	-163985	-166107	-153922	-169389	-170922	-162613	-171138	-170105	-168880
260	-84427.4	-85308.8	-86213.7	-87131.9	-78827.6	-89293.4	-91809.9	-79652.4	-100318	-100377	-91985.9	-103926	-103674	-103032
261	-132855	-133320	-133780	-134225	-129321	-136935	-137457	-123704	-142132	-143783	-135176	-145546	-143987	-142203
262	-73859.9	-74395.7	-74929.4	-75459.8	-62552.6	-78116.3	-80505	-46423.7	-85050.9	-89716.8	-68772	-90973.4	-90739.2	-88288.6
263	-196812	-196906	-196991	-197069	-196528	-197137	-197590	-196304	-197837	-198590	-198034	-199016	-199100	-199024
264	-76480.3	-76941.4	-77400.9	-77858.6	-67500.9	-79488.3	-81639.4	-54511	-84344.5	-87334.1	-71204.4	-89176.4	-90174	-89049.2
265	-193787	-194353	-194904	-195441	-191798	-197409	-198450	-188164	-201495	-204297	-198519	-206258	-205727	-204552
266	-149054	-149347	-149651	-149951	-140301	-154261	-153814	-122839	-166136	-168525	-143546	-164794	-159039	-155827
267	-190022	-190554	-191084	-191612	-185829	-195431	-195656	-179056	-202229	-206911	-193410	-204385	-201125	-198974
268	-97176	-97900.1	-98606.4	-99295.1	-94637.4	-102463	-103311	-89696.6	-108283	-112225	-102419	-111783	-110012	-108446
269	-79689.2	-80339.3	-80985.7	-81628.9	-69393.7	-84295.9	-86883.5	-54405.3	-91174.3	-96657.9	-76449	-97350.5	-97310.7	-95216.9
270	-127809	-128702	-129590	-130468	-130189	-132145	-133250	-131253	-134958	-136536	-135727	-138316	-139332	-140098
271	-165422	-165934	-166455	-166961	-159082	-171288	-170973	-146504	-181321	-178893	-162326	-181297	-177444	-174996
272	-216202	-216106	-216029	-215956	-209340	-218851	-217967	-200179	-224209	-219965	-207605	-221685	-219265	-217357
273	797.3779	797.3779	797.3779	797.3779	3184.65	1196.067	797.3779	6772.851	1594.756	1196.067	4779.405	1594.756	1196.067	1196.067
274	-185399	-185152	-184910	-184688	-177874	-187358	-186283	-168185	-192307	-189125	-176850	-190814	-187882	-185536
275	-176943	-177452	-177968	-178465	-167549	-184543	-182800	-147171	-199803	-198137	-169695	-196286	-188616	-185234
276	-65303.4	-67698.6	-69738.6	-71511.8	-70753.4	-74709.9	-76526.6	-71904.7	-79489.4	-84561.4	-81411.1	-85541.2	-86204.1	-86549.1
277	-104226	-104367	-104499	-104622	-91385.5	-106392	-108280	-74039.5	-111845	-113963	-92185.8	-114023	-113927	-111587

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278	-3562.51	-6582.86	-9515.99	-12365.4	-13262.8	-24306.2	-33872.8	-37488.8	-48220	-56959.8	-59524.4	-65767.6	-69088.7	-71705.6
279	-31821.1	-31878	-31970.2	-32079.9	-15387.1	-35117.5	-34837.2	17106.33	-47907.3	-47608.4	-15204.7	-50131.9	-46751.6	-43049
280	-88965.6	-89828.2	-90696	-91551.7	-86733.7	-94514.5	-95611.4	-80090.2	-101243	-103033	-93150.2	-104781	-104038	-103173
281	7177.202	7177.202	7177.202	7177.202	28665.04	10765.8	7177.202	60962.45	14354.4	10765.8	43019.45	14354.4	10765.8	10765.8
282	7002.436	7002.436	7002.436	7002.436	29655.47	11326.52	8680.438	73864.4	15682.87	13036.79	50436.89	15682.87	13036.79	13036.79
283	5654.717	5654.717	5654.717	5654.717	22584.39	8482.075	5654.717	48030.61	11309.43	8482.075	25939.35	-8190.09	-18773.5	-24541.7
284	-229000	-230015	-231027	-232035	-227853	-235722	-237920	-225288	-243472	-245062	-236397	-246834	-246306	-245517
285	-117338	-118235	-119142	-120047	-106670	-123860	-126552	-90608.3	-132717	-134053	-111380	-136400	-137332	-135820
286	507.4951	507.4951	507.4951	507.4951	2026.886	761.2427	507.4951	4310.614	1014.99	761.2427	3041.876	1014.99	761.2427	761.2427
287	-165402	-165558	-165725	-165876	-159897	-168704	-168921	-152676	-174597	-175971	-162882	-174542	-172224	-170226
288	-515521	-518940	-522324	-525683	-523692	-534100	-537455	-526695	-547786	-549527	-543403	-557072	-559190	-560854
289	-131901	-132588	-133274	-133961	-129802	-136752	-137716	-125732	-142285	-142355	-134610	-144525	-144437	-143831
290	-46886.7	-46944.9	-46999	-47057.1	-33894.3	-48716.8	-50660.4	-16766.4	-54204.2	-57961	-35764.4	-56974.3	-56753.8	-54370.9
291	-220784	-220498	-220211	-219922	-213908	-221493	-222648	-207742	-227125	-226192	-215787	-226422	-223805	-221154
292	-142700	-142774	-142904	-143067	-119717	-146390	-148787	-87793.8	-159443	-158381	-124526	-160020	-158481	-154904
293	-12968.3	-14291.7	-15534.4	-16701.4	-17382.5	-18775.9	-19966.5	-19989.6	-21898.5	-23054.1	-23428	-24878.9	-25704.1	-26365.1
294	-208179	-208533	-208906	-209278	-202341	-211806	-212428	-190842	-219899	-218104	-204502	-220877	-219350	-217797
295	-355504	-356929	-357215	-357973	-357937	-362219	-348523	-369405	-367112	-365839	-365909	-366582	-368382	-368772
296	-409890	-409692	-409740	-409897	-409069	-412646	-404632	-415406	-412833	-411902	-411645	-412681	-412185	-412091
297	-237700	-236856	-236288	-235885	-234982	-236342	-231740	-237048	-236160	-235546	-235109	-235389	-234913	-234553
298	-284156	-282807	-281751	-280828	-278957	-280666	-272313	-281830	-278486	-276583	-275307	-275277	-273815	-272733
299	-477340	-476694	-476292	-475984	-474688	-477679	-469156	-479608	-476533	-475144	-474419	-474984	-474019	-473458
300	-361588	-361511	-361668	-361906	-361112	-364582	-356413	-367754	-365045	-364138	-363918	-364995	-364512	-364438
301	-452079	-452134	-452357	-452631	-451663	-455739	-446046	-460040	-455753	-454667	-454504	-455833	-455128	-455062
302	1305.073	1305.073	1305.073	1305.073	1740.098	1305.073	4344.939	1305.073	1305.073	1305.073	1305.073	870.0488	870.0488	870.0488

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303	-244270	-243283	-242544	-241914	-240278	-242365	-233800	-244215	-240857	-239178	-238158	-238439	-237182	-236333
304	-366986	-366296	-365863	-365542	-364246	-367085	-358727	-369061	-366113	-364779	-364105	-364701	-363811	-363325
305	-270046	-270193	-270583	-271061	-270495	-274475	-266488	-278315	-275627	-274940	-275014	-276424	-276211	-276444
306	978.6548	978.6548	978.6548	978.6548	1304.873	978.6548	3258.204	978.6548	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365
307	-125744	-125676	-125787	-126008	-125682	-127339	-123379	-129591	-129330	-129313	-129453	-130329	-130413	-130626
308	-168341	-168164	-168183	-168313	-167712	-169490	-164006	-172261	-171236	-170797	-170676	-171528	-171304	-171291
309	-103057	-103409	-103929	-104540	-104297	-106561	-100867	-111267	-110240	-110132	-110454	-111899	-112068	-112536
310	-141286	-140848	-140693	-140700	-139924	-141636	-135452	-144964	-143462	-142858	-142687	-143627	-143309	-143281
311	-86606.8	-85508.1	-84839	-84485.4	-82124.6	-85251.1	-69548.4	-89805.9	-88627.2	-87901.5	-87496.8	-89572.8	-88911.5	-88554
312	-198927	-198825	-198722	-198619	-198417	-198520	-197755	-198429	-198330	-198226	-198120	-198118	-198006	-197895
313	-88175.3	-87530.9	-87082.1	-86799	-84842.5	-87155.5	-74540.2	-90203.9	-89641.1	-89286.8	-89090.6	-90837.4	-90445.1	-90225.3
314	-203787	-203333	-203106	-203042	-202395	-203700	-198970	-205887	-205273	-204998	-204935	-205681	-205546	-205560
315	-154622	-155191	-154592	-154457	-153491	-156044	-141697	-162389	-159236	-157127	-156379	-156240	-157177	-156737
316	-198380	-198401	-198674	-199039	-198389	-201167	-193677	-205622	-203147	-202441	-202426	-203727	-203446	-203585
317	-107905	-107874	-108096	-108438	-107937	-110169	-104110	-113770	-112419	-111983	-111987	-113083	-112935	-113074
318	-93845.9	-93012.2	-92570.6	-92413	-90307	-93601.5	-78706.8	-98062.8	-97181.3	-96697.7	-96504.3	-98668.6	-98320.3	-98317.7
319	-140832	-141538	-142226	-142896	-143361	-144288	-143622	-145787	-146413	-147022	-147619	-148399	-148954	-149504
320	-174167	-174539	-174335	-174450	-173653	-175881	-164879	-182002	-179238	-177808	-177430	-177960	-178602	-178738
321	-216844	-216974	-217316	-217738	-217068	-219299	-211678	-224421	-221713	-221014	-221019	-222366	-222004	-222128
322	1196.067	1196.067	1196.067	1196.067	1594.756	1196.067	3982.028	1196.067	1196.067	1196.067	1196.067	797.3779	797.3779	797.3779
323	-184487	-183917	-183540	-183245	-181890	-183529	-175210	-187453	-184048	-182733	-182171	-183015	-182119	-181737
324	-184407	-185568	-185144	-185306	-184505	-187124	-170926	-196237	-191583	-189225	-188738	-188868	-190318	-189991
325	-87028.8	-87612.3	-88269.9	-88982.1	-89347.4	-90774.6	-88811.8	-92944	-93589.7	-94281.5	-95011.6	-96158.7	-96848	-97570.7
326	-109887	-108670	-107805	-107191	-104541	-107118	-91188.4	-110870	-109393	-108341	-107589	-109293	-108276	-107548
327	-74036.2	-76135	-78041.4	-79790.6	-81136.5	-83188.8	-82703.4	-86241.8	-87449.3	-88616.5	-89755.2	-91139.8	-92188.8	-93224.4
328	-40554	-40221.7	-38709.2	-37717.5	-35712.5	-37325.3	-13647.5	-42797.8	-41991	-40149.1	-38921.2	-38157.3	-38922	-38161

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329	-102955	-103460	-103709	-104149	-103973	-105666	-98843.5	-109572	-109419	-109282	-109487	-110273	-110967	-111314
330	10765.8	10765.8	10765.8	10765.8	14354.4	10765.8	35842.25	10765.8	10765.8	10765.8	10765.8	7177.202	7177.202	7177.202
331	13036.79	11326.52	11326.52	11326.52	13972.6	11326.52	41756.46	13036.79	11326.52	11326.52	11326.52	10390.71	8680.438	8680.438
332	-28881.4	-32181.4	-34723.8	-36713.2	-36205.1	-40551.5	-26931.7	-46032.6	-45666.3	-45522.9	-45545.4	-47755.5	-47434.9	-47326.3
333	-245426	-245687	-246125	-246665	-246384	-248762	-243239	-252866	-251942	-251786	-252021	-253315	-253400	-253758
334	-134997	-134644	-134623	-134834	-132810	-136469	-120189	-142513	-141545	-141107	-141035	-143584	-143205	-143172
335	761.2427	761.2427	761.2427	761.2427	1014.99	761.2427	2534.381	761.2427	761.2427	761.2427	761.2427	507.4951	507.4951	507.4951
336	-169344	-168927	-168721	-168598	-167488	-169530	-161990	-173147	-170568	-169495	-169017	-169824	-169111	-168806
337	-563132	-565700	-568404	-571180	-573082	-577362	-573897	-586002	-587163	-589128	-591476	-594902	-597059	-599484
338	-143719	-143883	-144204	-144614	-144274	-146118	-140988	-149819	-149119	-149004	-149196	-150366	-150434	-150738
339	-52664.8	-51439.1	-50567	-49941.8	-47281.7	-50026.5	-34224.7	-53747.3	-52308.3	-51284.9	-50561.1	-52246.7	-51264.9	-50575.3
340	-219548	-218455	-217636	-216974	-215431	-216763	-209462	-219208	-216646	-215244	-214353	-214659	-213584	-212858
341	-152444	-152843	-150992	-149719	-146359	-149306	-116437	-156831	-155941	-153227	-151377	-150554	-151660	-150311
342	-26951.1	-27475.9	-27949.7	-28379.8	-28702.3	-29169.8	-29043.8	-29872.1	-30161.3	-30422.1	-30657.9	-30940.7	-31131	-31302.6
343	-216964	-217266	-216898	-216822	-216146	-217656	-207926	-222133	-221392	-220472	-220106	-220150	-220877	-220753
344	-369527	-370420	-371369	-369362	-374983	-374978	-375542	-376340	-377218	-378140	-380037	-380428	-381137	-381961
345	-412155	-412279	-412424	-410531	-413936	-413375	-413228	-413251	-413344	-413461	-413582	-413705	-413826	-413945
346	-234272	-234040	-233837	-232431	-233896	-233564	-233289	-233051	-232834	-232637	-232440	-232249	-232064	-231879
347	-271806	-270941	-270099	-267292	-269573	-268117	-267030	-266110	-265250	-264427	-263616	-262807	-262010	-261214
348	-473055	-472710	-472388	-470019	-472946	-471900	-471297	-470852	-470478	-470128	-469775	-469432	-469088	-468741
349	-364524	-364667	-364817	-362886	-366376	-365741	-365581	-365593	-365663	-365766	-365864	-365958	-366047	-366119
350	-455150	-455291	-455441	-453115	-457424	-456325	-456099	-456102	-456188	-456269	-456359	-456444	-456510	-456571
351	870.0488	870.0488	870.0488	1740.098	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488
352	-235644	-235017	-234414	-231750	-234446	-233125	-232249	-231546	-230917	-230313	-229708	-229117	-228525	-227933
353	-362987	-362723	-362486	-360236	-363235	-362319	-361832	-361517	-361265	-361051	-360851	-360652	-360454	-360270

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354	-276843	-277292	-277764	-276098	-280041	-279697	-279864	-280221	-280641	-281085	-281539	-281991	-282441	-282889
355	652.4365	652.4365	652.4365	1304.873	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365
356	-130924	-131274	-131655	-130811	-132937	-133195	-133515	-133879	-134274	-134682	-135097	-135520	-135941	-136361
357	-171392	-171560	-171756	-170381	-172922	-172798	-172844	-172966	-173133	-173318	-173511	-173711	-173909	-174105
358	-113149	-113828	-114542	-113449	-116953	-117188	-117694	-118330	-119019	-119739	-120458	-121186	-121912	-122637
359	-143393	-143568	-143763	-142206	-145106	-144857	-144852	-144953	-145116	-145298	-145489	-145688	-145875	-146071
360	-88405.6	-88407.8	-88516.2	-84214.8	-90226.4	-90126.1	-90155.6	-90279.8	-90467.7	-90701.8	-90966.6	-91253.3	-91551.5	-91860.9
361	-197785	-197675	-197566	-197253	-197361	-197252	-197142	-197031	-196921	-196809	-196697	-196583	-196470	-196355
362	-90138.1	-90154.7	-90252.4	-86778.4	-91459.5	-91497.6	-91611.2	-91779.4	-91989.7	-92229.6	-92489.9	-92767.7	-93060.7	-93362.4
363	-205663	-205815	-205997	-204802	-206945	-206922	-206987	-207108	-207260	-207418	-207581	-207750	-207917	-208082
364	-156661	-156743	-156886	-154053	-158936	-158094	-157846	-157853	-157956	-158107	-159239	-158855	-158798	-158872
365	-203888	-204267	-204658	-202953	-206732	-206346	-206452	-206735	-207080	-207462	-207838	-208227	-208603	-208991
366	-113340	-113668	-114015	-112595	-115643	-115533	-115665	-115913	-116210	-116526	-116850	-117171	-117500	-117814
367	-98564.7	-98990	-99542.2	-95873.5	-102068	-102481	-103013	-103632	-104310	-105031	-105779	-106542	-107316	-108101
368	-150048	-150590	-151127	-151274	-152233	-152751	-153266	-153777	-154282	-154784	-155280	-155771	-156256	-156736
369	-179194	-179784	-180421	-178449	-183243	-182968	-183245	-183740	-184318	-184918	-186069	-186364	-186852	-187398
370	-222407	-222751	-223107	-221287	-225214	-224697	-224746	-224992	-225317	-225667	-226015	-226377	-226739	-227101
371	797.3779	797.3779	797.3779	1594.756	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779
372	-181520	-181388	-181274	-178969	-182496	-181516	-181111	-180937	-180832	-180756	-180692	-180647	-180592	-180554
373	-190168	-190509	-190903	-187908	-193947	-192904	-192843	-193096	-193457	-193859	-195409	-195100	-195266	-195596
374	-98321.3	-99090.1	-99872.3	-99894.8	-101648	-102413	-103187	-103970	-104762	-105558	-106352	-107151	-107949	-108747
375	-107029	-106654	-106382	-101729	-107312	-106840	-106495	-106244	-106056	-105921	-105814	-105729	-105661	-105603
376	-94253.1	-95271.4	-96282.7	-96740.2	-98373.9	-99353.5	-100329	-101301	-102273	-103240	-104204	-105163	-106119	-107074
377	-37668.6	-37358.1	-37170.3	-31892.9	-38685.1	-38145.1	-37801.9	-37589.5	-37472.7	-37413.3	-38725.7	-38310.1	-38052.7	-37898.8
378	-111789	-112332	-112916	-111749	-114875	-115197	-115646	-116170	-116735	-117316	-118257	-118713	-119235	-119781
379	7177.202	7177.202	7177.202	14354.4	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202

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380	8680.438	8680.438	8680.438	15682.87	8680.438	8680.438	8680.438	8680.438	8680.438	8680.438	7002.436	7002.436	7002.436	7002.436
381	-47371.1	-47524.8	-47756.4	-43895.6	-49487.4	-49554.2	-49721.9	-49963.1	-50256.5	-50589.8	-50944.6	-51316.2	-51702.2	-52095.7
382	-254251	-254817	-255403	-254272	-257477	-257654	-258047	-258541	-259094	-259665	-260244	-260820	-261393	-261962
383	-143382	-143757	-144240	-140037	-146888	-147095	-147468	-147954	-148515	-149133	-149789	-150463	-151153	-151857
384	507.4951	507.4951	507.4951	1014.99	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951
385	-168664	-168585	-168544	-166449	-169667	-168931	-168622	-168485	-168407	-168366	-168337	-168306	-168274	-168241
386	-602019	-604610	-607214	-608035	-613307	-615430	-617777	-620220	-622696	-625195	-627685	-630154	-632614	-635055
387	-151161	-151655	-152189	-151111	-154048	-154265	-154647	-155126	-155653	-156199	-156754	-157318	-157890	-158452
388	-50115	-49848.8	-49719.4	-45261.8	-50970.7	-50689.7	-50547.9	-50500.6	-50522.8	-50594.5	-50692.9	-50817	-50954.5	-51104.3
389	-212285	-211785	-211322	-208955	-211482	-210463	-209777	-209240	-208773	-208328	-207893	-207458	-207024	-206600
390	-149421	-148884	-148580	-141296	-150699	-149980	-149552	-149316	-149215	-149204	-151373	-150777	-150428	-150242
391	-31458.1	-31597.9	-31723	-31695.2	-31938.5	-32024.4	-32098.6	-32161.9	-32215.2	-32258.4	-32292.3	-32316.9	-32333.2	-32341.8
392	-220836	-221033	-221297	-219357	-222880	-222756	-222837	-223038	-223303	-223594	-224557	-224586	-224753	-224993
393	-382841	-383741	-384638	-385531	-386422	-387308	-388192	-389072	-384000	-393181	-392621	-392893	-393495	-394238
394	-414062	-414177	-414278	-414389	-414485	-414592	-414685	-414776	-410780	-417339	-416003	-415510	-415358	-415339
395	-231685	-231497	-231302	-231106	-230909	-230711	-230512	-230313	-227673	-230755	-230236	-229829	-229487	-229189
396	-260407	-259613	-258820	-258028	-257236	-256446	-255656	-254868	-250122	-255528	-253448	-252128	-251117	-250251
397	-468393	-468031	-467679	-467313	-466945	-466576	-466217	-465845	-461370	-467502	-465669	-464711	-464097	-463618
398	-366187	-366263	-366322	-366377	-366416	-366462	-366493	-366519	-362352	-369070	-367534	-366940	-366709	-366600
399	-456642	-456694	-456742	-456785	-456824	-456859	-456875	-456902	-451992	-460336	-457904	-457212	-457000	-456932
400	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	870.0488	2610.146	870.0488	870.0488	870.0488	870.0488	870.0488
401	-227342	-226763	-226172	-225581	-225002	-224412	-223822	-223232	-218509	-224506	-222445	-221287	-220476	-219802
402	-360088	-359907	-359727	-359549	-359372	-359197	-359023	-358850	-354626	-360873	-359314	-358586	-358200	-357950
403	-283335	-283779	-284220	-284660	-285097	-285520	-285953	-286371	-282503	-289830	-288610	-288403	-288579	-288895
404	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	652.4365	1957.31	652.4365	652.4365	652.4365	652.4365	652.4365

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405	-136788	-137207	-137632	-138049	-138465	-138880	-139294	-139700	-137620	-141420	-141489	-141672	-141937	-142247
406	-174299	-174481	-174661	-174839	-175016	-175190	-175362	-175522	-172494	-177287	-176752	-176540	-176490	-176524
407	-123359	-124079	-124787	-125504	-126208	-126910	-127610	-128307	-125351	-131585	-131262	-131470	-131928	-132492
408	-146253	-146434	-146612	-146789	-146963	-147136	-147306	-147464	-144060	-149602	-148799	-148488	-148421	-148461
409	-92175.8	-92492.8	-92816.2	-93136.2	-93453.6	-93774.8	-94091.3	-94404.4	-85721.1	-97612.3	-97170.8	-96941.2	-96864.4	-96895.5
410	-196240	-196124	-196006	-195887	-195768	-195647	-195526	-195402	-194871	-195179	-195052	-194923	-194792	-194661
411	-93673.7	-93985.3	-94301.6	-94620.2	-94939.6	-95263.9	-95585.7	-95905.7	-88989.1	-98236.4	-98158	-98173.2	-98254	-98388.5
412	-208236	-208388	-208538	-208685	-208823	-208958	-209083	-209206	-206544	-210534	-210197	-210039	-209987	-209992
413	-159006	-159152	-159309	-159465	-159620	-159786	-159940	-160093	-154256	-162871	-161526	-161081	-160987	-161039
414	-209365	-209749	-210120	-210489	-210869	-211235	-211600	-211963	-208108	-215241	-214028	-213776	-213903	-214169
415	-118126	-118436	-118742	-119035	-119325	-119613	-119897	-120169	-116868	-122525	-121837	-121638	-121683	-121832
416	-108884	-109671	-110458	-111237	-112017	-112789	-113562	-114327	-106495	-118205	-118295	-118562	-118960	-119449
417	-157211	-157681	-158144	-158603	-159056	-159504	-159944	-160378	-160040	-161322	-161730	-162134	-162532	-162925
418	-187964	-188552	-189123	-189690	-190253	-190812	-191368	-191919	-187246	-195512	-194507	-194425	-194699	-195118
419	-227449	-227810	-228170	-228529	-228875	-229234	-229591	-229934	-225915	-233392	-231981	-231689	-231803	-232075
420	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	797.3779	2392.134	797.3779	797.3779	797.3779	797.3779	797.3779
421	-180518	-180484	-180453	-180423	-180396	-180384	-180360	-180352	-175929	-183153	-181329	-180689	-180450	-180372
422	-195979	-196375	-196784	-197192	-197599	-198005	-198410	-198814	-192361	-202891	-201063	-200724	-200877	-201194
423	-109545	-110337	-111128	-111919	-112708	-113498	-114282	-115065	-114290	-116983	-117673	-118382	-119101	-119828
424	-105556	-105508	-105467	-105428	-105390	-105353	-105316	-105279	-96327.4	-107743	-106975	-106418	-106008	-105703
425	-108025	-108972	-109915	-110855	-111790	-112722	-113649	-114576	-114406	-116595	-117480	-118368	-119255	-120142
426	-37819.4	-37786	-37783.5	-37803.8	-37842.7	-37891.4	-37945.1	-38001.5	-28865.4	-39749.7	-39292.4	-39003.7	-38824.6	-38723.5
427	-120351	-120928	-121503	-122076	-122648	-123217	-123785	-124351	-121355	-126585	-126666	-126943	-127338	-127791
428	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	7177.202	21531.61	7177.202	7177.202	7177.202	7177.202	7177.202
429	7002.436	7002.436	7002.436	7002.436	7002.436	7002.436	7002.436	7002.436	20975.04	8680.438	8680.438	8680.438	8680.438	8680.438
430	-52498.1	-52904.9	-53308.1	-53713.9	-54120.6	-54526.9	-54926.8	-55327.8	-47446.9	-58335.5	-58141.2	-58101.5	-58177	-58334.3

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431	-262527	-263089	-263639	-264185	-264729	-265258	-265783	-266305	-263356	-269044	-268672	-268733	-269009	-269385
432	-152560	-153269	-153980	-154691	-155400	-156108	-156814	-157511	-148669	-161820	-161612	-161678	-161928	-162309
433	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	507.4951	1522.485	507.4951	507.4951	507.4951	507.4951	507.4951
434	-168195	-168160	-168124	-168088	-168037	-167998	-167957	-167902	-163748	-170179	-168701	-168077	-167782	-167621
435	-637486	-639896	-642288	-644659	-647011	-649354	-651677	-653981	-652710	-660308	-661633	-663426	-665432	-667535
436	-159023	-159583	-160152	-160710	-161267	-161823	-162377	-162930	-160242	-165518	-165349	-165518	-165861	-166299
437	-51260.2	-51418.7	-51578	-51742.9	-51904.1	-52062.5	-52218.4	-52378.1	-43714.5	-55188	-54627.6	-54270	-54055.6	-53950.7
438	-206166	-205742	-205307	-204884	-204460	-204024	-203599	-203161	-198902	-204376	-202782	-201838	-201180	-200646
439	-150167	-150163	-150210	-150289	-150390	-150502	-150618	-150741	-136552	-153498	-152795	-152364	-152110	-151982
440	-32343	-32336.5	-32323.3	-32303.3	-32276.6	-32244	-32205.4	-32161	-31834	-32069.2	-32009.5	-31944.6	-31875.6	-31802.3
441	-225268	-225551	-225852	-226152	-226460	-226766	-227060	-227352	-223211	-229220	-228894	-228845	-228951	-229130
442	-395037	-395857	-400616	-368199	-415399	-407255	-403349	-403165	-402607	-402844	-404404	-404528	-405030	-405697
443	-415380	-415432	-419392	-401213	-425268	-420624	-417778	-416645	-416214	-416066	-417061	-416470	-416258	-416192
444	-228920	-228671	-230384	-220034	-232014	-230958	-229567	-228597	-227900	-227370	-227558	-226989	-226545	-226174
445	-249432	-248639	-250675	-233035	-255517	-250516	-246908	-244925	-243646	-242668	-242794	-241439	-240429	-239576
446	-463198	-462790	-466498	-447663	-471387	-466144	-462805	-461229	-460357	-459766	-460308	-459272	-458618	-458098
447	-366550	-366522	-370594	-351720	-376572	-371349	-368275	-367056	-366540	-366310	-367203	-366488	-366162	-365983
448	-456905	-456875	-461299	-439364	-470435	-462007	-458286	-457172	-456825	-456682	-457831	-456905	-456593	-456455
449	870.0488	870.0488	870.0488	8254.854	1740.098	1305.073	1305.073	1305.073	1305.073	1305.073	870.0488	870.0488	870.0488	870.0488
450	-219178	-218592	-221007	-202497	-226572	-221221	-217695	-215955	-214913	-214157	-214544	-213343	-212527	-211860
451	-357761	-357586	-361101	-342864	-366554	-361818	-358805	-357504	-356899	-356575	-357375	-356614	-356232	-356078
452	-289274	-289664	-294081	-275588	-301637	-296416	-293594	-292781	-292705	-292911	-294287	-293975	-294087	-294352
453	652.4365	652.4365	652.4365	6190.19	1304.873	978.6548	978.6548	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365	652.4365
454	-142586	-142939	-144212	-134193	-147489	-147252	-146598	-146318	-146282	-146397	-147237	-147273	-147430	-147662
455	-176605	-176712	-177657	-164228	-182210	-180710	-179181	-178424	-178068	-177922	-178689	-178357	-178215	-178178

Modeling Surface water-groundwater Interactions of Borkena River Catchment

456	-133120	-133760	-134445	-119670	-141981	-140224	-138876	-138596	-138818	-139279	-140748	-140892	-141309	-141856
457	-148541	-148653	-148842	-133900	-155123	-152974	-151136	-150308	-149974	-149865	-150757	-150346	-150203	-150187
458	-97003.5	-97165.5	-97369.3	-59512.9	-104330	-104925	-103202	-102065	-101334	-100894	-102917	-102180	-101735	-101493
459	-194529	-194395	-194460	-192732	-194287	-194263	-194109	-193947	-193781	-193615	-193552	-193380	-193210	-193042
460	-98564.2	-98769.2	-98996.2	-68596.5	-103054	-104308	-103516	-102972	-102621	-102421	-104151	-103730	-103472	-103342
461	-210027	-210086	-210254	-198592	-213725	-213127	-212113	-211531	-211207	-211033	-211632	-211325	-211165	-211080
462	-161139	-161275	-161411	-128905	-177432	-169163	-164912	-164240	-163122	-162756	-163709	-163170	-163032	-163064
463	-214483	-214810	-215147	-197632	-224566	-220544	-218170	-217455	-217388	-217563	-218883	-218550	-218621	-218843
464	-122022	-122242	-122459	-107532	-128839	-126823	-125096	-124393	-124159	-124158	-125152	-124847	-124809	-124886
465	-119999	-120593	-121222	-85348.8	-128284	-129489	-128402	-127809	-127573	-127595	-129948	-129687	-129684	-129866
466	-163313	-163696	-164075	-161194	-164823	-165379	-165715	-166046	-166375	-166701	-167218	-167515	-167815	-168114
467	-195583	-196069	-196564	-170781	-210242	-204011	-200824	-200389	-199977	-200092	-201433	-201220	-201412	-201751
468	-232386	-232709	-233043	-214825	-243232	-238555	-236011	-235296	-235255	-235450	-236819	-236432	-236506	-236736
469	797.3779	797.3779	797.3779	7565.366	1594.756	1196.067	1196.067	1196.067	1196.067	1196.067	797.3779	797.3779	797.3779	797.3779
470	-180348	-180339	-180345	-161688	-190089	-184910	-181993	-180975	-180628	-180509	-181598	-180910	-180676	-180616
471	-201550	-201934	-202316	-165101	-223937	-211496	-206489	-206224	-205276	-205214	-206592	-206185	-206298	-206574
472	-120564	-121304	-122043	-116192	-124317	-125260	-125766	-126324	-126922	-127552	-128593	-129170	-129785	-130422
473	-105474	-105299	-105165	-67260.8	-111283	-111590	-109589	-108148	-107107	-106355	-108045	-107002	-106242	-105688
474	-121028	-121910	-122791	-119035	-124759	-125875	-126672	-127479	-128289	-129106	-130198	-130977	-131766	-132561
475	-38677	-38666.1	-38680.7	19170.34	-53241.4	-48890	-46856.4	-45698.3	-43616.1	-42224.1	-42648.8	-41609.6	-40925.5	-40476.1
476	-128277	-128779	-129296	-112188	-135792	-134711	-133609	-133528	-133375	-133495	-134497	-134578	-134829	-135182
477	7177.202	7177.202	7177.202	68095.89	14354.4	10765.8	10765.8	10765.8	10765.8	10765.8	7177.202	7177.202	7177.202	7177.202
478	8680.438	8680.438	8680.438	80866.84	15682.87	13036.79	13036.79	11326.52	11326.52	11326.52	8680.438	8680.438	8680.438	8680.438
479	-58554.1	-58814.3	-59108.6	-24234.4	-64991.1	-66023.1	-64793.3	-63997.1	-63514.2	-63259.3	-65231.7	-64713.1	-64429.1	-64317
480	-269810	-270253	-271038	-256745	-277321	-275706	-274284	-273804	-273777	-273976	-275144	-275067	-275236	-275516
481	-162779	-163307	-163879	-144283	-176091	-171199	-168887	-168559	-168893	-169433	-171170	-171043	-171425	-171971

Modeling Surface water-groundwater Interactions of Borkena River Catchment

482	507.4951	507.4951	507.4951	4815.015	1014.99	761.2427	761.2427	761.2427	761.2427	761.2427	507.4951	507.4951	507.4951	507.4951
483	-167519	-167442	-167456	-150012	-175322	-171438	-168819	-167715	-167224	-166976	-167848	-167146	-166810	-166621
484	-669672	-671823	-673964	-661034	-683963	-683928	-684124	-685295	-686925	-688768	-691592	-693125	-694893	-696770
485	-166775	-167279	-167791	-154605	-173563	-172623	-171724	-171628	-171955	-172502	-173968	-174295	-174833	-175476
486	-53918.7	-53939.2	-53996	-16630.8	-60393.4	-60951.8	-59173.4	-57949.5	-57118.2	-56570.6	-58421.5	-57597.2	-57053.4	-56707.3
487	-200158	-199692	-199804	-183385	-206008	-202447	-199608	-198057	-197098	-196404	-196802	-195776	-195060	-194495
488	-151935	-151942	-152093	-93520.1	-165985	-162056	-158944	-158978	-156950	-155617	-157288	-155924	-155040	-154483
489	-31724.8	-31643	-31583.2	-30346.7	-31363.6	-31354.2	-31263.6	-31165.7	-31062	-30953.9	-30911.1	-30792.8	-30671.4	-30546.8
490	-229344	-229584	-229846	-206338	-238561	-235766	-233604	-233216	-232470	-232168	-232900	-232632	-232585	-232667
491	-406421	-391384	-415428	-412004	-411774	-412094	-411719	-411996	-412546	-414203	-414330	-414812	-414419	-416663
492	-416186	-407028	-421018	-418311	-418113	-417029	-416608	-416445	-416391	-417407	-416800	-416560	-415444	-417044
493	-225854	-220100	-226478	-225879	-225926	-225255	-224734	-224315	-223963	-224254	-223746	-223334	-222372	-222874
494	-238782	-229130	-241289	-238459	-237606	-235784	-234582	-233639	-232817	-233027	-231720	-230747	-228923	-229684
495	-457652	-448007	-461961	-458619	-457860	-456299	-455416	-454817	-454316	-454885	-453851	-453176	-451625	-452785
496	-365853	-356329	-371009	-367800	-367344	-366063	-365501	-365215	-365026	-365911	-365151	-364779	-363506	-365000
497	-456361	-445242	-463408	-458655	-458064	-456582	-456097	-455911	-455798	-456949	-456013	-455692	-454312	-456296
498	870.0488	4779.963	1740.098	1740.098	1305.073	1305.073	1305.073	1305.073	1305.073	870.0488	870.0488	870.0488	1305.073	870.0488
499	-211247	-201366	-214486	-211456	-210806	-209165	-208190	-207479	-206870	-207342	-206191	-205426	-203768	-204841
500	-356158	-347212	-361371	-358863	-358802	-357894	-357642	-357642	-357748	-358912	-358487	-358399	-357454	-359165
501	-294682	-285386	-300852	-298158	-298132	-297242	-297130	-297316	-297618	-299014	-298710	-298817	-298010	-300059
502	652.4365	3584.423	1304.873	1304.873	978.6548	978.6548	978.6548	978.6548	978.6548	652.4365	652.4365	652.4365	978.6548	652.4365
503	-147937	-142673	-149698	-149701	-150380	-150308	-150391	-150572	-150813	-151728	-151802	-151973	-151584	-152715
504	-178197	-171070	-180228	-179421	-179780	-179224	-178956	-178841	-178811	-179617	-179287	-179138	-178275	-179431
505	-142457	-134909	-146183	-145516	-146454	-146341	-146642	-147118	-147691	-149205	-149362	-149780	-149397	-151366
506	-150225	-142294	-153099	-152003	-152326	-151591	-151251	-151093	-151040	-151938	-151516	-151342	-150393	-151749

Modeling Surface water-groundwater Interactions of Borkena River Catchment

507	-101398	-81229.7	-103276	-103072	-105120	-104371	-103896	-103625	-103502	-105733	-105141	-104792	-102361	-105206
508	-192873	-191791	-192494	-192379	-192335	-192170	-192000	-191829	-191658	-191590	-191413	-191238	-190962	-190898
509	-103310	-87121.1	-103816	-103990	-105955	-105680	-105517	-105444	-105446	-107323	-107001	-106817	-104923	-107162
510	-211043	-204791	-212455	-212110	-212538	-212064	-211755	-211564	-211437	-212047	-211728	-211534	-210724	-211620
511	-163157	-147409	-170110	-166219	-165715	-165559	-164642	-164344	-164301	-165383	-164900	-164782	-163793	-165483
512	-219128	-209961	-223605	-221565	-221992	-221292	-221198	-221360	-221610	-222942	-222596	-222654	-221807	-223757
513	-125026	-117165	-127675	-126611	-127093	-126528	-126348	-126348	-126433	-127447	-127133	-127063	-126220	-127668
514	-130180	-111246	-132181	-132403	-134873	-134679	-134715	-134916	-135232	-137787	-137654	-137732	-135804	-138883
515	-168410	-166982	-168826	-169139	-169639	-169917	-170194	-170470	-170744	-171208	-171455	-171702	-171755	-172216
516	-202149	-189453	-208015	-205329	-205575	-205441	-205108	-205217	-205509	-206891	-206658	-206807	-206072	-208051
517	-237018	-227499	-241634	-239356	-239832	-239118	-239063	-239232	-239492	-240872	-240484	-240529	-239637	-241685
518	797.3779	4380.717	1594.756	1594.756	1196.067	1196.067	1196.067	1196.067	1196.067	797.3779	797.3779	797.3779	1196.067	797.3779
519	-180623	-170752	-184785	-182144	-182337	-181333	-180999	-180906	-180908	-182049	-181388	-181180	-180033	-181869
520	-206918	-189042	-215993	-210735	-210373	-210509	-209701	-209671	-209899	-211363	-210973	-211075	-210215	-212414
521	-131078	-128254	-132472	-133144	-134206	-134799	-135411	-136043	-136688	-137735	-138307	-138908	-139139	-140250
522	-105283	-84960	-105998	-105445	-107258	-106324	-105641	-105140	-104770	-106731	-105879	-105261	-102567	-105104
523	-133362	-131712	-134829	-135661	-136764	-137544	-138327	-139114	-139903	-140963	-141708	-142462	-142947	-144026
524	-40190.8	-12879.3	-44580.6	-41917	-43764.7	-43871.2	-42643	-41827.8	-41297.6	-42301.6	-41650.4	-41225.6	-39600.4	-41203.7
525	-135594	-127194	-138331	-137989	-138725	-138979	-138988	-139194	-139510	-140605	-140720	-140970	-140585	-141975
526	7177.202	39430.85	14354.4	14354.4	10765.8	10765.8	10765.8	10765.8	10765.8	3469.069	98.95938	-2212.49	-1351.45	-5675.31
527	8680.438	44402.54	15682.87	15682.87	13036.79	11326.52	11326.52	11326.52	11326.52	8680.438	8680.438	8680.438	11326.52	8680.438
528	-64324.3	-45800.1	-65408.4	-65401.5	-67578.8	-67182.1	-66980.1	-66921.7	-66972.4	-69160.6	-68790.2	-68604.8	-66492.5	-69156
529	-275846	-268406	-278730	-277968	-278645	-278297	-278309	-278496	-278752	-279916	-279804	-279917	-279263	-280833
530	-172570	-162861	-178290	-175877	-176643	-176170	-176425	-176914	-177484	-179209	-179057	-179400	-178763	-181226
531	507.4951	2788.129	1014.99	1014.99	761.2427	761.2427	761.2427	761.2427	761.2427	507.4951	507.4951	507.4951	761.2427	507.4951
532	-166480	-157172	-169581	-167480	-167613	-166599	-166123	-165879	-165721	-166620	-165909	-165564	-164345	-165817

Modeling Surface water-groundwater Interactions of Borkena River Catchment

533	-698693	-692643	-704764	-705502	-707750	-708940	-710492	-712207	-714000	-716710	-718087	-719691	-720511	-723597
534	-176174	-169629	-179360	-179231	-180316	-180438	-180849	-181403	-182034	-183516	-183823	-184313	-184094	-185929
535	-56506.5	-36595.5	-57693	-57341.9	-59347.2	-58607.6	-58122.4	-57826.5	-57659.9	-59782.1	-59150.5	-58744	-56299.4	-58994.5
536	-193988	-184921	-195896	-193875	-193680	-192382	-191546	-190920	-190388	-190862	-189873	-189183	-187670	-188650
537	-154145	-116534	-158814	-157143	-158555	-159140	-157472	-156386	-155687	-157774	-156692	-155993	-153027	-156112
538	-30419.8	-29668.7	-30053.4	-29928	-29869.4	-29735.8	-29599.1	-29460.9	-29320.2	-29246.9	-29100.3	-28952.1	-28733.4	-28654.2
539	-232804	-221343	-236039	-234875	-235125	-235249	-234766	-234597	-234594	-235468	-235259	-235234	-234515	-235767
540	-417031	-417599	-418237	-418920	-419601	-418297	-421098	-422670	-422794	-423212	-423785	-424415	-425067	-409485
541	-416666	-416519	-416458	-416432	-416417	-414360	-416565	-416446	-417427	-416795	-416530	-416422	-416363	-406885
542	-222504	-222178	-221874	-221591	-221316	-219831	-220603	-220399	-220788	-220335	-219956	-219621	-219314	-213486
543	-228619	-227745	-226955	-226202	-225474	-222769	-224157	-223349	-223572	-222290	-221342	-220525	-219769	-209356
544	-451984	-451405	-450911	-450455	-450022	-447546	-449332	-448775	-449314	-448263	-447582	-447048	-446564	-436043
545	-364458	-364166	-363960	-363778	-363618	-361369	-363517	-363201	-364009	-363197	-362775	-362502	-362291	-351629
546	-455591	-455341	-455206	-455101	-455009	-452448	-455306	-454846	-455884	-454907	-454561	-454389	-454276	-441972
547	870.0488	870.0488	870.0488	870.0488	870.0488	1740.098	1305.073	1305.073	870.0488	870.0488	870.0488	870.0488	870.0488	5214.988
548	-203944	-203271	-202699	-202152	-201633	-199054	-200794	-200154	-200633	-199512	-198765	-198166	-197631	-186966
549	-358946	-358943	-359023	-359124	-359247	-357341	-359642	-359648	-360725	-360226	-360078	-360075	-360130	-350282
550	-299984	-300179	-300475	-300797	-301143	-299340	-302079	-302257	-303605	-303265	-303348	-303597	-303897	-293809
551	652.4365	652.4365	652.4365	652.4365	652.4365	1304.873	978.6548	978.6548	652.4365	652.4365	652.4365	652.4365	652.4365	3910.641
552	-152930	-153190	-153480	-153784	-154095	-153167	-154571	-154955	-155953	-156074	-156270	-156518	-156789	-150961
553	-179278	-179211	-179191	-179198	-179223	-177658	-179201	-179253	-180093	-179759	-179596	-179518	-179478	-171523
554	-151727	-152240	-152806	-153415	-154034	-152834	-155311	-155895	-157409	-157554	-157949	-158463	-159031	-150529
555	-151544	-151478	-151476	-151506	-151546	-149823	-151664	-151703	-152634	-152219	-152049	-151997	-151987	-143117
556	-105042	-104995	-105031	-105124	-105255	-100933	-104634	-105102	-107753	-107454	-107305	-107263	-107298	-84965
557	-190725	-190553	-190382	-190211	-190041	-189668	-189615	-189452	-189392	-189223	-189053	-188885	-188717	-187536

Modeling Surface water-groundwater Interactions of Borkena River Catchment

558	-107126	-107161	-107247	-107374	-107530	-104080	-106939	-107376	-109586	-109521	-109531	-109595	-109706	-95321.9
559	-211469	-211375	-211313	-211276	-211247	-209833	-211059	-211086	-211787	-211514	-211348	-211239	-211170	-204193
560	-165243	-165221	-165297	-165396	-165508	-163600	-165921	-166892	-166494	-166336	-166348	-166422	-166531	-149770
561	-223648	-223778	-224010	-224278	-224571	-222738	-225354	-225489	-226774	-226405	-226440	-226626	-226861	-216602
562	-127552	-127573	-127657	-127772	-127897	-126237	-128178	-128279	-129286	-128955	-128859	-128879	-128952	-120151
563	-139119	-139460	-139869	-140333	-140826	-137690	-142315	-143273	-145091	-145037	-145374	-145866	-146395	-136000
564	-172459	-172699	-172940	-173180	-173417	-173266	-173738	-173987	-174425	-174641	-174857	-175071	-175284	-173584
565	-208045	-208272	-208583	-208930	-209287	-207594	-210191	-210963	-211442	-211356	-211541	-211823	-212140	-198336
566	-241529	-241662	-241886	-242149	-242437	-240521	-243273	-243358	-244673	-244232	-244251	-244439	-244679	-234023
567	797.3779	797.3779	797.3779	797.3779	797.3779	1594.756	1196.067	1196.067	797.3779	797.3779	797.3779	797.3779	797.3779	4779.405
568	-181450	-181338	-181333	-181368	-181418	-179255	-181816	-181663	-182764	-182101	-181902	-181877	-181905	-170968
569	-212269	-212464	-212754	-213085	-213429	-211506	-214482	-215715	-215255	-215319	-215575	-215885	-216222	-197187
570	-140871	-141502	-142142	-142791	-143438	-143315	-144534	-145230	-146306	-146894	-147495	-148105	-148724	-145467
571	-104661	-104335	-104085	-103896	-103746	-99166.8	-102546	-102731	-105089	-104517	-104095	-103781	-103543	-81120
572	-144781	-145540	-146301	-147062	-147822	-148034	-149158	-149945	-150998	-151729	-152458	-153191	-153923	-151926
573	-40959.9	-40801.7	-40708.9	-40650.7	-40624	-36795.2	-40509	-41912.5	-41526.8	-41278.2	-41116.2	-41020.1	-40959.2	-11306.1
574	-142256	-142596	-142977	-143374	-143787	-142760	-144486	-145294	-145966	-146159	-146444	-146780	-147141	-137962
575	-6195.23	-6565.59	-6830.37	-7026	-7178.41	-2390.53	-6488.72	-6850.17	-9571.51	-8997.43	-8622.83	-8380.71	-8235.31	16362.33
576	8680.438	8680.438	8680.438	8680.438	8680.438	13972.6	11326.52	9648.517	8680.438	8680.438	8680.438	8680.438	8680.438	47048.62
577	-69131.5	-69196.2	-69327.7	-69508	-69720.9	-65804.1	-69254.6	-69773.1	-72297.8	-72167	-72149.5	-72212.9	-72338.4	-51818.8
578	-280898	-281085	-281332	-281608	-281892	-280436	-282448	-282725	-283870	-283707	-283769	-283934	-284148	-275939
579	-181302	-181720	-182233	-182799	-183364	-181643	-184864	-185176	-186795	-186577	-186882	-187351	-187888	-176945
580	507.4951	507.4951	507.4951	507.4951	507.4951	1014.99	761.2427	761.2427	507.4951	507.4951	507.4951	507.4951	507.4951	3041.876
581	-165337	-165077	-164914	-164776	-164661	-162491	-164611	-164374	-165243	-164514	-164152	-163936	-163781	-153484
582	-725128	-726790	-728499	-730223	-731951	-731888	-735395	-737084	-739660	-740892	-742351	-743910	-745506	-738264
583	-186413	-186993	-187620	-188274	-188937	-187987	-190209	-190895	-192384	-192669	-193137	-193691	-194291	-186844

### Modeling Surface water-groundwater Interactions of Borkena River Catchment

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584	-58770.7	-58656.3	-58620.8	-58640.9	-58704	-54370	-57954	-58343.4	-60864.1	-60519.9	-60321.2	-60221.7	-60201	-38194
585	-187881	-187295	-186777	-186294	-185835	-183456	-184999	-184483	-184973	-183988	-183300	-182750	-182256	-172554
586	-155701	-155455	-155316	-155253	-155242	-150245	-154400	-156867	-156852	-156465	-156229	-156099	-156039	-118883
587	-28501.8	-28348.6	-28193.7	-28037.9	-27881.3	-27585	-27501.7	-27344.9	-27255.5	-27092.9	-26929.4	-26765	-26599.8	-25754.4
588	-235758	-235841	-235960	-236106	-236270	-234870	-236497	-237358	-237373	-237337	-237394	-237505	-237634	-225366

## Modeling Surface water-groundwater Interactions of Borkena River Catchment

### Appendix: 7 Existing Boreholes data in and around the study area

X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thickness	ID	Kebele	Woreda
564405	1226806	2282	0	2282	500	80	9	955	71							KCVTW-01-19	Gerado	Gerado
578915	1226614	1850	10	1840	600	76	9	978	70							KCVTW-02-19	Kombolcha	Kombolcha
586889	1189939	1445	0	1445	512	75	9	1030	76		45					KCVTW-03-19	Kemisse	
567288	1226698	2331	0	2331												SS	Sholla Sefer	Gerado
565155	1226185	2236	0	2236												GR	Gerado River	Gerado
593144	1212252	1817	0	1817	160	18	5	368	120	14							Adame	Kalu
579513	1225734	1806	4.25	1802	120	55	2.00	101.00	38	96	49					Aykel o1	Kombolcha)	Kalu
569164	1239609	2609	41.05	2568	133	7	18.10	744.00	1	534							Kebele 012	Desse
579428	1223639	1820	10.00	1810	300												Kebele 010	Kombolcha
590842	1185334	1415	0.00	1415	280	78	4.44	453.00	15	352							Kachre	Kemisse
595434	1187105	1482	3.77	1478	168	30	3.34	198.00	9	213							Bilacha	Dewa chefa
600040	1164990	1450	2.11	1448	239	62	2.24	168.00	33	164						JRTW1	Chefa Drie	Artuma Fursie
585874	1203916	1457	0.00	1457	324	49	2.42	246.00	45	115						HCKTW#5	Kebele33	Kalu
567663	1238587	2604	41.60	2562	220	25	23.75	534.00	11	188						Kebele12	Kebele12	Desse Zuria
597026	1188581	1558	29.00	1529	176	12	0.55	8.24	103	10							Dodo	Dewa Chefa
595252	1273727	1404	0.00	1404	310	20	0.20	9.75	134	12	19					JRTW2	Dimitu	Artuma Fursie
595787	1186010	1468	23.24	1445		5	0.89	26.70	18	20	6					BH-4	Kemisse	
596677	1186674	1480	11.13	1469		6	0.05	4.35	69	7						KW-1	Kemisse	
595177	1186027	1452	7.88	1444		12	0.01	7.60		13			0.011			KW-2	Kemisse	
595587	1186262	1465	5.97	1459		10	0.44	29.40	104	25			0.000135			KW-3	Kemisse	
595460	1186868	1476	5.84	1470		6	0.09	6.73	58	7	5					KW-4	Kemisse	
597223	1184755	1466	13.55	1452		25	0.45	29.60	54	36	28					KW-5	Kemisse	

Modeling Surface water-groundwater Interactions of Borkena River Catchment

X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thickness	ID	Kebele	Woreda
583702	1206651	1465	0.50	1465	250	39	0.41	37.10	79	43							Harbu	Kalu
579513	1225734	1464	4.25	1460	120	55	2.74	155.00	38	96	49					KW-2	Kombolcha)	
602477	1155480	1668	2.40	1666	200	10	0.79	61.50	17	53						Korimeda	Derensa	Artuma Fursie
561487	1244816	2670	3.20	2667	171	28	3.08	201.00	14	172						Kutaber	Kutaber	Kutaber
582702	1226019	1941	0.00	1941		25	4.44	128.50	10	207	31						Mitiko	Kombolcha
600930	1172719	1422	9.10	1413		17	0.30	14.40	54	27	17						Chereti	Artuma Fursie
595587	1186262	1465	6.24	1459		7	0.45	29.40	31								Kemisse	
585980	1192246	1460	0.00	1460	166	25	0.55	26.80	69	26							Tuche	Dewecheffa
590444	1185133	1417	0.00	1417	260	19	0.07	6.20	170	10						HCKPW-14	Gerbi	Dewa cheffa
602713	1135272	1430	4.00	1426	150	28	1.94	92.10	27	85							Awlal	Jile-Tumuga
559356	1214779	2922	0.00	2922	113	26	0.38	20.00	64	28							Gelsha	Desse Zuria
568373	1238516	2604	42.70	2561	234	27	6.66	399.50	26	87							Borumeda	Desse
585039	1206427	1475	6.00	1469	99			524.70									HrBH2	
586176	1205455	1471	0.00	1471	140												HrBH3	
584805	1208278	1485	0.00	1485	146	26	0.30	47.90	57	1							HrBH3	
584465	1208654	1489	0.00	1489	121	27	0.40	52.60	54	1							HrW4	
596618	1186473	1485	7.90	1477	148	5	0.10	9.00	61	0							KW2	
595618	1186264	1463	6.30	1457	150	14	0.30	44.00	32	0							KW3	
595373	1186685	1473	6.30	1467	146												KW4	
597030	1184800	1463	9.30	1454	145												KW5	
586788	1186744	1457	14.50	1443	60												CKBH1	
586162	1182360	1491	48.70	1442	70												MBH1	
582837	1207610	1504	5.00	1499	268	20	0.20	26.00	81	0							HCKTW1	

Modeling Surface water-groundwater Interactions of Borkena River Catchment

X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thickness	ID	Kebele	Woreda
587540	1182638	1447	8.30	1439	252	60	12.60	1895.60	3	18						HCKTW2		
590050	1185850	1424	0.00	1424	260	66	1.60	241.90	28	2						HCKTW3		
595255	1173713	1406	0.00	1406	310	19	0.10	15.10	135	0						HCKTW5		
585874	1203916	1459	0.00	1459	324	60	0.90	137.90	45	1						HCKTW4		
595434	1187105	1482	4.10	1478	168	30	1.70	255.20	12	3						Bilacha		
589089	1194117	1436	0.00	1436	150	34	0.70	110.60	32	1						Girma's bh		
593221	1172648	1423	0.00	1423	190											H/Mesno bh		
600930	1172719	1422	6.00	1416	144	17	0.20	32.30	54	0						Chereti bh		
595313	1167092	1478	11.00	1467	302		1.40	207.10		2						JRTW2		
600413	1162829	1466	0.00	1466	75	7	3.00	445.60	2	4						Cheri bh1		
600677	1162923	1462	3.00	1459	88	7	2.30	348.80	2	3						Cheri bh2		
567663	1238587	2604	41.60	2562	220	25	12.70									Desse Zuria		
593144	1212252	1817	2.00	1815	160	18	2.81	195.50	120							Adame Kebele		
569164	1239609	2609	41.00	2568	133	7	18.10	744.00	1							Boru Silasse Kb012		
583702	1206651	1465	0.00	1465	250	30	0.37	33.40	79							Harbu Kutaber		
590347	1193365	1439	5.40	1434	148	21										Dawachefa Shekla		
568373	1238516	2604	42.70	2561	234	27	6.70	399.50	26							Wollo University Desse		
596677	1186674	1480	11.13	1469		9	0.05	4.30	69							Kemmise Kw-1		
590842	1185334	1415	0.00	1415	280	78	4.25	433.50	15							Gerbi HCKPW 15		
595434	1187108	1484	4.00	1480	168	30	3.15	186.50	9							Bilacha DewaChefa		
590047	1185849	1408	0.00	1408	260	66	3.00	309.50	23							HCKTW 3 Dessie Zura		
590425	1186041	1417	0.00	1417	247	62	6.60	633.50	14							HCKPW07 Dewachefa		
578915	1226614	1850	0.00	1850	324	80										KCPW 2R		

Modeling Surface water-groundwater Interactions of Borkena River Catchment

X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thicknes	ID	Kebele	Woreda
602477	1155480	1668	2.40	1666	200	10	0.80	61.50	17							Derensa BH Chefa Robit Kori meda		
590444	1185133	1417	0.00	1417	260	20	0.08	7.30	144							HCKPW 14		
588407	1189227	1428	4.70	1423	300	65	36.60	172.00	34	2						KCPW-1	Mekoy	
579066	1226301	1838	6.96	1831	153	43	6.29	303.00	73	1						KCPW-2	Kombolcha	
578915	1226614	1850	0.00	1850	258	63	7.27	552.00	79	1						KCPW2R(Alluvial deposited)	Kombolcha	
573560	1278119	1558	58.40	1500	300	69	14.70	1580.00	39	2						KCPW-3	Urgesa	
564079	1227125	2218	0.00	2218	300	50	1.90	163.00	9	1						KCPW-5	Gerado	
579647	1226175	1836	0.00	1836	100	10										BH-1	Dewey	
579266	1228118	1855	0.00	1855	100	6										BH-3	Dewey	
579345	1226470	1836	0.00	1836	110	25		333.50								BH-4	Dewey	
578542	1226092	1840	0.00	1840	112	21		101.00								BH-5	Sheshaber	
578233	1226301	1844	0.00	1844	97	19		207.40								BH-6	Sheshaber	
579324	1224747	1831	0.00	1831												BGI-3	Werka	
579290	1224952	1850	36.00	1814	240	16										BGI-New-1	Werka	
579474	1224993	1829	40.00	1789	240	18										BGI-New-2	Werka	
579053	1225221	1832	19.00	1813	180	12										TEX-7	Eyole	
578959	1225361	1840	8.00	1832	71	8										TEX-1	Eyole	
579513	1225734	1833	5.57	1827	120	50			45							Well-2		
580142	1224437	1806	4.25	1802	120	50			45							Aykel-01		
579376	1226205	1835	1.66	1833	140		2.98	125.14	26	168						Well-one		
578936	1226045	1843	2.30	1841	144		2.67	125.71	17	153						Well-Two		
578718	1226240	1859	0.00	1859	113	14	2.01	81.40	16							PW1	Sheshaber	

Modeling Surface water-groundwater Interactions of Borkena River Catchment

X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thickness	ID	Kebele	Woreda
578528	1226346	1850	0.00	1850	105	14	2.61	135.00	12							PW2	Sheshaber	
579565	1226611	1848	0.00	1848	111	14	3.89	201.00	7							PW3	Dewey	
569164	1239609	2609	41.05	2568	133	7	18.10	744.00	1	534						Boru-Selassie	Hoteh	
603086	1163687	1447	3.00	1444	57	2										Delgo	Artuma-Fursi	
613895	1172141	1543	74.36	1469	131	6			24							Kichicho	Artuma-Fursi	
600930	1172719	1422	9.10	1413	144	17										Chereti	Artuma-Fursi	
603295	1164473	1460	6.00	1454	61											Delgo-2	Artuma-Fursi	
590425	1186041	1417	0.00	1417	247											HCKPW-7	Artuma-Fursi	
579350	1226465	1840	0.00	1840	110	14		201.00	7							PW-3	Dewey	Kombolcha
578231	1226297	1852	0.00	1852	105	14		135.00	12							PW-2	Sheshabir	Kombolcha
578537	1226089	1850	0.00	1850	113	14		81.40	16							PW-1	Sheshabir	Kombolcha
579513	1225734	1833	5.57	1827	120	50										W-4	Menafesha	Kombolcha
580183	1224417	1805		1805	182											W-5		Kombolcha
577636	1225730	1874	6.90	1867		7										KOSPI-1	Kospi factory	Kombolcha
569162	1239607	2606	41.50	2565	133	7		744.00	1							Boru-Selassie	Boru-Meda	Dessie
526730	1232362	2504	8.64	2495		6										MBH	Meteliya	Dessie
569589	1232065	2491	18.87	2472		10										GBH	Buanba weha	Dessie
569138	1232098	2497	26.10	2471												DDBH	Dawdo	Dessie
567817	1268256	1590	10.00	1580	125	6			21							TSW	Tisabalema	Ambasal
567983	1269605	1605	10.00	1595	183	12										WBH	Aromba	Ambasal
567514	1267867	1588	7.92	1580	253	57		519.00	14							TATW-1	Tisabalema	Ambasal
567307	1266660	1571	12.80	1558	248	62		343.00	21							TATW-2	Tisabalema	Ambasal
567094	1262617	1584	45.00	1539	51	1										GBOBH	Kentrie-wuha	Ambasal

Modeling Surface water-groundwater Interactions of Borkena River Catchment

X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thickness	ID	Kebele	Woreda
56741 1	126639 3	156 2	8.00	1554	51	4										TATW-3	Tissa(Manzerash)	Ambasal
56945 1	125824 2	166 6	20.0 0	1646	41											Mukwuha-1	Ambasal	Ambasal
56957 8	125654 6	167 1	4.00	1667	55	2										Jari-1	Ambasal	Ambasal
60350 4	116527 9	145 8	5.51	1452	76	19										CHW-3	Hulla-1	Artuma-Fursi
59509 2	118585 0	144 4	8.10	1436	150	10		71.12	74	12						KW-1	Goro Batu	Kemisse
59561 8	118647 3	148 0	6.81	1473	148	5	0.07	4.62	61	7						KW-2	Goro Batu	Kemisse
59561 8	118626 4	148 0	6.25	1474	150	14	0.53	35.16	32	36						KW-3	Goro Batu	Kemisse
59537 3	118668 5	146 3	6.33	1457	146	7	0.62	44.64	11	49						KW-4	Goro Batu	Kemisse
59703 0	118480 0	148 1	9.25	1472	145	19	1.97	130.20	12	137						KW-5	Jeneto	Kemisse
59084 2	118533 4	142 2	0.00	1422	280											KTW-1(HCKPW-15)	Kachur	Kemisse
59044 4	118513 3	142 8	0.00	1428	260											KTW-2(HCKPW-14)	Kachur	Kemisse
59005 0	118585 0	142 3	0.00	1423	260	66		316.00	28							HCKTW 3	Gerbi	Dawa-Chefa
59278 2	118417 0	141 8	0.00	1418												KW-6	Kachur	Kemisse
60327 9	116282 0	144 5	6.92	1438												JRW-1	Jara-kechema	Artuma-Fursi
59531 3	116709 2	149 0	12.7 0	1477	302	53	2.48	268.00	25							JRTW-2	Getem-Gogo wuha	Antsokia gemza
60247 7	115548 0	166 8	1.00	1667	200											Kori-1	Kori-Meda	Artuma-Fursi
59525 2	117372 7	140 7	0.00	1407	310	19			135							CHBH-3(JRTW-3)	Aba-Jilo	Artuma-Fursi
61389 5	117214 1	154 3	74.5 7	1468	131	6			24							Kich-1	Kichicho	Artuma-Fursi
60093 0	117271 9	142 2	9.15	1413	144	17			54							Cher-1	Chereti	Artuma-Fursi
60308 6	116368 7	144 7	3.00	1444	57	2										Delgo	Chefa Dire	Artuma-Fursi
60296 9	116023 7	150 4	3.00	1501	62	6										Merere	Jara Kachama	Artuma-Fursi
60329 5	116447 3	146 0	6.00	1454	61	0										Delgo-2	Ulatukuye	Artuma-Fursi
58503 9	120642 7	147 9	6.00	1473		7										HrBH-2	Harbu(Fecha)	Kalu

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X	Y	Z	SWL	GW L	Depth(m)	Q (l/s)	K (m/d)	T (m <sup>2</sup> /d)	Drawdown (m)	Sc (m <sup>2</sup> /d)	Sy (l/s)	Ss (l/m)	S	Kriv (m/d)	Aquifer Thickness	ID	Kebele	Woreda
580176	1205455	1466	0.00	1466		6										HrBH-1	Harbu(Fecha)	Kalu
585869	1203922	1470	0.00	1470	324											HrBH-5	Harbu(Mar bet)	Kalu
582837	1207610	1500	4.15	1496	268	20			86							HCKTW1	Harbu(Weraba)	Kalu
584805	1208278	1485	0.00	1485	146	26	1.12	405.00	57							HrBH-3	Harbu(Melka Chefa)	Kalu
579654	1226173	1843	0.00	1843	100											W1	Dewey	Kombolcha
579268	1228120	1866	0.00	1866	100	6										W3	Dewey	Kombolcha
578913	1226081	1837	2.30	1835	144	30	2.67	135.50	17							KBH-2	Sheshabir	Kombolcha
579350	1226465	1830	1.93	1828	140	50		216.00	26							KBH-1	Dewey	Kombolcha

Appendix: 8 Assigned River Cells and Observation Wells in to Modflow

# Borkena river catchment groundwater flow model										
# River (RIV) package input file										
# Assigned River Cells						#Observation Cells				
Layer	Row	Column	River Stage	River Conductance	River Elevation	No	Obs_well	Row	Column	layer of cell
49	0					16				
49	0					16				
1	12	13	1825.703	60000	1825.6	1	Kutaber Well	3	2	1
1	13	13	1800.413	60000	1800	2	Borusillase	5	6	1
1	14	13	1776.773	70000	1776.6	3	Wollouniversity	6	5	1
1	14	12	1759.223	70000	1759	4	KCVTW-02-19	12	11	1
1	15	12	1730.358	80000	1730.2	5	BGI New-2	13	11	1
1	16	12	1703.918	80000	1703.7	6	HCKTW1	21	13	1

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1	17	12	1675.774	90000	1675.6	7	Harbu	22	13	1
1	18	12	1658.238	90000	1657.9	8	KCVTW-03-19	30	15	1
1	18	11	1623.308	80000	1623.1	9	Bilacha Keb	32	19	1
1	19	11	1556.166	85000	1550.9	10	KW-2	32	19	1
1	20	11	1498.866	66667	1498.7	11	HCKTW2	34	15	1
1	21	11	1487.626	66667	1487.3	12	H/mesno bh	39	18	1
1	21	10	1482.738	77778	1482.3	13	Chereti bh	39	22	1
1	22	10	1473.258	78000	1472.9	14	Tuche	29	14	1
1	22	11	1469.728	88000	1469.7	15	KCPW#5	23	14	1
1	23	11	1459.906	98700	1459.8	16	HCKTW3	32	16	1
1	23	10	1459.786	100000	1459.6					
1	24	10	1457.326	100000	1457					
1	24	9	1453.228	120000	1453					
1	25	9	1449.956	120000	1449.9					
1	25	10	1447.746	130000	1447.6					
1	26	10	1447.446	133000	1447.3					
1	27	10	1443.566	133000	1443.2					
1	27	9	1441.238	135000	1441.4					
1	28	9	1440.818	140000	1440.7					
1	28	8	1436.908	145000	1436.8					
1	29	8	1435.321	155000	1435.2					
1	29	7	1431.606	155000	1431.5					
1	30	7	1430.908	155000	1430.8					
1	30	8	1430.816	167000	1430.7					
1	31	8	1426.646	167000	1426.5					

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1	32	8	1423.186	167000	1423
1	32	7	1422.708	171000	1422
1	33	7	1419.958	171000	1419.8
1	34	7	1416.346	171000	1416.2
1	34	6	1415.096	171000	1414.9
1	35	6	1412.996	178000	1412.9
1	34	6	1412.508	178000	1412.4
1	34	5	1412.408	178000	1412.3
1	35	5	1412.377	183000	1412.2
1	34	5	1411.996	183000	1411.9
1	34	4	1410.678	183000	1410.5
1	35	4	1410.407	185000	1410.2
1	36	4	1409.887	185000	1409.7

## Modeling Surface water-groundwater Interactions of Borkena River Catchment

### Appendix 9 Observed Flow Data for Calibration

No	Date	MM	DD	YY	Flow	Sim_F	No	Date	MM	DD	YY	Flow	Sim_F								
1	1/31/2000	1	31	2000	001	_	FLOW_OUT_1	FLOW_OUT_001_2000	1.486	4.061	51	3/31/2004	3	31	2004	051	_	FLOW_OUT_51	FLOW_OUT_051_2004	0.262	0.262
2	2/29/2000	2	29	2000	002	_	FLOW_OUT_2	FLOW_OUT_002_2000	0.417	3.44	52	4/30/2004	4	30	2004	052	_	FLOW_OUT_52	FLOW_OUT_052_2004	4.718	4.718
3	3/31/2000	3	31	2000	003	_	FLOW_OUT_3	FLOW_OUT_003_2000	0.028	2.54	53	5/31/2004	5	31	2004	053	_	FLOW_OUT_53	FLOW_OUT_053_2004	0.994	0.994
4	4/30/2000	4	30	2000	004	_	FLOW_OUT_4	FLOW_OUT_004_2000	0.028	4.04	54	6/30/2004	6	30	2004	054	_	FLOW_OUT_54	FLOW_OUT_054_2004	0.187	0.187
5	5/31/2000	5	31	2000	005	_	FLOW_OUT_5	FLOW_OUT_005_2000	2.191	5.12	55	7/31/2004	7	31	2004	055	_	FLOW_OUT_55	FLOW_OUT_055_2004	8.266	8.266
6	6/30/2000	6	30	2000	006	_	FLOW_OUT_6	FLOW_OUT_006_2000	0.027	1.56	56	8/31/2004	8	31	2004	056	_	FLOW_OUT_56	FLOW_OUT_056_2004	53.673	53.673
7	7/31/2000	7	31	2000	007	_	FLOW_OUT_7	FLOW_OUT_007_2000	8.55	3.862	57	9/30/2004	9	30	2004	057	_	FLOW_OUT_57	FLOW_OUT_057_2004	9.713	9.713
8	8/31/2000	8	31	2000	008	_	FLOW_OUT_8	FLOW_OUT_008_2000	45.55	34.09	58	10/31/2004	10	31	2004	058	_	FLOW_OUT_58	FLOW_OUT_058_2004	5.308	5.308
9	9/30/2000	9	30	2000	009	_	FLOW_OUT_9	FLOW_OUT_009_2000	32.016	15.39	59	11/30/2004	11	30	2004	059	_	FLOW_OUT_59	FLOW_OUT_059_2004	0.541	0.541
10	10/31/2000	10	31	2000	010	_	FLOW_OUT_10	FLOW_OUT_010_2000	7.843	13.74	60	12/31/2004	12	31	2004	060	_	FLOW_OUT_60	FLOW_OUT_060_2004	0.434	0.434
11	11/30/2000	11	30	2000	011	_	FLOW_OUT_11	FLOW_OUT_011_2000	6.781	6.205	61	1/31/2005	1	31	2005	061	_	FLOW_OUT_61	FLOW_OUT_061_2005	0.217	0.217
12	12/31/2000	12	31	2000	012	_	FLOW_OUT_12	FLOW_OUT_012_2000	3.76	3.684	62	2/28/2005	2	28	2005	062	_	FLOW_OUT_62	FLOW_OUT_062_2005	0.222	0.222
13	1/31/2001	1	31	2001	013	_	FLOW_OUT_13	FLOW_OUT_013_2001	1.43	0.9833	63	3/31/2005	3	31	2005	063	_	FLOW_OUT_63	FLOW_OUT_063_2005	3.119	3.119
14	2/28/2001	2	28	2001	014	_	FLOW_OUT_14	FLOW_OUT_014_2001	0.657	4.566	64	4/30/2005	4	30	2005	064	_	FLOW_OUT_64	FLOW_OUT_064_2005	1.599	1.599
15	3/31/2001	3	31	2001	015	_	FLOW_OUT_15	FLOW_OUT_015_2001	5.351	16.93	65	5/31/2005	5	31	2005	065	_	FLOW_OUT_65	FLOW_OUT_065_2005	9.805	9.805
16	4/30/2001	4	30	2001	016	_	FLOW_OUT_16	FLOW_OUT_016_2001	1.999	9.879	66	6/30/2005	6	30	2005	066	_	FLOW_OUT_66	FLOW_OUT_066_2005	0.581	0.581
17	5/31/2001	5	31	2001	017	_	FLOW_OUT_17	FLOW_OUT_017_2001	0.59	10.56	67	7/31/2005	7	31	2005	067	_	FLOW_OUT_67	FLOW_OUT_067_2005	24.646	10.54
18	6/30/2001	6	30	2001	018	_	FLOW_OUT_18	FLOW_OUT_018_2001	0.105	5.842	68	8/31/2005	8	31	2005	068	_	FLOW_OUT_68	FLOW_OUT_068_2005	37.245	41.27
19	7/31/2001	7	31	2001	019	_	FLOW_OUT_19	FLOW_OUT_019_2001	30.22	13.44	69	9/30/2005	9	30	2005	069	_	FLOW_OUT_69	FLOW_OUT_069_2005	20.356	10.75
20	8/31/2001	8	31	2001	020	_	FLOW_OUT_20	FLOW_OUT_020_2001	35.58	28.18	70	10/31/2005	10	31	2005	070	_	FLOW_OUT_70	FLOW_OUT_070_2005	5.393	5.393
21	9/30/2001	9	30	2001	021	_	FLOW_OUT_21	FLOW_OUT_021_2001	30.78	24.35	71	11/30/2005	11	30	2005	071	_	FLOW_OUT_71	FLOW_OUT_071_2005	1.045	1.045
22	10/31/2001	10	31	2001	022	_	FLOW_OUT_22	FLOW_OUT_022_2001	4.309	6.036	72	12/31/2005	12	31	2005	072	_	FLOW_OUT_72	FLOW_OUT_072_2005	0.519	0.519
23	11/30/2001	11	30	2001	023	_	FLOW_OUT_23	FLOW_OUT_023_2001	1.243	3.151	73	1/31/2006	1	31	2006	073	_	FLOW_OUT_73	FLOW_OUT_073_2006	0.469	0.469
24	12/31/2001	12	31	2001	024	_	FLOW_OUT_24	FLOW_OUT_024_2001	0.887	0.99	74	2/28/2006	2	28	2006	074	_	FLOW_OUT_74	FLOW_OUT_074_2006	0.327	0.327

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25	1/31/2002	1	31	2002	025	_	FLOW_OUT_	25	FLOW_OUT_025_2002	0.312	0.5402	75	3/31/2006	3	31	2006	075	_	FLOW_OUT_	75	FLOW_OUT_075_2006	0.419	0.419
26	2/28/2002	2	28	2002	026	_	FLOW_OUT_	26	FLOW_OUT_026_2002	0.495	0.4624	76	4/30/2006	4	30	2006	076	_	FLOW_OUT_	76	FLOW_OUT_076_2006	9.359	9.359
27	3/31/2002	3	31	2002	027	_	FLOW_OUT_	27	FLOW_OUT_027_2002	1.176	4.926	77	5/31/2006	5	31	2006	077	_	FLOW_OUT_	77	FLOW_OUT_077_2006	1.057	1.057
28	4/30/2002	4	30	2002	028	_	FLOW_OUT_	28	FLOW_OUT_028_2002	3.441	2.758	78	6/30/2006	6	30	2006	078	_	FLOW_OUT_	78	FLOW_OUT_078_2006	0.036	0.036
29	5/31/2002	5	31	2002	029	_	FLOW_OUT_	29	FLOW_OUT_029_2002	1.057	14.94	79	7/31/2006	7	31	2006	079	_	FLOW_OUT_	79	FLOW_OUT_079_2006	16.94	16.94
30	6/30/2002	6	30	2002	030	_	FLOW_OUT_	30	FLOW_OUT_030_2002	0.036	3.535	80	8/31/2006	8	31	2006	080	_	FLOW_OUT_	80	FLOW_OUT_080_2006	25.751	25.751
31	7/31/2002	7	31	2002	031	_	FLOW_OUT_	31	FLOW_OUT_031_2002	13.68	6.59	81	9/30/2006	9	30	2006	081	_	FLOW_OUT_	81	FLOW_OUT_081_2006	19.541	3.672
32	8/31/2002	8	31	2002	032	_	FLOW_OUT_	32	FLOW_OUT_032_2002	6.23	4.45	82	10/31/2006	10	31	2006	082	_	FLOW_OUT_	82	FLOW_OUT_082_2006	8.335	8.335
33	9/30/2002	9	30	2002	033	_	FLOW_OUT_	33	FLOW_OUT_033_2002	10.514	8.244	83	11/30/2006	11	30	2006	083	_	FLOW_OUT_	83	FLOW_OUT_083_2006	14.111	7.11
34	10/31/2002	10	31	2002	034	_	FLOW_OUT_	34	FLOW_OUT_034_2002	2.971	1.366	84	12/31/2006	12	31	2006	084	_	FLOW_OUT_	84	FLOW_OUT_084_2006	5.553	5.553
35	11/30/2002	11	30	2002	035	_	FLOW_OUT_	35	FLOW_OUT_035_2002	0.31	1.557	85	1/31/2007	1	31	2007	085	_	FLOW_OUT_	85	FLOW_OUT_085_2007	0.312	0.312
36	12/31/2002	12	31	2002	036	_	FLOW_OUT_	36	FLOW_OUT_036_2002	1.988	6.359	86	2/28/2007	2	28	2007	086	_	FLOW_OUT_	86	FLOW_OUT_086_2007	3.054	0.495
37	1/31/2003	1	31	2003	037	_	FLOW_OUT_	37	FLOW_OUT_037_2003	4.474	1.703	87	3/31/2007	3	31	2007	087	_	FLOW_OUT_	87	FLOW_OUT_087_2007	1.176	1.176
38	2/28/2003	2	28	2003	038	_	FLOW_OUT_	38	FLOW_OUT_038_2003	3.264	0.906	88	4/30/2007	4	30	2007	088	_	FLOW_OUT_	88	FLOW_OUT_088_2007	3.441	3.441
39	3/31/2003	3	31	2003	039	_	FLOW_OUT_	39	FLOW_OUT_039_2003	5.851	1.71	89	5/31/2007	5	31	2007	089	_	FLOW_OUT_	89	FLOW_OUT_089_2007	1.057	1.057
40	4/30/2003	4	30	2003	040	_	FLOW_OUT_	40	FLOW_OUT_040_2003	0.275	25.22	90	6/30/2007	6	30	2007	090	_	FLOW_OUT_	90	FLOW_OUT_090_2007	0.036	0.036
41	5/31/2003	5	31	2003	041	_	FLOW_OUT_	41	FLOW_OUT_041_2003	2.926	10.86	91	7/31/2007	7	31	2007	091	_	FLOW_OUT_	91	FLOW_OUT_091_2007	16.94	16.94
42	6/30/2003	6	30	2003	042	_	FLOW_OUT_	42	FLOW_OUT_042_2003	0.207	0.7664	92	8/31/2007	8	31	2007	092	_	FLOW_OUT_	92	FLOW_OUT_092_2007	25.751	25.751
43	7/31/2003	7	31	2003	043	_	FLOW_OUT_	43	FLOW_OUT_043_2003	6.112	15.93	93	9/30/2007	9	30	2007	093	_	FLOW_OUT_	93	FLOW_OUT_093_2007	3.672	3.672
44	8/31/2003	8	31	2003	044	_	FLOW_OUT_	44	FLOW_OUT_044_2003	50.546	35.53	94	10/31/2007	10	31	2007	094	_	FLOW_OUT_	94	FLOW_OUT_094_2007	5.645	5.645
45	9/30/2003	9	30	2003	045	_	FLOW_OUT_	45	FLOW_OUT_045_2003	27.928	29.56	95	11/30/2007	11	30	2007	095	_	FLOW_OUT_	95	FLOW_OUT_095_2007	2.011	2.3
46	10/31/2003	10	31	2003	046	_	FLOW_OUT_	46	FLOW_OUT_046_2003	7.621	2.28	96	12/31/2007	12	31	2007	096	_	FLOW_OUT_	96	FLOW_OUT_096_2007	1.341	1.341
47	11/30/2003	11	30	2003	047	_	FLOW_OUT_	47	FLOW_OUT_047_2003	0.75	0.8097												
48	12/31/2003	12	31	2003	048	_	FLOW_OUT_	48	FLOW_OUT_048_2003	1.616	0.9937												
49	1/31/2004	1	31	2004	049	_	FLOW_OUT_	49	FLOW_OUT_049_2004	0.85	0.3602												
50	2/29/2004	2	29	2004	050	_	FLOW_OUT_	50	FLOW_OUT_050_2004	1.527	1.701												

## Modeling Surface water-groundwater Interactions of Borkena River Catchment

### Appendix: 10 Observed flow data for Validation

No	Date	MM	DD	YY	Flow	No	Date	MM	DD	YY	Flow
1	1/31/2008	1	31	2008	001	1	1/31/2008	1	31	2008	1.321
2	2/29/2008	2	29	2008	002	2	2/29/2008	2	29	2008	0.851
3	3/31/2008	3	31	2008	003	3	3/31/2008	3	31	2008	0.652
4	4/30/2008	4	30	2008	004	4	4/30/2008	4	30	2008	0.652
5	5/31/2008	5	31	2008	005	5	5/31/2008	5	31	2008	0.652
6	6/30/2008	6	30	2008	006	6	6/30/2008	6	30	2008	0.652
7	7/31/2008	7	31	2008	007	7	7/31/2008	7	31	2008	13.848
8	8/31/2008	8	31	2008	008	8	8/31/2008	8	31	2008	48.019
9	9/30/2008	9	30	2008	009	9	9/30/2008	9	30	2008	14.285
10	10/31/2008	10	31	2008	010	10	10/31/2008	10	31	2008	6.414
11	11/30/2008	11	30	2008	011	11	11/30/2008	11	30	2008	2.282
12	12/31/2008	12	31	2008	012	12	12/31/2008	12	31	2008	0.925
13	1/31/2009	1	31	2009	013	13	1/31/2009	1	31	2009	4.474
14	2/28/2009	2	28	2009	014	14	2/28/2009	2	28	2009	3.264
15	3/31/2009	3	31	2009	015	15	3/31/2009	3	31	2009	8.234
16	4/30/2009	4	30	2009	016	16	4/30/2009	4	30	2009	6.321
17	5/31/2009	5	31	2009	017	17	5/31/2009	5	31	2009	2.094
18	6/30/2009	6	30	2009	018	18	6/30/2009	6	30	2009	0.828
19	7/31/2009	7	31	2009	019	19	7/31/2009	7	31	2009	17.537
20	8/31/2009	8	31	2009	020	20	8/31/2009	8	31	2009	43.575
21	9/30/2009	9	30	2009	021	21	9/30/2009	9	30	2009	26.292
22	10/31/2009	10	31	2009	022	22	10/31/2009	10	31	2009	1.969
23	11/30/2009	11	30	2009	023	23	11/30/2009	11	30	2009	1.022
24	12/31/2009	12	31	2009	024	24	12/31/2009	12	31	2009	4.863

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25	1/31/2010	1	31	2010	025	_	FLOW_OUT_	25	FLOW_OUT_025_2010	4.474	49	1/31/2012	1	31	2012	049	_	FLOW_OUT_	49	FLOW_OUT_049_2012	1.097
26	2/28/2010	2	28	2010	026	_	FLOW_OUT_	26	FLOW_OUT_026_2010	3.264	50	2/29/2012	2	29	2012	050	_	FLOW_OUT_	50	FLOW_OUT_050_2012	0.896
27	3/31/2010	3	31	2010	027	_	FLOW_OUT_	27	FLOW_OUT_027_2010	5.851	51	3/31/2012	3	31	2012	051	_	FLOW_OUT_	51	FLOW_OUT_051_2012	0.659
28	4/30/2010	4	30	2010	028	_	FLOW_OUT_	28	FLOW_OUT_028_2010	0.275	52	4/30/2012	4	30	2012	052	_	FLOW_OUT_	52	FLOW_OUT_052_2012	8.989
29	5/31/2010	5	31	2010	029	_	FLOW_OUT_	29	FLOW_OUT_029_2010	6.123	53	5/31/2012	5	31	2012	053	_	FLOW_OUT_	53	FLOW_OUT_053_2012	1.681
30	6/30/2010	6	30	2010	030	_	FLOW_OUT_	30	FLOW_OUT_030_2010	0.096	54	6/30/2012	6	30	2012	054	_	FLOW_OUT_	54	FLOW_OUT_054_2012	2.312
31	7/31/2010	7	31	2010	031	_	FLOW_OUT_	31	FLOW_OUT_031_2010	7.63	55	7/31/2012	7	31	2012	055	_	FLOW_OUT_	55	FLOW_OUT_055_2012	17.537
32	8/31/2010	8	31	2010	032	_	FLOW_OUT_	32	FLOW_OUT_032_2010	14.123	56	8/31/2012	8	31	2012	056	_	FLOW_OUT_	56	FLOW_OUT_056_2012	43.575
33	9/30/2010	9	30	2010	033	_	FLOW_OUT_	33	FLOW_OUT_033_2010	10.226	57	9/30/2012	9	30	2012	057	_	FLOW_OUT_	57	FLOW_OUT_057_2012	14.576
34	10/31/2010	10	31	2010	034	_	FLOW_OUT_	34	FLOW_OUT_034_2010	12.33	58	10/31/2012	10	31	2012	058	_	FLOW_OUT_	58	FLOW_OUT_058_2012	2.03
35	11/30/2010	11	30	2010	035	_	FLOW_OUT_	35	FLOW_OUT_035_2010	2.144	59	11/30/2012	11	30	2012	059	_	FLOW_OUT_	59	FLOW_OUT_059_2012	1.423
36	12/31/2010	12	31	2010	036	_	FLOW_OUT_	36	FLOW_OUT_036_2010	1.939	60	12/31/2012	12	31	2012	060	_	FLOW_OUT_	60	FLOW_OUT_060_2012	0.424
37	1/31/2011	1	31	2011	037	_	FLOW_OUT_	37	FLOW_OUT_037_2011	1.516	61	1/31/2013	1	31	2013	061	_	FLOW_OUT_	61	FLOW_OUT_061_2013	0.055
38	2/28/2011	2	28	2011	038	_	FLOW_OUT_	38	FLOW_OUT_038_2011	1.301	62	2/28/2013	2	28	2013	062	_	FLOW_OUT_	62	FLOW_OUT_062_2013	0.055
39	3/31/2011	3	31	2011	039	_	FLOW_OUT_	39	FLOW_OUT_039_2011	20.68	63	3/31/2013	3	31	2013	063	_	FLOW_OUT_	63	FLOW_OUT_063_2013	0.058
40	4/30/2011	4	30	2011	040	_	FLOW_OUT_	40	FLOW_OUT_040_2011	1.556	64	4/30/2013	4	30	2013	064	_	FLOW_OUT_	64	FLOW_OUT_064_2013	0.082
41	5/31/2011	5	31	2011	041	_	FLOW_OUT_	41	FLOW_OUT_041_2011	2.221	65	5/31/2013	5	31	2013	065	_	FLOW_OUT_	65	FLOW_OUT_065_2013	0.118
42	6/30/2011	6	30	2011	042	_	FLOW_OUT_	42	FLOW_OUT_042_2011	2.014	66	6/30/2013	6	30	2013	066	_	FLOW_OUT_	66	FLOW_OUT_066_2013	0.057
43	7/31/2011	7	31	2011	043	_	FLOW_OUT_	43	FLOW_OUT_043_2011	3.117	67	7/31/2013	7	31	2013	067	_	FLOW_OUT_	67	FLOW_OUT_067_2013	26.368
44	8/31/2011	8	31	2011	044	_	FLOW_OUT_	44	FLOW_OUT_044_2011	42.377	68	8/31/2013	8	31	2013	068	_	FLOW_OUT_	68	FLOW_OUT_068_2013	39.45
45	9/30/2011	9	30	2011	045	_	FLOW_OUT_	45	FLOW_OUT_045_2011	6.08	69	9/30/2013	9	30	2013	069	_	FLOW_OUT_	69	FLOW_OUT_069_2013	28.793
46	10/31/2011	10	31	2011	046	_	FLOW_OUT_	46	FLOW_OUT_046_2011	2.04	70	10/31/2013	10	31	2013	070	_	FLOW_OUT_	70	FLOW_OUT_070_2013	6.911
47	11/30/2011	11	30	2011	047	_	FLOW_OUT_	47	FLOW_OUT_047_2011	1.355	71	11/30/2013	11	30	2013	071	_	FLOW_OUT_	71	FLOW_OUT_071_2013	2.793
48	12/31/2011	12	31	2011	048	_	FLOW_OUT_	48	FLOW_OUT_048_2011	1.12	72	12/31/2013	12	31	2013	072	_	FLOW_OUT_	72	FLOW_OUT_072_2013	1.798
49	1/31/2012	1	31	2012	049	_	FLOW_OUT_	49	FLOW_OUT_049_2012	1.097	73	1/31/2014	1	31	2014	073	_	FLOW_OUT_	73	FLOW_OUT_073_2014	1.359
50	2/29/2012	2	29	2012	050	_	FLOW_OUT_	50	FLOW_OUT_050_2012	0.896	74	2/28/2014	2	28	2014	074	_	FLOW_OUT_	74	FLOW_OUT_074_2014	5.987

### Modeling Surface water-groundwater Interactions of Borkena River Catchment

51	3/31/2012	3	31	2012	051	_	FLOW_OUT_	51	FLOW_OUT_051_2012	0.659	75	3/31/2014	3	31	2014	075	_	FLOW_OUT_	75	FLOW_OUT_075_2014	2.847
52	4/30/2012	4	30	2012	052	_	FLOW_OUT_	52	FLOW_OUT_052_2012	8.989	76	4/30/2014	4	30	2014	076	_	FLOW_OUT_	76	FLOW_OUT_076_2014	5.547
53	5/31/2012	5	31	2012	053	_	FLOW_OUT_	53	FLOW_OUT_053_2012	1.681	77	5/31/2014	5	31	2014	077	_	FLOW_OUT_	77	FLOW_OUT_077_2014	1.539
54	6/30/2012	6	30	2012	054	_	FLOW_OUT_	54	FLOW_OUT_054_2012	2.312	78	6/30/2014	6	30	2014	078	_	FLOW_OUT_	78	FLOW_OUT_078_2014	0.419
55	7/31/2012	7	31	2012	055	_	FLOW_OUT_	55	FLOW_OUT_055_2012	17.537	79	7/31/2014	7	31	2014	079	_	FLOW_OUT_	79	FLOW_OUT_079_2014	24.114
56	8/31/2012	8	31	2012	056	_	FLOW_OUT_	56	FLOW_OUT_056_2012	43.575	80	8/31/2014	8	31	2014	080	_	FLOW_OUT_	80	FLOW_OUT_080_2014	37.123
57	9/30/2012	9	30	2012	057	_	FLOW_OUT_	57	FLOW_OUT_057_2012	14.576	81	9/30/2014	9	30	2014	081	_	FLOW_OUT_	81	FLOW_OUT_081_2014	29.098
58	10/31/2012	10	31	2012	058	_	FLOW_OUT_	58	FLOW_OUT_058_2012	2.03	82	10/31/2014	10	31	2014	082	_	FLOW_OUT_	82	FLOW_OUT_082_2014	21.58
59	11/30/2012	11	30	2012	059	_	FLOW_OUT_	59	FLOW_OUT_059_2012	1.423	83	11/30/2014	11	30	2014	083	_	FLOW_OUT_	83	FLOW_OUT_083_2014	2.193
60	12/31/2012	12	31	2012	060	_	FLOW_OUT_	60	FLOW_OUT_060_2012	0.424	84	12/31/2014	12	31	2014	084	_	FLOW_OUT_	84	FLOW_OUT_084_2014	1.341
61	1/31/2013	1	31	2013	061	_	FLOW_OUT_	61	FLOW_OUT_061_2013	0.055											
62	2/28/2013	2	28	2013	062	_	FLOW_OUT_	62	FLOW_OUT_062_2013	0.055											
63	3/31/2013	3	31	2013	063	_	FLOW_OUT_	63	FLOW_OUT_063_2013	0.058											
64	4/30/2013	4	30	2013	064	_	FLOW_OUT_	64	FLOW_OUT_064_2013	0.082											