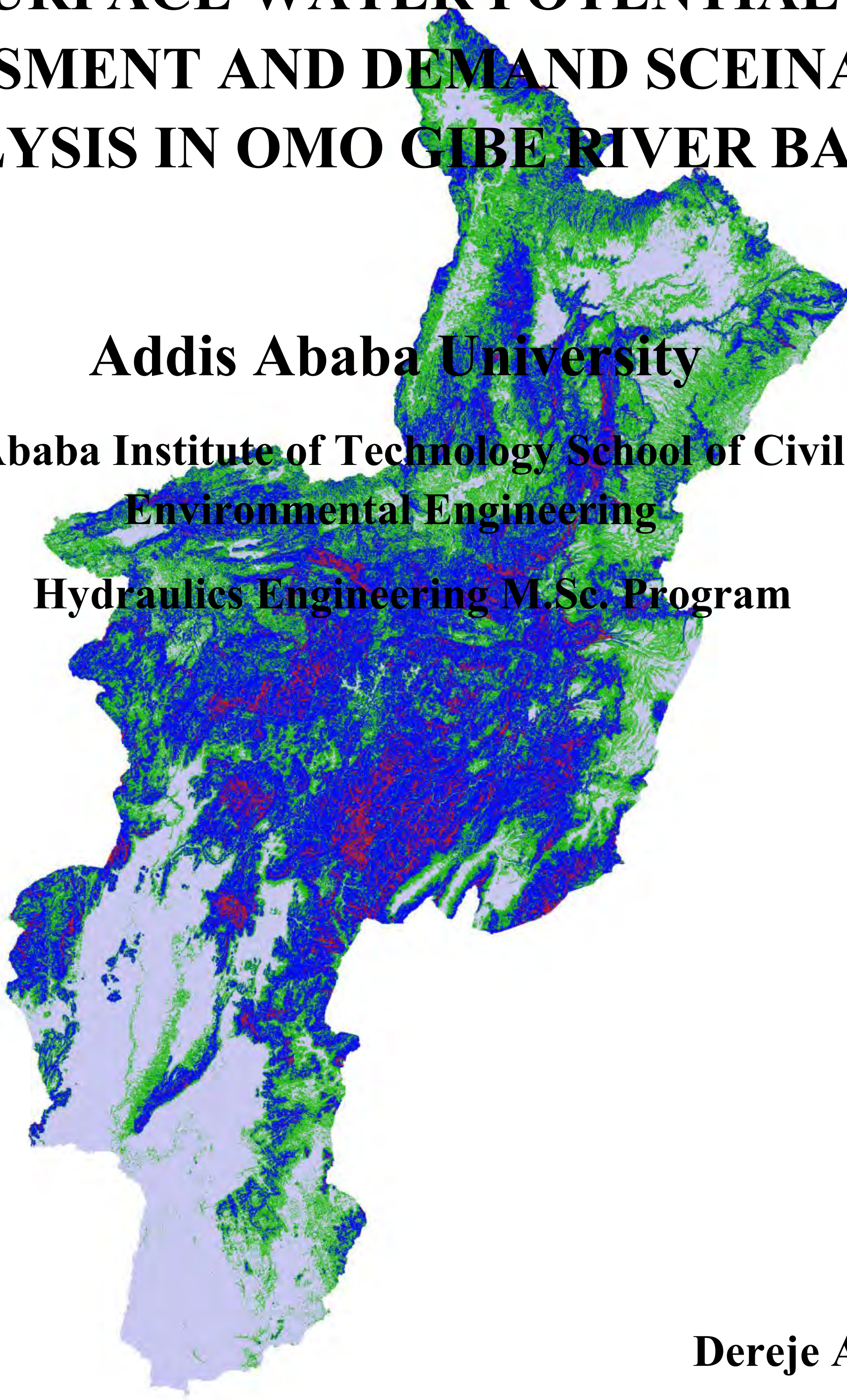
SURFACE WATER POTENTIAL ASSESSMENT AND DEMAND SCEINARIO ANALYSIS IN OMO GIBE RIVER BASIN



Addis Ababa University

Addis Ababa Institute of Technology School of Civil and Environmental Engineering

Hydraulics Engineering M.Sc. Program

Dereje Atinafu

May 5, 2015

SURFACE WATER POTENTIAL ASESSMENT AND DEMAND SCEINARIO ANALYSIS IN OMO GIBE RIVER BASIN

Thesis

Submitted in partial fulfillment of the requirements of the degree of Master of Science in Civil Engineering (Hydraulics Engineering)

By

Dereje Atinafu

Advisor

Dr Agizew Nigusse

School of Civil and Environmental Engineering

Addis Ababa Institute of Technology

Addis Ababa, Ethiopia

July, 2015

The Thesis entitled "**Surface Water Potential Assessment and Demand Scenario Analyses in Omo Gibe River Basin**" by Dereje Atinafu is approved for the degree of Master of Science in Civil Engineering (Hydraulic Engineering stream).

Board of Examiners

	Name	Signature
Advisor	………………………	……………………..
External Examiner	………………………	……………………..
Internal Examiner	………………………	…………………….

ACKNOWLEDGEMENTS

This thesis would not have been completed had it not been for the generous support and encouragement of different persons and institutions throughout the study period. First and foremost, I would like to thank my family for their continuous supports.

I would like to thank University of Gondar and Addis Ababa Institute of Technology for giving me the opportunity to pursue this postgraduate study in Hydraulic Engineering.

I am highly indebted to Mr Debebe Dereb for all the supports and guidance he has extended to me during my study. I do not think that I would have reached this stage without your genuine advice.

I would also like to thank Dr.Agezew Nigussie for his direction and guidance throughout the process My appreciation is also to Dr. Geremew Sahlu, for his invaluable inputs and supports.

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ACRONYMS

SUB	Sub basin
PET	Potential evapotranspiration (mm H2O).
ET	Actual evapotranspiration from the sub basin (mm).
SW	Soil water content (mm).
PERC	Water that percolates past the root zone during the time step (mm).
SURQ	Surface runoff (mm H2O).
GW_Q	Groundwater contribution to stream flow (mm).
WYLD	Water yield (mm H2O).
SYLD	Sediment yield (metric tons/ha).
CN	Curve Number
Arc SWAT	Arc GIS integrated SWAT hydrologic model
GIS	Global Information System
FAO	Food And Agricultural Organization of United Nations
ESCO	Soil evaporation compensation factor
Alpa_Bf	Base flow alpha factor(day)
HRU	Hydrologic Response Unit
DEM	Digital Elevation Model
SRTM	Shuffle Radar Topographic Mission
SWAT	Soil and Water Assessment Tool
WEAP	Water Evaluation And Planning
UTM	Universal Transverse Mercator
MoIWE	Ministry of Irrigation Water and Energy.
NMAE	National metrological Agency of Ethiopia.
SOL_AWC	Soil available water capacity (mm)
SOL_Z	Soil depth(mm)
REVAPmn	Threshold depth of water in shallow aquifer
KB1I	Kuraz Blok 1 Irrigation

Abstract

A study was conducted in Omo Gibe river basin surface water potential and demands using hydrological model SWAT and a program WEAP. A detail review of current water resources potential, current demand and future demand up to 2030 were properly estimated. Earlier, different commissions, agencies, researchers have estimated water resources of the country using different approaches. All these studies are based on the observed flows at terminal sites and upstream abstractions for irrigation and domestic consumptions. Limitations of these studies are: limited field data on abstraction, lumped approach in estimation at terminal sites of the basin no mechanism for cross validation and new large scale irrigation projects are not considered.

This study emphasizes on quantifying basin scale water wealth by transformation from presently adapted basin terminal gauge site runoff aggregation to meteorological based water budgeting exercise through hydrological modeling approach Integrating satellite image, geographical information tools, hydro-meteorological data and hydrological models. Daily rainfall data, daily temperature data were obtained for the last 20-30 years from the Ethiopian national metrological Department. Land use grids 90m resolution were used. Soil textural map, land use map, digital elevation map, and command area map were integrated to compute hydrological response grid of the basin. In this study Observed discharges at various gauge stations were obtained from Ministry of irrigation water and energy and model was thoroughly calibrated and validated. It is found that computed runoff is very well matching with the filed observed data with good accuracy. Missed hydro-metrological data was filed using appropriate method and the performance of the method also cheeked. Soil and Water Assessment Tool SWAT integrated with GIS were used to model the watersheds and to simulate runoff. Water Evaluation and Planning (WEAP) estimates the current and future water demands for irrigation, domestic, industrial/commercial, and livestock demands.

The results were compared and sensitivity analyses were computed for SWAT. ESCO and CN are the most sensitive parameters. The model calibrated for period of 1990-2002 and land use data of 2002 were used. Finally the model also validated for period of 2002-2010. Hydrograph characteristics of observed and simulated events are compared using different evaluation criteria consisting of Nash-Sutcliffe coefficient of efficiency (EF) and R-Squared, r-squared is another statistical measure of how well a regression line approximates real data points.

Addis Ababa university institute of technology wants to generate up-to-date information‟s on water and land resources management and development in Omo basin, and this study aims to provide water demands overview. Current water demand and future prediction in demand are estimated by considering different demand scenarios. Environmental flow, current irrigation potential, improvement in irrigation network efficiency, and irrigation projections are key Scenarios used in this study. Scenarios impacts on water demand are assessed based on the impacts on indicators; elaboration on Scenarios is based on the assumptions made, drivers to be changed and indicators to be analyzed. The indicator analyzed in this study is unmet demand. Irrigation schedule, Irrigation efficiency improvement, water requirement, population growth, inflows to the sub catchment, priority of demand i.e. irrigation, domestic, commercials and industrial, Land use area, crop type and varieties are drivers to be changed in each scenarios.

1. INTRODUCTION

1.1 Background

Ethiopia faces a number of water related challenges, including increasing water scarcity and competition for water between different sectors and states. Some of the river basins in the southern and western parts of the country are experiencing physical or economic water scarcity. In Omo Gibe River Basin the same is true as a result of huge development projects that depend on water resources. The basin is key for development of new hydropower and irrigation projects. Accurate assessment of Surface water potential and demands are therefore critical. The general target of Water resource management is the maximization of socio-economic welfare related to water resources, through coordination of multiple activities and resolution of conflicts arising between different users about the limited resource base. It is then fundamental to identify case by case the main problems to be properly faced at the basin level, and especially those connected with negative externalities at the basin scale (e.g. water pollution, allocate problems).

Omo-Gibe Basin is Ethiopia‟s thread largest river system in terms of annual surface water potential. It accounts 13% of the country‟s annual runoff, and being preceded by the Blue Nile and Baro-Akobo basins. Hydrological impacts of Omo-Gibe basin on surface water potential management is the result of interactions between different institutional subjects and different stakeholders in facing a specific set of problems, hence it has to be identified as a highly context-specific process. Sustainable water resources management requires data to enable to estimate water quantity, quality and prediction of demand. Information is required on the rates of transfers and storage of water within the catchment. Lack of adequate basin data introduces uncertainty in both the design and management of water resource system. And absence of information about the potential and quality of water resources of the basin arise from poorly developed water resources management practices.

Generally the study has investigated the hydrology of the basin using physically based, conceptual, computationally efficient and semi distributed model (SWAT) and WEAP (Water Evaluation and Planning) model to estimate current and future Water demands of Omo-Gibe River basin considering the effects of new and planed water resource projects by creating demand Scenarios.

1.2 Statement of the problem

Now a day's Ethiopia tries to exploit its river basin potential and develop strong water resources management techniques. Omo Gibe is one of the twelve river basins of Ethiopia with a potential for satisfying the demand of existing and proposed projects on the basin and downstream water users. Yet, there is a gap on concise and dynamic watershed management of the basin. Better understanding of the basin characteristics is necessary in Omo Gibe Basin, which is possible with knowing full potential of the available water and land resources and predicting the demand scenarios of the basin. Increasing demands for sources of clean water, combined with changing land use practices, growth, and climate change and variability, pose significant problem to the water resources of Omo Gibe.

The main water resources problem in Omo Ghibe basin is uneven distribution of the rainfall. According to MoWE(2001), 80-90% of Ethiopia's water resources is found in the four river basins namely: Abay (Blue Nile), Tekeze, Baro Akobo, and Omo Gibe in the west and south-western part of Ethiopia where the population is no more than 30 to 40 percent. On the other hand, the water resources available in the east and central river basins are only 10 to 20 percent whereas the population in these basins is over 60 percent (MoWE, 2001). Existing power generation in Ethiopia is highly dominated by hydropower resources which contribute to 95% of current total electricity.

The basin water resources are under threat due to increasing population, new infrastructure and new large scale irrigation projects like Kuraz Sugar 175,000ha and global warming. The potential impacts of different water demand scenarios vis-à-vis the water resources potential of the basin should also be investigated. Consequently, there is a need to assess the surface water resources potential of the basin and predict the demands corresponding to different development scenarios. These are fundamental information that contribute to the basin"s sustainable water resources management

1.3 Research question

The research output should have the capability to answer the following question:

- What conditions/parameters threaten the reliability of Omo-Gibe river basin water potential?
- What factors are most significant and effective in ensuring the sustainability and integrity of surface water resources?
- Can the Omo-Gibe Basin Surface water potential satisfy future demand scenarios for the proposed and existing projects?

1.4 Objectives

1.4.1 General objective of the study

To assess the current water resources potential of the basin and to predict future demands which can be used as input for development of sustainable water resources management of the basin.

1.4.2 Specific Objectives

- To estimate current surface water potential.
- To evaluate the observed stream flow and rainfall data of the basin.
- To assess the hydrological response Using rainfall-runoff method that best fits the hydro-geo-morphological situation of the basin.
- To estimate the current and future water demands of the basin

The study focused on assessment of basin wide water situation under different scenarios including water availability and demands of medium to large scale projects by using relevant techniques and tools. These may include

- Adoption of compressive water balance based model
- Calibration and Validation of hydrological water resources data and tools.
- Assessment of likely current and future situations of the basin surface water potential with changes in demand, land use/Cover, precipitation and PET.
- Hydrologic response unit generation

Divide the basin area in to small areas which have the same land use and soil type and these small areas are homogenous in hydrological change to land cover. So in this study it is possible to assess the surface water potential of the basin with directly by assessing the hydrologic response unit areas. In addition to the derived hydrological response unit the basin can be sub divided in to the irrigation command area boundaries.

The study also focused on Estimation of past and current water demand in Omo Gibe River Basin. Future water demand prediction is very important; so considering Likely future demand Scenarios the estimation will don. The basic scenarios used in this study are Environmental flow, Current irrigation potential, Improvement in irrigation Efficiency and Projections in irrigation area.

Generally the scope of this study covers the following:-

- quantification of the surface water resources within Omo Gibe River Basin
- Estimation of current and Likely future water demand
- calibration of a computer rainfall-run-off model for the catchment
- assessment of the impact of current levels Large scale irrigation development on Demand
- assessment of model case scenarios to study future impacts, for facilitation of future catchment management decisions
- identification of data deficiencies and recommendation of future monitoring requirements

1.5 Significance of the study

The importance of assessing surface water has been highlighted by many researchers for Planning and sustainable management of water resources in many parts of the world. Regarding water resources use there is always a problem because of the change in hydro-geo-morphological characteristics of the basin. Ministry of Irrigation; water and energy in Ethiopia is a governmental institution which is responsible for the countries water and energy development, with the mission to play a significant goal in socio-economic development of Ethiopia through development and management of its water and energy resources in a sustainable manner. It is clear that the hydro-geo-morphological change has severed impact on surface water resources potential in Omo Gibe Basin.

Integrated water resource analysis that takes in to account the availability of water together with prediction of major demands is very important for the development of sustainable water resources management plan. This research tried to estimate the surface water potential and major water demands of Omo-Gibe Basin using relevant techniques and models and the results contribute to the development of dynamic and integrated water resources in Omo-Gibe River Basin. The study recommends that future studies should focus on areas with highest development potential and formulation of development scenarios on the basin with different level of details.

2: Literature review

2.1 General overview

The knowledge and understanding that the scientist has about the world is often represented in the form of models. The goal of the scientific method is to simplify and explain the complexity and confusion of the world. A model is a representation containing the essential structure of some event in the real world. It can be classified as quantitative and qualitative model. In science and engineering, the most essential attribute of model is that of quantitative which yields numerical value. A quantitative model is essential to determine physical variables that cost much to measure in the field. To understand the hydrological process in the system which is essential in decision making, models have been used long in water resources management.

A model used in water resources management should be sufficiently accurate to be used for the intended purpose. The existence of observations determines the validity of the model. Model prediction is compared with field measurement to evaluate its performance without any adjustment to the model parameters (Ward *et al.,* 1999). This process is termed as model validation or verification.

It is essential to determine the amount of water available in the system in order to state the available water potential within the river basin system. Hence, it requires understanding and properly describing water inflow and outflow from the system. In order to describe the movement of water, it would be necessary to have rainfall data and information on runoff, evaporation, infiltration, percolation etc.

2.2 Hydrological Processes

Hydrological process in Surface-water hydrology is a field that encompasses all surface waters of the globe (overland flows, rivers, lakes, wetlands, oceans, etc), the subset of the hydrologic cycle that does not include atmospheric and ground waters. Surface-water hydrology relates the dynamics of flow in surface-water systems (rivers, canals, streams, lakes, ponds, wetlands, marshes, oceans, etc.). This includes the field measurement of flow (discharge); the statistical variability at each setting; floods; drought susceptibility and the development of the levels of risk; and the fluid mechanics of surface waters.

River basin modeling requires a clear understanding on the hydrologic cycle at sub-catchment scale. The catchment hydrologic cycle involves many processes. The basis of generating rainfall-runoff processes lies in the hydrological cycle. The hydrological cycle can be explained by the interdependence and movement of all forms of water on earth. It usually is described in terms of six major components which are precipitation, infiltration, evaporation, transpiration, surface runoff and groundwater flow. This is shown in Figure1.

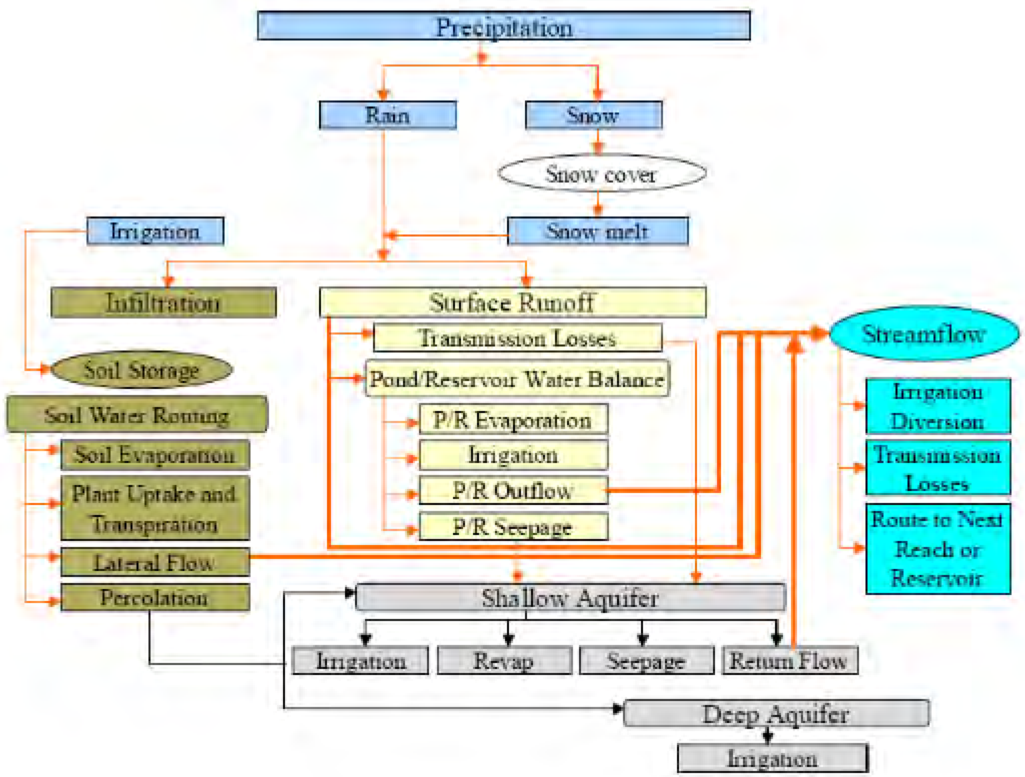


Figure 1 Hydrological system in SWAT (Neitsch et al., 2005)

2.3 Model Selection

2.3.1 Problems to be considered

Hydrological practice would be improved if models were objectively chosen on the basis of making the best use of the information available and following some systematic procedure of selection and verification (Dooge, 1984). The choice of the best model depends to a large extent on the problem. Generally speaking, items that should be considered in the selection process include (Haan et al. 1982):

(a) The nature of the physical processes involved,
(b) The use to be made of the model,
(c) The quality of the data available and
(d) The decisions that rest on the outcome of the model's use.

In examining the nature of the physical processes involved, one should ask and attempt to answer such questions as: what are the processes that interact to produce the phenomenon under investigation? Are they amenable to solution by stochastic processes? Are they independent processes? Are they independent of time? Are values of the parameters likely to change with time, i.e., are they seasonal? Is the process stationary? Must future man-induced changes to be represented? If so, how?

In studying the use to be made of the model, one needs to answer: How much information is needed concerning the process being modeled? Do the data need to be presented in short time intervals or is monthly or annual data sufficient?

The quality of hydrological data describing a phenomenon affects the problem of fitting useful information from complex processes that produced the phenomenon. Several models may be capable of describing the same process, and, to a great extent, selection of the one to be used depends on a comparison of sampled data and model output.

Finally, in model selection, decisions that may rest upon the outcome of the model‟s use must be considered. To a great extent, these decisions will dictate the criteria that should be used to judge the quality of the model‟s performance.

2.3.2 Criteria of selection

Thus far the problems to be considered in choosing a suitable model in general have been discussed. In most situations, however, absolute objective methods of choosing the best model for a particular problem have not yet been developed, so this choice remains a part of the art of hydrological modeling. Dawdy and Lichty (1968) suggested four criteria that can be used to choose between alternative models:

1) Accuracy of prediction
2) Simplicity of the model
3) Consistency of parameter estimate
4) Sensitivity of results to change in parameter values

Accuracy of prediction of system output is obviously very important; it is desired when all other factors being equal, the model with minimum error variance would be superior. Simplicity refers to the number of parameters that must be estimated and the ease with which the model can be explained to clients or public bodies. When all other factors are being equal, one should choose the simplest model. Consistency of parameter estimation is an important consideration in developing hydrological models using parameters estimated by optimization techniques. If the optimum values of the parameters are very sensitive to the particular period of the record used, or if they vary widely between similar catchments, the model will probably be unreliable. Finally, models should not be extremely sensitive to input variables that are difficult to measure. Generally the model used in this study is passed through the following evaluation as shown below.

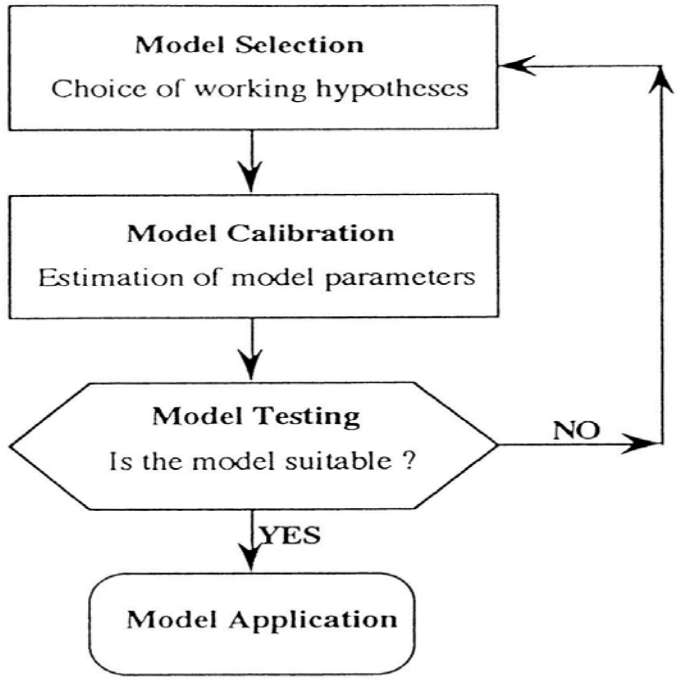


Figure 2 phases of model selection and evaluation

2.4 The Selected Model

2.4.1 SWAT model

Soil and Water Assessment Tool (SWAT) is a physically-based continuous-event hydrologic model developed to predict the impact of land management practices on water, sediment, and agricultural chemical yields in large, complex watersheds with varying **soils**, **land use**, and **management conditions** over long periods of time. For simulation, a watershed is subdivided into a number of homogenous sub basins (**hydrologic response units or HRUs**) having unique soil and land use properties. The input information for each sub basin is grouped into categories of weather; unique areas of land cover, soil, and management within the sub basin; ponds/reservoirs; groundwater; and the main channel or reach, draining the sub basin. The loading and movement of runoff, sediment, nutrient and pesticide loadings to the main channel in each sub basin is simulated considering the effect of several physical processes that influence the hydrology. For a detailed description of the capabilities of the SWAT refer (Neitsch et al., 2002). Total hydrological processes in SWAT and how SWAT model solve problem is as shown figure 1. SWAT water balance equation is shown below:

$$SW_t = SW_0 + \sum_{i=1}^{t}(R_{day} - Q_{surf} - E_a - w_{seep} - Q_{gw}) \quad \text{..............................2.1}$$

SW_t = final water content of soil (mm)
SW_o = initial water content of soil on day I (mm)
R_{day} = Rainfall amount on day I (mm)
Q_{surf} = Amount of surface runoff on day I (mm)
Ea = Amount of evaporation on day I (mm)
Wseep = Amount of water entering the vadose zone from the soil profile on day i(mm)
Q_{gw} = Amount of return flow on day I (mm)

2.4.2 WEAP model

WEAP is short for Water Evaluation and Planning System. It is a computer tool for integrated water resources planning. It provides a comprehensive, flexible and user-friendly framework for policy analysis. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP is a laboratory for examining alternative water development and management strategies (SEI, 2005).

WEAP is operating on the basic principles of a water balance. The analyst represents the system in terms of its various supply sources (e.g. rivers, groundwater, and reservoirs); withdrawal, transmission and wastewater treatment facilities; ecosystem requirements, water demands and pollution generation. The data structure and level of detail may be easily customized to meet the requirements of a particular analysis, and to reflect the limits imposed by restricted data.

Operating on these basic principles WEAP is applicable to many scales; municipal and agricultural systems, single catchments or complex trans-boundary river systems. WEAP does not only incorporate water allocation but also water quality and ecosystem preservation modules. This makes the model suitable for simulating many of the fresh water problems that exist in the world nowadays

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

WEAP also calculates a water and pollution mass balance for every node and link in the system. Water is dispatched to meet stream and consumptive requirements, subject to demand priorities, supply preferences, mass balance and other constraints. Point loads of pollution into receiving bodies of water are computed, and stream concentrations of polluting elements are calculated.

2.5 Irrigation and Hydropower development in the basin and constraints

2.5.1 Irrigation

The Omo-Gibe Basin was an early candidate for development of irrigation and hydropower for the following reasons, there is no significant use of the Omo River by any other country and the river enters Lake Turkana within the boundaries of Ethiopia. While most of the lakes lies within Kenyan territory that is a sparsely inhabited semi-desert pastoralist region with no significant use of lakes waters.

It is not surprising that the Omo Basin was promoted as "an early candidate for development" water is without doubt one of Ethiopians key natural resources. The country is the main water tower for the River Nile, and development of the country‟s water resources is an inevitable response to the country‟s escalating needs.

In Omo Gibe basin a combined total of existing and potential small scale irrigation area found to be 31782 ha. The potential land is three times of the existing according to the master plan study. It is stated in the master plan study that 1.5L/s/ha was adopted as the applicable unit water for all irrigation areas including small scale irrigations with the overall irrigation efficiency of 45%. Hence in terms of water demand small scale irrigation have significant and can‟t never be overlook. the big constraint in small scale irrigation is poor irrigation efficiency; water demand is more than the demand recommended by the master plan and poor drainage network.

Currently in Omo Gibe basin large scale irrigation projects for sugar production are developing by the government of Ethiopia which is not seen in master plan study before. A total of 175,000ha of land under development, which needs significant quantity of water; the master plan studies investigates a potential of 265,000 ha of land distributed all over of the basin; following further study areas suitable for irrigation within the potential area is reduced from 265000ha to 74 000ha and following further soil study suitable area is reduced to 54,670ha. This study does not include any potential within the protected areas (national parks and wild life reserve) and Lower Omo basin. Generally the investigated potential land approaches to 445,501ha; some of land investment deals in the basin is shown below.

Table 1 details of land investment deals in Omo

Name	area Size(ha)	Purpose	Investor
Kuraz Block 1	82600	Sugar	Stat-owned
Kuraz Block 2	81250	Sugar	Stat-owned
Kuraz Block 3	81300	Sugar	Stat-owned
Daniel Fasil Bihon	5000	Cotton and grains	Diaspora
Lucci	4003	Cotton	Ethiopian
Mela	5000	Cotton	Ethiopian
Whitefield cotton farm	10000	Cotton	Indian
Reta	2137	Cotton and grains	Diaspora
Rahwa	3000	Cotton and grains	Ethiopian
Tsegaye demose Ag Development	1000	Cotton, sesame and soybean	Diaspora
Tamil Hadgu	5000	cotton, seeds	Diaspora
Adama	18516	cotton	Diaspora
other agricultural area investment	57695	NA	NA
land available from fed land bank	89000		
Total agricultural investment lands	445,501		

Contracts available at http://media.oklandinstitute.org/land-deals-africa/ethiopia Source the Oakland institute (Oakland 2011)

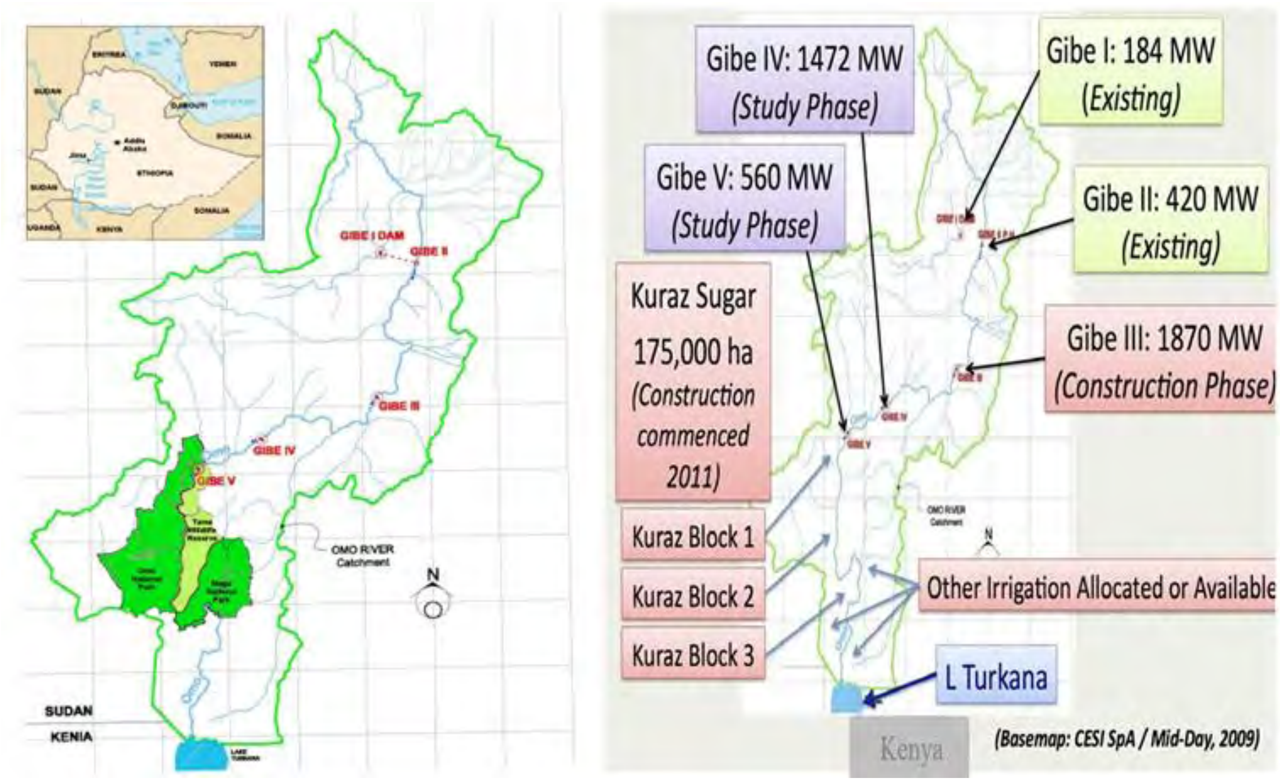


Figure 3 Basic fetchers and water resource projects in Omo Gibe river basin

2.5.2 Hydropower

Middle and upper Omo Gibe basin topography shows the basin is suitable for hydropower development; the Ethiopian Electric power corporation (EEPCo) tries to satisfy rapidly growing electricity demand by developing hydropower plants on main river of Gibe, i.e Gibe I, Gibe II and Gibe III hydro dames. In addition the government planned to develop Gibe VI and Gibe V for power production and for vast irrigation development in lower Omo. The country has a hydropower potential of 45,000MW up to now it is able to produce 2060MW and it is planned to produce 15,000MW within next few years. The country also has a very good potential for power trade between Ethiopia and Kenya, Sudan, Djibouti, Egypt and other neighboring countries. Construction of a cascade hydropower schemes in the basin will be discussed below:

Gibe I

The single plant adopted scheme is a purely hydroelectric project, aimed to increase energy and power supply to the National Grid. It is located on the Gilgel Gibe River, some 260 km South- West of Addis Ababa and 70 km North East of Jimma in the Oromiya Region. The general fetcher of the project is shown below.

Table 2 Basic fetchers of Gilgel Gibe I project (EEPCo)

fetcher	
Catchment area	4225Km^2
Average annual flow	50.4m^3/s
Annual runoff	1573Mm^3
Reservoir maximum normal water level	1652m a.s.l
Reservoir Normal operating level	1671m a.s.l
total storage	839Mm^3
Dam Crust elevation	1675m a.s.l
Dam maximum height	40m
Installed capacity	184MW

Gibe II

The Gilgel Gibe II Power station is the second hydroelectric power station on the Omo River. The power station receives water from a tunnel entrance 7°55′27″N 37°23′16″E on the Gilgel Gibe River. It has an installed capacity of 420 MW and was inaugurated on January 14, 2010. Almost two weeks after inauguration, a portion of the head race tunnel collapsed causing the station to shut down; repairs were complete on December 26, 2010.

The Gilgel Gibe II consists of a power station on the Omo River that is fed with water from a headrace tunnel and sluice gate on the Gilgel Gibe River. The headrace tunnel runs 25.8 km (16 mi) under the Fofa Mountain and converts into a penstock with a 500 m (1,600 ft) drop. When the water reaches the power station, it powers four Pelton turbines that operate four 107MW generator. The Gibe II plant uses the waters discharged by Gilgel Gibe I and has a gross head of 505 m used by an open air power station of 420 MW installed capacity. This new head is created by a waterway that bypasses about 10 Km of the two rivers (Gilgel Gibe and Omo).The intake is located on the Gilgel Gibe river about 200 m downstream of the Gilgle Gibe I outlet. The following table shows the basic features of this hydropower station.

Table 3 basic fetchers of Gibe II project (EEPCo)

Features	
Catchment area	4304KM^2
Average flow	101.5m^3/s
Reservoir max probable flood level	1437.6m a.s.l
Normal operating level	1431.5m a.s.l
Minimum operating level	1424m a.s.l
Total storage	1.9Mm^3
Weir crest Elevation	1439m a.s.l
Maximum height	49m
crest length	140m

Gibe III

The Gibe III hydroelectric is located within the Omo Gibe River basin in the middle reach of the Omo River around 450km by road South of Addis Ababa. The dam for Gibe III is on the Omo River and the reservoir stretches to its tributaries the Gibe and Gojeb Rivers. The scheme, from the end of the reservoir to its tailrace out fall, extends over a corridor 150 km long (EEPCo, 2009). It is under construction which has 243 m high roller-compacted concrete dam with an associated hydroelectric power plant on the Omo River . Once completed it would be the largest hydroelectric plant in Africa with a power output of about 1870MW. The Gibe III dam would be part of the Gibe cascade, a series of dams including the existing Gibe I dam (184 MW) and Gibe II power station (420MW) as well as the planed Gibe IV (1472MW) and Gibe V (560MW) dams.

Table 4 Basic fetchers of Gibe III project (EEPCo)

Features	
Catchment area	34,150km^2
Average annual runoff	438.2m^3/s
Average annual volume	13820Mm^3
Minimum reservoir operating level	800m a.s.l
Normal reservoir operating level	889m a.s.l
Maximum water level in the reservoir	892m a.s.l
Live storage volume	11750Mm^3
Dam height	243m
Crest Elevation	896m a.s.l
Crest length	580m

Basic constraints that can be considered as the challenge in full development of the basin are exist and identified. These challenges are summarized below.

i. Difficulty in selecting projects for implementation on financial, economic and technical merit within an environment of physical and socio-economic impact assessment and political constraint.

ii. Finite national development budgets.

iii. Hydrology, the length of record and confidence in the analyses

iv. Technical issues: sedimentation and potential effects on reservoirs, subsurface conditions and potential effect at dam foundations and underground structures; tectonic and potential seismic effect.

v. Socio economic issue: current land use and population density; relocation.

vi. Access issues.

vii. International water treaties.

2.6 Water Demand

Water demand in the basin can be categorized according to the following (DFID, 2005)

- **Purpose of use: sectoral water demands** (agriculture, livestock, domestic...) what is water needed for? How much water is needed per sector (past, present, future)?
- **Place of use** (close to the river vs. reliant on groundwater, rural vs. urban) Where is water needed? How much water is needed at the different locations? What are the implications for water distribution?
- **Time of use** (mainly cropping seasons and cycles) When water is needed, e.g. irrigation requirements depending on rainfall and evapotranspiration? and
- **User groups** (e.g. pastoralists vs. sedentary farmers) who needs/demands for water, based on different lifestyles, social hierarchies and traditional forms of management? How much water is needed per user group?

Over the year‟s population growth and urbanization, industrialization and the expansion of irrigated agriculture are arresting rapidly increasing in demands. It is critically vital to develop the knowledge and soft skills that are necessary to address river basin demand without altering the socio-economic development in order to manage resource s availability in a suitably way. Generally Total water demand in Omo Gibe basin is cumulative sum of each sectoral demand as shown below.

2.6.1 Irrigation Water Demand

Agriculture is an important activity in Omo-Gibe in terms of food security, economic activity and water use. Irrigated agriculture, moreover, plays important role because it is generally two to three times more productive than rain-fed agriculture. Irrigation is largely reserved for high value crops such as fruits and vegetables, but sugar cane occupies 175,000 ha alone. Other irrigated crops include wheat, cotton, maize, coffee, tea and tobacco.

Critical to any irrigation management approach is an accurate estimate of the amount of water applied to a field. Too often, farmers or growers apply water to make the fields and rows “look good” (blacken-up the beds) or continue irrigating until the water reaches the end of every furrow. However, quite often they never realize just how much water they have applied. When growers do not take their system‟s efficiency into account, they may apply too little or too much water. Too little water causes unnecessary water stress and can result in yield reductions. Too much water can cause water logging, leaching, and may also result in loss of yield.

Estimating the amount of water applied to a field or to a set is fairly easy for surface systems. The Equation, Q x t = d x A, can be used to estimate the depth of water applied. In the equation:

$$Q \times t = d \times A \qquad \text{……………………………………..……2.2}$$

Q is the flow rate, in cubic feet per second (cfs); t is the set time or total time of irrigation (hours); d is the depth of water applied (inches) and A is the area irrigated (acres).

The possibility of using the Omo River to irrigate massive agricultural areas in the Lower Omo Basin has been formally considered for decades. The Ethiopian Government‟s Omo-Gibe Basin Master Plan (1996), financed by the African Development Bank, revealed that upriver dams on the

Omo River would be necessary to supplement the river‟s low flows for irrigation needs. It also noted that the process of developing the region would require trans-boundary dialogue with Kenya and the involvement of local people in negotiations to ensure that they were able to meet their own development priorities and that impact on their resources were minimized.

Ethiopia has ambitions to become one of Africa‟s main sugar producers (World Bulletin, 2014). The government has made plans to increase production from 300,000 tons to 2.25 million tons per year by building sugar factories and increasing sugarcane cultivation as part of the first phase of Ethiopia‟s Growth and Transformation Plan (Mwanza, 2014). Large amounts of infrastructure for production of sugar and ethanol are being developed. In the South Omo Zone, 200,000 hectares of state-run sugar plantations and seven sugar processing factories are planned. The first of the seven factories is expected to be fully operational in 2015 and will be able to crush 12,000 tons of sugarcane per day.

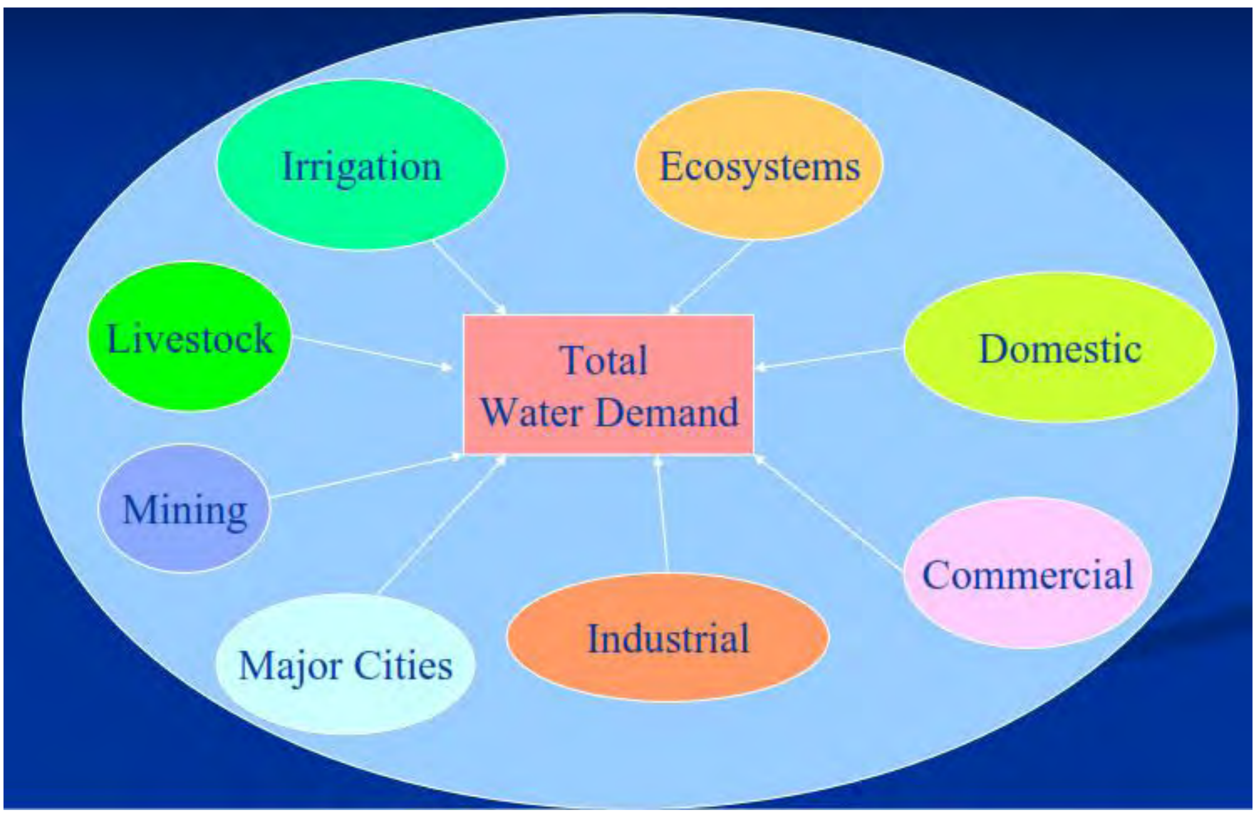


Figure 4 Sectoral Water Demands

2.6.2 Environmental Flow Requirement

The basic flow requirements for rural communities and other unregulated use must be considered in terms of meeting these demands as well as ensuring that the hydrological impacts on these are acceptable. Similarly, minimum flow requirements for environmental or aesthetic needs are also important. Sustainability is the key.

The environment is increasingly being considered a legitimate water user in many countries. As a consequence the water requirement of the environment needs to be estimated. The amount of water that will be allocated to the environment is a decision made by society, and is to some extent arbitrary. The quantity of water allocated to the environment will always be less than what the environment ideally would require, namely the natural, undisturbed, flow regime of a river. Society, therefore has to weigh the potential costs and benefits to the environment and to all other water users, of allocating (or not) a certain amount of water to the environment. In so doing, society accepts a certain modification of the natural environment. This accepted level of modification may differ from river to river, and is sometimes defined in terms of "ecological management classes".

The environmental or in stream flow requirement is often defined as how much of the original flow regime of a river should continue to flow down it in order to maintain the river ecosystem in a prescribed state. However, an environmental in stream flow often fulfils a number of different functions. In addition to the ecology of a watercourse there may be a need to recommend in stream flow requirements for the following reasons:

- Protection of the rights of other abstractors;
- Navigation;
- Maintenance of the flood carrying capacity of the channel;
- Cultural and social reasons;
- Maintenance of the channel diversity.

Environmental flow assessment methods

The environmental flow assessments are used as a method for estimating the quantity of water required. An environmental flow assessment produces one or more descriptions of possible future flow regimes for a river each linked to an objective relating to the condition or the health of the riverine ecosystem. For example the requirement may be stated as “a water depth of at least 50 cm is required throughout the year to provide adequate wetted perimeter for a particular fish species”. Alternatively it may be more complex detailing a comprehensive flow regime that specifies magnitudes, timing and duration of low flow and floods at a number of temporal scales.

There is a range of methods available for assessing instream flow requirements based on:

- Simple hydrological indices;
- Hydrological simulations;
- Consensus and discussion based approaches;
- Historical data analysis.

Few, if any, of the approaches available provide a complete solution and hence a wide range of approaches may be appropriate, especially for different levels of planning. The environmental or instream flow requirement for a watercourse is the minimum flow required to enhance or maintain aquatic and riparian life. There are several assessment procedures for determining environmental flows. The decision on which method to use is dependent on the following:

- Type of river (e.g. perennial, seasonal, high base flow, flashy);
- Perceived environmental importance;
- Complexity of the decision to be made;

- Increased cost and difficulty of collecting large amounts of information;
- Severity of different resource developments.

The level of detail required will be case dependent. In many countries a two-tier system is used comprising catchment wide and scoping method for "level-one" studies and more detailed methods for "level-two" studies. Level two studies move away from standard setting (i.e. setting a single minimum flow) and towards an incremental approach (i.e. quantification of varying instream requirements) that enable various management options to be assessed.

Stages in determining the minimum flow requirement may be as follows:

- Outlining of requirements;
- Data collection method;
- Modeling and analysis process and the use of this information to set an instream flow requirement in a rational manner;
- Use of tools in an active manner (e.g. reservoir releases);
- Follow up monitoring of success and revision of goals.

Knowledge concerning the environmental requirements of rivers is likely to remain incomplete for the foreseeable future. As a consequence there will always be a danger that an instream flow requirement will be set too low, resulting in damage to the riverin environment or too high resulting in potential waste of resources or exploitation of other more sensitive water resources. It should also be noted that too much water during natural low flow periods could lead to undesirable changes especially in the arid and semi- arid areas that exist in southern Ethiopia.

The methods are shown below, each method differs in its data requirements, procedures for selecting flow requirements, ecological assumptions and effects on river hydraulics.

Environmental flow assessment methods
Hydrological index methods
• Tennant method; • Texas method; • Flow duration curve method; • Aquatic base flow method; • Range of variability approach.
Hydraulic rating methods
• Wetted perimeter method.
Habitat Simulation methods
• Building block methodology
Holistic method
• Instream flow incremental methodology.

Figure 5 Environmental flow Assessment methods

2.6.3 Domestic water demand

The population estimates for the basin are given in the study on Demography (Richard W, 1996). The data include population projection for the years 2009 and 2024 to witch reference is made in later portion of the thesis. The population is separated in to rural and urban/semi urban for the purpose of estimating the demand and these figures are shown by wereda.

For the purpose of estimating water demand, it has been assumed that the rural population consumes water at an average rate of 15 liter per capita per day; urban consumption has been assumed to be at an average rate of 40 liter per capita per day. This latter figure is based on the fact that only a proportion of the urban population receives water in their houses.

2.6.4 Livestock water use

The water requirements of livestock are influenced by several factors, including:

- Type of livestock,
- Lactation;
- Type of diet;
- Feed intake;
- Temperature.

Estimating total livestock consumption is relatively simple. The assessment of livestock consumption should be carried out as follows.

- Determine types of livestock;
- Use typical water consumption figures per head for each type of livestock;
- Determine number of each type of livestock in the area being assessed.

The estimated animal populations in the basin are given in the report on livestock and rangelands (master plan Volume XII, G2) the numbers of livestock have been aggregated to Tropical Livestock units (TLUs) on the following basis:

- Cattle 0.8TLU
- Sheep 0.1TLU
- Horses 0.7TLU

The water demand has been taken as 2l/TLU/day on this basis the present water demand has been calculated.

2.6.5 Industrial Water Demand

Industrial water use includes water used for the following:

- Industrial processes such as fabrication, processing, washing and cooling;
- Mining;
- Hydropower generation;
- Thermal electric power generation.

Urban industries tend to be metered, usually according to the volume of water used. Where larger commercial and industrial users tend to be metered, determining demands can be facilitated through analyzing meter records. Alternatively, they may have their own source, especially if they are outside urban centers. Monitoring records may exist or there may be some indication as to the energy consumption of pumps or other references to demand and use.

The factors affecting water demand vary widely between the different industrial operations. The major factors common to the industrial and commercial sectors in determining water demand are:

- Economic activity at a local, national and international level;
- Population;
- Industrial composition;
- Price of water;
- Access to supply and alternative supplies;
- Access to technology;
- Working practices.

Omo-Gibe River Basin is relatively undeveloped in the industrial and commercial sector, even in the urban settlements. Her are no data available on the usage of water in these sector, but, based on the master plan study report, the present usage is estimated to be between 10 and 13% of that used for domestic purposes in the urban areas and 5% in rural area.

2.7 previous studies approaches and Gaps

Master plan (1992) studies are based on the observed flows at terminal sites and upstream abstractions for irrigation, domestic consumptions and weather data. Limitations of these studies are: lumped approach in estimation at terminal sites of the basin, no hydrological models were used for assessing water resources availability, and no calibration and validation of the methods used was made. This study emphasizes on quantifying basin scale surface water potential by using rainfall-runoff model instead of aggregating basin‟s gauged runoff. It involved use of satellite-based datasets, geographical information tools, Observed hydro-meteorological data and Calibrated hydrological model. The study recommends that the future studies should focus on areas with highest development potential and formulation of development scenarios on the basin with different level of details.

Bogale (2011) Predicts discharge at un-gagged catchment using rainfall-runoff WATBAL model. The general objective of the study was to apply a hydrological model and regionalization technique and simulate runoff for un-gagged catchment. The author concludes that one must take close observation of the watershed areas and recommends use of WATBAL model for watershed area size ranging from 39.7km^2-3241.68km^2. The model used in this study, i.e., SWAT, has the capacity to better simulate runoff from larger catchments.

Abdela (2013) predicts the climate change impact on the basin by using climate model. The general objective of the study was to apply climate model and the downscaling methodologies were employed to down scale regional and global climate model output in Omo Gibe Basin. The author suggests that the output of climate model he used can be the input for hydrological model in the ungaugd catchment area for future study.

FAO 1997, assess the potential irrigation total area in Omo Gibe Basin is estimated to be 445,000ha, FAO also reported that the basin area of 76,545Km^2 and the gross water requirement is found to be 4.01Km^3/s; however the FAO estimated water requirement is too low relative to the estimated irrigation are.

IWMI report, 2007; the IWMI document summarizes the following points on water resources and irrigation developments in Ethiopia; total catchment area of the basin is estimated to be 79,000Km^2 and the annual runoff is found to be 16.6Km^2/year (ibid) and the potential irrigable area of 67ha.The potential land estimated is based on the data of Ministry of Irrigation, Water and Energy, however vast area of lower Omo irrigation potential is not considered.

MIWE data, 2009, the irrigation and drainage development studies department of Ethiopian Ministry of irrigation, water and energy assessed the irrigation potential of Omo Gibe basin as 70,275 ha. In 2009 AFDB reported with communication of Ministry of Irrigation water and Energy of Ethiopia giving that the irrigation area in the basin if found to be 100,000ha. However the MIWE data did not foreseen the 175,000ha of land for Kuraz irrigation development.

AFDB report, 2009-2010, at the start of the AFDB report there was no large scale irrigation schemes. Data from MIWE provided an expectation of 100,000ha which is similar to the data reported by Sogreah in 2010, but this data is not consider published agricultural area today specially in the south Omo. Parallel AFDB irrigation study by maina commissioned in 2010 assessed the water demand from 7300ha only; this figure did neither reflect the correct situation in the entire basin nor agreed to the Master plan expectation.

Sogreah report, 2010, consultant Sogreah assessed the existing population dependence in south Omo. Sogreah estimated that 82,000 people depend directly to the river. the outer looked at potential irrigable area downstream of Gibe III and he conclude that 5000ha out of 99716 ha is highly suitable, 60,000ha is moderately Suitable, 140,000ha is marginally Suitable. This report missed what is actually happening right know in the basin and did not include the areas being excised from wildlife protection areas at that time.

The Oakland Institute Report, 2011, a resent irrigation development in Omo are reported in Oakland Institute, see table 1 above. The Oakland institute put attention to large national park excision for sugar plantation reported by the Ethiopian Wild Life Conservation Agency in 2011 a very much larger area of land under irrigation is now developing. Some inaccuracy in the data of Oakland institute report that 245,000 ha for sugar development is corrected by Ethiopian Sugar development corporation to be a maximum of only 175,000ha is expected to develop for sugar production. Details of land investment deals, purposes, allocations and Contracts available at http://media.oklandinstitute.org/land-deals-africa/ethiopia

3. METHDOLOGY AND MATERIAL

3.1 Description of the study area

The Omo-Gibe basin is one of the major river basins in Ethiopia and is situated in the south western part of the country covering parts of Southern Nations, Nationalities and Peoples Region (SNNPR) and Oromia Region. The basin covers an area of 79,000 km^2 with a length of 550 km and an average width of 140 km. The basin lies between $4^{0}00$"N & $9^{0}22$,,N latitude and between $34^{0}44$,,E & $38^{0}24$,,E longitude. It is an enclosed river basin that flows in to Lake Turkana in Kenya which forms its southern boundary.

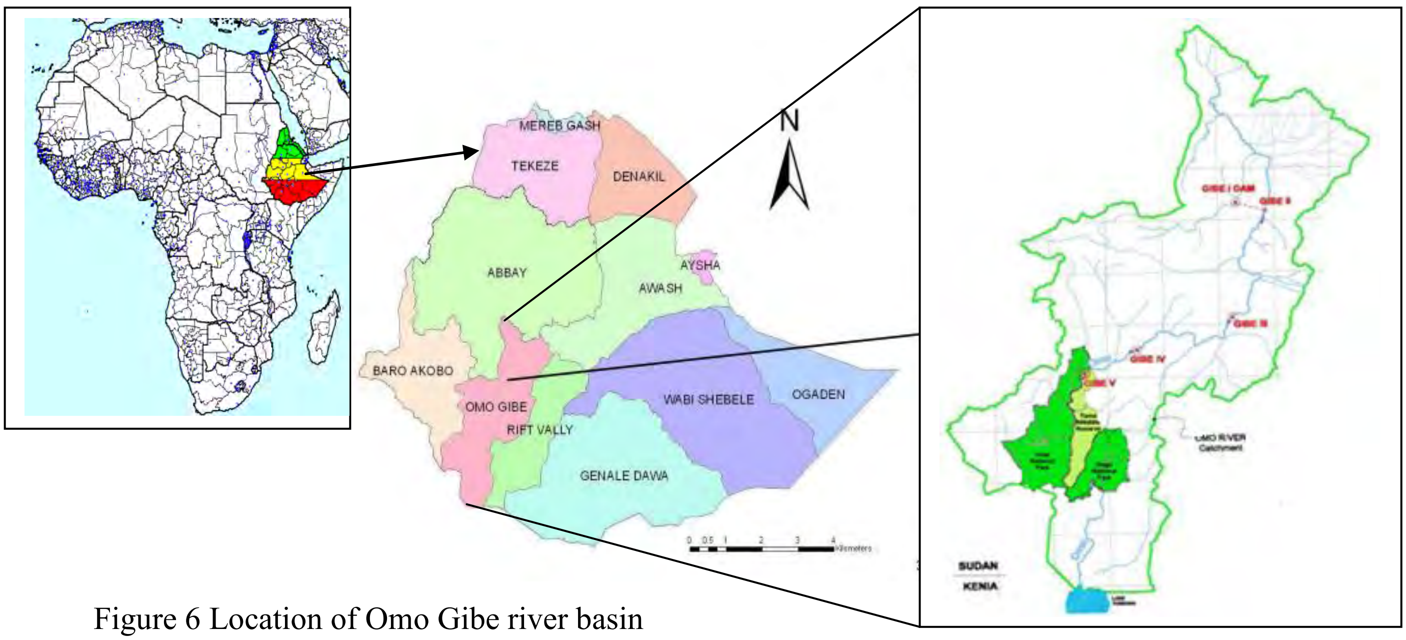


Figure 6 Location of Omo Gibe river basin

The western watershed is characterized by range of hills and mountains that separate the Omo-Gibe Basin from the Baro-Akobo Basin. To the north and northwest the basin is bounded by the Blue- Nile Basin with small area in the northeast bordering the Awash Basin. The whole of the easternside borders the Rift Valley Lakes Basin (Richard Woodroofe and Associates, 1996).

3.2 Climate of the study area

The climate of Omo-Gibe River basin varies from a hot arid climate in the southern part of the floodplain to a tropical humid one in the highlands that include the extreme north and north-western part of the Basin. Intermediate between these extremes and for the greatest part of the basin the climate is tropical sub-humid.

3.2.1 Rainfall

Rainfall in Omo-Gibe basin varies from over 1900 mm per annum in the north central areas to less than 300mm per annum in the south. The amount of rainfall decreases throughout the Omo-Gibe catchments with a decrease in elevation. Moreover, the rainfall regime is unimodal for the northern and central parts of the basin and bimodal for southern part.

Generally the Basin can be split in to four regions, three of them having a unimodal and one is a bimodal rainfall regime. The northern part of the basin, including Bako, Weliso, Welkite and south to just north of Jima, has rainfall for about seven months, from March to September with a range of 1100-1800 mm per annum. The small rains are from March to May and the main from June to September with a marked increase in July and august.
The middle and north-central area, including Bonga, Jimma, Shebe, Hossana and Sodo, has a more even distribution of rainfall over March to September without any peak in July and august. The region generally receives more than 1200mm, rising to 2000 mm on the western fringes North West of Bonga. This part of the region is the wettest part as compared to the other two regions.
The southern part of the basin includes, Jinka, Sawula and Morka. Eventhogh, the magnitude of the rainfall in this part of the region is small as compared to the other two regions, but it has a prolonged rainy season of bimodal type.

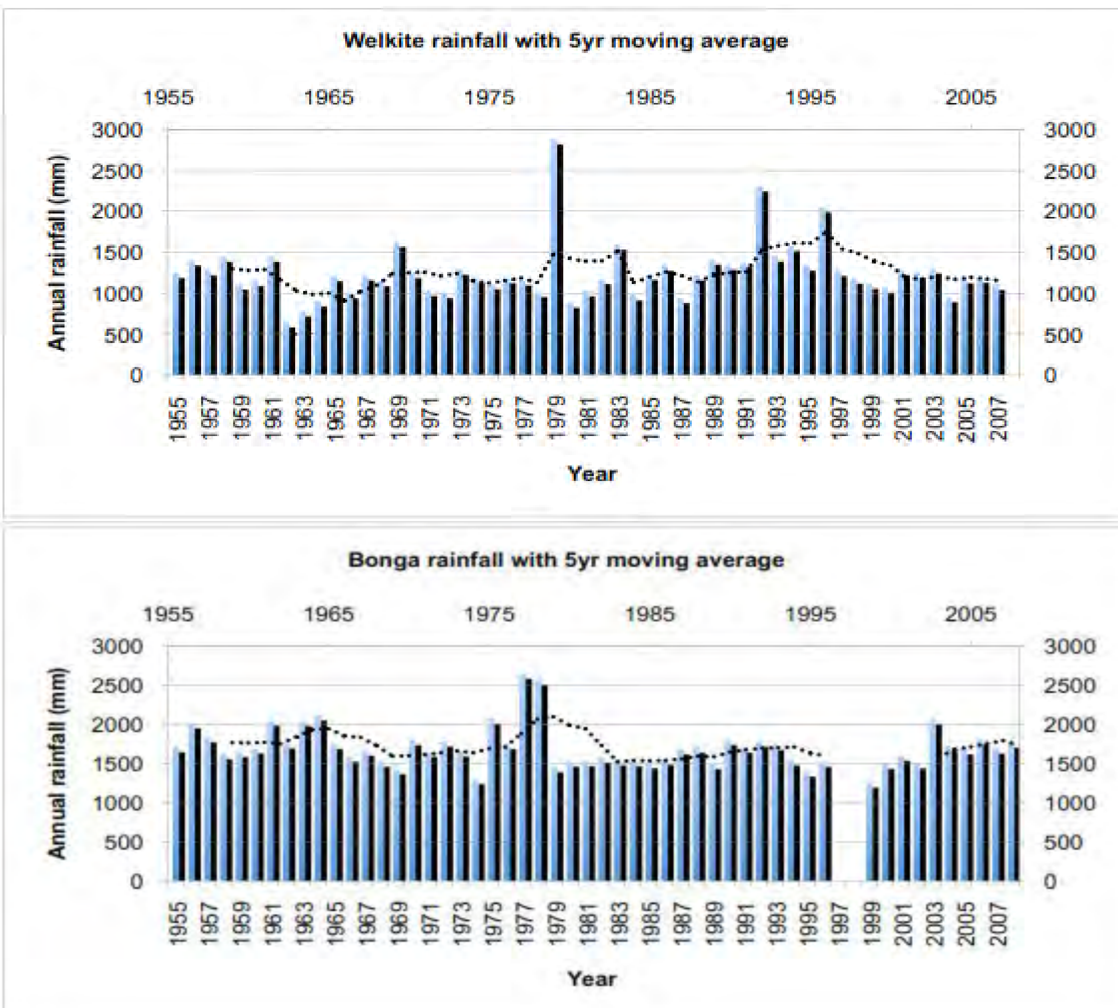


Figure 7 Annual rainfall variations between selected stations

Source of monthly rainfall data: National Metrological Agency (NMA), Addis Ababa.

Avery 2010 (AFDB study)

3.2.2 Temperature

The mean annual temperature in Omo-Gibe basin varies from 16^{0}C in the highlands of the north to over 30^{O}C in the lowlands of the south. The maximum temperature is higher at the southern part of the basin especially at Morka mean annual maximum temperature reaches up to 30.6^{0}C. There is a little variation in minimum temperature which varies from 9.2^{0}C in northern part of the basin example in Gedo to 16^{O}C in southern part of the basin at Jinka.

3.2.3 Topography and slope

The topography of Omo Gibe basin as a whole is characterized by its physical variation. The northern two-thirds of the basin has mountainous to hilly terrain cut by deeply incised gorges of the Omo, Gojeb, and Gilgel-Gibe Rivers, while the southern one-third of the basin is a flat alluvial plain punctuated by hilly areas. The northern and central half of the basin lies at an altitude greater than 1500masl with maximum elevation of 3360masl (located between Gilgel- Gibe and Gojeb tributaries), and the plains of the lower Omo lies between 400-500masl (Richard Woodroofe & associates Vol VI, 1996).

The northern part of the catchment has a number of tributaries. Most of the rivers from upper part of the catchment drain largely cultivated land. The head waters of the Great-Gibe River are at an elevation of about 2200masl. Although there are some important tributaries from different directions, the general direction of flow of the Gibe River is southwards, towards the Omo River and then to Lake Turkana a fault feature, filled with alluvial sediments of recent origin associated with the Great Rift Valley. The Gibe River is known as the Omo River in its lower reaches, south-westwards from the confluence with the Gojeb River. This is the reason behind the name Omo-Gibe River Basin.

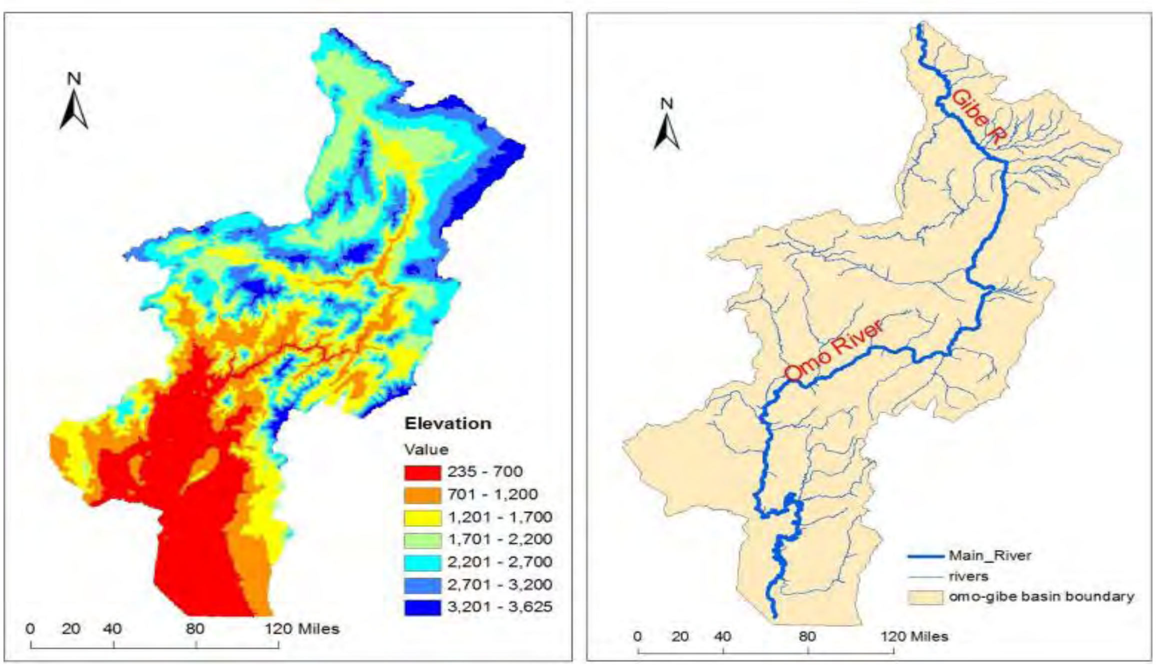


Figure 8 Elevation and River network as extracted from SRTM

3.3 Geology soil and land use

3.3.1 Geology

There is limited information available on the geological formation of the study area. But according to master plan study of the basin the geology can be characterized by tertiary and quaternary age rhyolite and basalt volcanic in the north and middle part of the basin with quaternary alluvial overlying Precambrian basement gneisses and granite in the south. Approximately 11% of the Omo-gibe basin is underlain by Precambrian metamorphic gneisses and 80% of the Basin is underlain by Tertiary volcanic rocks.
The geology of the Omo-Gibe Basin can be divided tentatively in to five groups of rocks according to their age relationships. These groups are:

- The pre-Cambrian crystalline basement rocks
- The early "flood basalts" of late Eocene to early Miocene age
- A transitional series of intercalated basaltic and felsic volcanic of late Oligocene to early Miocene age
- A series of felsic volcanic ranging from early Miocene to late Miocene in age
- The post-rift sediments and volcanic, of Poliocene and Quaternary age

3.3.2 Soil

More specific soil studies in the basin have concentrated on the irrigation potential of the lower Omo valley with some work on erosion and conservation measures. During the study of Omo Gibe integrated development master plan detailed soil survey especially on the upper part of the basin were carried out. On this study soil morphology of the basin also included. Soil morphology relates to the appearance of the soil in the field in terms of; depth, color, texture, structure, consistence, drainage and presence or absence of stone and carbonates. These together with soil chemistry, are the criteria used to categorize the soils in to units.
The majority of the soils in the basin are deep to very deep, red and reddish brown clay looms over clays. These soils are well drained. They are wide spread over the whole of the northern basin. Soils developed from volcanic parent materials, often with an ash or pumice layer tend to occur on high ground with in the basin. They are moderately deep to deep, well drained, dark brown to dark reddish brown sandy clay loams to clays. These soils occur on the northern boundary. The other soils in this general category include soils developed on acidic igneous parent materials characterized by brown color. In the south of the basin in the areas of lower rainfall the soils developed are characterized by the presence of a course sand fraction. They are moderately deep to very deep, well drained yellowish brown course grained sandy loams to sandy clays.

Table 5 Soil type

SOIL_TYPE	OID	VALUE	AREA (%)
eutric cambisols	0	0	11.29
chromic luvisols	1	1	2.18
eutric nitisols	2	2	0.91
eutric fluvisols	3	3	10.97
chromic vertisols	4	4	8.28
pellic vertisols	5	5	24.56
dystric fluvisols	6	6	4.95
dystric nitisols	7	7	0.01
leptosols	8	8	4.28
chromic cambisols	9	9	3.92
calcic xerosols	10	10	0.39
dystric cambisols	11	11	0.81
vertic luvisols	12	12	27.4
vertic andosols	13	13	0.05

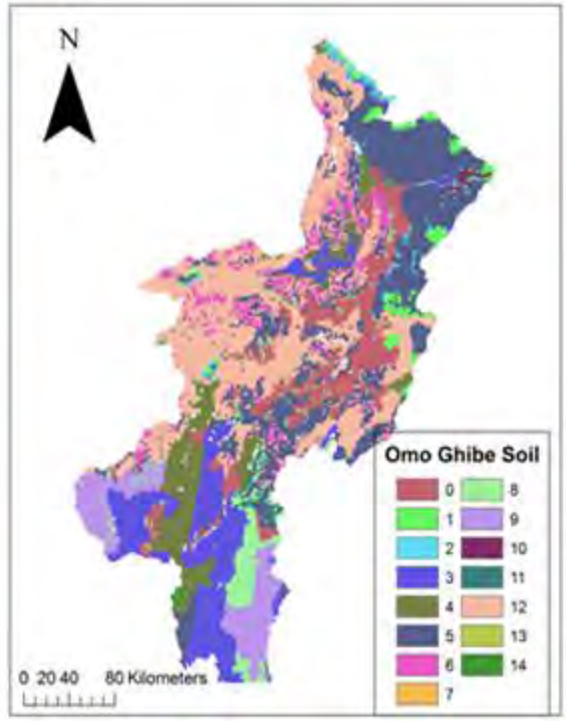


Figure 9 Map of Omo Gibe Soil

3.3.3 Land use

Land use pattern of northern catchment is characterized by extensive cultivation with increased land pressure. According to the field visit that has been made in 2014 forest areas are now confined to areas too steep and inaccessible to farm.

Generally central western part of the basin boundary area has extensive tracts of high forest. The Gibe, Gojeb and Omo gorges are relatively unpopulated and support a cover of open woodland and bush land through inaccessible area, such as where the Addis Ababa to Jimma road crosses the Gibe Gorge, woodlands are being cleared for charcoal. Eastern catchment boundary has some of the most densely populated and intensively farmed areas in the basin. The south of the basin is more sparsely populated with a greater population of natural vegetation.

S no.	Land use type	Area km^2	Percentage of land use type
1	Woodland	23794	30.02
2	Intensive cultivation	23637	29.82
3	Bushland	7978	10.06
4	Forest	6722	8.48
5	Grassland	5906	7.45
6	Moderate cultivation	5609	7.08
7	Marsh	2103	2.65
8	Shrubland	1111	1.4
9	Bare soil	1037	1.31
10	Plantation and fallow	1001	1.26
11	Open water	321	0.41
12	Afro-Alpine	38	0.05
13	Urban	18	0.02
Total			**100**

Figure 10 Percent Land use

3.4 Data collection Gap filling and Quality control test

3.4.1 Data Collection

Data necessary for the modeling work and basin‟s water resources assessment can be classified in to two. These are spatial data and physical data. Spatial data include Land use/cover map, Soil map, DEM and areal map of watershed which can be displayed in GIS. Physical data include meteorological data (rainfall, temperature, relative humidity and sunshine hours), hydrological (stream flow) data, soil physical properties and crop data (Kc, growth period and crop season).
The SWAT model requires meteorological and hydrological input data at daily time step including rainfall, temperature, relative humidity, sunshine hours and monthly flow data at each sub-basin outlet. Daily temperatures, relative humidity and sunshine hour data were compiled for all available stations in the basin. All of the meteorological stations for which data were collected are located inside the basin, and record lengths of these stations vary from a few years to more than 30 years.

3.4.2 Hydrological data

Hydrological data is very important data in this study. Depending on the location and availability of data gauged stations were selected in main and tributary rivers of omo Gibe River. Hydrological data used in this study are collected from:-

- Ministry of Irrigation, water and Energy of Ethiopia, hydrology department 20 selected stations record data of 20-35 years were collected.

- Master plan study on Omo Gibe River Basin hydrological report.

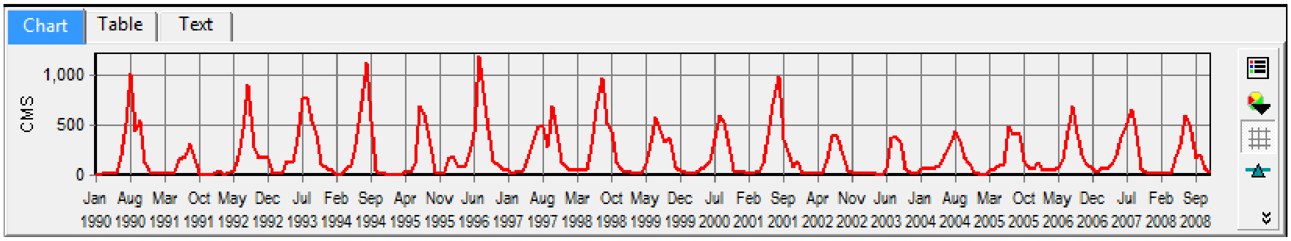


Figure 11 Gibe River flow at Ability gagged 1990-2010

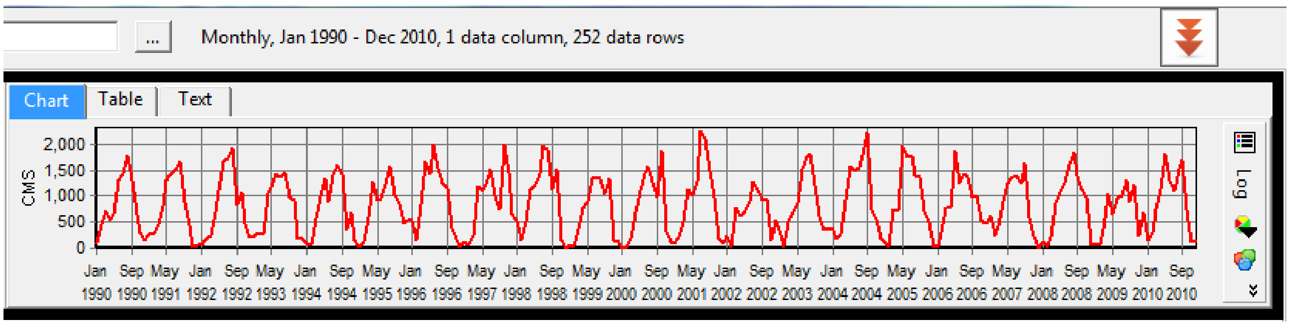


Figure 12 Omo River discharge

Table 6 Summary of hydrological stations used

number	Station	Lat	Long	Area	Record Period
1	Darge @Tedela			457.5 sq km	1987-2010
2	GILGELGHIBE NR.ASENDABO	7:45: 0 N	37:11: 0 E	2966.0 sq km	1980-2009
3	G.GIBE @ ABELTI	8:14: 0 N	37:35: 0 E	15746.0 sq km	1980-2010
4	Ghibe Nr. Baco	9: 7: 0 N	37: 3: 0 E	288.1 sq km	1979-2009
5	Ghibe nr. Limu Genet	8: 6: 0 N	36:56: 0 E	533.0 sq km	1984-2004
6	GOJEB NR.SHEBE	7:25: 0 N	36:23: 0 E	3577.0 sq km	1970-2004
7	KULIT Nr. TEDELE			350.0 sq km	1983-2006
8	MEGECH Nr. GUBERE	8:11: 0 N	37:28: 0 E	286.0 sq km	1967-2006
9	WABI Nr. WOLKITE	8:15: 0 N	37:46: 0 E	1866.0 sq km	1967-2007
10	WALGA Nr. WOLKITE			1792.0 sq km	1971-2005
11	WERABESA Nr. SELKAMBA			234.0 sq km	1982-2004
12	Ajancho River Nr Areka	7: 8: 0 N	37:43: 0 E	306.0 sq km	1985-2005
13	Demie River	6:38: 0 N	37:31: 0 E	1119.0 sq km	1987-2006
14	DINCHA AT BONGA	7:12: 0 N	36:17: 0 E	443.8 sq km	1982-2006
15	GHIBE NR SEKA	7:36: 0 N	36:45: 0 E	280.4 sq km	1980-2007
16	Gogera River Nr. Dana1	6:43: 0 N	37:32: 0 E	266.0 sq km	1982-2006
17	GUMA NR.ANDARACHA	7: 9: 0 N	36:15: 0 E	231.3 sq km	1981-2003
18	Mazie Nr. Morka	6:26: 0 N	37:12: 0 E	937.0 sq km	1987-2006
19	Nerie Nr Jinka			166.0 sq km	1982-2006
20	Sokie Nr Areka			103.0 sq km	1987-2006

3.4.3 Metrological data

The most important time series data used in this study are metrological data. The source of raw metrological data‟s is the National Metrological Service Agency (NMSA) of Ethiopia. Daily rainfall, maximum and minimum temperature, relative humidity and sunshine hours were collected for 20-30 years of records depending on the availability of data. From the total metrological stations only 17 stations were selected in this research depending on the percent of missed data. If the percent of missed data is less than 20% or in other word if the recorded data for total length of record is 80% full the station was used in the study. Summary of meteorological stations used are shown in Table 7. Meteorological parameters such as relative humidity and sun-shine hours are recorded every 6 hours. SWAT model needs full humidity and sunshine hour‟s data in addition to rainfall and temperature; in order to calculate evapotranspiration using Penman Monteth method. If there is missed data for humidity and sunshine hour data, SWAT needs weather generator stations in the catchment. In this study Jima station was used as weather generator stations.

Table 7 summary of meteorological stations used

No	Meteor-Stations	latitude	longitude	Record period	% of Missed
1	Bita Woshi	71900	360200	1990-2013	12.1
2	Bonga	73000	363000	1990-2013	7.2
3	Busa	75600	371200	1990-2013	16.4
4	Chekorsa	73700	364400	1990-2013	11.7
5	Delbi	72200	365200	1990-2013	13
6	Deri Goma	73000	361500	1990-2013	15.9
7	Jinka	72200	365200	1990-2013	9.8
8	Sawula	6.3	36.88333	1990-2013	19.6
9	Limu Genet	80400	365700	1990-2013	6.2
10	Sekoru	7.91231	37.42811	1990-2013	11.76
11	Hosana	73402	375114	1990-2013	5.9
12	Jimma	7.667	36.8333	1990-2013	5.3
13	Woliso	83300	375900	1990-2013	7.7
14	woliata	6.31803	36.50841	1990-2013	12.3
15	Ejaji	8.999	37.32661	1990-2013	17.3
16	Baco	55400	363400	1990-2013	14.5
17	Wolkite	8.28333	37.78333	1990-2013	16.1

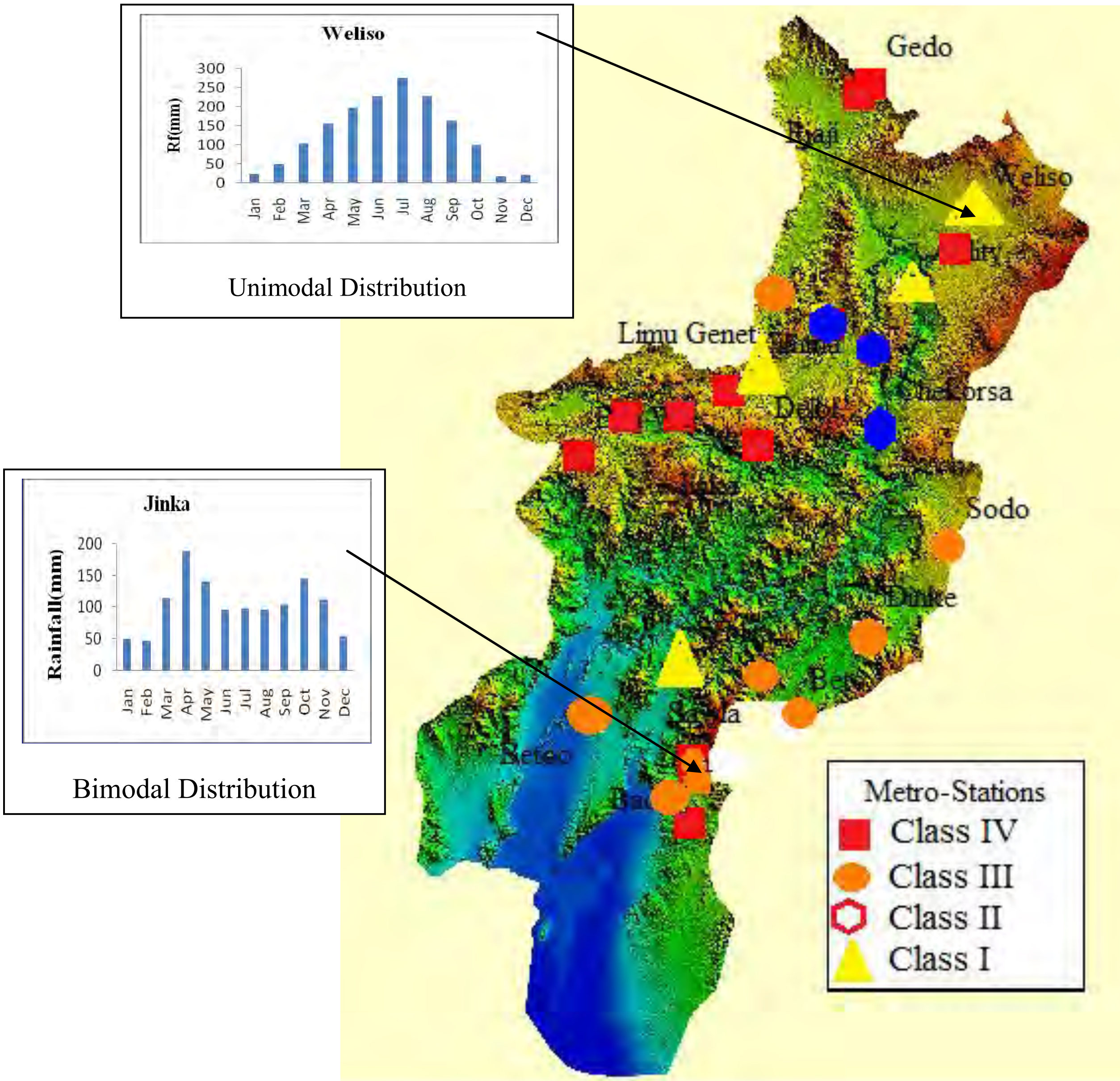


Figure 13 Metrological stations used

A rain gauge station represents a rainfall at a single location. This point rainfall should be converted to aerial precipitation, the depth of rainfall considering the enclosed area is important in WEAP model hydrological analyses and it is one of very important parameter in hydrology. Computation of average areal rainfall is done by theissen polygon method. Rainfall varies in intensity and duration horizontally from place to place, hence the rainfall recorded by each metrological station should be weighted according to the area assumed to represent.

The area of influence of each gauge was calculated by constructing Thiessen polygons using Global mapper15 software. (Figure 14 and Table 8)

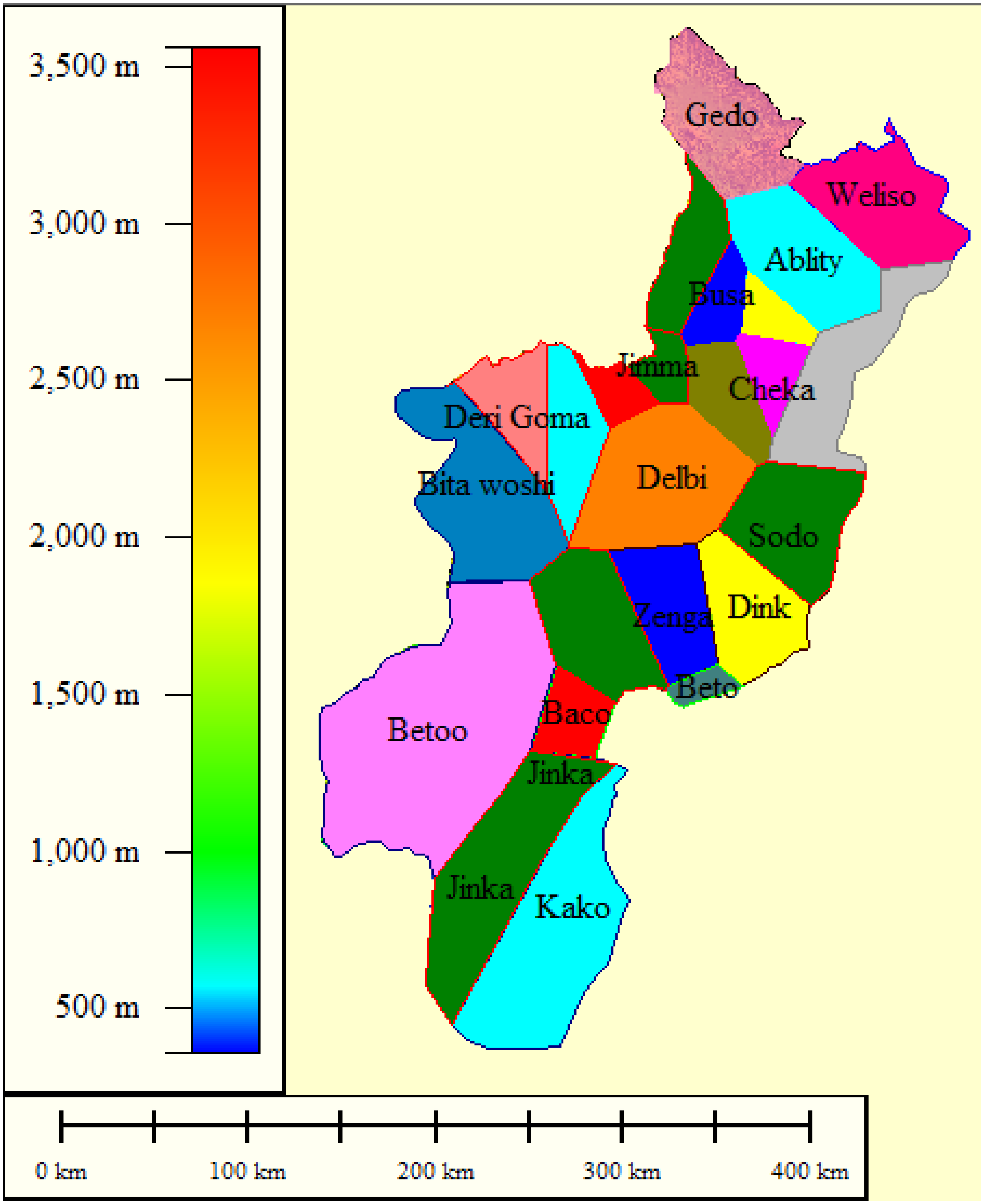


Figure 14 Thiessen polygon created for areal precipitation estimation

Table 8 Thiessen polygon gauge weights used

Polygon name	Perimeter (km)	Area Weight (Km2)	Gauge Weight (%)
Gedo	369.14	4381.7	5.55
Weliso	347.88	6333.3	8.02
Limu Genet	195.71	1870.5	2.37
Busa	198.27	2072.3	2.62
Cheka	239.92	2952.7	3.74
Hosana	287.48	2868.4	3.63
Ambuye	90.143	502.06	0.723
Assendabo	183.16	1967.6	2.49
Sodo	243.88	3659.8	4.32
Morka	236.84	3369.9	4.27
Delbi	284.47	5181	6.56
Chekorsa	166.18	1195	1.51
Bonga	255.89	2305.6	2.92
Deri Goma	200.61	1818.7	2.3
Bita Woshi	395.51	6112.8	7.74
Zenga	123.77	408.68	0.64
Beto	87.532	382.66	0.587
Lote	248.82	2428.8	3.07
Sawla	205.67	1462.2	1.85
Bulki	254.31	3045.6	3.86
Baco	319.01	5686	7.19
Jinka	494.4	9427.3	11.93
Kako	422.22	9567.4	12.11
Total		79000	100

Coverage of functional rainfall stations over the basin is estimated using standards shown in Table 9. 75% of Omo-Gibe River basin is Mountainous areas, so the minimum density of rainfall stations is 100-250(Km2/gauge). One station can represent from 11.3-17.85 km of diameter as shown in figure 15.

Table 9 Standards in minimum density range for Gauge stations (WMO)

Regions	Minimum density range (km^2/gauge)
Temperate, Mediterranean and tropical zones Flat areas Mountainous areas	 600-900 100-250
Small mountainous islands (< 20,000 km^2)	25
Arid and polar zones	1,500-10,000

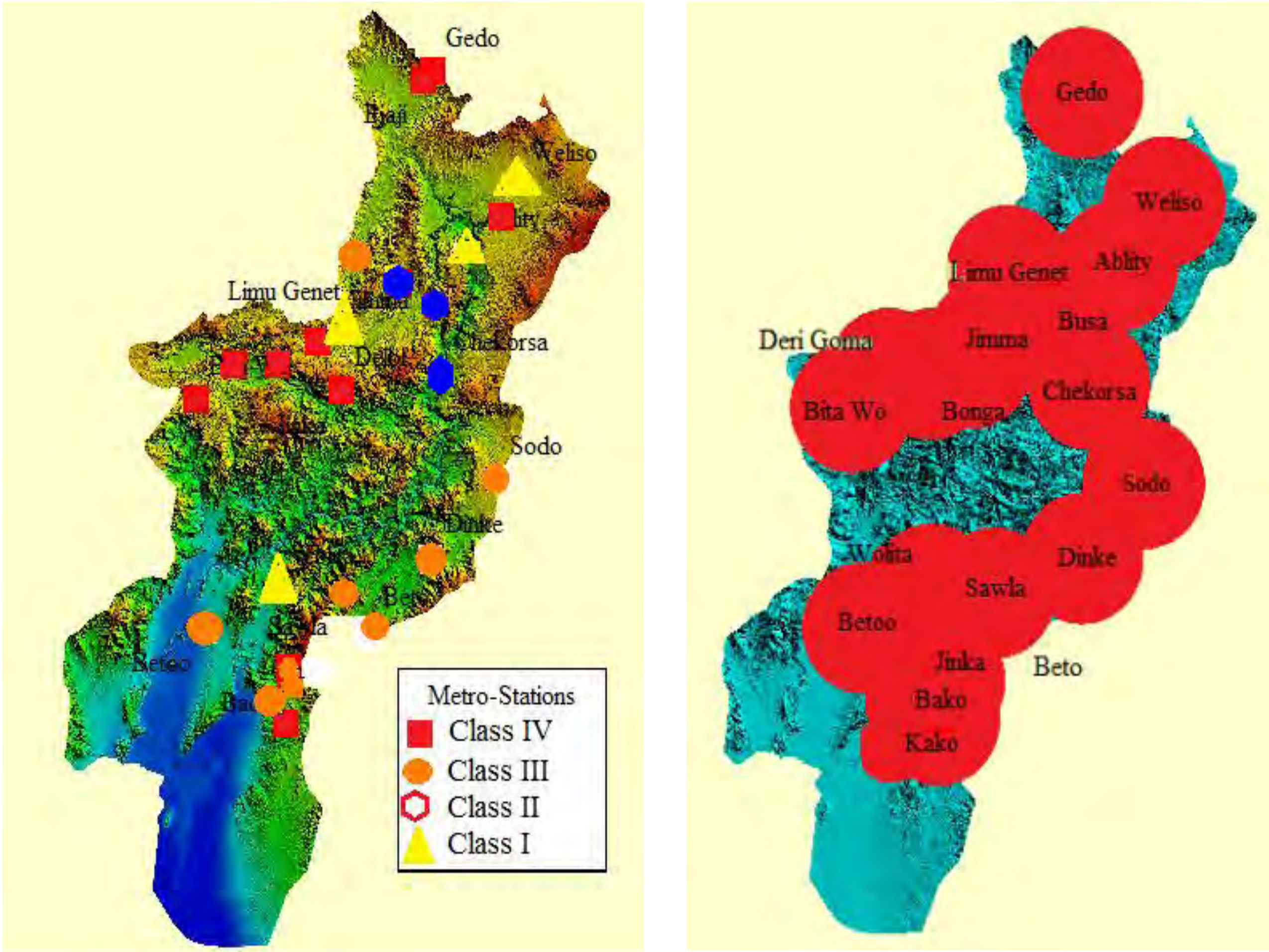


Figure 15 Coverage of metro stations in Omo-Gibe Basin

Isohyets are a line joining places of equal rainfall intensities on a rainfall map of the basin. An isohyetal map represents spatial rainfall distribution of the basin. Data for isohyetal map preparation was collected from National Meteorological Service Agency and processed in Arc GIS. Isohyetal map of mean annual rainfall of the basin is shown in Figure 16.

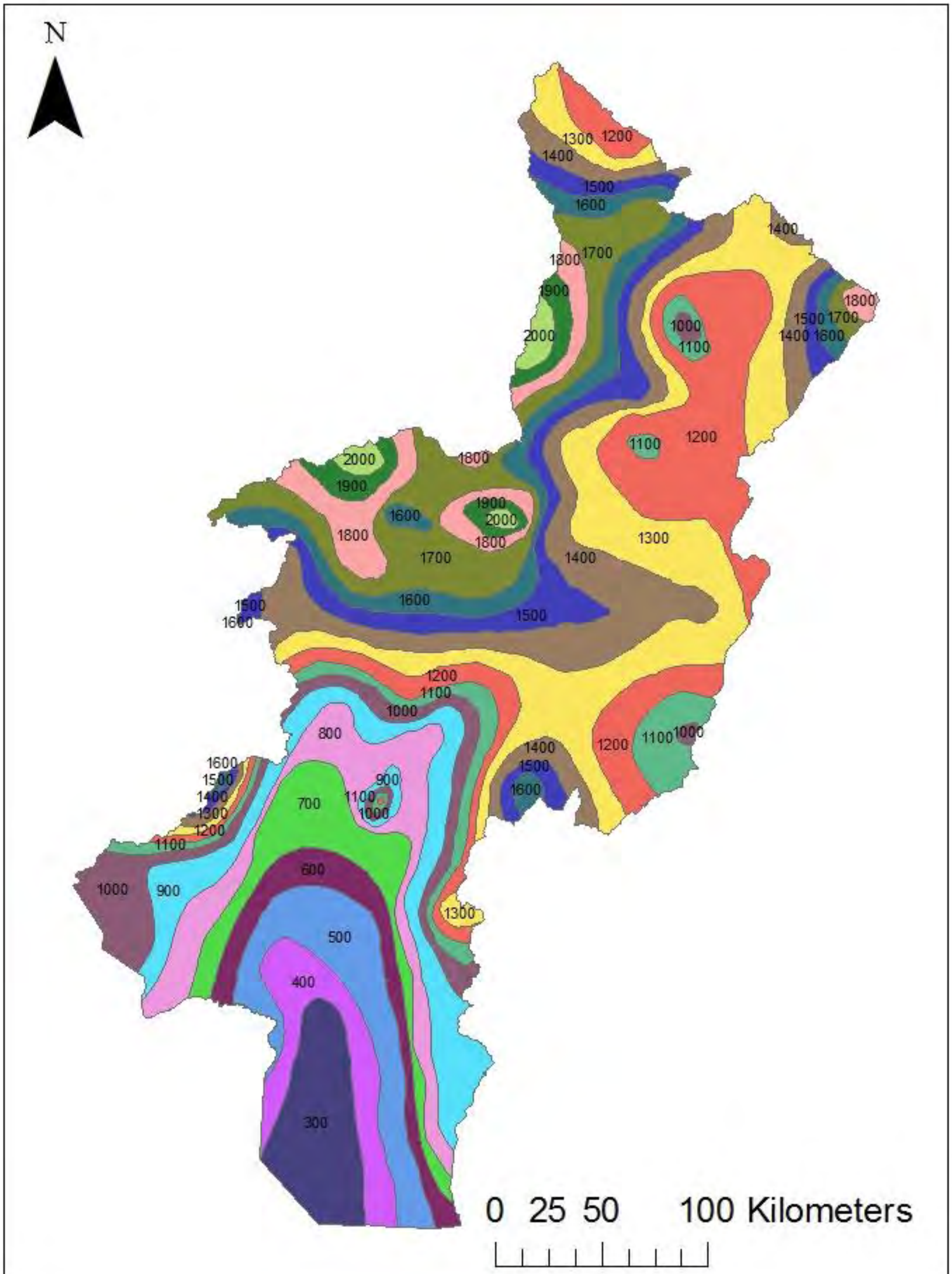
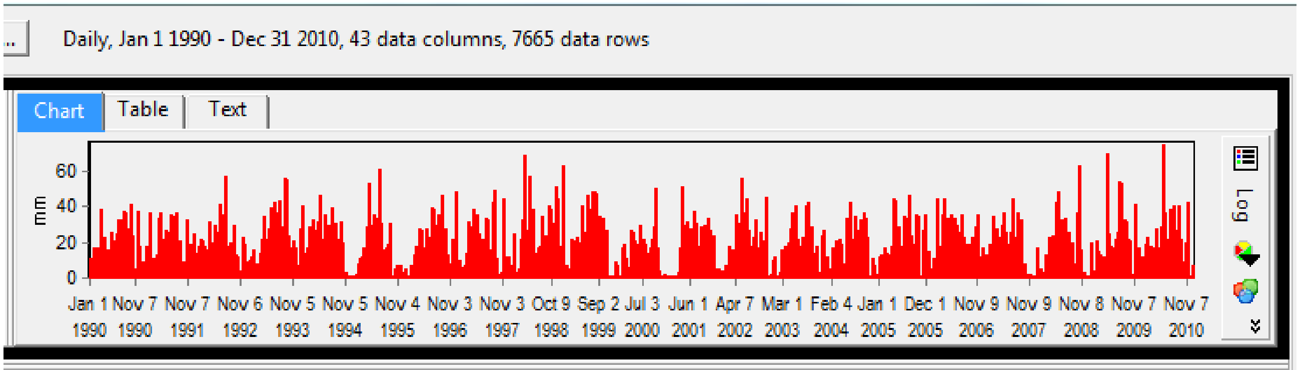
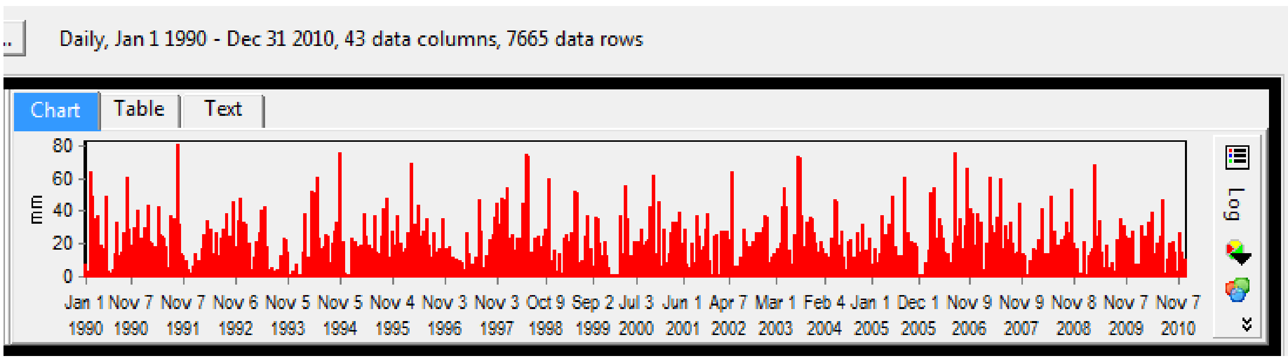


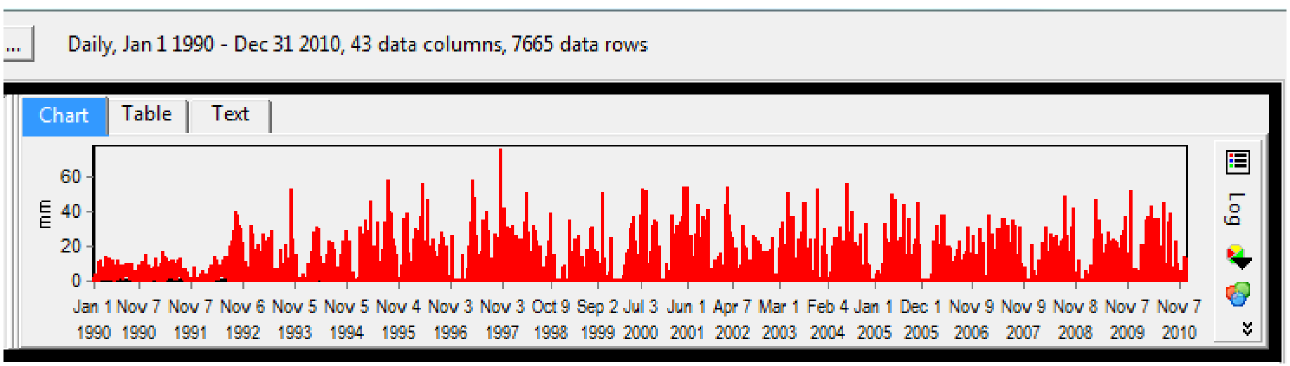
Figure 16 Mean annual rainfall isohyetal map (mm)



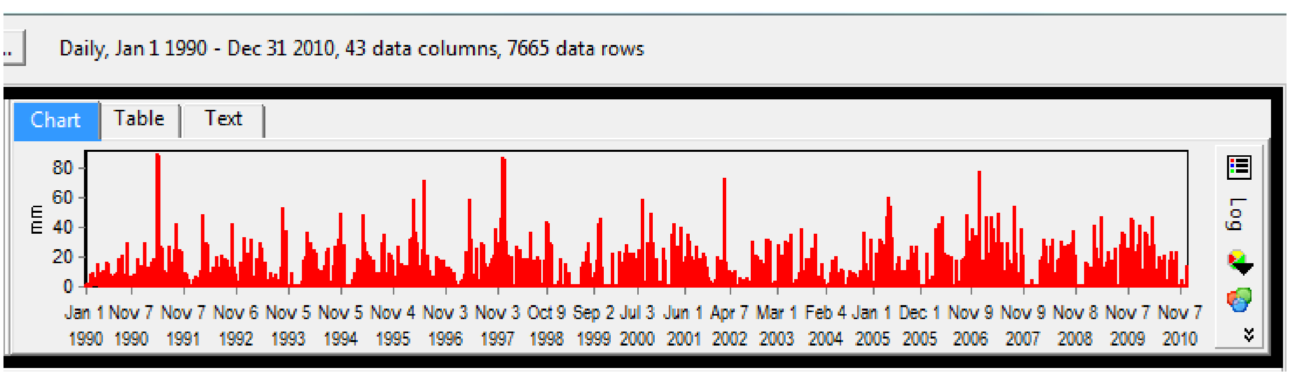
Daily precipitation at Weliso



Daily precipitation at Sawula



Daily precipitation at Limu Genet



Daily precipitation at Jinka

3.4.4 Missing data estimation

The continuity of a record may be broken with missing data due to many reasons such as damage or fault in a rain gauge during a period. The missing data can be estimated by using the data of the neighboring stations. If the total annual rainfall at any of them region gauges differs from the annual rainfall at the point of interest by more than 10%, the normal-ratio method is preferable. Because this method is more advanced than station average method and simple, it used for filling missed rainfall data in this study. The general formula for computing P is:

$$P_x = \frac{N_x}{M}\left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + .. + \frac{P_m}{N_m}\right] \quad \text{……………………………..3.1}$$

Where:

N_x=Average annual precipitation at the missing data.

N_1, N_2, N_3, N_m=Average annual precipitation at the adjacent site.

How to check the performance of Normal ratio method?

The performance of the selected method is tested by considering the recorded data as missed; the missed data filed by the selected method and considers it as simulated output. Comparison between computed and recorded data indicates the performance of the method. The result is shown below; we can conclude that normal ratio method is appropriate for filling missed data.

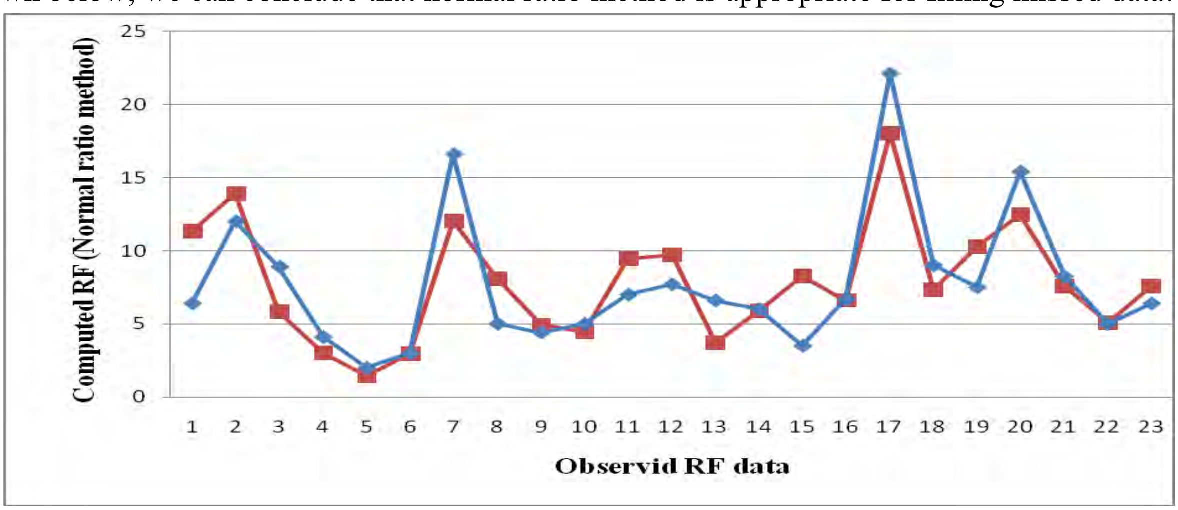


Figure 17 performance test result on normal ratio method

3.4.5 Data Quality Control tests

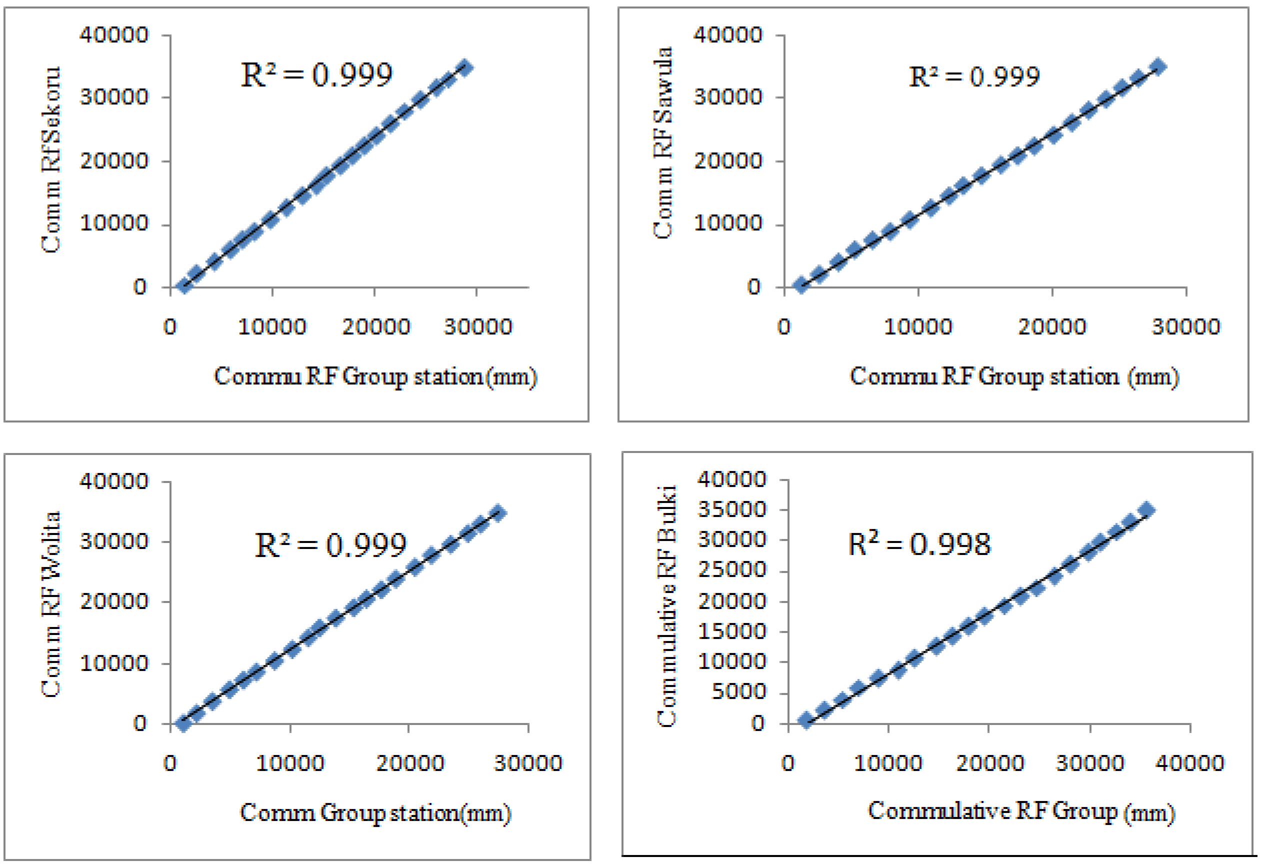
3.4.5.1 Test for record consistency

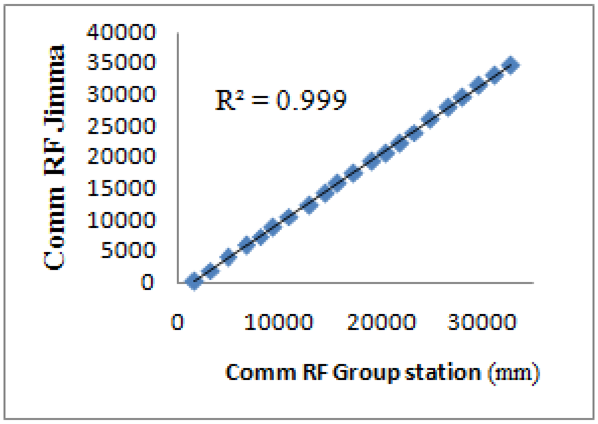
Double mass curve is a simple, visual and practical method, and it is widely used in the study of the consistency and long-term trend test of hydrometeo-rological data (Mu, et al., 2010). The theory of the double-mass curve is based on the fact that a plot of the two cumulative quantities during the same period exhibits a straight line so long as the proportionality between the two remains unchanged, and the slope of the line represents the proportionality. This method can smooth a time series and suppress random elements in the series, and thus show the main trends of the time series.

Some of the common causes for inconsistency of record include:

- Shifting of a rain gauge station to a new location,
- The neighborhood of the station undergoing a marked change.
- Personal/recorder errors.

A group of *n* (usually 5 to 10) base stations in the neighborhood of the problem station *X* is selected which are class I stations. Annual (or monthly mean) rainfall data of station *X* and also the average rainfall of the group of base stations covering a long period is arranged in the reverse chronological order (i.e. the latest record as the first entry and the oldest record as the last entry in the list). The result is shown figure 3.4:-




R² = 0.999
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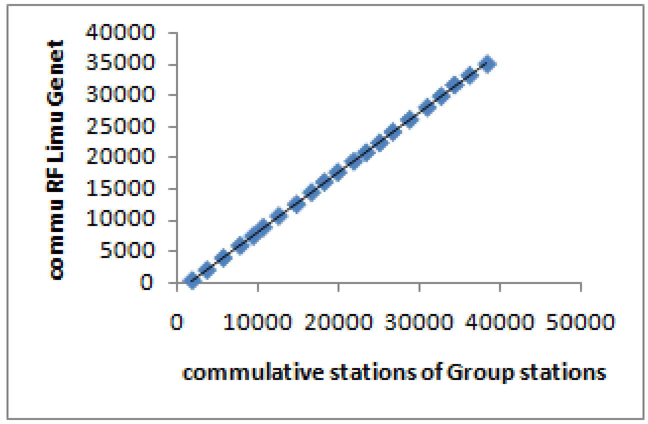
Comm RF Group station (mm)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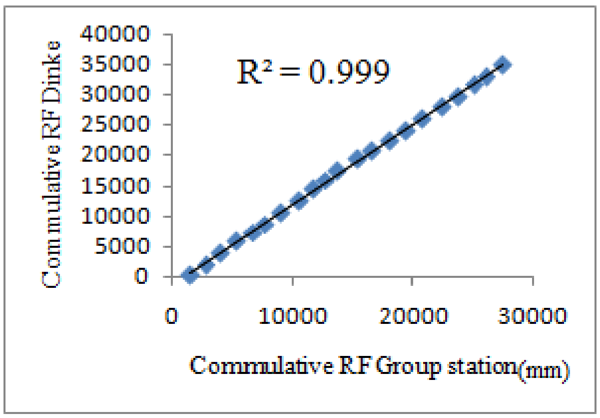
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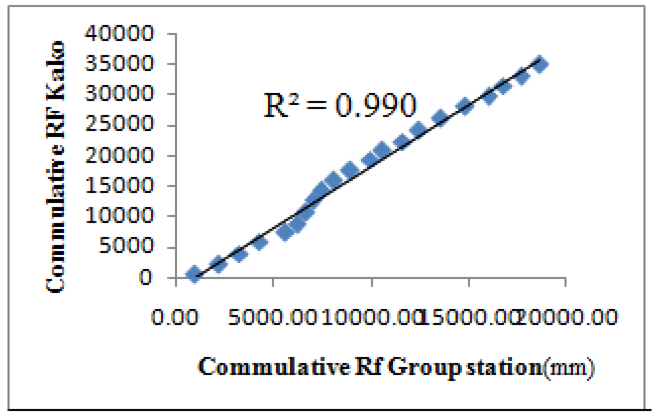
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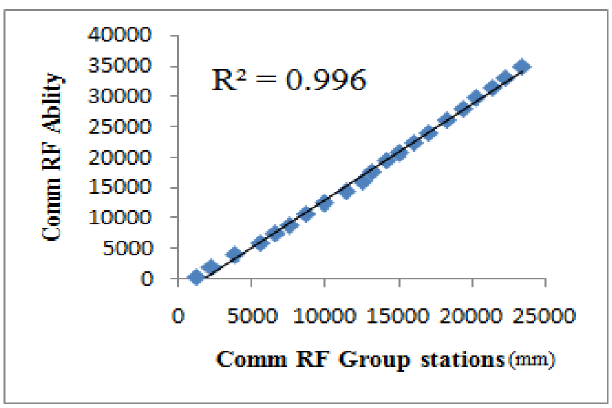
R² = 0.996
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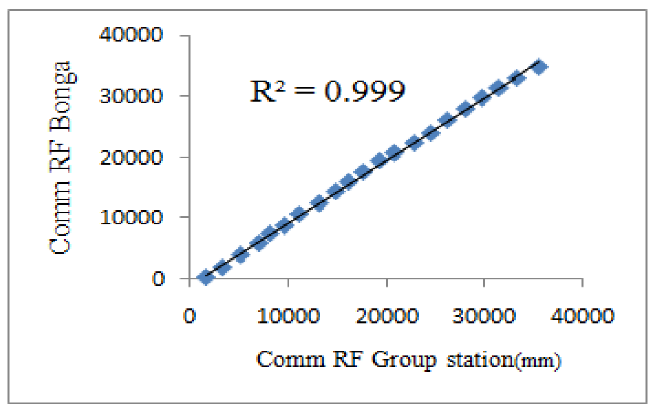
25000
Comm RF Group stations (mm)


R² = 0.999
Comm RF Bonga
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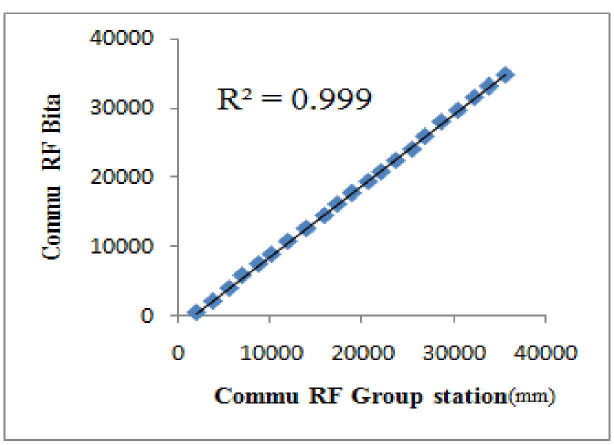
Comm RF Group station(mm)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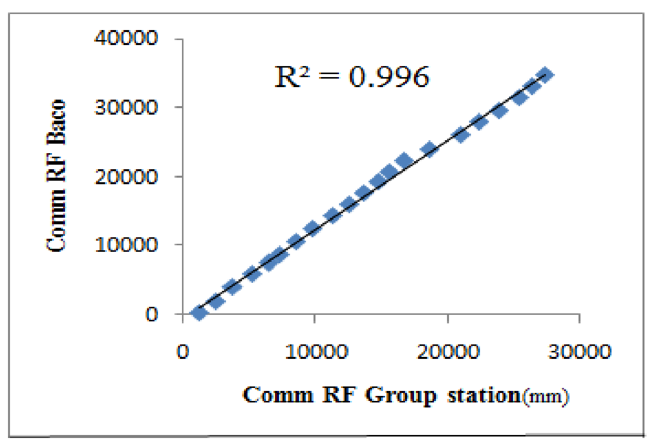
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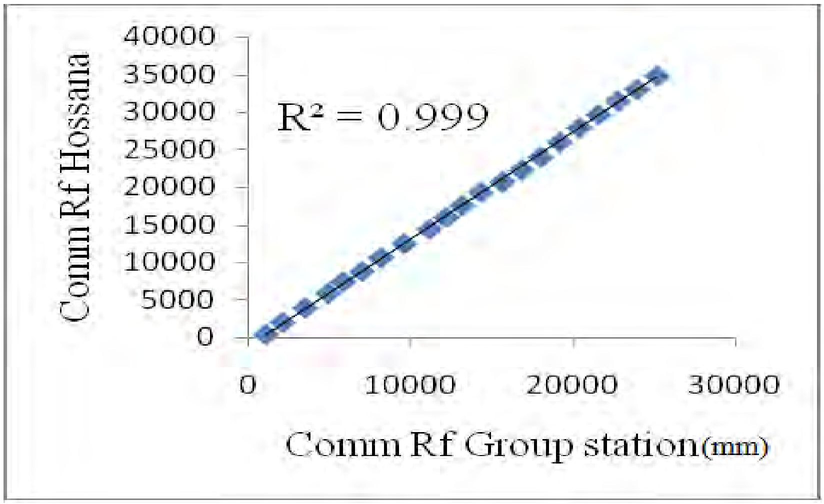


Figure 3.4 Consistency test on selected stations

3.4.5.2 Outlier test

The identification of outliers has been the primary emphasis of quality control work; outliers are observations very distant from the mean value that can be due to measurement errors or to extreme meteorological events in observed metrological data. When outliers are undoubtedly erroneous measurements those extreme data can be rejected and the problem is converted into one of missing data treatment. On the one hand, extreme data carry very valuable climatological information that should not be dismissed, yet statistical parameters are highly affected by presence of outliers. An alternative that would combine keeping the information of extreme data and showing consideration for effects of outliers would be to censor outliers by means of replacing them by some threshold value that keeps the information of an extreme event and yet does not have such an important influence on nonresistant statistics.

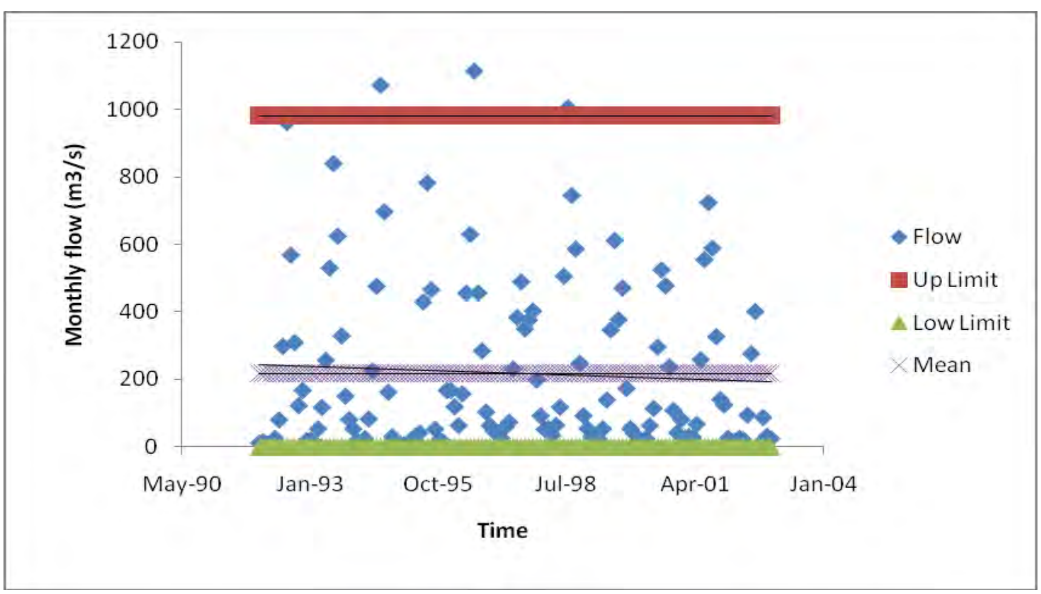


Figure 18 Outlier test on Ablity stream flow data

Outliers were identified as those values trespassing a maximum threshold for each time series (Trenberth and Paolino 1980; Peterson et al. 1998a) defined by

$$P_{out} = q_{0.75} + 3IQR, \quad \text{………………………………………………..3.3}$$

Where $q_{0.75}$ is the third quartile and IQR the interquartilic range. The IQR has been used in quality control of climate data (Eischeid et al. 1995) because it is resistant to outliers. Values over P_{out} were substituted by this limit. This way of proceeding reduces the bias caused by outliers and yet keeps the information of extreme events (Barnett and Lewis 1994).

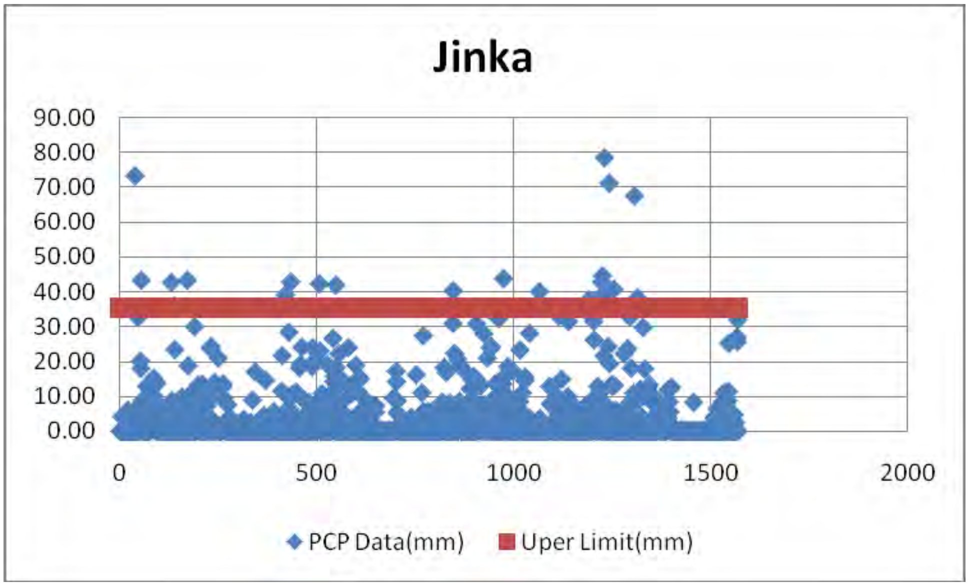


Figure 19 Precipitation data Outlier test at Jinka Station

3.4.6 Digital Elevation Model Data

Digital Elevation Model (DEM) well define the topography of the area by describing the elevation of any point at a given location and specific spatial resolution as a digital file. It is one of the essential spatial inputs for SWAT to delineate the watershed in to a number of sub watersheds or sub basins based on elevation. Drainage pattern, slope, channel width and stream length with in the watershed were processed using DEM. The raw DEM were obtained from Ethiopian Mapping Agency at 30x30m resolution and projected using Arc GIS 9.3 software package.

SRTM DEM of 30m resolution is used to delineate the watershed and sub-watershed boundaries of the Omo Gibe basin. In water resource assessment 30m resolution DEM model is satisfactory for watershed analysess. Flow direction and flow accumulation grids were computed using the DEM and subsequently basin and sub basin boundaris were delineated.

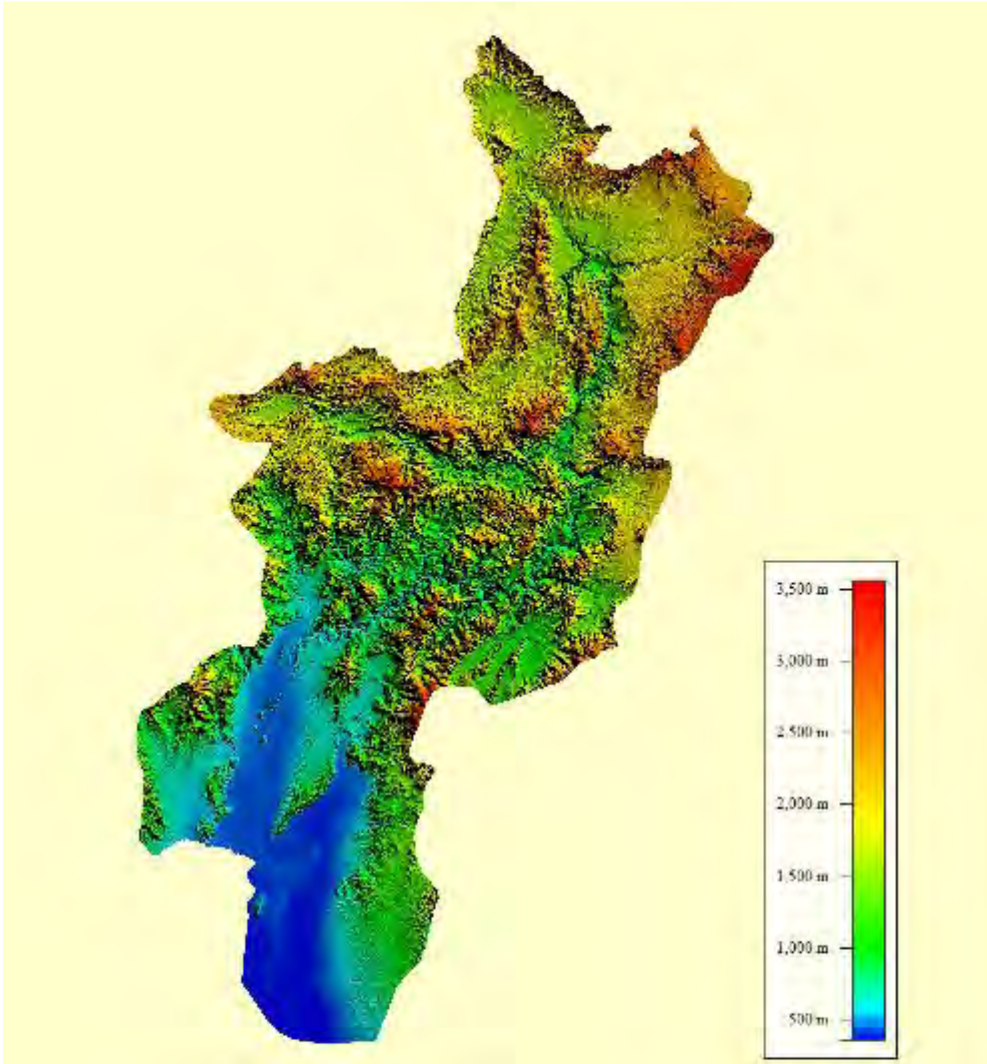


Figure 20 Omo Gibe DEM 30m resolution

3.4.7 Land use Land cover data

In very broad terms most of the northern catchment is under extensive cultivation with increased land pressure meaning the expansions of cultivated areas into increasingly marginal lands at the expense of woodlands. Forested areas are now confined too areas to steep and inaccessible to farm, such as west of Shenen, Botor Becho and between Limu Genet and Jimma where a forest often has an understory of coffee. The basin areas west of Jimma and Bonga areas have extensive tracts of high forest, though even in this relatively inaccessible area encroachment is noticeable.

The flatter poorer drained bottom lands of the northern catchments are usually not cultivated but are used for dry season grazing and, if suitable, brick making. The Gibe, Gojeb and Omo gorges are relatively unpopulated and support a cover of open woodland and bush land though woodland lands are cleared for charcoal. The eastern catchments boundary has some of the most densly populated and intensively farmed areas in the country, let alone the basin. These gorges in the north and Welayta Sodo in the south are dominated by farming system based on ***enset***.

South of Sodo towards Sawla the land scape is one of high mountainous with broad valleys which are less intensively cultivated. The South of the basin generally south of a line from Bonga to Chida and on to Waka in the west and east of the Omo River is more sparely populated with greater proportion of natural vegetation, though even here deforestation is taking place at an alarming rate.

3.4.8 Soil data

Soil morphology relates to the appearance of the soil in the field in terms of; depth, color, texture, structure, consistence, drainage and presence or absence of stone and carbonates. These together with soil chemistry, are the criteria used to categorize the soils in to units. From soil map of the basin collected from MoIWE we have 15 soil units and the physical property of the soil is prepared from soil survey of the basin and FAO soil classification system.

3.5 General Methodology

Assessment of basin wise water situation under present scenarios including water availability and demands of medium to large scale projects by using SOIL AND WATER ASSESSMENT TOOL (SWAT) include:-

- Adoption of compressive water balance based model
- Fitting models to basin using current data.
- Assessment of likely current and future situations of the basin surface water potential with changes in demand, land use, precipitation, PET.
- **Hydrologic response unit generation**

Hydrologic response unit generation requires division of the basin area in to small areas which have the same land use and soil type and these small areas are hydrologically homogenous. Hence we can assess the surface water potential of the basin by directly assessing the hydrologic response unit areas. In addition to the derived hydrological response unit the basin can be sub divided in to the irrigation command area boundaries. and this can be used to assess the potential demand.
HRU analysis: - divide the sub basin in to similar land use, soil, and slope includes the following steps.

- Watershed delineation and calculation of sub basin parameters
- Land Use: - Select and reclassify
- Soil: - Select and reclassify
- Slope: - reclassify
- Overlay slop, soil and land use

This research work used hydrological model for analysis and prediction of surface runoff and demand in Omo Gibe River Basin. The method used included review of previous studies in the basin, data collection from deferent institutions, filling data gaps and data quality control assessments. After the calibration and validation, SWAT model was used to simulate surface runoff in Omo Gibe river basin and WEAP model used for estimation of current and future water demand. The general methodological flow chart used in SWAT and adopted in the research is shown in figure 21.

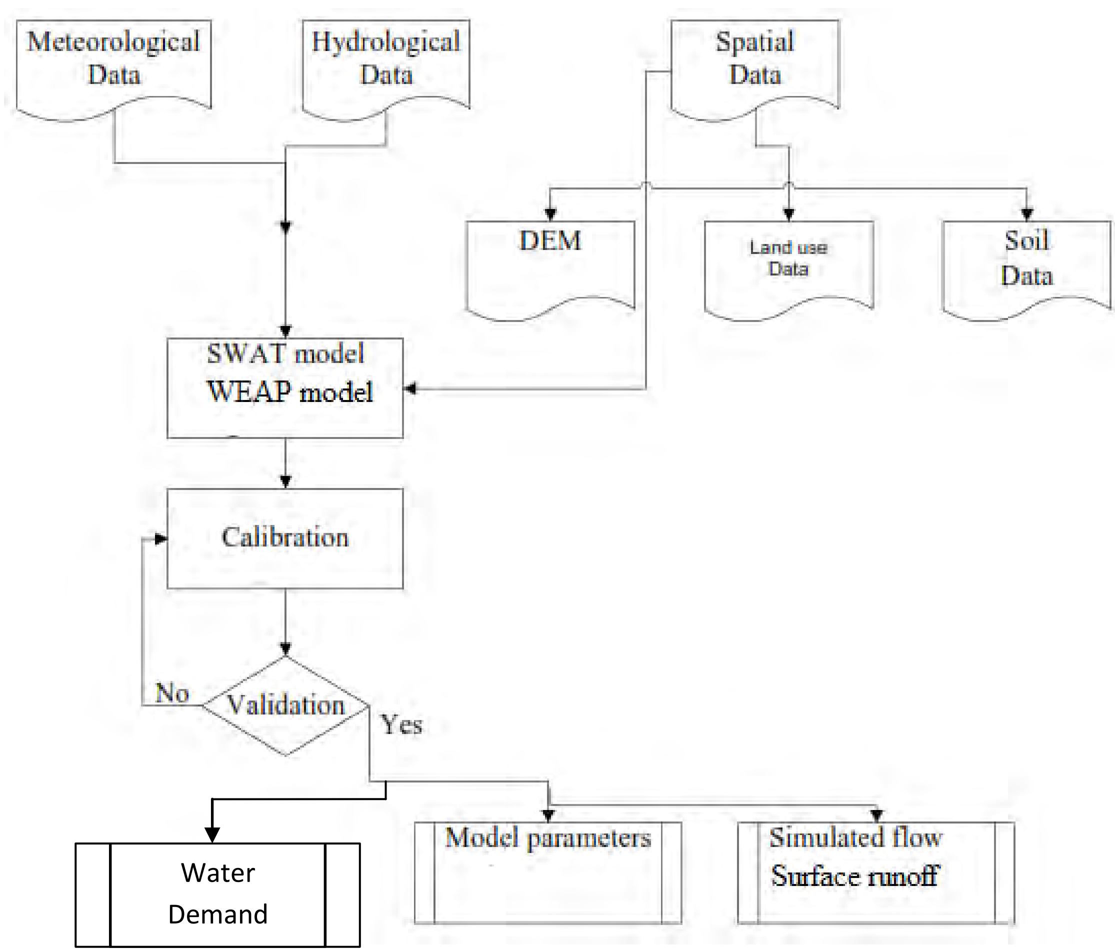


Figure 21 General methodological flow chart

3.5.1 Parameterization

A total of 27 parameters were selected for sensitivity analyses. These parameters have high potential impacts on SWAT model outputs. Sensitivity analysis determines the degree of effect that model parameters has on the output and thus reducing the number of parameters for calibration. The initial estimate value of a model parameter is the average and most applicable value for that particular parameter and is defaulted by the model interface. Most of the model inputs in the SWAT model are process-based except for a few important variables such as runoff curve number, evaporation coefficients, and others that are not well defined physically. These parameters, therefore, must be constrained by their applicability limits.

In the sensitivity analysis, surface runoff was treated as the response or dependent variable, while model parameters were the explanatory or independent variables. The sensitivity coefficients and indices were examined to characterize surface runoff under different parameter ranges. The method below summarizes how to analyze sensitivity coefficients and sensitivity indices of selected parameters corresponding to the changes in surface runoff volumes in response to changes in the model parameter. In general, the higher the absolute values of the sensitivity index, the higher the sensitivity of the corresponding parameter.

3.5.2 Influence Coefficient Method

The influence coefficient method is one of the most common methods for computing sensitivity coefficients in surface and ground water problems. The method evaluates the sensitivity by changing each of the independent variables, one at a time. A sensitivity coefficient represents the change of a response variable that is caused by a unit change of an explanatory variable, while holding the rest of the parameters constant.

$$\frac{\Delta F}{\Delta P} = \frac{F(P_1, P_2, \ldots, P_i + \Delta P_i, \ldots P_N) - F(P_1, P_2, \ldots, P_i, \ldots P_N)}{\Delta P_i} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.3$$

Where F is the response variable (Surface Runoff), P is the independent parameter, and N is the number of parameters considered. The sensitivity coefficients can be positive or negative. A negative coefficient indicates an inversely proportional relation between a response variable and an explanatory parameter.

To meaningfully compare different sensitivities, the sensitivity coefficient was normalized by reference values, which represent the ranges of each pair of dependent variable and independent parameter. The normalized sensitivity coefficient is called the sensitivity index and is given as:

$$s_i = \frac{P_m}{F_m} \frac{\Delta F}{\Delta P} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.4$$

Where s_i *is* the sensitivity index, and F_m *and* P_m, are the mean of lowest and highest values of the selected range for the explanatory parameter and the response variable, respectively. A higher absolute value of sensitivity index indicates higher sensitivity and a negative sign shows inverse proportionality.

3.6 Model Calibration and Validation

Model calibration is a process of changing the values of model input parameters, in order to match the observed values within some acceptable criteria. Model was calibrated for the sub-basin 5 watershed, equipped with automatic runoff recorder at Ablity gage station. Sub-watershed is representative of the area, with dominance of maize and banana crops, followed by forest type. Detailed and reliable datasets for land cover/use, soil properties, management practice and daily rainfall were provided for better simulation of the reality.

The calibration and validation method used were both automatic and manual calibration techniques with split sampling approach. The algorism in this method is called SUNGLASSE (Source of Uncertainty Global Assessment Using Split Sample), which is very important in model performance evaluation. Data set from 1990 to 1992 is used for warming up, and that from 1993-2002 for calibration while data set from 2003 to 2011 was used for validation.

The model performance was evaluated using standard statistics; mean error (ME), mean square error (MSE) and model coefficient of efficiency (EF) shown in Equations 3.5-3.8.

$$E_Q = Q_m - Q_o \quad \text{(Model residual)} \qquad \text{.......... 3.5}$$

$$ME = \overline{E}_Q = \sum_{i=1}^{n} \frac{Q_m(i) - Q_o(i)}{n} = \sum_{i=1}^{n} \frac{E_Q(i)}{n} \qquad \text{.......... 3.6}$$

$$MSE = \sum_{i=1}^{n} \frac{(Q_m(i) - Q_o(i))^2}{n} = \sum_{i=1}^{n} \frac{(E_Q(i))^2}{n} \qquad \text{.......... 3.7}$$

$$EF = \left[1 - \frac{\sum_{i=1}^{n}(Q_m(i) - Q_o(i))^2}{\sum_{i=1}^{n}(Q_o(i) - \overline{Q}_o)^2}\right] = \left[1 - \frac{MSE}{S_{Q_o}^2}\right] \qquad \text{.......... 3.8}$$

Where,

Qo - observed flow

Qm – simulated flow

ME - Mean Error

MSE - Mean Squared Error

EF- Model Efficiency Coefficient

n- The number of data points

s- Variance (squared standard deviation)

The *ME* and *MSE* reflects the bias or systematic deviation in the model results and the random error after correction. They have the disadvantage that their magnitudes highly depend on the flow magnitude, and thus on the river under study. The model efficiency coefficient *EF* of Nash and Sutcliffe (1970), which is a dimensionless and scaled version of the *MSE* for which the values range between 0 and 1 (0 or 1 for a perfect model) gives a much clearer evaluation of the model results and performance. R-Squared is another statistical measure of how well a regression line approximates real data points; an r-squared of 1.0 (100%) indicates a perfect fit. The formula for r-squared is:

$$r^2 = \frac{\sum_{i=1}^{n}(Qmi - \bar{Q}m)(Qoi - \bar{Q}o)\hat{}2}{\sum_{i=1}^{n}(Qmi - \bar{Q}m)\hat{}2\sum_{i=1}^{n}(Qoi - \bar{Q}m)\hat{}2} \qquad \text{.......... 3.9}$$

3.7 SWAT model implementation

3.7.1 DEM set up

First step in modeling was defining the DEM data to the model. DEM data of 30m resolution (SRTM) were provided and the results were analyzed. Horizontal and vertical units of the DEM were defined in meters and it was projected to the Universal Transverse Mercator (UTM) under zone 37. (DEM data was a projected data). Mask containing the spatial extent of the study area was provided for reducing the time of processing. Drainage lines were provided to the model for better hydrographic segmentation and sub-basin delineation (Neitsch et al., 2005). DEM data was then processed to remove all the non-draining zones (sinks).

3.7.2 Stream definition

In this section, initial stream network and sub-basin outlets were defined. The interface put 6000 km^2 as a maximum sub-basin area.

3.7.3 Outlet and inlet definition

Watershed delineation was more refined in this section by defining the outlet point of discharge for the sub-basin and for the whole watershed. Spatial location of the automatic runoff recorder was provided to the interface directly. Outlet for the whole watershed was defined by selecting the whole outlet location.

Final step in the delineation of the watershed was calculation of basin parameters such as geomorphic parameters and relative stream reach. Topographic report was created which contained the summary and distribution of discrete land surface elevations in the sub-basins.

3.7.4 Hydrologic Response Unit (HRU) Generation

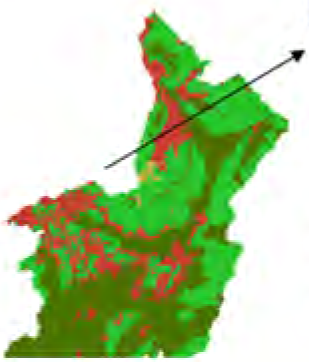
Defining the number of HRUs was an Eight-step process, first the basin delineation should have completed, land-uses were chosen and then the different soils for each land use were chosen. In first step number of land use units were defined, which were to be considered for generating HRUs. The number is controlled by threshold value given for each sub-basin. Suppose if the threshold values is given 5%, then the model will exclude all the land cover classes from modeling that occupy less than 5% of area in particular sub-basin. When the area of threshold was defined small value (1%), the model included the residential and road network types in HRU creation which affected the model output in terms of the increase in runoff amounts. But when the threshold area was increased (10%) then it excluded the residential and road area in HRU creation and thus runoff decreased sharply. Thereafter the threshold value was calibrated and adjusted appropriately to account various land use types covering significant area in the watershed while defining HRUs. Second step control was not altered as soil types were defined on the basis of physiographic units, so they occupied more or less same area as land use types.

3.7.5 Defining land use/soil data

Land use

For each of the delineated sub-basin, land use and soil data were defined for modeling of various hydrological and other physical processes. The prepared composite land-use from visual and digital maps was given as input to the model. The look up table containing various SWAT land cover/use class codes was used for linking the SWATs land use database to the land use layer. Based on the table values the land use reclassified. Fig. 22 shows the linkage of land use layer with the land use database through look up table.

Land use Layer **Look up table** **Land Use Database**



VALUE	LANDUSE
0	Silviculture
1	Agriculture
2	Pastoral
3	Water
4	FWCU
5	Urban
6	Bare Land

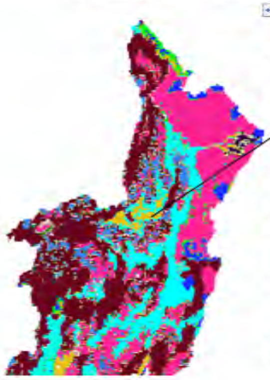
CROPNAME	BIO_E	HVSTI	BLAI
Bare land	33.5	0.45	3
Agriculture	39	0.5	3
silviculture	30	0.4	4
Hay	35	0.9	4
Water	0	0	o
Pastorial	35	0.9	4
Forest with coffee under	15	0.76	5

Figure 22 linking land use layer with the data base

Soil

Soil physical attributes were initially stored to the SWAT database through an interface, relevant information required for hydrological modeling. The database was linked to the database through the look up table which was again linked to the soil map, which was given as input to SWAT model.

SOIL LAYEAR **LOOK UP TABLE** **SOIL DATABASE**



VALUE	SOIL_TYPE
0	eutric cambisoils
1	chromic luvisoils
2	eutric nitisoils
3	eutric fluvisols
4	chromic vertisols
5	pellic vertisols
6	dystric fluvisols
7	dystric nitisols
8	leptosols
9	chromic cambisols
10	calcic fluvisols
11	calcic xerosols
12	dystric cambisols
13	vertic luvisols

SNAM	S5ID	HYDGRP	SOL_ZMX
Chromic cambisols	ET046	A	1500
Calcic fluvisols	ET005	A	1000
Pellic vertisols	ET044	B	50
Chromic vertisols	ET036	B	900
Eutric nitisols	ET022	A	1000
Chromic luvisols	ET017	B	900
Vertic luvisols	ET006	C	200
Dystric fluvisols	ET033	A	1200
Calcic xerosols	ET018	C	1250

Figure 23 linking soil layer with database

3.8 WEAP Model

3.8.1 WEAP model implementation

Although it is widely acknowledged that SWAT performs better to simulate the entire hydrological cycle, it has weaknesses in demand prediction and evaluation. Moreover, a very user-friendly and comprehensive scenario analysis options is one of the main strengths of WEAP. It was therefore decided to construct the WEAP model to estimate and predict demands in Omo Gibe river basin. While WEAP model focus only the demand water resource assessment results like stream flow from SWAT model used as input data in WEAP.

3.8.2 Current account

The Current Accounts represent the basic definition of the water system as it currently exists, and forms the foundation of all scenarios analysis. 2013/14 is the current account in this study and used as a reference in creation of scenarios and scenario analysis, which can be viewed as a reference step in the development of an application, provide a snapshot of the actual water demand, resources and supplies for the system. Generally in current account year the basin major demands i.e Irrigation, Domestic, Livestock, commercial and industrial demands are estimated.

3.8.3 Demand Scenarios development

It is the heart of using WEAP. Scenarios are self-consistent story-lines of how a future system might evolve over time in a particular socio-economic setting and under a particular set of policy and technology conditions. The comparison of these alternative scenarios proves to be a useful guide to development policy for water systems from local to regional scales. Scenarios build on the Current Accounts and allow one to explore the impact of alternative assumptions or policies on future water availability and use. Finally, the scenarios are evaluated with regard to water sufficiency, compatibility with environmental targets, and sensitivity to uncertainty in key variables.

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if water conservation is introduced? What if ecosystem requirements are tightened? What if a more efficient irrigation technique is implemented?

Four water demand sectors were modeled within the basin. These were irrigation, domestic, industrial and commercial, environmental flow requirement and livestock requirement. Data on water demand for each of the sectors were obtained from the Ministry of Irrigation, water and energy of Ethiopia. In the current study, with the exception of irrigation, all demands were entered into the WEAP model as consumption. For irrigation, the demands were entered as a gross requirement, but with an estimate of the return flow.

3.8.4 Setting up Model

The basis for the WEAP model is the catchment approach. The basin has been divided into 13 catchments. Each catchment provides water resources through a rainfall-runoff process from SWAT model output and observed stream flow gauged stations. These catchments are similar to the delineation used in SWAT. A screenshot of the model set up can be seen in Figure.

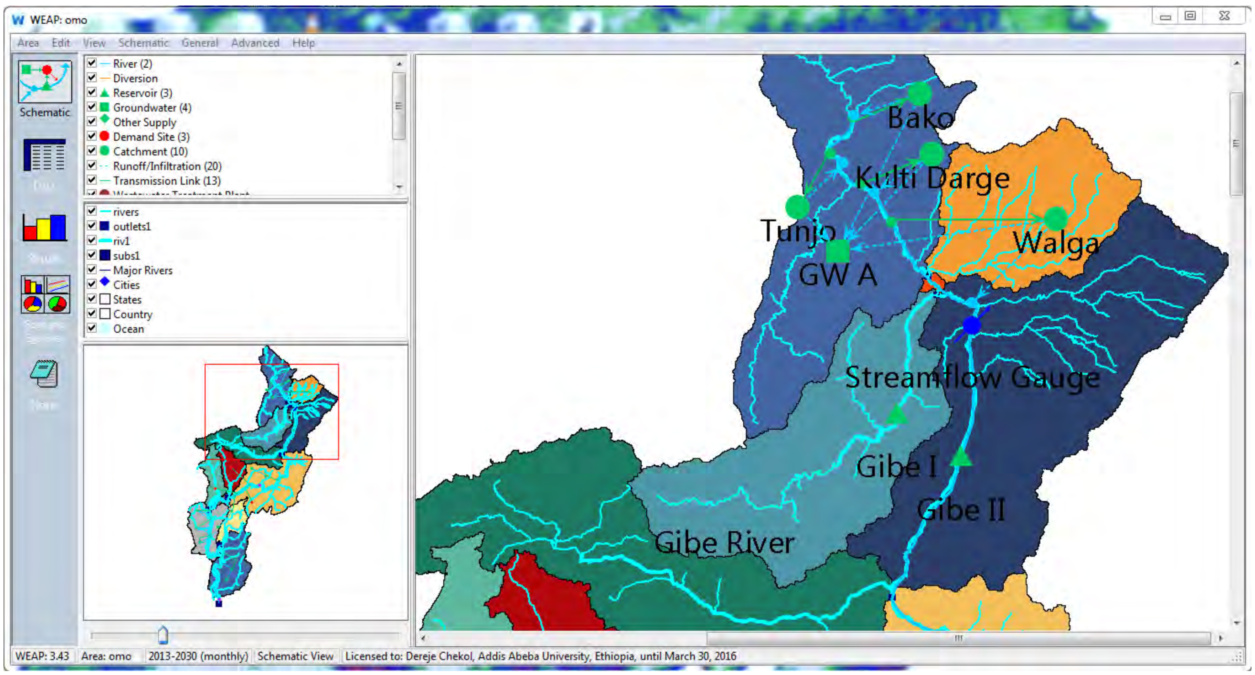


Figure 24 WEAP model setting out snapshot

3.8.5 Scenarios

The main reason to apply models is their ability to explore different scenarios. These scenarios can capture aspects that cannot directly be influenced, such as population growth and climate change (Droogers and Aerts, 2005). These are often referred to as projections. Contrary to this are the adaptation measures (or management scenarios or interventions) where water managers and policy makers can make decisions that will have a direct impact. Examples are changes in reservoir operation rules, water allocation between sectors, investment in infrastructure such as agricultural/irrigation practices. In other words: models enable to change focus from a re-active towards a pro-active approach (Figure 25).

In WEAP the typical scenario modeling effort consists of three steps. First, a “Current Accounts” year is chosen to serve as the base year of the model; Current Accounts has been what you have been adding data to in the model. A “Reference” scenario is established from the Current Accounts to simulate likely evolution of the system without intervention. Finally, “what-if” scenarios can be created to alter the “Reference Scenario” and evaluate the effects of changes in policies and/or technologies.

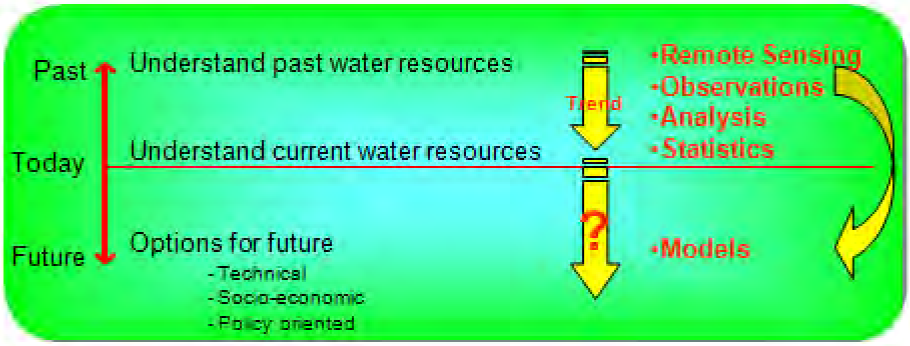


Figure 25 the concept of using simulation models in scenario analysis (source: Droogers and perry, 2008)

The elaboration of the various scenarios with WEAP was an iterative process, referring to

- Assumptions to be made: - the Scenario and assumptions developed in this study.
- Drivers to be changed: - Irrigation schedule, Irrigation efficiency improvement, water requirement, population growth, inflows to the sub catchment, priority of demand i.e. irrigation, domestic, commercials and industrial, Land use area, crop type and varieties.
- Indicators to be analyzed. Unmet water demand.

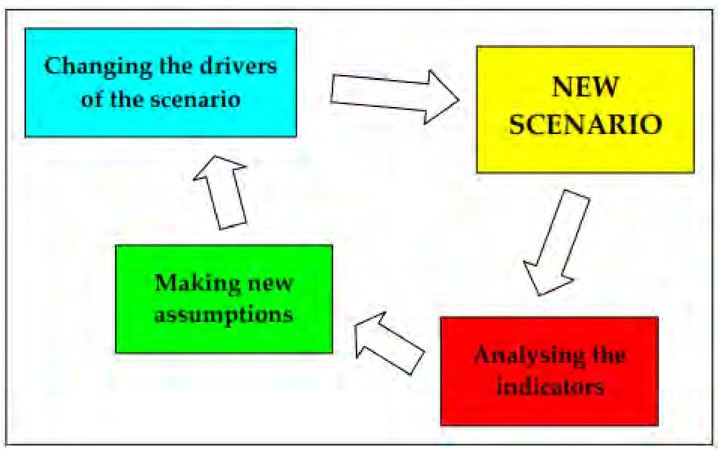


Figure 26 uses of indicators, drivers and assumptions for scenario analyses

Omo Gibe River Basin is one of the strategic River basins for Irrigation, Hydropower and Tourism development, new potential irrigable land, infrastructure, urbanization, increment in population are basic fetchers in this River Basin. Rapid water demand growth and Environmental flow consideration is critical issue in the basin, hence the following Scenarios are likely observed.

The following scenarios were included in this study:-

- **Reference Scenario: -** In WEAP the typical scenario modeling effort consists of three steps. First, a "Current Accounts" year is chosen to serve as the base year of the model; Current Accounts has been what you have been adding Current data. A "**Reference**" scenario is established from the Current Accounts to simulate likely evolution of the system without intervention and it show currently existing situation. Generally Reference Scenario show current demand, Irrigation Efficiency and current water resources management rules. Data to be entered is combination of measured and assumptions concerning water abstractions, natural flow and water management rules. Finally, "what-if" scenarios can be created to alter the "Reference Scenario" and evaluate the effects of changes in policies and/or technologies.

- **Scenario 1. Environmental flow:** - this scenario shows the impact of minimum flow requirement on the water demand. This scenario included in the model by adding minimum flow requirement to downstream users. 25% of Omo-Gibe River flow is considered as environmental flow and the effect of satisfying this flow on Omo-Gibe River basin water demand is estimated.

- **Scenario 2. Current irrigation potential:** - this scenario shows the impact of additional identified irrigation areas full development. This scenario is implemented in the model by increasing the irrigation area. Omo-Gibe River basin is strategic basin for irrigation development. Sugar and cotton takes significant number in recent years, many irrigation areas are identified suitable for irrigation yet not developed because of financial and other factors so this scenario shows the impact in water demand if this identified irrigation areas are fully developed.

- **Scenario 3. Improvement in irrigation Efficiency:** - this scenario shows the impact in improvement of current irrigation efficiency. This is implanted in the model by increasing the irrigation efficiency from 55% to 80%. The Current irrigation efficiency in the basin is not greater than 45% which is very poor in using irrigation water effectively, more than 55% of the water diverted from Main River is lost dew infiltration, evaporation and other factors. So improving irrigation efficiency is critical scenario in Omo Gibe River Basin.

- **Scenario 4. Projections in irrigation area:** - irrigation in this basin is rapidly growing in terms of area and yield. Additional irrigation projects are identified by different institutions yet the developed irrigation projects are quite small. Hence this scenario shows the impact of irrigation development by 200%. The basin is not fully developed in terms of irrigation; there are potential areas suitable for irrigation in south Omo. hence if these potential areas fully developed, what will be the effect in water demand will assess in projection in irrigation area scenario.

4. RESULTS AND ANALYSES

4.1 Modeling Runoff with SWAT model

SWAT is a diversified and complex model; analysis was carried out while implementing the model and checked after the calibration and validation. Several model parameters of runoff and erosion were derived and tested to simulate surface runoff and erosion for the Omo Gibe watershed. SWAT model was implemented systematically as discussed below.

4.2 Automatic Basin Delineation

The most common method used for watershed delination is called the D8 or eight direction pour point model. Using this model, the flow direction for each cell is assigned based on the direction of the steepest slop from among the eight possible direction to the adjacent cells. Based on the flow direction, flow is accumulated towardes the outlet of the watershed. In this process,one of the most sensitive parameters is the threshold area used to define the beginning of a stream channel. Choosing a small threshold area will result in a high drainage density with more number of sub-basins and stream channels where as choosing a large threshold area will result in delination with less drainage density with only few sub-basins. Most often the threshold area chosen for delination is subjective and depends on the level of detail needed.

4.3 Basin and Sub-basin boundaries

Basin and sub-basin boundaries have been delineated using the topographic maps, SRTM DEM (30m resolution). As the study area is very big it is divided in to various sub-basins based on the drainage pattern and the modeling requirements. Sub-basin boundaries are extracted through automatic process using the programs available in GIS software. Flow accumulation grids were computed for sub-basin delineation, keeping in view of the drainage pattern. Omo Ghibe basin has been sub divided in to 13 sub-basins.

Dividing the basin in to smaller area is very important in studding the sensitive parameters in detail which is the first step in water resource study of large areas. Filling sinks in DEM, flow direction, flow accumulation and drainage pattern grids are the requirements process for proper sub-basin classification. Figure below shows sub-basins of Omo-Gibe River Basin.

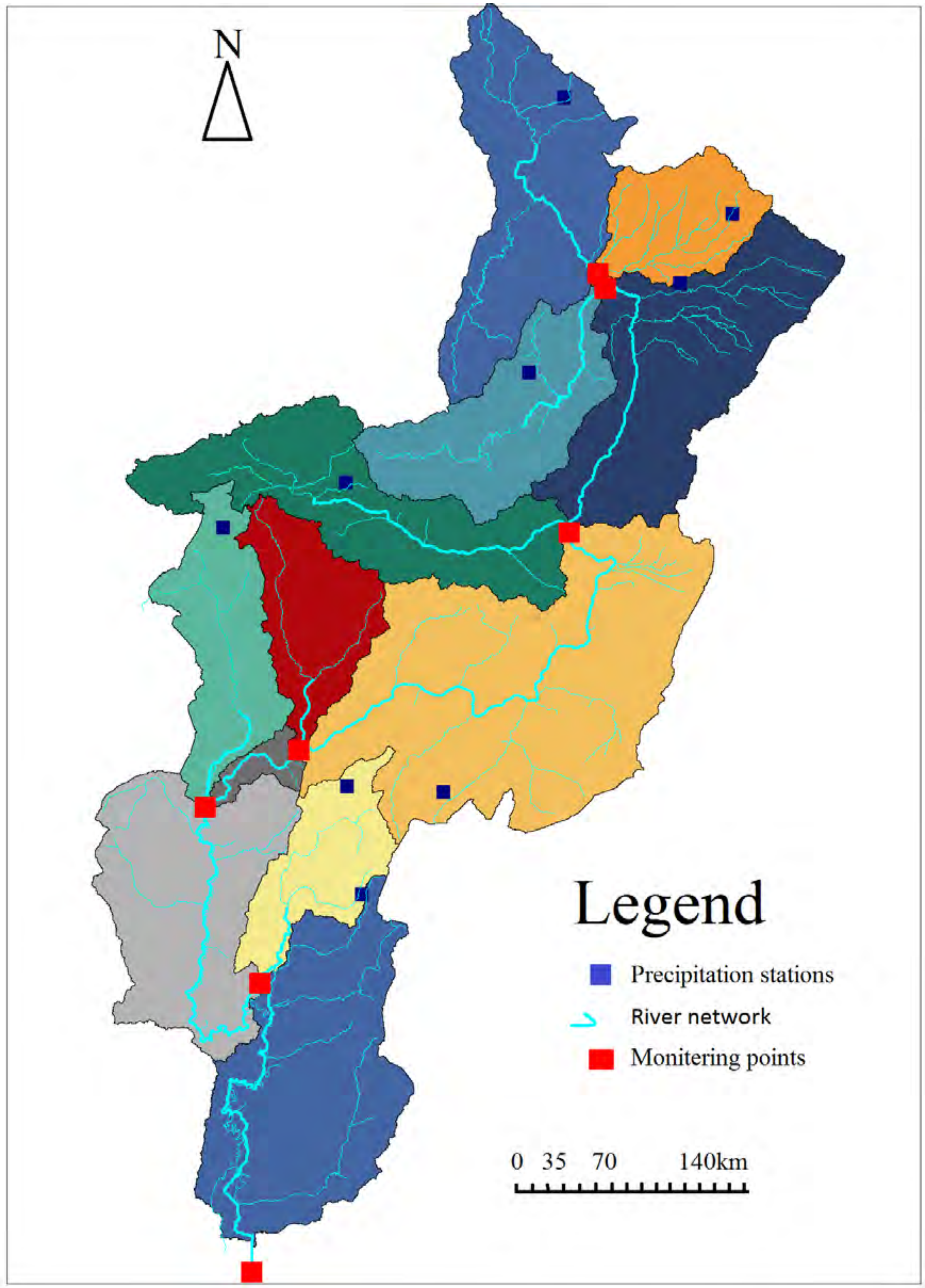


Figure 27 sub-basins as delineated using Arc SWAT GIS extension

4.4 Hydrologic Response Units (HRU) Generation

Defining the number of HRUs was an Eight-step process, first the basin delineation should have completed, land-uses were chosen and then the different soils for each land use were chosen. In first step number of land use units were defined, which were to be considered for generating HRUs. The number is controlled by threshold value given for each sub-basin. Suppose if the threshold values is given 5%, then the model will exclude all the land cover classes from modeling that occupy less than 5% of area in particular sub-basin. When the area of threshold was defined small value (1%), the model included the residential and road network types in HRU creation which affected the model output in terms of the increase in runoff amounts. But when the threshold area was increased (10%) then it excluded the residential and road area in HRU creation and thus runoff decreased sharply. Thereafter the threshold value was calibrated and adjusted appropriately to account various land use types covering significant area in the watershed while defining HRUs. Second step control was not altered as soil types were defined on the basis of physiographic units, so they occupied more or less same area as land use types.

A threshold of 5% for land use and 5% for soil was used, which deducted any land use that occupied less than 5% of the land in sub-basin and any soil that represented less than 5% of land use in the sub-basin.see the HRU map and report on Annex A.

4.5 Sensitivity Analyses

27 parameters sensitivity analyses were done. Sensitivity analysis determines the degree of effect that the model parameter has on the output and thus reducing the number of parameters for calibration. The initial estimate value of a model parameter is the average and most applicable value for that particular parameter and is defaulted by the model interface. Most of the model inputs in the SWAT model are process-based except for a few important variables such as runoff curve number, evaporation coefficients, and others that are not well defined physically. These parameters, therefore, must be constrained by their applicability limits.

In the sensitivity analysis, surface runoff was treated as the response or dependent variables, while model parameters were the explanatory or independent variables. The sensitivity coefficients and indices were examined to characterize surface runoff under different parameter ranges. Table 5 below summarizes the sensitivity coefficients and sensitivity indices of selected parameters corresponding to the changes in surface runoff volumes in response to changes in the model parameter. In general, the higher the absolute values of the sensitivity index, the higher the sensitivity of the corresponding parameter. A negative sign indicates an inverse relationship between the parameter and response variable. Results in Table 10 below indicate sensitive parameters to surface runoff.

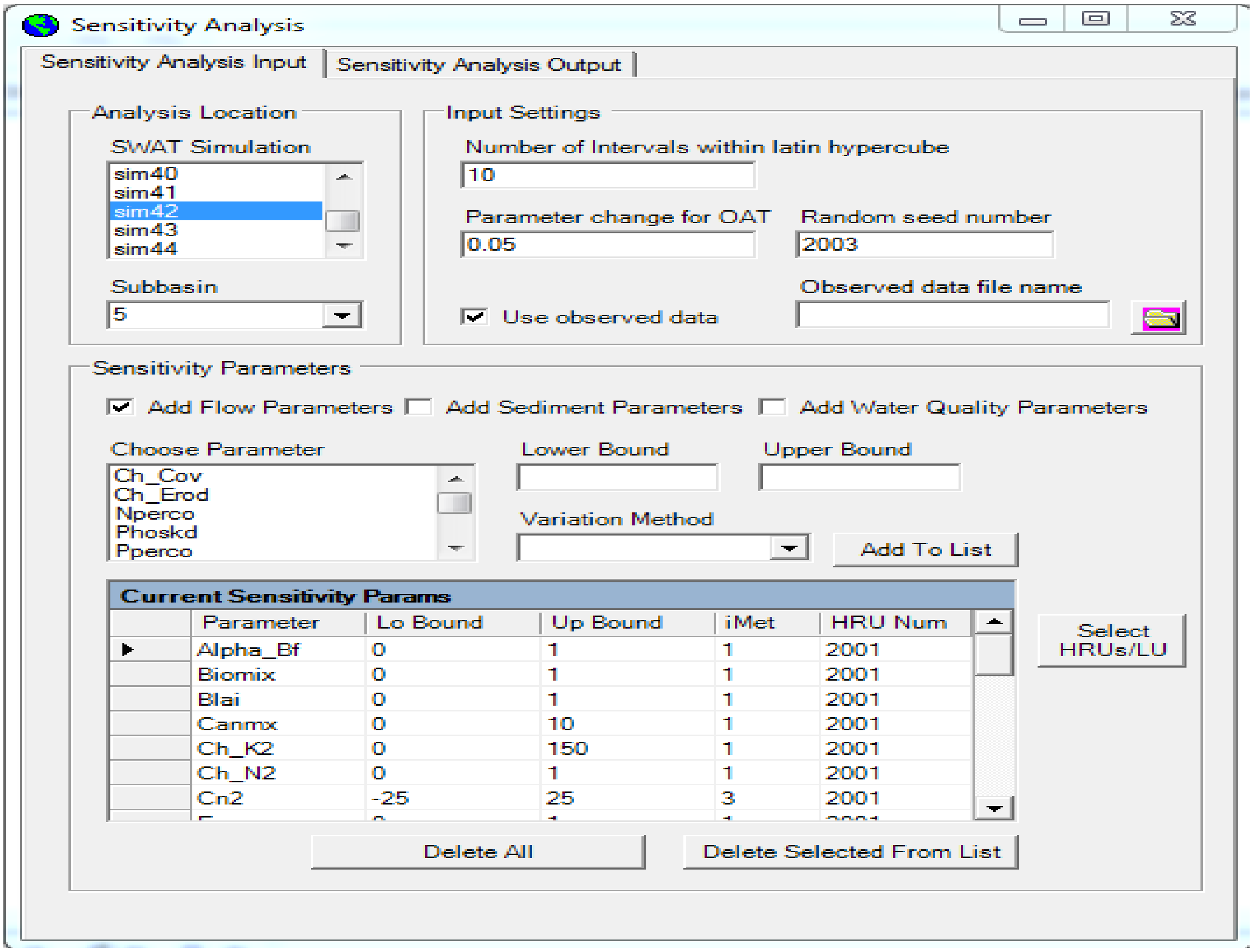


Figure 28 sensitivity analyses setup

Table 10 sensitivity of the model range and initial, estimates

Model parameter	Variable Name	Range	Model Initial estimate
Curve Number	CN	35-85	85
Soil evaporation compensation factor	ESCO	0-1	0.3
Base-flow alpha factor(day)	Alpa_Bf	0-1	0.05
Soil depth(mm)	Sol_Z	0-3000	45
Threshold depth of water in shallow Aquifer for "revap"(mm)	REVAPmn	0-500	33
Shallow aquifer for flow(mm)	Gwqmn	0-5000	41
Soil available water capacity (mm)	SOL_AWC	0-1	0.048

Further analysis was conducted for the top two most influencing parameters: CN and ESCO. CN, an empirically established dimensionless number, is related to land use, soil type, and antecedent moisture condition, and is well-accepted for rainfall-runoff modeling. Figure 28 shows response of surface runoff when CN was changed from −10% to +10% with an increment of 5%. As expected, higher CN values resulted in increased surface runoff.

Figure 28 again shows the impact of ESCO on surface runoff and base flow as its value changed from defaulted values. ESCO adjusts the depth distribution for evaporation from the soil to account for the effect of capillary action, crusting, and cracking. Decreasing ESCO allows lower soil layers to compensate for a water deficit in upper layers and causes higher soil evapotranspiration, which in turn reduces both surface runoff and base flow.

Table 11 Sensitivity coefficients and indices

Parameter	Initial value	Parameter				Response Variable (Surface Runoff)					
		p_1	P_2	ΔP	Mean (Pm)	F_1	F_2	ΔF	Mean (Fm)	ΔF/ΔP	$\frac{\Delta F}{\Delta P} * \frac{Pm}{Fm}$
CN	85	35	98	63	66.5	4.45	38.7	34.25	21.575	0.54365	1.67567916
ESCO	0.3	0	1	1	0.5	5.61	49.6	43.99	27.605	43.99	0.79677595
Alpa_Bf	0.05	0	1	1	0.5	19.2	19.45	0.25	19.325	0.25	0.00646831
Sol_Z	45	0	3000	3000	1500	27.2	27.2	0	27.2	0	0
REVAPmn	33	0	500	500	250	11.45	11.45	0	11.45	0	0
Gwqmn	41	0	5000	5000	2500	21.3	21.3	0	21.3	0	0
Canmx	1.01	0	10	10	5	13.62	13.62	0	13.62	0	0
SOL_AWC	0.048	0	1	1	0.5	17.6	12.54	-5.06	15.07	-5.06	-0.167883

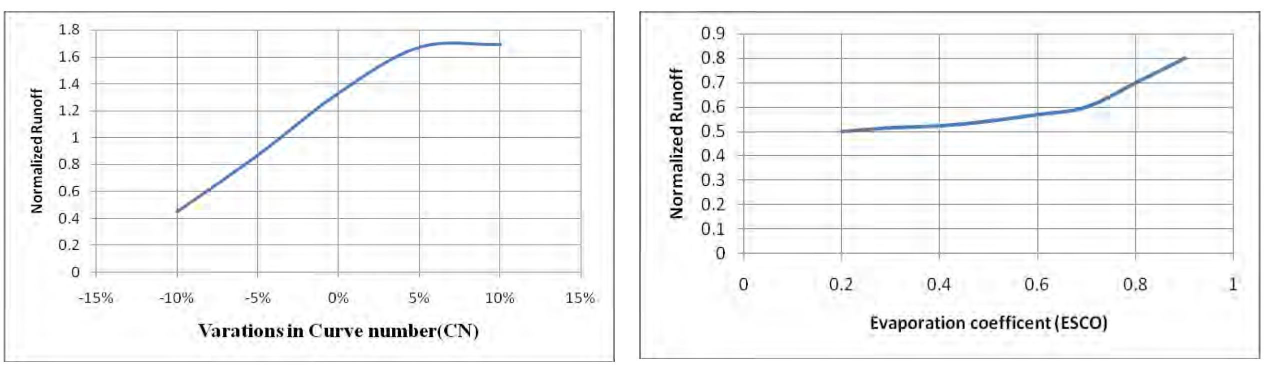


Figure 29 response of surface runoff to CN and ESCO parameter change

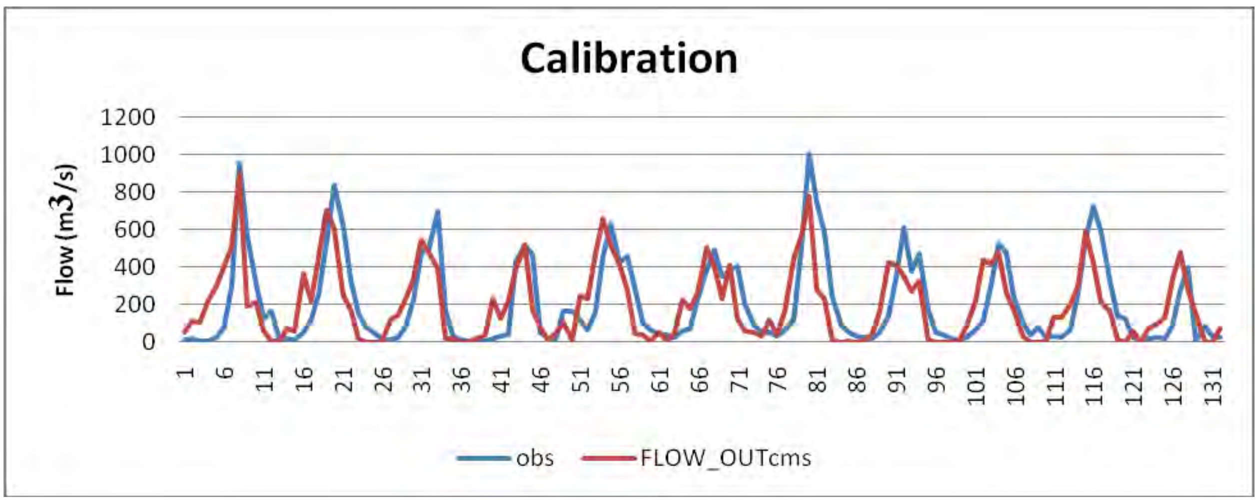
4.6 Model Calibration and validation

Model calibration is a process of changing the values of model input parameters, in order to match the observed values within some acceptable criteria. Model was calibrated for the sub-basin 5 watershed, equipped with automatic runoff recorder at Ablity gage station. Sub-watershed is representative of the area, with dominance of maize and banana crops, followed by forest type.

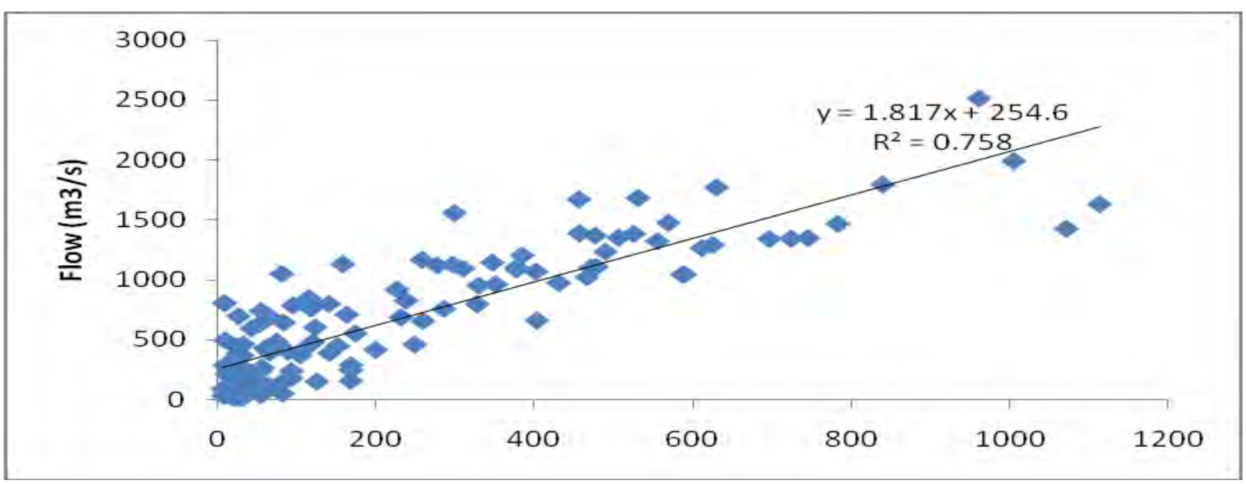
Detailed and reliable datasets for land cover/use, soil properties, management practice and daily rainfall were provided for better simulation of the reality.

The *ME* and *MSE* reflects the bias or systematic deviation in the model results and the random error after correction. They have the disadvantage that their magnitudes highly depend on the flow magnitude, and thus on the river under study. The model efficiency coefficient *EF* of Nash and Sutcliffe (1970), which is a dimensionless and scaled version of the *MSE* for which the values range between 0 and 1 (0 or 1 for a perfect model) gives a much clearer evaluation of the model results and performance. The analysis was done and the EF was found to be 0.8. EF indicates that the model is good. R-Squared is another statistical measure of how well a regression line approximates real data points; an r-squared of 1.0 (100%) indicates a perfect fit.
The model results had an r-squared value of 0.76 >0.6 which is again an indicator of good fit!!!

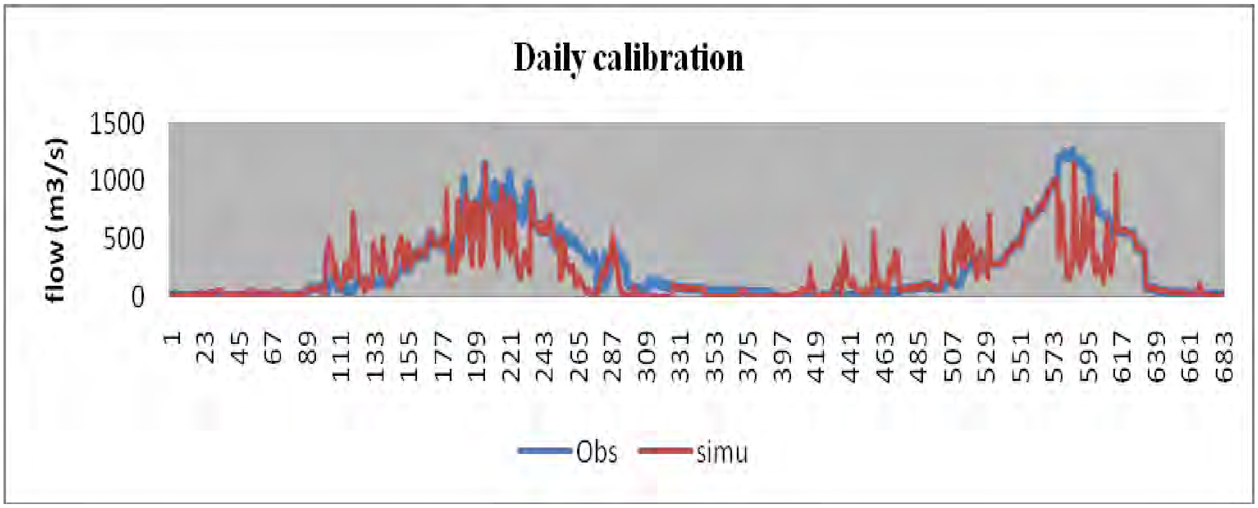
Daily stream flow calibration were checeked, resulting in o.56 and o.54 for r-squared and model efficiency coefficient *EF* of respectively.



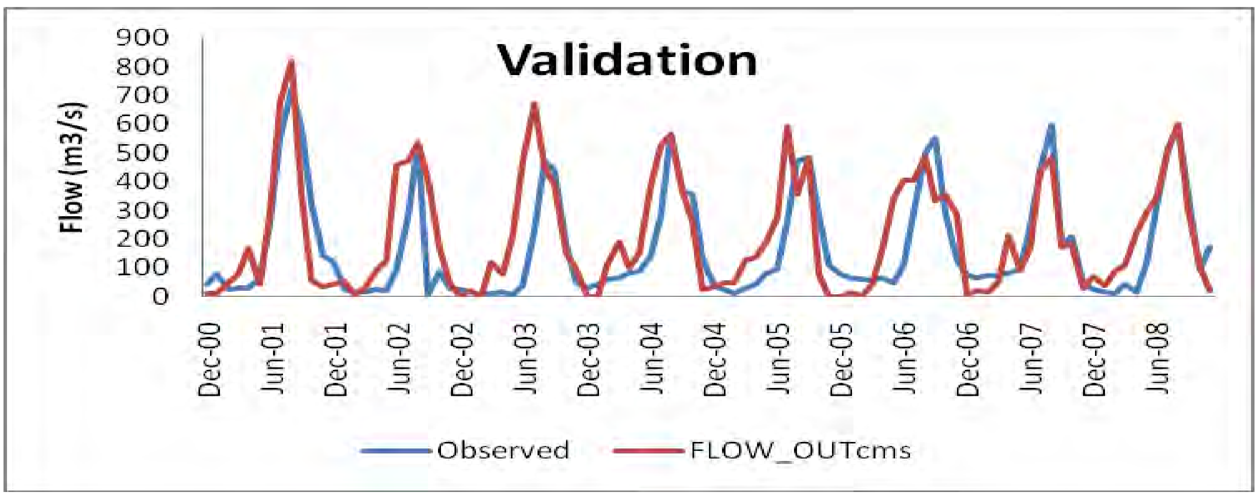
a)



b)



c)



d)

Figure 30 SWAT calibration and validation results (a) and (b) monthly calibration (c) daily calibration (d) monthly validation

	Annually	Monthly	Daily
Coefficient *EF* of Nash and Sutcliffe	**0.91**	**0.80**	**0.54**
R-Squared how regression line approximates real data?	**0.922**	**0.76**	**0.56**

Figure 31 SWAT calibration result

WEAP Calibration

WEAP model is simple, user-friendly and power ful tool for demand assessment. Even though WEAP is designed mainly for demand estimation it can simulate and predict stream flow of the catchments at each demand site nodes. Observed and simulated stream flow at Ablity gauge station were compared and were found to be good agreement, the model efficiency coefficient *EF* of Nash and Sutcliffe was found to be 0.799 and an r-squared value of 0.709. Hence the model was judged to be very good and used to estimate water demands in Omo Gibe river basin. Observed and simulated values are shown in figure 32.

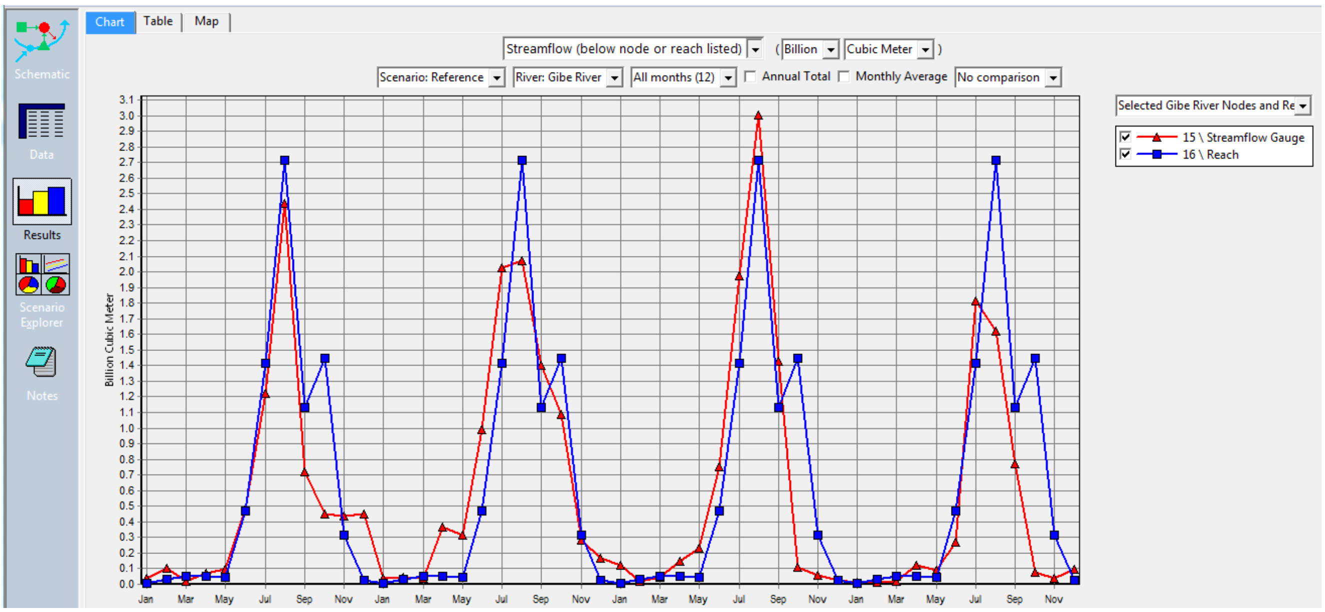


Figure 32 WEAP model calibration results

Model efficiency coefficient *EF=0.799 > 0.5 Ok!!*

R-squared value = 0.709 > 0.6 Ok!!

4.7 Surface runoff potential map generation

After the calibration process, model was run on the daily scale to show the runoff from each HRU (SWAT predicts runoff from HRU). Analysis of the results was done in context of the sub-watershed 5. During field work runoff pattern within the sub-watershed was properly understood. It was observed that for low to high intensity rain, every area was contributing to runoff, but still the runoff initiation from these areas was fast in comparison to others and therefore, logically overall contribution was high.

SWAT modeled runoff according to the land use, soil type and slop, since land use types vary with the soil type. Thereby, 163 HRUs were created for the sub-watershed according to major land uses in the sub-watershed and major soil type of the basin area. Appendix A show surface runoff (mm) from hydrologic response units of omo basin, The total annual surface runoff output in the basin is 18BCM and related output is shown in the Appendix.

Surface Runoff map is a very important tool for water resources management development, It can indicate the contribution of runoff from each cell or unit area of the sub basin, the land cover, slop and soil of the sub-basin, it can be used as input for design of water resource development projects like dames and diversion structures, flood risk management and so on. Generally Surface runoff Map can be used as input for development of dynamic water Resources management techniques.

The SWAT model was run on daily data for Omo Gibe river basin; the result showed that the basin receives 1414.8mm of mean annual rainfall and 117.9mm of mean monthly rainfall, which are 111.77BMC and 9.31BMC of rainfall respectively. The mean annual Surface Runoff outflow which Omo Ghibe contributes to Lake Turkana is found to be 18BMC which is 16.64% of annual rainfall. Evaporation loss takes significant number in the basin because of the basin faces high temperature, covered by green and Wend speed is high which increases the evaporation loss. Hence evaporation loss is found to be 522.7mm or 36.9% of mean annual rainfall. Additional results on hydrologic cycle of the basin are shown below and see on Appendix A.

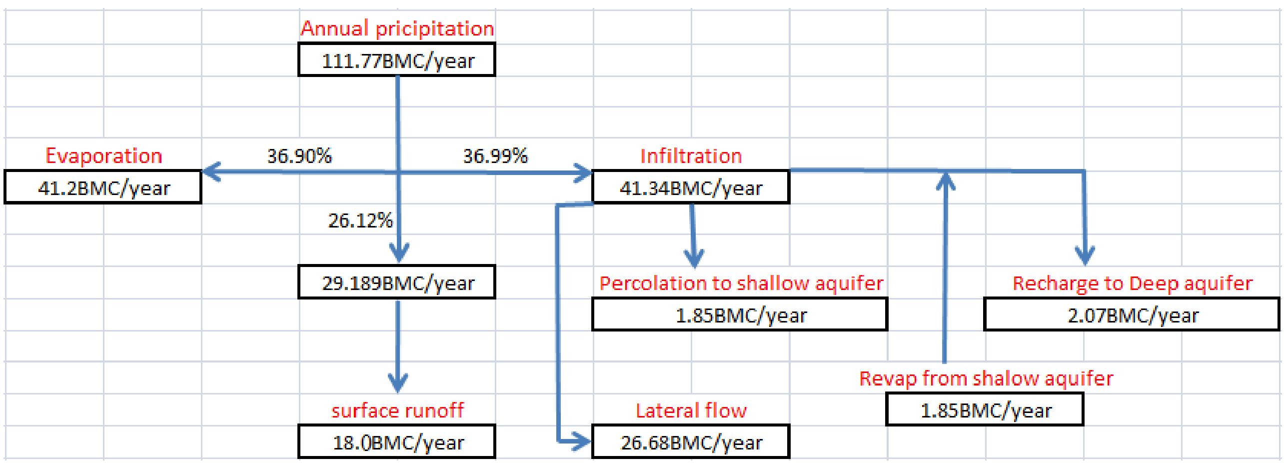


Figure 33 SWAT water balance result

4.7.1 Comparisons of surface water potential to previous studies

In current and previous governments of Ethiopia different institutions and researchers tried to estimate water resources potential of Omo Gibe river basin with different methods. The methodology used for estimation is different in each study and water resources projects development is quite different from year to year in Omo Gibe river basin. Currently during this study medium and large scale irrigation development is emerging in this basin which has not been the case in many studies before. This study has included such new developments and plans and made estimates of surface water potential and total demand of the basin.

Table 12 Comparisons of Assessments

	FAO 1997 Assessment	IWMI 2007 Report	MoWR 2009 data	World bank Concept paper 2004	This research
Area(Km^2)of the basin	76,545	79,000	79,000	-	79,000
Surface Water(BMC	16.1	16.6	17	17	18
Potential Land(ha)	445,300	67,928	70,275-100,000	348,000	445,501

4.8 Demand Scenario analyses

Different demand sectors are considered in this study irrigation, urban, rural and commercial/industrial. The procedures and scenarios considered are discussed in the previous chapter and in this section the results presented.

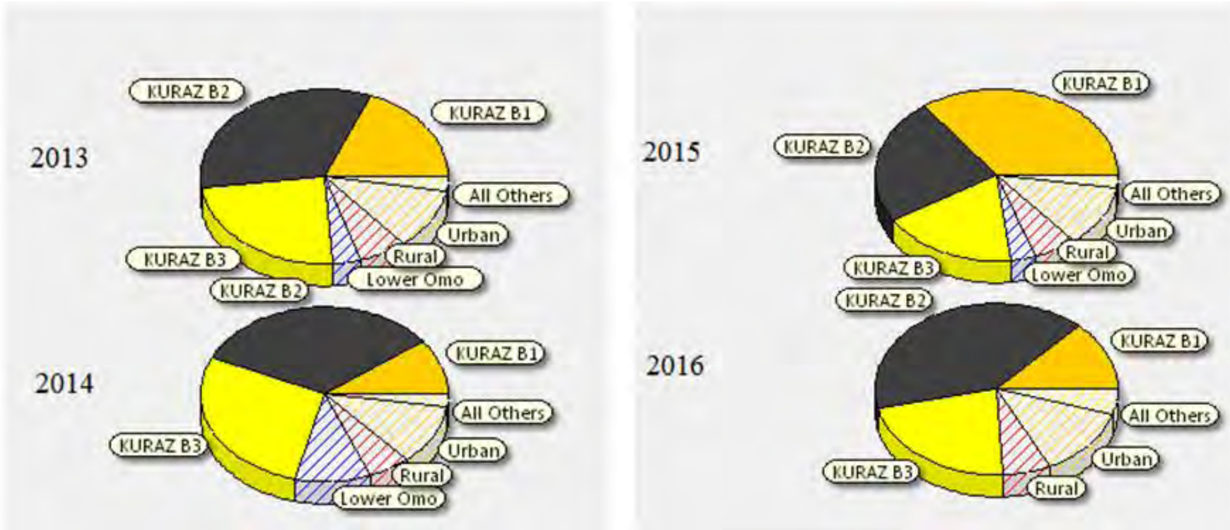
4.8.1 Current situation: reference scenario

In the current situation the total demand was estimated to be 5.379BCM including the large Kuraz Sugar irrigation development and Lower Omo irrigation demand. From which 74.79% is consumed by Kuraz Sugar irrigation project.

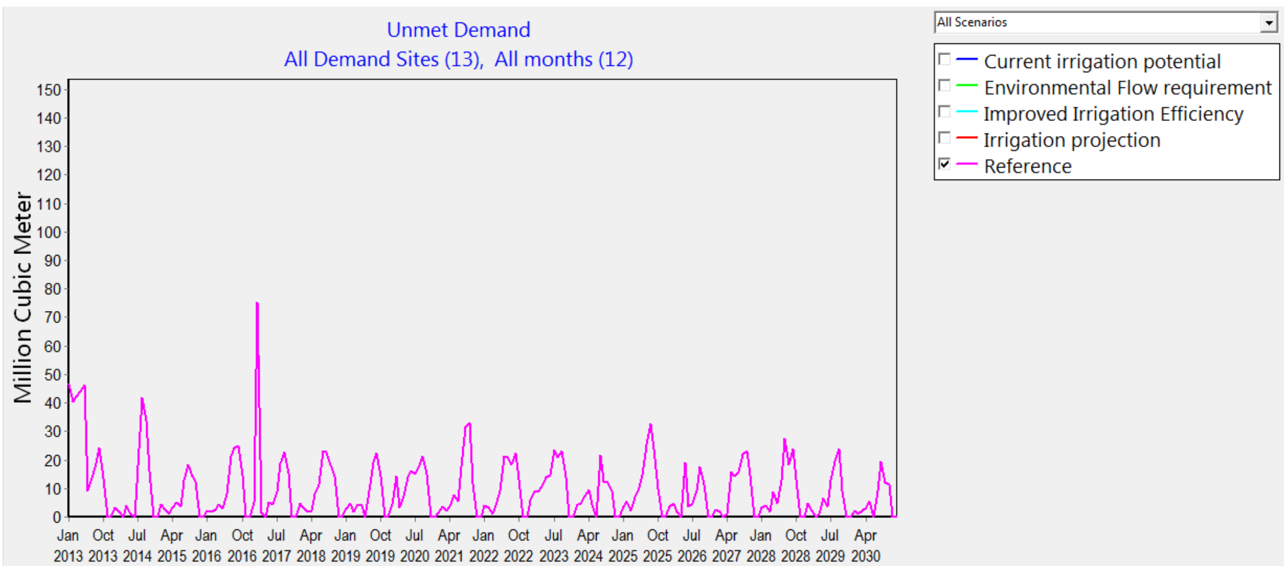
In this Scenario the maximum unmet demand for Kuraz Sugar irrigation project was found to be 560MCM which is 13.9% of the demand required by the irrigation project. In other words 86.1% of the demand is satisfied. 88.9% of Lower Omo irrigation demand is satisfied. The rest irrigation projects in current /reference scenario are satisfied by more than 96%. Hence, in the current situation the demand is almost satisfied for all projects except Kuraz Block 1 irrigation project. See figure 35 for demands and unmet demands of different projects and sectors.

Table 13 Sectoral Water demand

sector	Water Demand(MMC)	%
KURAZ B1	1030.7	18.7138
KURAZ B2v	1749.4	31.7628
KURAZ B3	1243.6	22.5793
Lower Omo	267.7	4.860468
Rural	322.4	5.853623
Urban	636.3	11.55292
All Others	257.6	4.677088



a)



b)

Figure 34 Reference Scenario Indicators. a). water demand b) Unmet demand

Indicators shows that except kuraz block 1 and Lower Omo irrigation project the demand is more than 96% satisfied. Hence a new scenario is developed by changing the drivers; the Environmental flow.

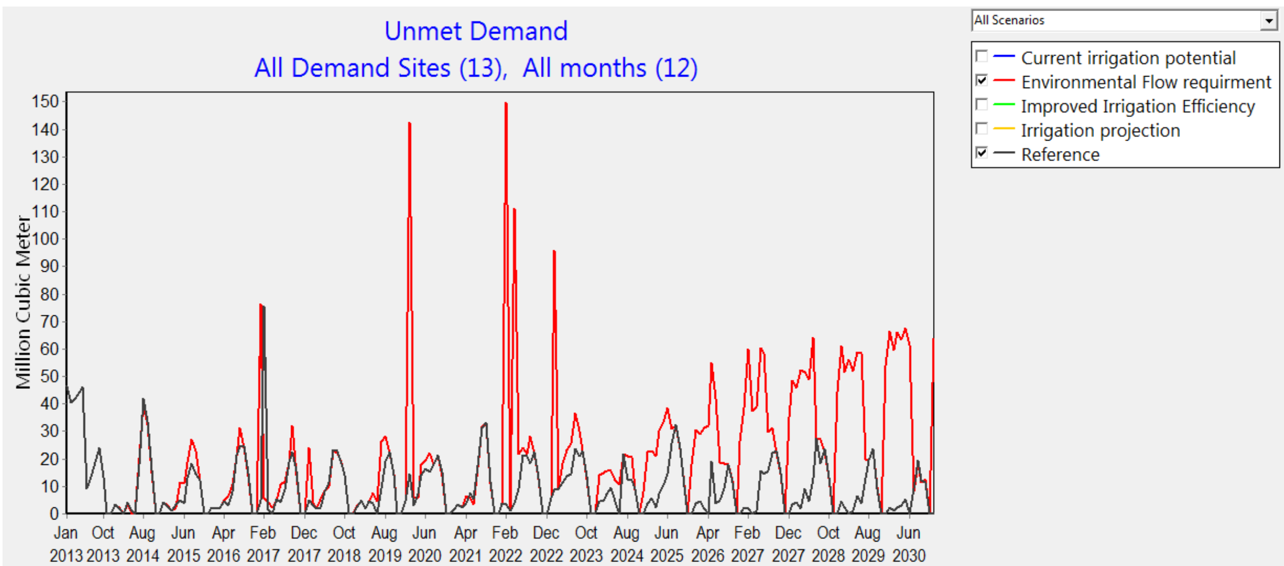
4.8.2 Scenario 1 Environmental flow requirement

The following were assumed regarding Environmental flow scenario

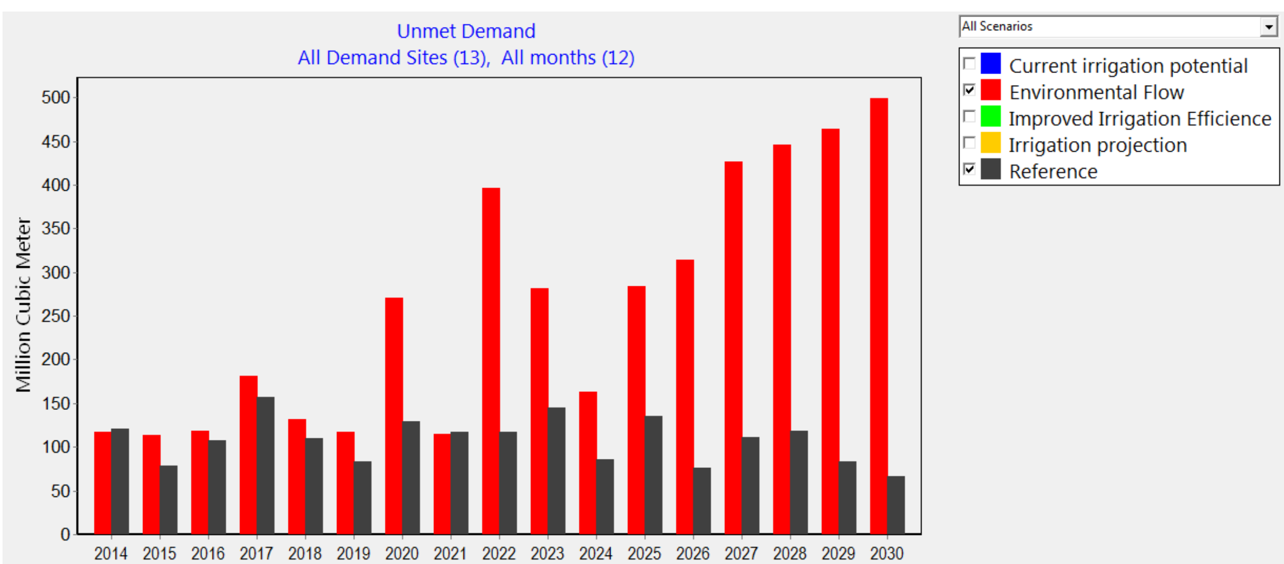
- Use 25% of Omo River flow as environmental flow
- Give higher priority for environmental flow.

The indicators shows that

- The unmet demand is increasing due to Environmental flow constraint.
- The total unmet demand found to be 770MCM by the year 2022 and 1BCM by the year 2030 GC.
- Slight improvement in irrigation technology from current year up to 2030 leads a reduction in unmet demand growth rate.
- Increment in unmet demand by 20-25MCM in each month due to Environmental-flow requirement.



a)



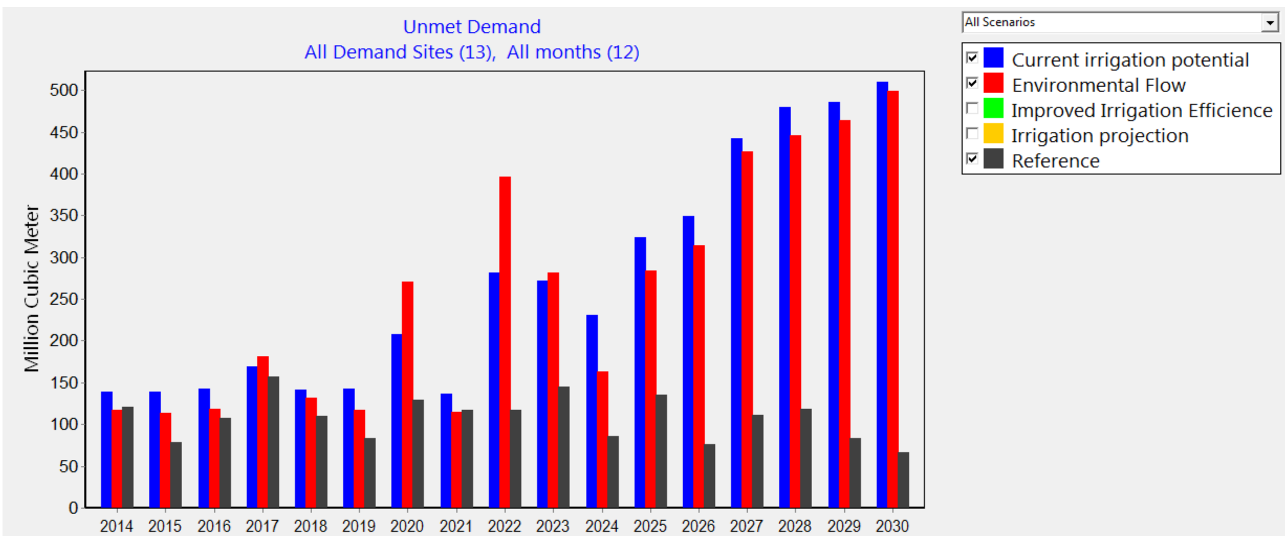
b)

Figure 35 Scenario 1 indicators. (a) and (d) are monthly unmet demands,

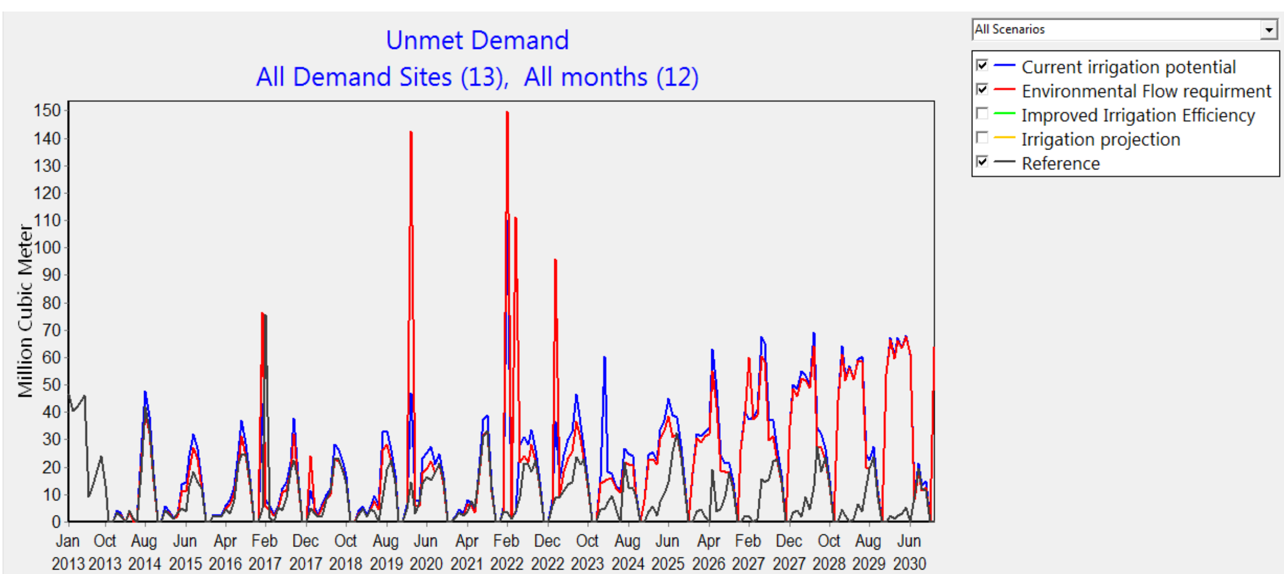
4.8.3 Scenario 2 current irrigation potential

Therefore, in scenario 2 the drivers are modified in such a way that it results in increase in irrigation area assuming that currently identified irrigation projects will be fully developed

- Irrigation area increment and Environmental-flow requirement leads to aver-all unmet demand increment.
- Unmet demand was found to be 1.1BCM by the year 2030 if environmental flow and slight irrigation technology improvement is adopted in the basin.
- Increment in unmet demand by 25-30MCM in each month due to Full irrigation development and E-flow constraint.



a)



b) Figure 36 Scenario 2 indicators. (a) Yearly unmet demand, (b) monthly unmet demand

4.8.4 Scenario 3 Improved Irrigation efficiency

Therefore in scenario 3 the drivers are modified in such a way that increase in the overall irrigation efficiency from 55% to 85% assuming that currently identified irrigation projects are fully developed. This assumption can be practically applied by:-

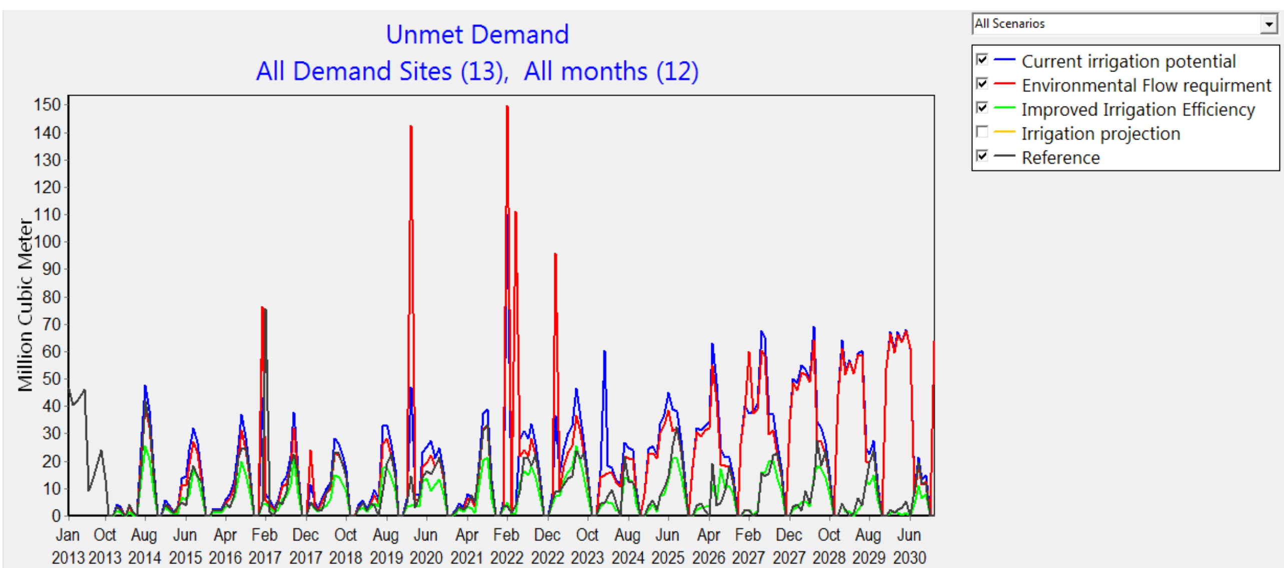
- Avoiding loss of water from conveyance structures. Use Lined canals.
- Reducing evaporation loss from canals. Use Night storage, transport water during low temperature.

The indicators show that

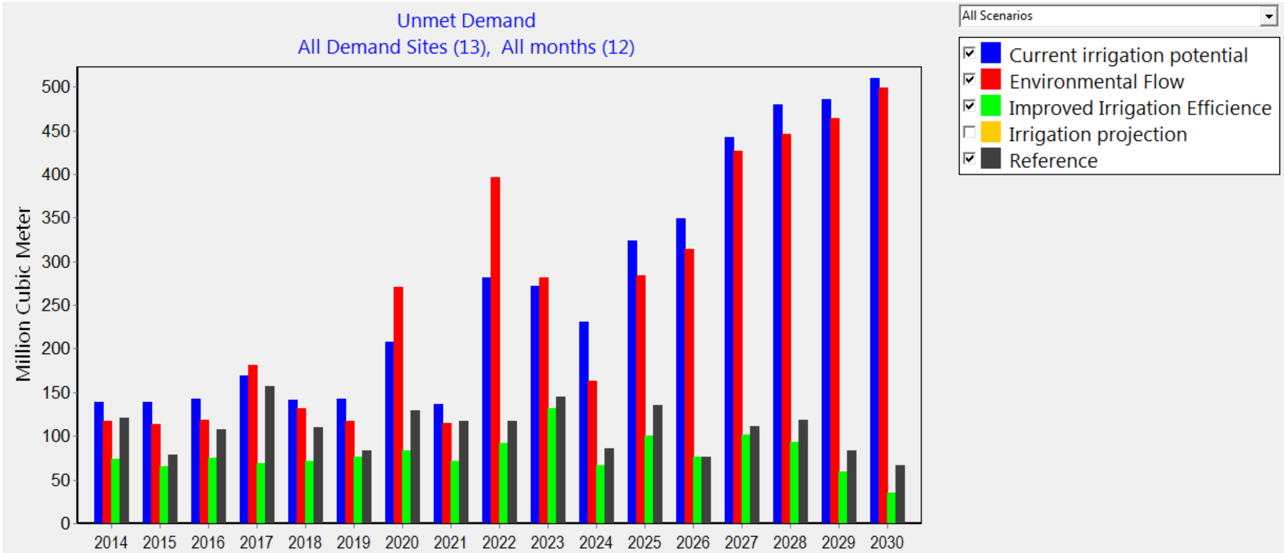
- The unmet demand is better than the rest scenario and even better than reference scenario.
- All large scale irrigation projects are satisfied.

Therefore this scenario could be an objective scenario for short term management or development of the system water resources.

- Implementation of environmental flow.
- Increase in irrigation efficiency.
- Increase in irrigation area.



a)



b)

Figure 37 scenario 3 indicators. (a) Monthly unmet demand (b) yearly unmet demand

4.8.5 Scenario4 Irrigation projection

For the following scenario, the drivers will be modified in order to account for possible long term development by increasing the irrigation area by 200%.

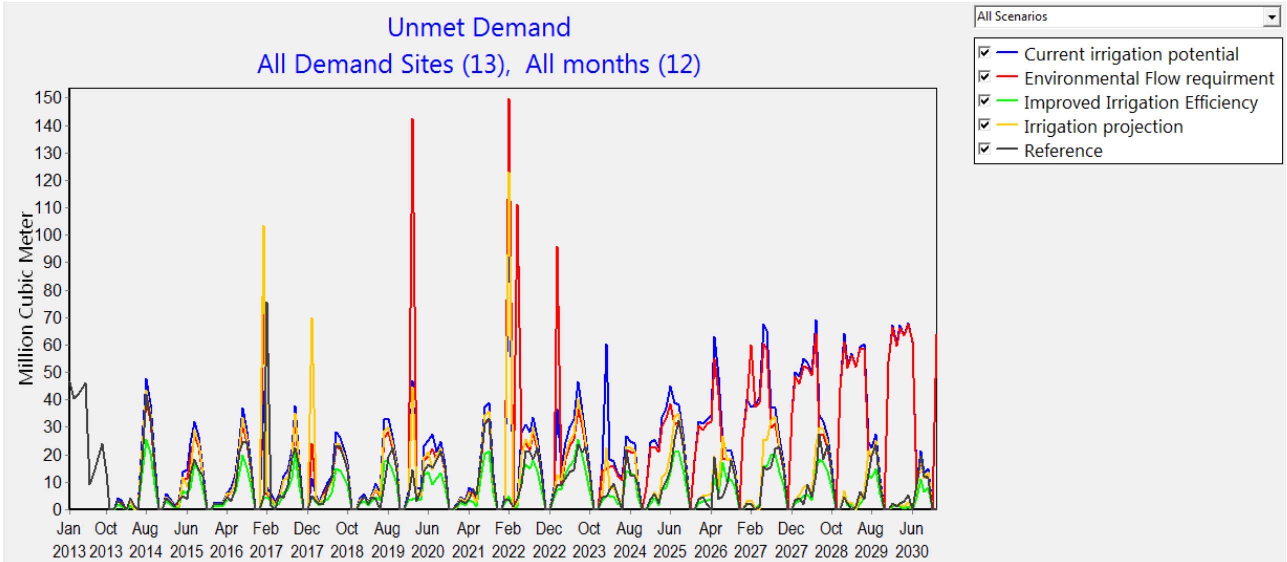
The indicators show that

Even though the irrigation area is doubled the growth in unmet demand is minimum because of the network efficiency improvement.

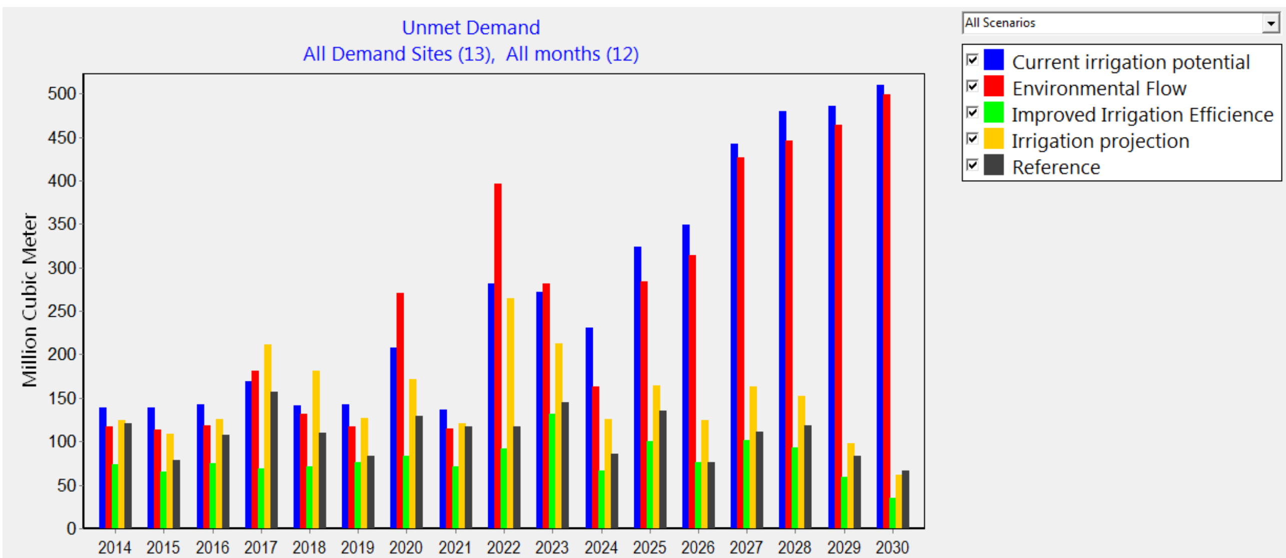
- The unmet demand is found to be 0.5BMC by the year 2030 which is quite small figure. This will be satisfied by new infrastructure construction like new reservoir or development of ground water.

Generally in Omo Gibe basin the long term objective scenario will be:

- Implementation of environmental flow.
- Increase in network efficiency.
- Full irrigation area development with better network efficiency and better irrigation technology.



a)



b)

Figure 38 Scenario 4 indicators. (a) Monthly unmet demand and (c) yearly unmet demand.

5. CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

Estimating the runoff potential of a river basin is important for water resources management. In this research runoff was estimated by with the distributed SWAT hydrological model that requires soil, land use/cover, topographic slope and weather data as basic inputs. Hydrologic Unit areas were used to predict the runoff potential and runoff potential zones of the basin.

The result of sensitivity analysis showed that soil parameter CN is the most sensitive parameter. The second sensitive parameter identified is ESCO. Thus, further detail study on soil and Ground water could possibly improve model performance and accuracy, The model was calibrated and validated using long term records and resulted in good model efficiency.

Generally the following specific conclusions are drawn.

- As can be seen in the meteorological-station coverage map, the lower Omo area needs additional meteorological station installation.
- The total water requirement is 1/3 of the total runoff with full development of Kuraz Sugar Project. Though the total water requirement is only one-third of the annual runoff, the development of the irrigation potential for 445300 ha would require important storage works.
- It is clear that the present water demand estimated is small proportion of the overall water resource potential; however there is a water shortage in some areas of the basin particularly in south and south-west parts, where rainfall is relatively low and potential evapotranspiration is very high.
- Scenario 3 Improved Irrigation efficiency shows that No water problems are expected for the development of new water resources projects, though a high improvement in irrigation method and irrigation efficiency and lot of storage works will be necessary.
- Hydrologic Response Areas shows that high Soil erosion is found at high runoff potential zones.
- Improvement in irrigation efficiency, reduction in evaporation loss, changing irrigation method (use sprinkler instead of furrow), and adoption of water harvesting technique in southern and western part of the basin are important and effective in ensuring the sustainability and integrity of surface water resources.
- Generally in this basin the long term objective or demand can be satisfied by implementation of environmental flow, improvement in irrigation efficiency and full area development with better irrigation technologies.

5.3 RECOMMENDATION

- The ground water potential plays crucial role on the people life living in Omo; hence for full study water resource potential of the basin ground water assessment is necessary.
- According to sensitivity analysis report the highly sensitive parameters are Esco and CN. ESCO shows the soil physical property therefore it is recommended to conduct further study on soil types and reclassification may be necessary to improve model performance and accuracy.
- Further runoff data from field sized plots for dominant land cover/use types in the watershed may help to characterize and validate generation mechanism and also for better improvement to the model.
- The performance of the model used is very good in Omo Gibe basin for simulating different hydrological process and as the model is public domain model and freely available it is worthwhile to use this model on other basins for similar purpose.
- Weather and stream flow gauge stations are concentrated in northern part of the basin, hence more weather and stream flow stations should be installed in southern part of the study area.
- Improvement in irrigation efficiency plays a critical point in water resources development and management of Omo river stream flow in order to have full development in the basin with satisfaction of Environmental flow to downstream water users. More than 50% of water in irrigation fields is lost; hence it is worthwhile to improve overall irrigation efficiency.
- A river gauging station equipped with automatic measurement at Omo River at Omorate should be reestablished. And just upstream of diversion canal to Kuraz irrigation scheme gauging station is critically necessary for better estimation and simulation of river basin water resources assessment.
- Evaporation measurements in lower Omo must be recorded with other climate data in order to know accurately the crop water requirement in the basin, for better estimation of abstraction water in lower Omo irrigation.
- It has been observed in Omo-Gibe River Basin that saving water rather than the development of new sources is often the best „next‟ source of water, both from an economic and from an environmental point of view. Water demand management therefore is seen as the preferred alternative to meet increasing water demand and can be defined as a strategy to improve efficiency and sustainable use of water resources taking into account economic, social and environmental considerations.

REFRANCE

1. Abdela K, 2013, Climate change impact on water resources potential in Omo gibe river basin, PhD Dissertation, Munchen, German.

2. Avery S, 2010, Hydrological Impact of Ethiopian Omo Gibe basin on Kenyans Lake Turkana water Level and fisheries, Hydrological study report, London, England.

3. Bogale 2013, predicting discharge at ungagged catchment in omo Gibe basin using Rainfall-Runoff model, MSc theses, Addis Ababa, Ethiopia.

4. Bekele, S., Ahmed, A., Haileselassie, A., Yilma, A, Bashar, McCartney, Steenhuis, T., Erkossa, T., Shiferaw, Y. S., and Easton, Z., 2010, Improved water and land management in the Ethiopian highlands and its impact on downstream stakeholders dependent on the Blue Nile, research report, Addis Ababa, Ethiopia.

5. Dawdy and Lichty, 1968, Development and application of a physically based landscape water balance in SWAT, Msc theses, London England.

6. DFID, 2005, Hand Book for the Assessment of catchment water demand and use, in collaboration of University of Zimbabwe, University of Zambia, and University of Zulula.

7. Dooge 1984, Simulator for water resources in rural basins, journal of engineering hydrology, Berlin, German.

8. Droogers, 2006, a) comparisons of models, Application and Selection procedures, Study report, USA.

9. FAO (1999), Cropwat Version 8.0, copyright FAO 2009 user manual, USA.

10. FAO (2000), FAO irrigation and drainage paper No.56, Crop Evapotranspiration (guidelines for computing crop water requirements), by R.G. Allen, L.S.Pereira, D.Raes, M.Smith, USA.
11. FAO (1997), Irrigation Potential in Africa: A basin approach, FAO Land and Water Bulletin4, research report, London, England.
12. Haan 1982, statistical methods in hydrology 2nd edition, Hydrology text book, Frank Fert, German.
13. SEI,2008,Institutional Support to Ministry of Environment and Spatial Planning and River Basin Authorities, WEAP modeling manual.2009, Sweden.

14. Jack Sieber, 2004, water system modeler, david Puriky, SEI-US water system, WEAP User Manual, Stockholm, Sweden.

15. Jablone, Mohamed and Sahali Ali, 2012, WEAP-MABIA tutorial a collection of standalone modules to aid in learning the WEAP-MABIA module, Stockholm, Sweden.

16. MoWE, 2001 Ministry of Irrigation Water and Energy report on water resources of Omo Gibe river basin, Addis Ababa, Ethiopia.

17. Muet, 2010, Sensitivity analyses calibration and validation for multi variable SWAT model. Journal of American water resources, USA.

18. Nash, J. E. and J. V. Sutcliffe, 1970 River flow forecasting through conceptual models part I: A discussion of principles, Journal of hydrology 10,282-290, Netherland.

19. Neitsch, Arnold, Kiniry, and Williams, 2001, Soil and Water Assessment, study report, USA.

20. SEI, 2009, Stockholm environmental institute WEAP application report, 2005, Stockholm, Sweden.

21. USDA Soil conservation Service, 1972 National engineering Handbook section 4 Hydrology, chapter 4-10, USA.

22. USDA – NRCS, 2004. Part 630, Hydrology, National Engineering handbook, available at http://policy.nrcs.usda.gov/media/pdf/H_210_630_9.pdf, USA.

24 Wared, 1982, principles of hydrology 3rd edition. Hydrology text book, London.

25 Waterworks Enterprise for new Sugar Development, 30 Jan 2011 http://www.addisfortune.com/waterworks%20Enterprise%bedins%20Surveying%20for%20New%20Sugar%20Dev‟t.htm

26 Woodroofe R and Associate, 1996, Omo Gibe River Basin integrated Master plan final report Volume V, VI and VII. Ministry of Irrigation water and Energy, Addis Ababa, Ethiopia.

27 Woodroofe, Richard & Associate (1994). Environmental policies for EVDSA: River Basin Master plans and Irrigation Development. EVDSA Institutional Support Project, Report No M2/C2/S3/2, January 1994, Addis Ababa, Ethiopia.

28 SEI, 2005,WEAP Tutorial a collection of standalone modules to aid in learning the WEAP software, Stockholm, Sweden.

29 World Bank (2004a), Concept Paper, Ethiopians path to survival and development: Investing in water infrastructure, background note for FY04 CEM, USA.

APPENDEX A

Table A2. HRU land use /soil /slop report

Detailed LANDUSE/SOIL/SLOPE distribution SWAT model class Date: 2/28/2015 12:00:00 AM Time: 10:35:42.3297178

	Area [ha]	Area[acres]
Watershed	7116103.4634	17584247.4632
Number of Subbasins: 13		

		Area [ha]	Area[acres]	%Wat.Area
LANDUSE:				
	silviculture --> AGRC	1006010.0726	2485901.1898	14.14
	Agriculture --> AGRR	2317183.6338	5725876.6183	32.56
	pastoral --> PAST	3713792.0443	9176965.8311	52.19
	water --> WATR	1001.6876	2475.2202	0.01
	Forest with coffee unders --> FRSE	37531.6314	92742.5377	0.53
	urban --> URBN	1594.8949	3941.0650	0.02
	Bareland --> AGRL	38989.4988	96345.0011	0.55
SOILS:				
	Calcic fluvisols	27770.5973	68622.5344	0.39
	Calcic xerosols	57571.4550	142261.9439	0.81
	Chromic cambisols	280433.5120	692965.2299	3.94
	Chromic luvisols	153651.9457	379681.6403	2.16
	Chromic vertisols	589832.7084	1457506.1141	8.29
	dystric cambisols	1949027.4352	4816144.2438	27.39
	Dystric fluvisols	351364.2712	868238.6825	4.94
	dystric nitosols	221.1518	546.4772	0.00
	Eutric cambisols	803866.9053	1986395.3163	11.30
	Eutric fluvisols	781723.9713	1931679.0192	10.99
	Eutric nitisols	64254.5762	158776.2704	0.90
	Leptosols	304754.1410	753062.7201	4.28
	Pellic vertisols	1748220.7187	4319940.8070	24.57
	Vertic luvisols	3410.0743	8426.4641	0.05
SLOPE:				
	0-5	2103209.2780	5197135.2863	29.56
	15-50	2477314.8940	6121568.9689	34.81
	50-9999	226220.9629	559003.3103	3.18
	5-15	2309358.3285	5706539.8977	32.45

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	1	736925.9919	1820980.9722	10.36	
LANDUSE:					
	silviculture --> AGRC	247694.3706	612065.1744	3.48	33.61
	Agriculture --> AGRR	338184.4903	835670.7846	4.75	45.89
	pastoral --> PAST	119117.5718	294345.4759	1.67	16.16
	Forest with coffee unders --> FRSE	26043.8786	64355.7262	0.37	3.53
SOILS:					
	Chromic cambisols	265.3822	655.7726	0.00	0.04
	Chromic luvisols	30917.0239	76397.5120	0.43	4.20
	Chromic vertisols	34653.1887	85629.7620	0.49	4.70
	dystric cambisols	332144.0103	820744.4565	4.67	45.07
	Dystric fluvisols	47461.7816	117280.4353	0.67	6.44
	dystric nitosols	221.1518	546.4772	0.00	0.03
	Eutric cambisols	6618.9438	16355.7410	0.09	0.90
	Eutric fluvisols	16072.9671	39717.1054	0.23	2.18
	Eutric nitisols	33178.8433	81986.5807	0.47	4.50
	Leptosols	749.3144	1851.5933	0.01	0.10
	Pellic vertisols	228757.7043	565271.7252	3.21	31.04
SLOPE:					
	0-5	165960.9956	410097.9181	2.33	22.52
	15-50	208620.7473	515512.2977	2.93	28.31
	50-9999	6004.0550	14836.3201	0.08	0.81
	5-15	350454.5134	865990.6253	4.92	47.56

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	2	290055.8443	716742.4942	4.08	
LANDUSE:					
	silviculture --> AGRC	8625.7881	21314.7537	0.12	2.97
	Agriculture --> AGRR	254793.7775	629608.1640	3.58	87.84
	pastoral --> PAST	28657.8063	70814.8724	0.40	9.88
	water --> WATR	515.1536	1272.9704	0.01	0.18
SOILS:					
	Calcic fluvisols	194.2667	480.0427	0.00	0.07
	Chromic luvisols	23336.2866	57665.1309	0.33	8.05
	Eutric cambisols	3538.4291	8743.6351	0.05	1.22
	Pellic vertisols	265523.5433	656121.9517	3.73	91.54
SLOPE:					
	0-5	150168.1541	371073.0172	2.11	51.77
	15-50	36359.9604	89847.2801	0.51	12.54
	50-9999	613.1543	1515.1348	0.01	0.21
	5-15	105451.2569	260575.3283	1.48	36.36

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	3	4121.8220	10185.2282	0.06	
LANDUSE:					
	silviculture --> AGRC	44.2304	109.2954	0.00	1.07
	pastoral --> PAST	4147.2470	10248.0547	0.06	100.62
SOILS:					
	Chromic vertisols	457.0471	1129.3862	0.01	11.09
	Eutric cambisols	3173.3117	7841.4120	0.04	76.99
	Eutric nitisols	182.1250	450.0400	0.00	4.42
	Pellic vertisols	378.9935	936.5119	0.01	9.19
SLOPE:					
	0-5	501.2775	1238.6816	0.01	12.16
	15-50	2061.4818	5094.0247	0.03	50.01
	50-9999	219.4173	542.1911	0.00	5.32
	5-15	1409.3008	3482.4527	0.02	34.19

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	4	513464.9062	1268797.4564	7.22	
LANDUSE:					
	silviculture --> AGRC	23971.1224	59233.8419	0.34	4.67
	Agriculture --> AGRR	448492.4145	1108247.1807	6.30	87.35
	pastoral --> PAST	30892.7406	76337.5066	0.43	6.02
	Forest with coffee unders --> FRSE	11487.7528	28386.8115	0.16	2.24
	urban --> URBN	1165.6002	2880.2563	0.02	0.23
SOILS:					
	Chromic vertisols	95042.3780	234854.4682	1.34	18.51
	dystric cambisols	161380.1176	398778.3395	2.27	31.43
	Dystric fluvisols	89890.8416	222124.7642	1.26	17.51
	Eutric cambisols	29078.4284	71854.2506	0.41	5.66
	Eutric fluvisols	94420.5512	233317.9030	1.33	18.39
	Eutric nitisols	1203.7597	2974.5504	0.02	0.23
	Leptosols	1256.6627	3105.2763	0.02	0.24
	Pellic vertisols	43736.8912	108076.0449	0.61	8.52
SLOPE:					
	0-5	81698.6845	201881.5344	1.15	15.91
	15-50	182863.9325	451865.9203	2.57	35.61
	50-9999	6350.0925	15691.3962	0.09	1.24
	5-15	245096.9208	605646.7462	3.44	47.73

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	5	771894.5298	1907389.9780	10.85	
LANDUSE:					
	silviculture --> AGRC	26601.5281	65733.7060	0.37	3.45
	Agriculture --> AGRR	405787.5651	1002721.3627	5.70	52.57
	pastoral --> PAST	348815.3882	861940.2649	4.90	45.19
SOILS:					
	Calcic fluvisols	27576.3306	68142.4917	0.39	3.57
	Calcic xerosols	15016.6420	37106.8731	0.21	1.95
	Chromic cambisols	4168.9286	10301.6309	0.06	0.54
	Chromic luvisols	43974.5210	108663.2400	0.62	5.70
	Chromic vertisols	5824.5318	14392.7092	0.08	0.75
	dystric cambisols	16909.8750	41785.1465	0.24	2.19
	Dystric fluvisols	28044.6521	69299.7376	0.39	3.63
	Eutric cambisols	140982.1147	348373.8547	1.98	18.26
	Eutric fluvisols	18877.6925	46647.7220	0.27	2.45
	Eutric nitisols	19849.8932	49050.0786	0.28	2.57
	Leptosols	20646.0398	51017.3966	0.29	2.67
	Pellic vertisols	439333.2602	1085614.4526	6.17	56.92
SLOPE:					
	0-5	185306.1423	457900.7430	2.60	24.01
	15-50	210986.6381	521358.5321	2.96	27.33
	50-9999	15179.6872	37509.7661	0.21	1.97
	5-15	369732.0137	913626.2924	5.20	47.90

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	6	686015.1368	1695177.7037	9.64	
LANDUSE:					
	silviculture --> AGRC	307382.8122	759558.2980	4.32	44.81
	Agriculture --> AGRR	188606.9416	466057.1830	2.65	27.49
	pastoral --> PAST	183688.6986	453903.9588	2.58	26.78
SOILS:					
	Chromic cambisols	3738.7666	9238.6792	0.05	0.54
	Chromic vertisols	833.4388	2059.4690	0.01	0.12
	dystric cambisols	359134.0717	887438.2479	5.05	52.35
	Dystric fluvisols	65055.0590	160754.3036	0.91	9.48
	Eutric cambisols	105297.7515	260196.0088	1.48	15.35
	Eutric nitisols	388.5334	960.0854	0.01	0.06
	Leptosols	25223.4487	62328.4030	0.35	3.68
	Pellic vertisols	120007.3827	296544.2430	1.69	17.49
SLOPE:					
	0-5	58187.2110	143783.5078	0.82	8.48
	15-50	366511.0025	905667.0128	5.15	53.43
	50-9999	30333.3566	74955.2408	0.43	4.42
	5-15	224646.8823	555113.6785	3.16	32.75

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	7	351835.4143	869402.9005	4.94	
LANDUSE:					
	silviculture --> AGRC	130375.5002	322164.3797	1.83	37.06
	Agriculture --> AGRR	85880.6220	212215.3110	1.21	24.41
	pastoral --> PAST	140804.3260	347934.5298	1.98	40.02
SOILS:					
	Chromic luvisols	39.0268	96.4372	0.00	0.01
	dystric cambisols	213511.2379	527596.9444	3.00	60.68
	Dystric fluvisols	33775.5196	83460.9976	0.47	9.60
	Eutric cambisols	48368.0704	119519.9203	0.68	13.75
	Leptosols	18170.8739	44901.1381	0.26	5.16
	Pellic vertisols	43195.7197	106738.7831	0.61	12.28
SLOPE:					
	0-5	16603.7315	41028.6506	0.23	4.72
	15-50	204607.0587	505594.2723	2.88	58.15
	50-9999	25645.8053	63372.0673	0.36	7.29
	5-15	110203.8528	272319.2303	1.55	31.32

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	8	1419488.7935	3507627.7832	19.95	
LANDUSE:					
	silviculture --> AGRC	151134.2840	373460.3725	2.12	10.65
	Agriculture --> AGRR	475840.6551	1175826.0509	6.69	33.52
	pastoral --> PAST	802659.6766	1983412.1938	11.28	56.55
	water --> WATR	486.5340	1202.2498	0.01	0.03
	urban --> URBN	193.3994	477.8997	0.00	0.01
SOILS:					
	Calcic xerosols	4434.3107	10957.4035	0.06	0.31
	Chromic cambisols	195.1340	482.1858	0.00	0.01
	Chromic luvisols	44286.7353	109434.7373	0.62	3.12
	Chromic vertisols	22863.6288	56497.1698	0.32	1.61
	dystric cambisols	500623.5348	1237065.7856	7.04	35.27
	Dystric fluvisols	43664.0412	107896.0289	0.61	3.08
	Eutric cambisols	345728.8026	854313.1577	4.86	24.36
	Eutric fluvisols	13295.1268	32852.9232	0.19	0.94
	Eutric nitisols	3292.9939	8137.1526	0.05	0.23
	Leptosols	30838.9703	76204.6377	0.43	2.17
	Pellic vertisols	420923.8892	1040123.9764	5.92	29.65
	Vertic luvisols	167.3816	413.6082	0.00	0.01
SLOPE:					
	0-5	179985.4898	444753.1445	2.53	12.68
	15-50	751217.1623	1856295.1689	10.56	52.92
	50-9999	102204.2278	252551.7572	1.44	7.20
	5-15	396907.6692	980778.6960	5.58	27.96

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	9	406217.3671	1003783.4249	5.71	
LANDUSE:					
	silviculture --> AGRC	58430.0444	144383.5612	0.82	14.38
	Agriculture --> AGRR	102239.7856	252639.6222	1.44	25.17
	pastoral --> PAST	242926.1640	600282.6975	3.41	59.80
SOILS:					
	Chromic cambisols	105.8060	261.4518	0.00	0.03
	Chromic luvisols	8482.6899	20961.1508	0.12	2.09
	Chromic vertisols	75960.8790	187703.1300	1.07	18.70
	dystric cambisols	261335.5350	645773.1737	3.67	64.33
	Dystric fluvisols	27071.5841	66895.2379	0.38	6.66
	Eutric cambisols	1362.4686	3366.7281	0.02	0.34
	Eutric fluvisols	3878.3958	9583.7099	0.05	0.95
	Eutric nitisols	6158.4276	15217.7826	0.09	1.52
	Leptosols	608.8179	1504.4196	0.01	0.15
	Pellic vertisols	15388.6974	38026.2406	0.22	3.79
	Vertic luvisols	3242.6927	8012.8558	0.05	0.80
SLOPE:					
	0-5	82010.0316	202650.8886	1.15	20.19
	15-50	171749.9696	424402.7624	2.41	42.28
	50-9999	10419.2860	25746.5766	0.15	2.56
	5-15	139416.7068	344505.6533	1.96	34.32

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	10	62940.2982	155528.6239	0.88	
LANDUSE:					
	silviculture --> AGRC	168.2488	415.7513	0.00	0.27
	pastoral --> PAST	60544.4292	149608.3118	0.85	96.19
SOILS:					
	Calcic xerosols	1513.3722	3739.6185	0.02	2.40
	Chromic vertisols	8522.5839	21059.7310	0.12	13.54
	dystric cambisols	11689.8248	28886.1417	0.16	18.57
	Dystric fluvisols	134.4256	332.1724	0.00	0.21
	Eutric cambisols	11815.5778	29196.8836	0.17	18.77
	Eutric fluvisols	15226.5194	37625.4907	0.21	24.19
	Leptosols	888.9436	2196.6240	0.01	1.41
	Pellic vertisols	10921.4307	26987.4013	0.15	17.35
SLOPE:					
	0-5	23798.5372	58807.3754	0.33	37.81
	15-50	20204.6034	49926.5852	0.28	32.10
	50-9999	836.0406	2065.8981	0.01	1.33
	5-15	15873.4968	39224.2044	0.22	25.22

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	11	311149.3727	768865.6575	4.37	
LANDUSE:					
	silviculture --> AGRC	7561.6576	18685.2340	0.11	2.43
	Agriculture --> AGRR	13298.5959	32861.4954	0.19	4.27
	pastoral --> PAST	286240.6985	707315.0781	4.02	91.99
SOILS:					
	Calcic xerosols	21750.9316	53747.6395	0.31	6.99
	Chromic vertisols	50047.0897	123668.8609	0.70	16.08
	dystric cambisols	23670.1824	58490.2043	0.33	7.61
	Dystric fluvisols	7830.5088	19349.5788	0.11	2.52
	Eutric cambisols	36920.2117	91231.6890	0.52	11.87
	Eutric fluvisols	62962.3557	155583.1291	0.88	20.24
	Leptosols	27765.3937	68609.6762	0.39	8.92
	Pellic vertisols	76154.2784	188181.0296	1.07	24.48
SLOPE:					
	0-5	109078.1466	269537.5543	1.53	35.06
	15-50	115799.4273	286146.1749	1.63	37.22
	50-9999	12349.8112	30517.0010	0.17	3.97
	5-15	69873.5668	172661.0773	0.98	22.46

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	12	701848.2890	1734302.2146	9.86	
LANDUSE:					
	silviculture --> AGRC	35306.2370	87243.4770	0.50	5.03
	pastoral --> PAST	648436.2052	1602318.2849	9.11	92.39
	Bareland --> AGRL	17016.5482	42048.7414	0.24	2.42
SOILS:					
	Chromic cambisols	48066.2632	118774.1397	0.68	6.85
	Chromic vertisols	272490.2591	673337.0548	3.83	38.82
	dystric cambisols	67808.6159	167558.4804	0.95	9.66
	Dystric fluvisols	8435.8577	20845.4262	0.12	1.20
	Eutric cambisols	48401.8936	119603.4992	0.68	6.90
	Eutric fluvisols	215646.4370	532873.1281	3.03	30.73
	Leptosols	14347.1157	35452.4402	0.20	2.04
	Pellic vertisols	25562.5482	63166.3347	0.36	3.64
SLOPE:					
	0-5	456258.7459	1127438.1740	6.41	65.01
	15-50	122987.2950	303907.7553	1.73	17.52
	50-9999	11654.2671	28798.2767	0.16	1.66
	5-15	109858.6825	271466.2973	1.54	15.65

		Area [ha]	Area[acres]	%Wat.Area	%Sub.Area
SUBBASIN #	13	860145.6975	2125463.0258	12.09	
LANDUSE:					
	silviculture --> AGRC	8714.2488	21533.3446	0.12	1.01
	Agriculture --> AGRR	4058.7863	10029.4638	0.06	0.47
	pastoral --> PAST	816861.0922	2018504.6019	11.48	94.97
	urban --> URBN	235.8953	582.9090	0.00	0.03
	Bareland --> AGRL	21972.9507	54296.2597	0.31	2.55
SOILS:					
	Calcic xerosols	14856.1985	36710.4093	0.21	1.73
	Chromic cambisols	223893.2316	553251.3699	3.15	26.03
	Chromic luvisols	2615.6623	6463.4322	0.04	0.30
	Chromic vertisols	23137.6836	57174.3730	0.33	2.69
	dystric cambisols	820.4299	2027.3232	0.01	0.10
	Eutric cambisols	22580.9013	55798.5363	0.32	2.63
	Eutric fluvisols	341343.9258	843477.9079	4.80	39.68
	Leptosols	164258.5602	405891.1153	2.31	19.10
	Pellic vertisols	58336.3801	144152.1120	0.82	6.78
SLOPE:					
	0-5	593652.1304	1466944.0968	8.34	69.02
	15-50	83345.6151	205951.1822	1.17	9.69
	50-9999	4411.7619	10901.6843	0.06	0.51
	5-15	170433.4658	421149.6158	2.40	19.81

Table A3. General SWAT input/output report

1
SWAT Sept '05 VERSION2005 0/ 0/ 0 0: 0: 0

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Number of years in run: 21
Area of watershed: 71161.031 km2

1
SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 1 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)----------------						
1	26.89	0.00	5.43	0.00	5.05	0.00	57.60	33.08	126.20	5.43	0.00	0.00	0.09	1.00	0.00	0.00	0.00	0.00
2	81.40	0.08	17.32	0.00	15.45	0.00	66.81	38.90	94.23	17.40	0.05	0.00	0.19	2.33	0.23	0.07	0.00	0.01
3	124.18	1.33	28.41	0.00	20.26	0.00	77.46	61.99	117.59	29.66	0.35	0.00	3.42	41.38	45.72	0.65	0.00	0.08
4	76.75	0.02	18.15	0.00	12.01	0.00	44.72	80.63	140.25	18.16	0.00	0.00	0.51	7.17	20.63	0.00	0.00	0.00
5	135.14	0.07	27.00	0.00	18.25	0.00	57.47	76.56	113.31	27.06	0.00	0.00	0.07	0.49	10.22	0.01	0.00	0.00
6	218.07	5.79	40.96	0.00	76.86	0.00	80.45	69.74	90.70	46.30	0.39	0.01	0.24	1.69	3.66	0.80	0.00	0.10
7	227.26	4.58	44.61	0.00	105.22	0.00	86.65	67.09	88.52	48.61	0.09	0.01	0.44	2.51	2.31	0.28	0.00	0.03
8	245.19	5.45	60.74	0.00	113.97	0.00	91.51	59.11	78.06	65.51	0.69	0.03	0.58	3.56	1.43	1.84	0.00	0.23
9	152.31	2.23	43.99	0.00	47.66	0.00	87.05	64.44	89.28	45.97	0.32	0.02	0.51	2.75	0.91	0.89	0.00	0.12
10	63.27	1.28	22.21	0.00	13.90	0.00	57.32	56.87	121.32	23.35	0.11	0.01	0.28	1.37	0.55	0.37	0.00	0.05
11	39.73	0.15	11.35	0.00	5.30	0.00	53.19	27.10	101.17	11.48	0.01	0.00	0.15	0.54	0.00	0.04	0.00	0.00
12	19.77	0.00	5.81	0.00	1.01	0.00	48.38	18.19	93.96	5.81	0.00	0.00	0.05	0.08	0.47	0.00	0.00	0.00
1990	1409.97	20.99	325.98	0.00	434.94	0.00	48.38	653.73	1254.58	344.73	2.02	0.08	6.52	64.87	86.13	4.94	0.00	0.62

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 2 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)----------------						
1	50.34	0.00	12.27	0.00	4.86	0.00	54.94	26.44	94.39	12.27	0.00	0.00	0.13	0.34	1.19	0.00	0.00	0.00
2	57.78	0.00	11.29	0.00	10.61	0.00	57.75	32.95	87.06	11.29	0.00	0.00	0.10	0.55	0.94	0.00	0.00	0.00
3	83.86	0.03	17.51	0.00	13.87	0.00	56.83	53.46	134.71	17.54	0.00	0.00	2.65	29.22	27.23	0.00	0.00	0.00
4	123.84	0.44	30.95	0.00	18.54	0.00	68.03	62.27	125.68	31.33	0.05	0.00	1.00	11.47	21.50	0.12	0.00	0.01
5	206.94	1.64	48.45	0.00	73.07	0.00	83.35	67.16	90.54	49.85	0.11	0.00	0.44	6.95	12.67	0.32	0.00	0.04
6	208.60	1.58	50.83	0.00	85.62	0.00	89.01	63.79	84.51	52.16	0.11	0.01	0.31	1.91	7.10	0.30	0.00	0.04
7	224.68	4.19	50.05	0.00	114.38	0.00	89.67	55.43	83.81	53.60	0.33	0.01	0.35	1.99	1.94	0.86	0.00	0.11
8	202.47	6.71	53.10	0.00	91.27	0.00	91.03	49.74	81.99	59.01	0.52	0.03	0.67	3.43	0.35	1.27	0.00	0.16
9	130.34	0.30	30.88	0.00	47.75	0.00	86.48	58.05	105.96	31.07	0.02	0.00	0.49	2.47	0.19	0.08	0.00	0.01
10	73.17	0.13	15.59	0.00	25.35	0.00	72.43	47.26	121.40	15.67	0.00	0.00	0.26	1.29	0.12	0.01	0.00	0.00
11	10.19	0.00	1.25	0.00	0.37	0.00	58.61	22.59	121.94	1.25	0.00	0.00	0.07	0.10	0.00	0.00	0.00	0.00
12	22.19	0.00	3.48	0.00	2.50	0.00	54.49	20.30	114.20	3.48	0.00	0.00	0.11	0.16	0.97	0.00	0.00	0.00
1991	1394.41	15.02	325.65	0.00	488.22	0.00	54.49	559.47	1246.21	338.52	1.16	0.06	6.57	59.90	74.20	2.96	0.00	0.37

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 3 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	31.24	0.00	4.08	0.00	4.98	0.00	53.66	22.87	100.81	4.08	0.00	0.00	0.08	0.39	2.42	0.00	0.00	0.00
2	53.08	0.00	8.02	0.00	11.04	0.00	56.84	30.53	98.10	8.02	0.00	0.00	0.20	0.57	1.62	0.00	0.00	0.00
3	74.32	0.07	12.63	0.00	7.73	0.00	55.18	55.00	140.67	12.69	0.01	0.00	1.26	17.67	33.06	0.02	0.00	0.00
4	131.43	0.31	26.32	0.00	26.61	0.00	61.81	70.79	124.43	26.60	0.06	0.00	0.60	16.47	19.76	0.09	0.00	0.01
5	175.36	0.63	40.67	0.00	41.30	0.00	75.94	78.98	110.26	41.20	0.05	0.00	0.39	4.21	17.06	0.11	0.00	0.01
6	248.00	9.96	45.94	0.00	118.94	0.00	85.22	62.09	91.00	54.69	0.15	0.02	0.22	1.82	6.02	0.40	0.00	0.05
7	231.43	5.75	55.54	0.00	113.37	0.00	92.99	49.47	83.04	60.58	0.41	0.02	0.45	2.49	0.76	0.97	0.00	0.12
8	259.54	11.07	53.31	0.00	151.12	0.00	88.94	48.02	85.18	63.46	0.96	0.04	0.65	4.61	0.47	2.68	0.00	0.33
9	119.42	1.08	28.24	0.00	41.63	0.00	84.67	54.15	109.24	29.10	0.01	0.00	0.46	2.74	0.15	0.04	0.00	0.00
10	127.78	2.46	36.50	0.00	51.70	0.00	75.07	47.48	110.38	38.54	0.11	0.01	0.70	4.72	0.09	0.38	0.00	0.05
11	68.24	0.28	18.28	0.00	16.01	0.00	73.70	34.74	117.93	18.51	0.03	0.00	0.26	1.16	0.06	0.09	0.00	0.01
12	23.81	0.02	7.17	0.00	2.10	0.00	64.20	24.94	111.94	7.17	0.00	0.00	0.09	0.20	1.15	0.00	0.00	0.00
1992	1543.66	31.63	336.71	0.00	586.55	0.00	64.20	579.06	1282.99	364.65	1.79	0.11	5.35	57.06	82.61	4.77	0.01	0.59

1

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 4 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	40.13	0.03	11.19	0.00	7.22	0.00	61.34	24.28	119.83	11.21	0.00	0.00	0.07	0.43	2.52	0.00	0.00	0.00
2	59.61	0.01	11.79	0.00	12.03	0.00	63.68	33.20	108.97	11.79	0.00	0.00	0.10	0.39	1.17	0.00	0.00	0.00
3	68.48	0.03	12.18	0.00	11.77	0.00	50.65	57.18	151.55	12.20	0.00	0.00	1.40	26.84	28.42	0.00	0.00	0.00
4	183.59	0.71	39.89	0.00	48.63	0.00	74.96	68.81	103.94	40.46	0.08	0.00	0.92	14.56	18.44	0.11	0.00	0.01
5	173.99	2.44	38.92	0.00	52.47	0.00	77.91	77.85	115.30	41.08	0.07	0.01	0.48	3.02	12.82	0.17	0.00	0.02
6	211.88	8.13	41.24	0.00	90.93	0.00	84.59	63.52	95.38	48.69	0.74	0.03	0.21	1.62	11.80	1.35	0.00	0.17
7	206.61	10.93	36.22	0.00	106.93	0.00	84.27	53.21	105.83	46.41	1.82	0.03	0.32	2.06	2.10	2.84	0.00	0.35
8	223.97	7.09	43.12	0.00	117.26	0.00	88.48	52.32	102.81	49.29	0.73	0.04	0.54	3.54	0.25	1.62	0.00	0.19
9	133.54	3.58	30.78	0.00	51.80	0.00	85.42	51.47	108.62	34.10	0.09	0.01	0.60	3.35	0.07	0.31	0.00	0.04
10	118.44	1.85	33.51	0.00	36.63	0.00	84.99	46.98	113.95	35.08	0.13	0.01	0.72	4.98	0.02	0.35	0.00	0.04
11	15.34	0.04	5.21	0.00	3.09	0.00	65.70	27.56	118.38	5.25	0.00	0.00	0.09	0.39	0.00	0.00	0.00	0.00
12	22.30	0.13	7.53	0.00	2.30	0.00	60.55	17.49	104.85	7.64	0.01	0.00	0.13	0.42	1.00	0.03	0.00	0.00
1993	1457.88	34.97	311.56	0.00	541.06	0.00	60.55	573.86	1349.42	343.21	3.67	0.13	5.58	61.59	78.61	6.79	0.01	0.83

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 5 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	20.55	0.00	3.70	0.00	0.63	0.00	56.69	20.25	96.13	3.70	0.00	0.00	0.04	0.11	2.64	0.00	0.00	0.00
2	19.45	0.00	3.31	0.00	2.97	0.00	45.72	23.96	91.78	3.31	0.00	0.00	0.40	1.49	2.30	0.00	0.00	0.00
3	106.45	0.51	24.28	0.00	25.65	0.00	47.54	52.82	117.72	24.72	0.10	0.03	1.13	26.58	23.73	0.14	0.00	0.02
4	146.17	0.47	37.65	0.00	31.13	0.00	66.04	56.75	102.84	38.04	0.03	0.01	0.73	8.16	15.15	0.07	0.00	0.01
5	188.47	1.38	47.03	0.00	55.07	0.00	79.21	73.46	100.29	48.12	0.11	0.00	0.56	4.94	14.04	0.21	0.00	0.03
6	156.72	1.14	31.13	0.00	67.19	0.00	84.58	52.15	86.70	32.12	0.17	0.00	0.34	1.88	9.39	0.25	0.00	0.03
7	225.39	6.62	45.03	0.00	105.36	0.00	93.36	57.45	101.65	50.95	0.41	0.02	0.53	3.44	2.16	0.91	0.00	0.11
8	212.14	6.10	49.40	0.00	107.14	0.00	90.61	53.49	90.20	54.44	0.30	0.03	0.87	5.58	0.13	0.80	0.00	0.10
9	170.03	11.18	34.39	0.00	84.80	0.00	80.34	50.94	106.15	44.96	0.27	0.04	0.71	4.96	0.08	0.83	0.00	0.09
10	50.01	0.04	14.94	0.00	6.48	0.00	72.64	36.78	133.63	14.96	0.00	0.00	0.18	0.70	0.00	0.00	0.00	0.00
11	66.15	0.91	23.89	0.00	15.90	0.00	68.01	30.51	110.77	24.73	0.10	0.00	0.34	1.73	0.00	0.26	0.00	0.03
12	16.07	0.00	5.23	0.00	2.75	0.00	57.04	19.20	125.91	5.23	0.00	0.00	0.05	0.20	1.12	0.00	0.00	0.00
1994	1377.58	28.34	319.97	0.00	505.09	0.00	57.04	527.75	1263.78	345.28	1.50	0.14	5.87	59.77	70.74	3.47	0.01	0.41

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 6 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	10.04	0.00	2.53	0.00	0.56	0.00	48.83	15.17	92.49	2.53	0.00	0.00	0.04	0.25	2.56	0.00	0.00	0.00
2	28.65	0.00	5.66	0.00	2.90	0.00	50.40	18.31	70.78	5.66	0.00	0.00	0.05	0.17	1.76	0.00	0.00	0.00
3	98.03	0.29	24.95	0.00	15.65	0.00	61.37	45.17	92.30	25.18	0.02	0.01	1.74	19.51	33.18	0.06	0.00	0.01
4	164.69	2.22	44.43	0.00	53.31	0.00	75.04	50.52	72.95	46.34	0.27	0.01	0.83	14.78	17.74	0.51	0.00	0.06
5	132.59	0.96	34.76	0.00	28.07	0.00	83.53	59.77	85.13	35.60	0.06	0.01	0.48	1.34	17.26	0.17	0.00	0.02
6	140.55	1.71	32.69	0.00	52.70	0.00	87.87	49.03	78.51	34.19	0.14	0.01	0.18	0.74	8.22	0.27	0.00	0.03
7	173.57	4.78	37.44	0.00	91.86	0.00	92.00	35.59	60.86	41.52	0.17	0.01	0.36	1.71	1.09	0.45	0.00	0.05
8	202.30	8.75	47.66	0.00	101.50	0.00	92.23	42.58	71.71	55.64	0.68	0.04	0.66	3.52	0.25	1.91	0.00	0.24
9	110.82	1.64	32.39	0.00	45.82	0.00	90.08	35.15	60.95	33.70	0.10	0.01	0.64	3.75	0.04	0.31	0.00	0.04
10	75.90	1.34	29.93	0.00	27.17	0.00	83.01	25.36	54.90	31.09	0.12	0.01	0.52	3.02	0.00	0.42	0.00	0.05
11	34.92	2.24	13.64	0.00	8.29	0.00	71.09	23.53	74.14	15.71	0.16	0.01	0.18	0.88	0.00	0.60	0.00	0.07
12	75.22	0.45	21.19	0.00	16.49	0.00	78.87	28.61	80.33	21.54	0.05	0.00	0.32	2.00	1.28	0.15	0.00	0.02
1995	1247.28	24.37	327.28	0.00	444.31	0.00	78.87	428.78	895.05	348.70	1.76	0.11	6.00	51.67	83.39	4.86	0.01	0.59

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 7 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)------------------						
1	74.29	0.49	19.00	0.00	18.01	0.00	79.56	36.61	78.67	19.40	0.02	0.00	0.17	1.39	2.85	0.05	0.00	0.01
2	32.15	0.00	6.32	0.00	5.96	0.00	70.84	28.34	82.95	6.32	0.00	0.00	0.31	1.81	1.73	0.00	0.00	0.00
3	142.80	0.52	32.58	0.00	42.76	0.00	85.37	50.81	81.12	32.99	0.12	0.00	1.93	36.62	29.35	0.22	0.00	0.03
4	174.70	5.88	54.18	0.00	60.88	0.00	86.55	51.89	72.07	59.62	0.68	0.02	1.10	9.02	18.74	1.51	0.00	0.19
5	202.95	2.63	48.60	0.00	85.43	0.00	88.52	65.20	83.93	50.95	0.44	0.01	0.43	3.49	13.76	0.76	0.00	0.09
6	236.24	8.76	58.31	0.00	119.88	0.00	87.27	50.84	66.28	66.24	1.08	0.02	0.17	1.37	5.22	2.20	0.00	0.27
7	227.06	6.27	49.47	0.00	124.23	0.00	92.61	40.24	64.19	54.90	0.43	0.02	0.53	2.95	3.76	0.84	0.00	0.10
8	181.12	2.89	42.03	0.00	89.59	0.00	86.43	53.28	95.06	44.42	0.14	0.01	0.47	2.64	0.37	0.41	0.00	0.05
9	141.08	2.19	37.92	0.00	51.00	0.00	87.03	50.76	97.89	39.81	0.14	0.01	0.54	3.12	0.18	0.41	0.00	0.05
10	42.57	0.06	13.94	0.00	11.64	0.00	68.44	36.61	126.83	13.98	0.00	0.00	0.23	1.15	0.00	0.01	0.00	0.00
11	38.45	0.00	8.48	0.00	3.65	0.00	65.15	29.64	133.92	8.48	0.00	0.00	0.16	0.26	0.00	0.00	0.00	0.00
12	8.65	0.00	1.34	0.00	0.39	0.00	54.73	17.45	111.57	1.34	0.00	0.00	0.02	0.09	1.49	0.00	0.00	0.00
1996	1502.08	29.71	372.17	0.00	613.42	0.00	54.73	511.65	1094.48	398.45	3.04	0.09	6.07	63.91	77.45	6.42	0.01	0.78

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 8 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)------------------						
1	43.16	0.00	7.27	0.00	5.60	0.00	62.53	22.23	72.40	7.27	0.00	0.00	0.10	0.23	2.87	0.00	0.00	0.00
2	3.35	0.00	0.63	0.00	1.60	0.00	40.65	23.35	94.49	0.63	0.00	0.00	0.01	0.07	2.63	0.00	0.00	0.00
3	62.08	0.01	12.14	0.00	9.33	0.00	38.09	42.76	109.72	12.16	0.00	0.00	1.13	22.37	34.65	0.00	0.00	0.00
4	183.14	1.21	45.08	0.00	35.35	0.00	73.43	63.99	97.21	46.16	0.05	0.00	0.65	8.12	18.04	0.15	0.00	0.02
5	155.95	0.91	39.09	0.00	45.39	0.00	84.70	60.37	83.39	39.85	0.04	0.00	0.43	5.48	13.66	0.12	0.00	0.01
6	206.14	6.38	37.90	0.00	94.30	0.00	95.33	52.96	90.63	43.62	0.15	0.02	0.21	2.11	6.75	0.33	0.00	0.04
7	173.96	8.20	43.91	0.00	84.03	0.00	89.72	46.61	79.23	51.43	0.67	0.03	0.43	2.29	1.40	1.73	0.00	0.21
8	152.57	2.50	34.23	0.00	65.99	0.00	88.88	51.57	91.67	36.47	0.43	0.02	0.58	3.34	0.19	1.06	0.00	0.13
9	109.36	0.83	25.39	0.00	37.28	0.00	84.07	50.85	88.48	26.10	0.10	0.01	0.60	3.26	0.07	0.29	0.00	0.04
10	217.10	15.03	57.80	0.00	85.86	0.00	91.95	48.00	78.69	71.75	2.87	0.06	1.07	8.06	0.00	5.79	0.01	0.71
11	123.19	5.34	42.08	0.00	54.25	0.00	85.98	30.10	55.20	46.99	0.85	0.02	0.37	2.96	0.00	1.32	0.00	0.16
12	60.80	2.11	22.30	0.00	19.15	0.00	83.36	20.52	54.17	24.25	0.31	0.01	0.18	0.98	0.80	0.67	0.00	0.08
1997	1490.79	42.52	367.83	0.00	538.12	0.00	83.36	513.31	995.29	406.69	5.46	0.16	5.77	59.25	81.07	11.47	0.03	1.40

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 9 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)------------------						
1	60.58	0.78	19.99	0.00	16.68	0.00	75.35	31.12	77.58	20.69	0.17	0.00	0.10	0.64	3.01	0.24	0.00	0.03
2	23.92	0.00	5.20	0.00	4.25	0.00	64.68	25.12	76.60	5.21	0.00	0.00	0.10	0.53	1.74	0.00	0.00	0.00
3	97.63	0.11	19.86	0.00	19.60	0.00	68.29	54.59	93.60	19.93	0.01	0.00	1.50	25.75	33.99	0.03	0.00	0.00
4	122.07	2.92	39.57	0.00	28.07	0.00	67.26	51.71	88.27	42.33	0.21	0.01	0.78	9.05	20.58	0.43	0.00	0.05
5	162.68	2.53	42.26	0.00	46.82	0.00	81.82	56.62	83.12	44.52	0.21	0.01	0.29	2.77	11.69	0.46	0.00	0.06
6	220.60	3.53	47.80	0.00	113.94	0.00	94.70	40.65	68.42	50.64	0.15	0.01	0.33	2.64	6.21	0.39	0.00	0.05
7	251.01	9.49	59.99	0.00	146.63	0.00	94.11	34.47	56.76	68.09	0.35	0.03	0.48	4.20	1.75	0.83	0.01	0.10
8	216.56	16.72	47.60	0.00	118.41	0.00	92.10	35.91	65.65	63.50	1.67	0.07	0.50	3.96	0.26	3.78	0.01	0.49
9	142.42	6.38	29.99	0.00	74.91	0.00	89.06	36.12	72.23	35.64	0.12	0.02	0.52	3.48	0.06	0.36	0.01	0.04
10	143.49	4.62	48.73	0.00	59.97	0.00	84.07	36.27	75.75	52.69	0.40	0.02	0.80	5.77	0.00	1.03	0.00	0.13
11	19.30	0.00	4.55	0.00	4.16	0.00	73.92	21.33	87.15	4.55	0.00	0.00	0.06	0.27	0.00	0.00	0.00	0.00
12	4.81	0.00	0.71	0.00	0.13	0.00	65.71	12.30	87.30	0.71	0.00	0.00	0.02	0.16	1.29	0.00	0.00	0.00
1998	1465.07	47.08	366.25	0.00	633.57	0.00	65.71	436.21	932.44	408.49	3.30	0.17	5.48	59.20	80.58	7.53	0.03	0.95

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 10 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)------------------						
1	13.25	0.00	3.07	0.00	0.31	0.00	57.28	18.36	79.97	3.07	0.00	0.00	0.09	0.04	2.95	0.00	0.00	0.00
2	7.35	0.00	1.71	0.00	0.63	0.00	44.95	17.29	79.70	1.71	0.00	0.00	0.02	0.24	2.57	0.00	0.00	0.00
3	58.98	0.01	17.32	0.00	4.90	0.00	44.16	36.32	100.11	17.33	0.00	0.00	1.29	8.22	33.04	0.00	0.00	0.00
4	117.30	0.29	29.26	0.00	16.94	0.00	67.16	47.08	86.31	29.49	0.01	0.00	0.51	5.97	22.30	0.04	0.00	0.00
5	154.37	0.57	32.35	0.00	46.73	0.00	80.81	61.33	90.43	32.84	0.04	0.00	0.31	4.26	15.09	0.09	0.00	0.01
6	183.56	8.49	35.82	0.00	92.89	0.00	87.62	39.41	66.92	43.84	0.19	0.02	0.18	3.63	3.57	0.36	0.01	0.05
7	210.09	3.50	45.88	0.00	117.63	0.00	90.98	39.26	66.22	48.71	0.27	0.02	0.55	3.82	2.29	0.55	0.00	0.07
8	164.69	7.04	41.19	0.00	76.67	0.00	89.77	41.15	76.26	47.43	0.34	0.04	0.67	3.70	0.72	0.92	0.01	0.11
9	148.17	1.40	35.50	0.00	61.97	0.00	89.51	50.01	89.40	36.54	0.11	0.01	0.61	4.38	0.12	0.29	0.00	0.04
10	152.68	4.22	43.20	0.00	71.54	0.00	84.58	39.42	75.72	47.12	0.45	0.02	0.76	5.63	0.00	0.96	0.00	0.12
11	13.07	0.00	4.94	0.00	2.18	0.00	68.07	23.28	97.03	4.94	0.00	0.00	0.09	0.30	0.00	0.00	0.00	0.00
12	16.16	0.00	5.05	0.00	1.11	0.00	61.10	17.06	99.25	5.05	0.00	0.00	0.05	0.08	1.33	0.00	0.00	0.00
1999	1239.67	25.51	295.29	0.00	493.50	0.00	61.10	429.95	1007.33	318.06	1.41	0.10	5.15	40.28	83.98	3.22	0.02	0.40

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 11 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)----------------						
1	4.39	0.00	1.23	0.00	0.05	0.00	43.34	21.02	106.77	1.23	0.00	0.00	0.03	0.01	3.26	0.00	0.00	0.00
2	8.93	0.00	1.06	0.00	2.66	0.00	32.58	15.91	99.47	1.06	0.00	0.00	0.02	0.44	2.53	0.00	0.00	0.00
3	39.22	0.00	10.28	0.00	4.52	0.00	25.15	31.41	115.63	10.28	0.00	0.00	0.91	11.49	34.44	0.00	0.00	0.00
4	104.82	0.31	27.08	0.00	15.39	0.00	45.22	40.74	75.46	27.36	0.04	0.00	0.60	7.82	15.68	0.10	0.00	0.01
5	168.85	1.59	39.13	0.00	42.37	0.00	71.28	60.19	93.84	40.50	0.13	0.00	0.48	8.91	14.71	0.22	0.00	0.03
6	219.99	5.53	43.21	0.00	101.34	0.00	88.31	51.88	86.04	47.77	0.09	0.02	0.33	4.11	5.22	0.28	0.01	0.03
7	191.29	5.16	51.97	0.00	87.33	0.00	93.37	41.67	70.83	56.71	0.47	0.04	0.66	3.26	0.87	1.34	0.00	0.16
8	141.86	4.57	40.73	0.00	65.14	0.00	86.65	39.29	68.21	44.98	0.56	0.03	0.77	5.12	0.34	1.52	0.00	0.18
9	142.50	2.32	33.29	0.00	59.97	0.00	90.05	42.54	73.28	35.20	0.08	0.01	0.58	4.17	0.02	0.23	0.00	0.03
10	179.38	7.80	58.48	0.00	77.88	0.00	83.80	42.29	76.84	65.61	1.13	0.03	0.74	5.31	0.00	1.98	0.01	0.24
11	44.95	0.01	10.65	0.00	11.82	0.00	73.84	33.53	92.00	10.66	0.00	0.00	0.11	0.75	0.00	0.00	0.00	0.00
12	18.05	0.06	5.55	0.00	2.09	0.00	65.06	19.25	91.69	5.61	0.00	0.00	0.09	0.25	1.67	0.02	0.00	0.00
2000	1264.23	27.36	322.66	0.00	470.56	0.00	65.06	439.72	1050.05	346.96	2.50	0.13	5.31	51.62	78.74	5.68	0.02	0.68

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 12 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)----------------						
1	17.19	0.00	3.74	0.00	2.48	0.00	51.78	24.30	101.77	3.74	0.00	0.00	0.04	0.17	2.72	0.00	0.00	0.00
2	29.90	0.00	8.22	0.00	2.68	0.00	44.00	26.65	96.97	8.22	0.00	0.00	0.05	2.36	2.08	0.00	0.00	0.00
3	111.10	0.18	21.14	0.00	13.07	0.00	62.06	58.17	108.60	21.30	0.08	0.00	1.09	20.15	34.30	0.09	0.00	0.01
4	134.68	1.83	42.31	0.00	32.31	0.00	64.08	53.99	85.16	43.97	0.17	0.00	0.70	6.77	19.80	0.32	0.00	0.04
5	161.98	1.60	33.83	0.00	41.87	0.00	69.57	80.88	120.81	35.28	0.07	0.00	0.23	1.68	14.23	0.15	0.00	0.02
6	188.74	1.43	45.17	0.00	59.34	0.00	83.15	68.62	121.09	46.28	0.02	0.00	0.26	1.16	8.29	0.07	0.00	0.01
7	266.06	16.14	62.98	0.00	121.52	0.00	92.10	54.72	97.44	77.98	0.89	0.05	0.47	3.08	1.32	2.20	0.01	0.26
8	243.34	13.11	59.86	0.00	112.33	0.00	90.04	60.67	107.45	71.90	0.49	0.05	0.73	4.77	0.38	1.38	0.01	0.16
9	152.62	2.90	50.43	0.00	48.03	0.00	86.35	55.21	103.58	52.96	0.20	0.02	0.75	4.57	0.08	0.56	0.00	0.07
10	99.21	2.35	31.05	0.00	32.49	0.00	74.25	47.55	101.64	33.18	0.29	0.01	0.45	3.06	0.00	0.65	0.00	0.08
11	23.84	0.04	6.49	0.00	3.22	0.00	55.54	33.10	123.68	6.51	0.00	0.00	0.13	0.49	0.00	0.00	0.00	0.00
12	14.47	0.00	4.16	0.00	1.28	0.00	43.79	21.10	123.20	4.16	0.00	0.00	0.05	0.14	1.25	0.00	0.00	0.00
2001	1443.13	39.58	369.37	0.00	470.60	0.00	43.79	584.95	1291.40	405.48	2.21	0.14	4.95	48.40	84.45	5.41	0.03	0.65

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 13 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)----------------						
1	47.93	0.00	11.11	0.00	6.90	0.00	42.88	30.76	121.15	11.11	0.00	0.00	0.09	0.54	3.53	0.00	0.00	0.00
2	24.77	0.01	5.27	0.00	4.09	0.00	36.69	19.33	121.86	5.28	0.00	0.00	0.25	1.87	1.74	0.01	0.00	0.00
3	94.40	0.96	28.82	0.00	15.52	0.00	37.69	49.18	135.97	29.74	0.32	0.00	1.54	20.40	30.83	0.47	0.00	0.06
4	104.26	0.26	24.39	0.00	17.53	0.00	28.77	70.64	137.86	24.64	0.03	0.00	0.60	11.71	25.80	0.05	0.00	0.01
5	116.40	0.49	26.96	0.00	27.27	0.00	30.67	60.25	122.07	27.41	0.04	0.00	0.19	3.02	9.99	0.09	0.00	0.01
6	177.99	2.36	29.37	0.00	51.61	0.00	67.65	57.02	99.45	31.54	0.02	0.01	0.14	0.98	9.03	0.03	0.00	0.00
7	181.34	3.72	42.57	0.00	78.80	0.00	86.42	37.39	69.90	45.92	0.19	0.02	0.40	2.75	3.13	0.61	0.00	0.07
8	144.29	3.83	36.24	0.00	70.11	0.00	85.56	35.21	71.35	39.58	0.14	0.02	0.64	2.97	0.31	0.42	0.00	0.05
9	100.84	1.06	30.46	0.00	34.02	0.00	84.46	37.23	84.88	31.30	0.05	0.01	0.57	2.65	0.05	0.20	0.00	0.02
10	82.62	9.67	23.17	0.00	29.70	0.00	77.69	27.14	82.73	32.70	0.05	0.02	0.42	2.53	0.02	0.15	0.01	0.02
11	17.67	0.00	5.60	0.00	2.69	0.00	70.01	17.47	79.49	5.60	0.00	0.00	0.09	0.28	0.01	0.00	0.00	0.00
12	68.72	0.10	22.28	0.00	16.51	0.00	75.60	23.51	66.74	22.35	0.00	0.00	0.41	2.63	1.05	0.00	0.00	0.00
2002	1161.22	22.46	286.25	0.00	354.76	0.00	75.60	465.14	1193.45	307.18	0.84	0.07	5.35	52.33	85.48	2.04	0.03	0.25

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 14 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCO LATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												----------------(kg nutrient/ha)----------------						
1	33.02	0.03	9.28	0.00	7.63	0.00	64.45	27.91	86.23	9.30	0.00	0.00	0.10	0.69	3.74	0.00	0.00	0.00
2	28.34	0.00	3.60	0.00	8.91	0.00	50.84	28.85	95.77	3.60	0.00	0.00	0.04	0.41	1.85	0.00	0.00	0.00
3	73.59	0.22	20.72	0.00	11.26	0.00	49.20	42.95	102.26	20.92	0.06	0.00	1.54	18.29	30.43	0.12	0.00	0.01
4	95.69	0.69	25.08	0.00	24.08	0.00	48.17	46.92	87.24	25.73	0.09	0.00	0.56	13.69	23.57	0.20	0.00	0.03
5	93.20	2.37	30.14	0.00	25.46	0.00	39.10	43.99	90.66	32.29	0.11	0.01	0.37	1.51	14.76	0.30	0.00	0.04
6	207.66	3.25	50.63	0.00	59.44	0.00	77.78	55.36	79.29	53.48	0.21	0.01	0.20	2.35	9.29	0.55	0.00	0.07
7	270.03	14.57	46.29	0.00	140.87	0.00	94.11	49.60	78.83	59.61	0.82	0.04	0.34	2.30	3.81	1.84	0.02	0.22
8	185.46	9.56	54.38	0.00	90.21	0.00	86.30	41.21	76.99	63.40	1.33	0.07	0.75	4.04	0.57	3.60	0.01	0.41
9	165.72	2.62	41.74	0.00	72.62	0.00	92.89	41.56	72.61	44.05	0.26	0.02	0.62	3.76	0.05	0.72	0.00	0.09
10	58.75	1.11	19.06	0.00	27.69	0.00	79.62	26.10	58.50	20.00	0.07	0.01	0.37	2.00	0.00	0.24	0.00	0.03
11	62.37	0.43	15.52	0.00	15.90	0.00	85.01	24.14	58.53	15.92	0.05	0.00	0.32	1.59	0.00	0.09	0.00	0.01
12	32.32	0.55	11.69	0.00	10.11	0.00	71.84	24.24	85.26	12.19	0.03	0.00	0.21	1.36	1.03	0.08	0.00	0.01
2003	1306.16	35.39	328.14	0.00	494.18	0.00	71.84	452.83	972.18	360.51	3.03	0.17	5.43	51.99	89.08	7.74	0.03	0.91

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 15 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ (kg nutrient/ha)	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
1	60.16	0.02	16.26	0.00	11.38	0.00	68.87	34.91	94.30	16.28	0.00	0.00	0.15	0.96	3.97	0.00	0.00	0.00
2	19.33	0.17	5.33	0.00	4.90	0.00	44.13	34.36	128.61	5.46	0.01	0.00	0.07	0.35	2.06	0.02	0.00	0.00
3	58.16	0.24	12.77	0.00	5.26	0.00	41.04	42.28	113.69	12.98	0.03	0.00	1.11	11.00	33.15	0.06	0.00	0.01
4	149.52	0.56	35.57	0.00	24.18	0.00	52.05	76.38	127.04	36.05	0.03	0.00	0.71	13.80	20.85	0.05	0.00	0.01
5	188.27	3.53	56.43	0.00	47.15	0.00	70.19	63.03	94.97	59.59	0.21	0.01	0.41	4.10	13.01	0.54	0.00	0.07
6	228.02	5.40	42.65	0.00	107.12	0.00	87.24	56.16	90.78	47.31	0.43	0.02	0.27	2.28	9.59	0.89	0.00	0.10
7	215.51	8.42	45.19	0.00	111.55	0.00	91.95	45.45	85.15	52.82	0.94	0.04	0.55	3.69	1.96	2.24	0.01	0.26
8	246.28	9.81	51.41	0.00	134.52	0.00	92.57	49.59	90.00	60.07	0.44	0.04	0.94	5.76	0.11	1.21	0.01	0.14
9	281.99	19.55	50.39	0.00	165.67	0.00	91.74	46.97	80.18	68.15	0.15	0.06	0.81	6.32	0.00	0.47	0.03	0.06
10	58.84	2.99	22.66	0.00	20.48	0.00	71.80	34.83	95.54	25.52	0.61	0.02	0.40	2.44	0.00	1.32	0.00	0.15
11	61.45	0.45	21.31	0.00	14.42	0.00	67.86	29.30	93.64	21.65	0.01	0.00	0.30	1.81	0.00	0.04	0.00	0.01
12	33.93	0.01	7.49	0.00	3.12	0.00	69.56	21.84	90.62	7.49	0.00	0.00	0.10	0.35	1.21	0.00	0.00	0.00
2004	1601.46	51.16	367.47	0.00	649.75	0.00	69.56	535.10	1184.51	413.38	2.87	0.19	5.84	52.84	85.91	6.85	0.06	0.81

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
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Annual Summary for Watershed in year 16 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ (kg nutrient/ha)	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
1	25.08	0.00	4.43	0.00	4.46	0.00	55.15	30.75	104.80	4.43	0.00	0.00	0.07	0.78	3.75	0.00	0.00	0.00
2	17.40	0.00	2.79	0.00	3.44	0.00	34.95	31.31	133.38	2.79	0.00	0.00	0.05	0.11	2.55	0.00	0.00	0.00
3	169.54	1.71	26.28	0.00	45.49	0.00	54.11	76.48	139.34	27.63	0.01	0.01	1.07	24.90	39.55	0.03	0.00	0.00
4	149.91	0.91	26.73	0.00	37.76	0.00	64.12	71.31	116.92	27.43	0.01	0.00	0.36	6.72	21.63	0.02	0.00	0.00
5	245.75	10.33	55.57	0.00	98.66	0.00	79.78	67.28	105.88	64.79	0.26	0.02	0.19	2.64	12.28	0.58	0.02	0.07
6	250.28	13.33	44.08	0.00	125.34	0.00	90.16	56.65	94.78	56.25	0.59	0.05	0.34	2.19	6.38	1.02	0.02	0.12
7	263.55	13.39	47.47	0.00	157.20	0.00	95.58	38.49	65.94	59.50	0.90	0.05	0.44	3.48	0.70	2.14	0.01	0.26
8	208.48	5.23	42.75	0.00	117.88	0.00	92.20	47.56	88.50	47.05	0.20	0.02	0.60	3.81	0.07	0.58	0.01	0.07
9	188.09	3.39	45.57	0.00	92.38	0.00	85.66	53.81	92.51	48.45	0.24	0.02	0.79	5.36	0.00	0.76	0.00	0.10
10	80.95	2.10	26.13	0.00	20.01	0.00	76.44	42.00	102.44	28.17	0.61	0.01	0.41	2.43	0.00	1.08	0.00	0.12
11	46.41	0.58	14.69	0.00	11.09	0.00	65.78	32.32	88.53	15.23	0.10	0.00	0.20	1.27	0.00	0.16	0.00	0.02
12	2.77	0.00	0.46	0.00	1.96	0.00	50.19	16.27	87.69	0.46	0.00	0.00	0.01	0.12	1.05	0.00	0.00	0.00
2005	1648.21	50.97	336.96	0.00	715.67	0.00	50.19	564.24	1220.71	382.18	2.92	0.20	4.53	53.81	87.98	6.38	0.06	0.76

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 17 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ (kg nutrient/ha)	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
1	8.41	0.00	1.89	0.00	0.08	0.00	39.26	17.37	79.47	1.89	0.00	0.00	0.06	0.02	4.16	0.00	0.00	0.00
2	43.29	0.66	10.82	0.00	6.57	0.00	37.93	26.46	99.17	11.46	0.30	0.00	0.42	2.26	2.76	0.37	0.00	0.03
3	122.46	0.41	31.81	0.00	22.43	0.00	50.51	53.25	106.16	32.14	0.07	0.00	1.69	28.44	35.03	0.12	0.00	0.01
4	88.70	0.49	26.96	0.00	19.50	0.00	39.65	54.17	102.09	27.39	0.03	0.00	0.46	7.56	23.73	0.07	0.00	0.01
5	213.58	12.33	57.95	0.00	46.86	0.00	75.53	59.31	99.14	70.04	1.34	0.03	0.31	2.01	12.62	2.64	0.01	0.33
6	182.51	3.24	38.88	0.00	78.98	0.00	87.50	49.91	99.63	41.51	0.14	0.01	0.21	2.39	4.91	0.39	0.00	0.05
7	219.71	6.96	44.96	0.00	116.85	0.00	93.12	44.01	88.16	51.00	0.49	0.02	0.42	2.88	1.09	1.23	0.01	0.15
8	212.73	4.21	45.95	0.00	118.09	0.00	90.19	47.80	98.37	49.72	0.47	0.03	0.57	4.43	0.02	1.19	0.00	0.14
9	156.62	2.29	33.96	0.00	75.05	0.00	90.46	45.25	95.95	35.98	0.26	0.02	0.68	4.49	0.01	0.80	0.00	0.10
10	115.70	1.83	35.23	0.00	44.10	0.00	88.59	37.30	89.92	36.86	0.19	0.01	0.68	4.99	0.00	0.46	0.00	0.05
11	52.00	0.29	18.15	0.00	14.12	0.00	79.68	29.21	96.79	18.38	0.01	0.00	0.25	1.57	0.00	0.03	0.00	0.00
12	73.37	0.13	19.78	0.00	18.77	0.00	85.24	28.51	84.87	19.85	0.00	0.00	0.23	1.22	0.97	0.00	0.00	0.00
2006	1489.07	32.84	366.34	0.00	561.39	0.00	85.24	492.55	1139.73	396.24	3.30	0.13	5.96	62.27	85.29	7.30	0.03	0.87

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 18 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ (kg nutrient/ha)	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
1	65.74	1.11	21.08	0.00	15.38	0.00	74.37	39.67	99.60	22.07	0.13	0.00	0.24	1.51	4.30	0.26	0.00	0.03
2	44.56	0.00	8.13	0.00	5.35	0.00	57.59	48.18	116.84	8.13	0.00	0.00	0.05	0.24	2.77	0.00	0.00	0.00
3	119.00	0.19	19.44	0.00	16.35	0.00	69.70	69.92	143.72	19.57	0.03	0.00	1.23	21.86	35.78	0.04	0.00	0.00
4	162.34	2.73	29.98	0.00	41.13	0.00	67.56	90.02	134.97	32.46	0.00	0.01	0.44	5.13	23.26	0.01	0.01	0.00
5	208.62	3.56	41.95	0.00	69.43	0.00	81.33	79.15	120.56	44.91	0.02	0.01	0.19	1.84	12.80	0.07	0.01	0.01
6	172.77	1.83	46.09	0.00	69.49	0.00	83.78	53.93	110.96	47.60	0.05	0.01	0.26	3.28	3.46	0.16	0.00	0.02
7	203.03	5.22	45.79	0.00	92.12	0.00	92.40	49.67	117.49	50.47	0.61	0.02	0.47	3.60	1.63	1.20	0.00	0.13
8	184.81	2.28	43.47	0.00	92.40	0.00	92.40	47.06	96.81	45.47	0.19	0.01	0.65	4.42	0.04	0.56	0.00	0.06
9	210.44	4.83	53.33	0.00	109.33	0.00	91.05	44.42	84.10	57.73	0.54	0.03	0.92	6.32	0.01	1.54	0.00	0.17
10	68.91	0.51	19.42	0.00	30.20	0.00	79.83	32.05	98.06	19.83	0.02	0.00	0.26	1.50	0.00	0.07	0.00	0.01
11	28.00	0.19	9.26	0.00	3.86	0.00	73.05	21.76	99.96	9.41	0.02	0.00	0.13	0.37	0.00	0.05	0.00	0.01
12	0.25	0.00	0.18	0.00	0.10	0.00	62.29	10.89	106.16	0.18	0.00	0.00	0.00	0.01	1.24	0.00	0.00	0.00
2007	1468.47	22.44	338.13	0.00	545.14	0.00	62.29	586.73	1329.22	357.83	1.62	0.10	4.83	50.08	85.30	3.95	0.02	0.44

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 19 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	22.98	0.00	5.32	0.00	1.19	0.00	50.89	27.89	118.40	5.32	0.00	0.00	0.14	0.22	4.29	0.00	0.00	0.00
2	17.39	0.00	3.59	0.00	0.30	0.00	35.31	28.88	121.60	3.59	0.00	0.00	0.10	0.62	3.02	0.00	0.00	0.00
3	45.12	0.00	10.87	0.00	3.72	0.00	30.05	35.00	131.77	10.87	0.00	0.00	0.68	7.44	22.75	0.00	0.00	0.00
4	119.20	0.19	32.04	0.00	17.35	0.00	32.05	67.60	123.92	32.20	0.01	0.00	0.49	6.33	22.14	0.03	0.00	0.00
5	198.08	0.62	41.92	0.00	41.90	0.00	70.00	73.93	125.73	42.37	0.02	0.01	0.74	10.40	19.31	0.05	0.00	0.01
6	209.77	3.52	39.36	0.00	94.80	0.00	85.48	57.15	113.60	42.28	0.11	0.01	0.27	3.25	3.43	0.26	0.01	0.03
7	263.30	8.19	47.41	0.00	145.60	0.00	89.96	57.22	111.08	54.06	0.20	0.03	0.50	4.07	2.71	0.62	0.01	0.08
8	249.43	5.88	61.23	0.00	123.92	0.00	92.05	56.20	106.47	66.17	0.32	0.03	0.77	5.46	0.33	0.92	0.01	0.11
9	165.61	2.17	47.11	0.00	65.71	0.00	87.71	56.43	108.39	48.97	0.13	0.01	0.81	4.77	0.02	0.43	0.00	0.05
10	131.45	5.99	39.31	0.00	43.83	0.00	89.97	36.53	95.30	44.95	0.96	0.03	0.75	4.29	0.00	2.51	0.00	0.26
11	89.90	3.64	24.53	0.00	52.60	0.00	71.23	32.31	110.32	27.74	0.29	0.01	0.33	3.43	0.00	0.69	0.00	0.08
12	15.82	0.00	4.23	0.00	0.39	0.00	65.08	17.34	111.19	4.23	0.00	0.00	0.07	0.04	1.45	0.00	0.00	0.00
2008	1528.06	30.21	356.92	0.00	591.32	0.00	65.08	546.48	1377.76	382.75	2.05	0.14	5.65	50.31	79.46	5.51	0.04	0.61

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SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 20 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	24.97	0.00	5.66	0.00	2.09	0.00	55.42	26.89	104.46	5.66	0.00	0.00	0.08	0.32	3.97	0.00	0.00	0.00
2	21.61	0.00	3.39	0.00	2.44	0.00	37.43	33.56	131.97	3.39	0.00	0.00	0.16	0.83	2.58	0.00	0.00	0.00
3	56.24	0.05	15.71	0.00	5.88	0.00	32.32	39.59	126.54	15.75	0.00	0.00	1.05	7.67	22.13	0.01	0.00	0.00
4	125.79	1.29	38.40	0.00	24.73	0.00	34.96	58.00	119.89	39.47	0.13	0.06	0.94	13.04	17.63	0.27	0.00	0.03
5	101.37	0.06	25.56	0.00	12.35	0.00	43.24	55.70	140.33	25.60	0.00	0.00	0.25	8.12	14.93	0.00	0.00	0.00
6	166.26	1.31	34.60	0.00	43.53	0.00	73.42	55.68	136.09	35.69	0.03	0.00	0.32	1.75	6.61	0.09	0.00	0.01
7	198.97	2.29	34.56	0.00	97.27	0.00	87.67	49.79	123.44	36.34	0.11	0.01	0.62	4.66	0.86	0.27	0.00	0.03
8	204.41	5.94	39.01	0.00	108.02	0.00	88.18	51.49	117.05	44.14	0.59	0.03	0.71	5.68	0.11	1.43	0.01	0.15
9	109.92	0.59	33.16	0.00	36.98	0.00	82.89	44.81	119.15	33.62	0.03	0.00	0.65	3.06	0.00	0.11	0.00	0.01
10	120.11	5.68	38.08	0.00	44.23	0.00	80.93	35.22	104.36	43.41	0.64	0.03	0.73	4.80	0.00	1.96	0.00	0.18
11	37.03	0.32	11.09	0.00	4.86	0.00	76.96	24.26	116.79	11.37	0.01	0.00	0.15	0.56	0.00	0.03	0.00	0.00
12	65.06	2.26	22.42	0.00	17.61	0.00	73.19	27.07	107.78	24.55	0.31	0.01	0.38	2.29	1.08	0.56	0.00	0.07
2009	1231.74	19.79	301.65	0.00	399.99	0.00	73.19	502.05	1447.84	318.98	1.84	0.15	6.05	52.78	69.92	4.74	0.02	0.49

SWAT Sept '05 VERSION2005

General Input/Output section (file.cio): ArcSWAT 2.3.4
3/14/2015 12:00:00 AMARCGIS-SWAT interface AV

Annual Summary for Watershed in year 21 of simulation

UNIT TIME	PREC (mm)	SURQ (mm)	LATQ (mm)	GWQ (mm)	PERCOLATE (mm)	TILE Q (mm)	SW (mm)	ET (mm)	PET (mm)	WATER YIELD (mm)	SED YIELD (t/ha)	NO3 SURQ	NO3 LATQ	NO3 PERC	NO3 CROP	N ORGANIC	P SOLUBLE	P ORGANIC
												(kg nutrient/ha)						
1	24.51	0.00	5.73	0.00	4.30	0.00	60.71	27.42	103.84	5.73	0.00	0.00	0.06	0.27	4.81	0.00	0.00	0.00
2	53.42	0.03	12.67	0.00	9.92	0.00	49.04	42.20	123.61	12.69	0.00	0.00	0.28	1.27	2.92	0.00	0.00	0.00
3	92.41	1.71	28.78	0.00	18.89	0.00	44.02	46.84	124.33	30.36	0.30	0.01	1.68	17.27	22.37	0.64	0.00	0.07
4	124.90	1.64	39.32	0.00	30.57	0.00	39.51	58.34	123.77	40.82	0.27	0.02	1.21	14.99	19.38	0.52	0.00	0.06
5	231.52	4.01	64.05	0.00	53.82	0.00	66.34	82.49	122.64	67.70	0.24	0.01	0.74	7.14	18.02	0.56	0.01	0.07
6	211.08	2.34	44.00	0.00	80.07	0.00	83.25	67.49	117.19	45.81	0.05	0.01	0.24	2.10	6.22	0.17	0.00	0.02
7	182.49	2.42	40.00	0.00	75.44	0.00	87.25	60.24	130.50	42.09	0.32	0.01	0.41	2.56	2.91	0.66	0.00	0.07
8	210.51	10.08	45.84	0.00	92.27	0.00	92.00	55.99	117.62	55.23	0.93	0.03	0.52	3.23	0.17	2.00	0.01	0.21
9	167.98	7.42	51.19	0.00	60.55	0.00	85.91	57.47	123.57	58.12	0.79	0.05	0.72	4.43	0.01	2.20	0.01	0.21
10	92.69	1.18	27.45	0.00	28.85	0.00	76.19	45.51	128.70	28.52	0.08	0.01	0.35	1.93	0.00	0.20	0.00	0.02
11	19.17	0.00	5.19	0.00	2.33	0.00	60.84	27.40	132.91	5.19	0.00	0.00	0.10	0.28	0.00	0.00	0.00	0.00
12	30.85	0.00	6.40	0.00	1.61	0.00	62.49	20.73	117.49	6.40	0.00	0.00	0.08	0.35	1.62	0.00	0.00	0.00
2010	1441.52	30.82	370.63	0.00	458.61	0.00	62.49	592.12	1466.15	398.66	2.98	0.14	6.38	55.81	78.42	6.96	0.03	0.73

Table A4. HRU statistics report

AVE ANNUAL VALUES

HRU	SUB	CPMN	SOIL	AREAkm2	CN	AWCmm	USLE_LS	IRRmm	AUTONkh	AUTOPkh	MIXEF	PRECmm	SURQmm	GWQmm	ETmm	SEDth	NO3kgh	ORGNkgh	BIOMth	YLDth
1	1	AGRC	dystric	.817E+03	55.00	124.00	2.11	0.00	163.20	0.00	0.20	1326.78	62.13	388.46	598.45	4.19	9.16	14.82	11.26	3.49
2	1	AGRC	dystric	.476E+03	55.00	124.00	3.50	0.00	139.39	0.00	0.20	1326.78	23.93	671.01	558.90	3.95	15.19	11.12	9.96	3.09
3	1	AGRC	Dystric	.245E+03	55.00	124.00	2.27	0.00	162.53	0.00	0.20	1326.78	60.95	400.83	597.10	4.29	9.44	14.95	11.23	3.48
4	1	AGRC	Dystric	.197E+03	55.00	124.00	3.60	0.00	139.38	0.00	0.20	1326.78	23.92	671.05	558.90	3.80	15.20	10.84	9.96	3.09
5	1	AGRC	Pellic v	.512E+03	55.00	4.80	3.69	0.00	97.19	0.74	0.20	1326.78	0.67	787.80	316.07	0.34	16.85	0.68	1.87	0.58
6	1	AGRC	Pellic v	.323E+03	55.00	4.80	2.14	0.00	182.76	1.80	0.20	1326.78	0.74	94.14	333.17	0.15	2.81	0.38	2.83	0.88
7	1	AGRR	dystric	.132E+04	55.00	124.00	1.79	0.00	191.31	0.00	0.20	1326.78	71.32	371.88	564.69	12.74	8.56	30.50	22.52	8.61
8	1	AGRR	dystric	.378E+03	55.00	124.00	3.13	0.00	185.75	0.00	0.20	1326.78	26.48	689.63	526.71	8.52	16.21	21.64	22.04	8.38
9	1	AGRR	dystric	.521E+03	55.00	124.00	0.46	0.00	201.32	0.00	0.20	1326.78	93.01	110.13	580.96	4.32	3.03	17.53	22.35	8.57
10	1	AGRR	Pellic v	.750E+03	55.00	4.80	1.92	0.00	211.58	2.21	0.20	1326.78	0.86	87.31	347.06	0.21	3.02	0.52	4.47	1.57
11	1	AGRR	Pellic v	.249E+03	55.00	4.80	0.48	0.00	273.15	2.68	0.20	1326.78	0.90	20.13	347.32	0.04	0.88	0.15	4.95	1.77
12	1	AGRR	Pellic v	.288E+03	55.00	4.80	3.15	0.00	190.72	2.36	0.20	1326.78	0.83	530.60	337.19	0.38	18.88	0.79	4.62	1.64
13	1	PAST	Chromic	.939E+02	55.00	119.00	0.40	0.00	0.00	0.00	0.20	1326.78	25.72	7.91	653.31	0.13	0.07	0.12	2.03	1.18
14	1	PAST	Chromic	.477E+02	55.00	119.00	1.53	0.00	0.00	0.00	0.20	1326.78	25.56	34.81	652.59	0.47	0.11	0.35	2.03	1.18
15	1	PAST	dystric	.332E+03	55.00	124.00	0.31	0.00	0.00	0.00	0.20	1326.78	79.64	80.20	663.72	0.08	0.29	0.37	3.17	1.83
16	1	PAST	dystric	.131E+03	55.00	124.00	1.44	0.00	0.00	0.00	0.20	1326.78	59.05	325.13	648.04	0.24	0.60	1.02	3.18	1.84
17	1	PAST	Pellic v	.190E+03	55.00	4.80	1.56	0.00	0.00	0.00	0.20	1326.78	0.46	75.79	365.44	0.04	0.17	0.10	0.27	0.15
18	1	PAST	Pellic v	.440E+03	55.00	4.80	0.27	0.00	0.00	0.00	0.20	1326.78	0.46	8.72	367.98	0.01	0.02	0.03	0.24	0.13
19	2	AGRR	Pellic v	.164E+04	55.00	4.80	0.40	0.00	266.82	2.13	0.20	1206.24	0.18	15.82	333.69	0.00	0.74	0.02	4.24	1.55
20	2	AGRR	Pellic v	.994E+03	55.00	4.80	1.61	0.00	257.78	2.42	0.20	1206.24	0.20	70.76	332.29	0.03	3.23	0.08	4.58	1.71
21	2	PAST	Chromic	.126E+02	55.00	168.00	2.37	0.00	0.00	0.00	0.20	1206.24	17.87	50.42	644.31	0.25	0.11	0.81	3.19	1.81
22	2	PAST	Chromic	.230E+02	55.00	168.00	4.01	0.00	0.00	0.00	0.20	1206.24	16.22	324.83	625.54	0.34	0.51	1.09	3.20	1.83
23	2	PAST	Eutric c	.390E+01	55.00	56.70	0.54	0.00	0.00	0.00	0.20	1206.24	12.77	9.64	546.57	0.15	0.04	0.34	1.35	0.75
24	2	PAST	Eutric c	.918E+01	55.00	56.70	2.01	0.00	0.00	0.00	0.20	1206.24	12.76	40.11	545.49	0.62	0.10	1.04	1.35	0.75
25	2	PAST	Eutric c	.214E+02	55.00	56.70	3.69	0.00	0.00	0.00	0.20	1206.24	12.09	455.02	521.36	0.82	0.78	1.30	1.49	0.84
26	2	PAST	Pellic v	.101E+03	55.00	4.80	1.58	0.00	0.00	0.00	0.20	1206.24	0.17	69.61	336.40	0.01	0.16	0.04	0.25	0.13
27	2	PAST	Pellic v	.124E+03	55.00	4.80	0.42	0.00	0.00	0.00	0.20	1206.24	0.18	16.31	337.56	0.00	0.04	0.01	0.22	0.12
28	3	PAST	Chromic	.177E+01	55.00	119.00	2.17	0.00	0.00	0.00	0.20	1374.66	32.81	46.05	638.65	1.28	0.15	0.80	1.94	1.13
29	3	PAST	Chromic	.247E+01	55.00	119.00	3.77	0.00	0.00	0.00	0.20	1374.66	27.51	513.17	618.79	1.95	0.86	1.05	2.00	1.18
30	3	PAST	Chromic	.656E+00	55.00	119.00	0.44	0.00	0.00	0.00	0.20	1374.66	33.14	8.98	639.58	0.22	0.08	0.21	1.93	1.12
31	3	PAST	Eutric c	.233E+02	55.00	56.70	3.79	0.00	0.00	0.00	0.20	1374.66	20.22	542.14	546.76	2.02	0.97	2.57	1.60	0.92
32	3	PAST	Eutric c	.137E+02	55.00	56.70	2.07	0.00	0.00	0.00	0.20	1374.66	21.15	48.19	573.55	1.29	0.13	1.95	1.43	0.81
33	4	AGRR	Chromic	.166E+03	55.00	119.00	2.82	0.00	215.64	0.68	0.20	1612.05	33.68	354.15	654.37	13.73	11.77	11.78	18.13	7.02
34	4	AGRR	Chromic	.609E+03	55.00	119.00	1.88	0.00	234.30	0.68	0.20	1612.05	35.59	51.28	663.36	9.46	1.96	9.71	17.87	6.92
35	4	AGRR	Chromic	.247E+03	55.00	119.00	0.48	0.00	239.27	0.68	0.20	1612.05	35.92	11.70	661.17	2.38	0.59	4.21	18.50	7.17
36	4	AGRR	dystric	.847E+03	55.00	124.00	3.45	0.00	189.67	0.00	0.20	1612.05	41.66	840.51	608.41	14.05	17.70	29.88	22.28	8.59
37	4	AGRR	dystric	.971E+03	55.00	124.00	2.21	0.00	228.64	0.68	0.20	1612.05	89.83	497.62	641.02	18.96	13.49	37.39	22.30	8.64
38	4	AGRR	Dystric	.517E+03	55.00	124.00	2.21	0.00	228.69	0.68	0.20	1612.05	89.84	497.66	640.89	20.43	13.46	38.57	22.29	8.63
39	4	AGRR	Dystric	.453E+03	55.00	124.00	3.35	0.00	189.68	0.00	0.20	1612.05	41.66	840.42	608.45	14.54	17.69	30.42	22.26	8.58
40	4	AGRR	Eutric f	.638E+03	55.00	88.42	1.70	0.00	208.21	0.00	0.20	1612.05	48.45	8.28	650.46	7.83	0.56	18.46	16.88	6.54
41	4	AGRR	Eutric f	.380E+03	55.00	88.42	0.46	0.00	212.89	0.68	0.20	1612.05	48.68	1.89	649.47	2.09	0.29	8.62	17.39	6.74
42	4	PAST	Chromic	.286E+02	55.00	119.00	1.50	0.00	0.00	0.00	0.20	1612.05	33.19	42.63	738.95	2.09	0.14	1.03	2.65	1.85
43	4	PAST	Chromic	.503E+02	55.00	119.00	0.35	0.00	0.00	0.00	0.20	1612.05	33.40	8.72	739.64	0.50	0.08	0.36	2.65	1.85
44	4	PAST	Eutric c	.281E+02	55.00	56.70	2.37	0.00	0.00	0.00	0.20	1612.05	20.97	61.45	673.71	2.16	0.15	2.74	2.04	1.42
45	4	PAST	Eutric c	.118E+03	55.00	56.70	3.82	0.00	0.00	0.00	0.20	1612.05	19.99	631.77	656.05	3.16	1.07	3.49	2.27	1.59
46	4	PAST	Eutric f	.340E+02	55.00	88.42	1.50	0.00	0.00	0.00	0.20	1612.05	45.40	7.23	742.56	1.31	0.11	2.95	3.94	2.75
47	4	PAST	Eutric f	.731E+02	55.00	88.42	0.35	0.00	0.00	0.00	0.20	1612.05	45.55	1.44	742.74	0.32	0.10	1.00	3.95	2.76
48	5	AGRR	Pellic v	.227E+04	55.00	4.80	1.67	0.00	268.32	2.61	0.20	1374.66	2.08	84.68	331.50	0.41	3.46	1.04	5.00	1.78
49	5	AGRR	Pellic v	.143E+04	55.00	4.80	0.50	0.00	247.09	2.01	0.20	1374.66	1.97	21.89	333.70	0.13	0.83	0.44	4.16	1.45
50	5	AGRR	Pellic v	.499E+03	55.00	4.80	3.75	0.00	253.77	3.32	0.20	1374.66	1.99	595.48	321.68	1.08	26.21	2.09	6.17	2.14
51	5	PAST	Eutric c	.776E+03	55.00	56.70	2.07	0.00	0.00	0.00	0.20	1374.66	20.88	47.85	583.16	1.71	0.13	2.38	1.44	0.81
52	5	PAST	Eutric c	.954E+03	55.00	56.70	3.35	0.00	0.00	0.00	0.20	1374.66	19.98	517.15	557.63	2.28	0.93	2.77	1.60	0.92
53	5	PAST	Pellic v	.871E+03	55.00	4.80	1.76	0.00	0.00	0.00	0.20	1374.66	0.98	86.57	350.45	0.32	0.20	0.70	0.24	0.13
54	5	PAST	Pellic v	.270E+03	55.00	4.80	3.35	0.00	0.00	0.00	0.20	1374.66	0.90	567.75	336.03	0.24	1.24	0.54	0.48	0.28
55	5	PAST	Pellic v	.739E+03	55.00	4.80	0.46	0.00	0.00	0.00	0.20	1374.66	1.01	20.34	351.47	0.09	0.05	0.29	0.20	0.11
56	6	AGRC	dystric	.108E+04	55.00	124.00	3.88	0.00	179.59	0.00	0.20	1682.03	25.65	867.03	668.95	1.62	16.99	7.44	14.76	4.57
57	6	AGRC	dystric	.907E+03	55.00	124.00	2.17	0.00	189.90	0.00	0.20	1682.03	62.69	518.28	700.06	2.35	10.65	10.80	14.35	4.45
58	6	AGRC	Dystric	.194E+03	55.00	124.00	2.17	0.00	189.90	0.00	0.20	1682.03	62.69	518.29	700.05	2.44	10.65	11.08	14.35	4.45
59	6	AGRC	Dystric	.197E+03	55.00	124.00	3.96	0.00	179.69	0.00	0.20	1682.03	25.65	867.10	668.91	1.79	16.99	7.97	14.76	4.57
60	6	AGRC	Pellic v	.800E+02	55.00	4.80	11.72	0.00	179.52	2.70	0.20	1682.03	0.38	1078.52	403.62	0.17	32.22	0.36	4.28	1.33
61	6	AGRC	Pellic v	.516E+03	55.00	4.80	3.94	0.00	186.87	2.55	0.20	1682.03	0.38	1013.43	407.33	0.08	30.34	0.19	4.28	1.33
62	6	AGRC	Pellic v	.103E+03	55.00	4.80	2.44	0.00	287.70	2.40	0.20	1682.03	0.40	129.34	425.91	0.06	4.65	0.15	3.98	1.23
63	6	AGRR	dystric	.111E+03	55.00	124.00	0.46	0.00	282.97	0.00	0.20	1682.03	96.28	144.96	685.45	4.14	5.08	17.46	22.37	8.67
64	6	AGRR	dystric	.466E+03	55.00	124.00	3.55	0.00	211.20	0.00	0.20	1682.03	29.01	884.20	638.31	10.11	20.10	25.15	24.25	9.39
65	6	AGRR	dystric	.498E+03	55.00	124.00	2.21	0.00	254.30	0.68	0.20	1682.03	65.52	533.24	666.78	14.37	15.66	32.11	23.32	9.03
66	6	AGRR	Dystric	.114E+03	55.00	124.00	3.55	0.00	211.20	0.00	0.20	1682.03	29.03	884.27	638.19	9.43	20.11	24.20	24.27	9.40
67	6	AGRR	Dystric	.434E+02	55.00	124.00	0.44	0.00	282.97	0.00	0.20	1682.03	96.57	140.56	685.72	3.63	4.94	16.12	22.37	8.67
68	6	AGRR	Dystric	.152E+03	55.00	124.00	2.11	0.00	254.17	0.68	0.20	1682.03	66.47	523.30	667.26	13.44	15.23	31.17	23.33	9.04
69	6	AGRR	Pellic v	.413E+03	55.00	4.80	3.90	0.00	264.69	3.65	0.20	1682.03	0.35	1002.17	424.19	0.15	42.48	0.32	6.18	2.35
70	6	AGRR	Pellic v	.881E+02	55.00	4.80	2.48	0.00	294.79	2.22	0.20	1682.03	0.34	129.36	444.98	0.10	4.94	0.22	3.94	1.49
71	6	PAST	dystric	.111E+03	55.00	124.00	0.42	0.00	0.00	0.00	0.20	1682.03	102.45	140.07	640.35	0.10	0.51	0.45	3.03	0.43
72	6	PAST	dystric	.371E+03	55.00	124.00	2.21	0.00	0.00	0.00	0.20	1682.03	68.64	547.11	630.52	0.30	1.21	1.32	3.19	0.53
73	6	PAST	dystric	.463E+03	55.00	124.00	2.99	0.00	0.00	0.00	0.20	1682.03	30.23	908.31	608.70	0.15	1.77	0.69	3.31	0.57
74	6	PAST	Eutric c	.686E+03	55.00	56.70	3.60	0.00	0.00	0.00	0.20	1682.03	14.25	700.43	574.15	0.27	1.37	0.52	1.62	0.22
75	6	PAST	Eutric c	.207E+03	55.00	56.70	2.34	0.00	0.00	0.00	0.20	1682.03	14.83	67.95	597.15	0.24	0.17	0.44	1.51	0.17
76	7	AGRC	dystric	.437E+03	55.00	124.00	3.93	0.00	183.57	0.00	0.20	1693.53	21.58	862.72	689.31	1.32	17.38	6.08	14.93	4.62
77	7	AGRC	dystric	.305E+03	55.00	124.00	2.27	0.00	188.76	0.00	0.20	1693.53	54.32	528.00	718.69	2.02	10.64	9.43	14.22	4.40
78	7	AGRC	Dystric	.150E+03	55.00	124.00	2.11	0.00	188.52	0.00	0.20	1693.53	55.69	511.99	719.56	1.85	10.31	8.87	14.17	4.39
79	7	AGRC	Dystric	.748E+02	55.00	124.00	3.52	0.00	183.52	0.00	0.20	1693.53	21.59	862.45	689.35	1.05	17.38	5.16	14.93	4.62
80	7	AGRC	Dystric	.300E+02	55.00	124.00	0.52	0.00	183.92	0.00	0.20	1693.53	81.13	155.52	733.52	0.60	3.31	3.33	13.22	4.09
81	7	AGRC	Pellic v	.506E+02	55.00	4.80	11.93	0.00	186.58	2.20	0.20	1693.53	0.51	1075.22	420.50	0.22	33.23	0.48	4.12	1.28
82	7	AGRC	Pellic v	.384E+02	55.00	4.80	2.51	0.00	270.91	2.64	0.20	1693.53	0.58	131.03	443.57	0.03	4.36	0.12	4.23	1.31
83	7	AGRC	Pellic v	.219E+03	55.00	4.80	4.16	0.00	188.88	2.35	0.20	1693.53	0.51	1021.98	423.42	0.09	30.83	0.24	4.16	1.29
84	7	AGRR	dystric	.424E+03	55.00	124.00	3.70	0.00	212.17	0.00	0.20	1693.53	22.87	885.28	654.21	7.85	20.43	19.65	24.19	9.37
85	7	AGRR	dystric	.312E+03	55.00	124.00	2.31	0.00	268.92	1.36	0.20	1693.53	55.00	544.81	683.95	12.19	16.82	28.84	23.86	9.25
86	7	AGRR	Dystric	.263E+02	55.00	124.00	0.46	0.00	295.52	0.00	0.20	1693.53	84.04	145.92	701.89	3.02	5.25	13.54	22.27	8.63
87	7	AGRR	Dystric	.219E+02	55.00	124.00	3.11	0.00	215.39	0.00	0.20	1693.53	22.92	885.14	653.75	5.12	21.01	15.25	24.33	9.43
88	7	AGRR	Dystric	.754E+02	55.00	124.00	1.98	0.00	270.16	1.36	0.20	1693.53	58.09	511.99	683.74	9.94	15.98	25.90	23.97	9.29
89	7	PAST	dystric	.400E+03	55.00	124.00	2.21	0.00	0.00	0.00	0.20	1693.53	61.24	552.87	637.96	0.28	1.22	1.19	3.13	0.42
90	7	PAST	dystric	.618E+03	55.00	124.00	3.29	0.00	0.00	0.00	0.20	1693.53	25.70	915.64	616.72	0.13	1.77	0.59	3.39	0.56
91	7	PAST	Eutric c	.721E+02	55.00	56.70	11.37	0.00	0.00	0.00	0.20	1693.53	14.90	951.31	566.60	0.45	1.80	0.96	1.75	0.23
92	7	PAST	Eutric c	.317E+03	55.00	56.70	4.27	0.00	0.00	0.00	0.20	1693.53	15.81	738.92	583.02	0.36	1.47	0.67	1.67	0.19
93	8	AGRC	dystric	.103E+03	55.00	124.00	2.34	0.00	173.35	0.00	0.20	1333.71	40.88	391.70	668.93	6.06	10.31	14.63	11.95	3.70
94	8	AGRC	dystric	.257E+03	55.00	124.00	3.46	0.00	139.22	0.00	0.20	1333.71	17.60	637.29	628.49	5.46	14.18	11.29	11.85	3.67
95	8	AGRC	Eutric c	.374E+03	55.00	56.70	3.39	0.00	151.35	0.00	0.20	1333.71	12.46	455.44	645.25	3.60	16.43	5.40	6.62	2.05
96	8	AGRC	Eutric c	.151E+03	55.00	56.70	2.34	0.00	159.94	0.00	0.20	1333.71	13.68	45.73	664.90	2.19	1.59	3.95	6.69	2.07
97	8	AGRC	Pellic v	.109E+03	55.00	4.80	11.72	0.00	171.11	1.95	0.20	1333.71	0.95	834.02	351.31	1.74	30.73	2.61	3.57	1.10
98	8	AGRC	Pellic v	.518E+03	55.00	4.80	4.36	0.00	171.45	1.97	0.20	1333.71	0.96	801.04	353.76	0.74	28.43	1.38	3.58	1.11
99	8	AGRR	dystric	.647E+03	55.00	124.00	0.50	0.00	251.88	0.00	0.20	1333.71	63.05	112.16	673.18	4.56	4.64	15.73	19.85	7.69

100	8	AGRRdystric .108E+04	55.00	124.00	1.79	0.00	231.08	0.00	0.20	1333.71	45.11	354.61	657.72	12.32	12.69	24.85	20.73	8.03
101	8	AGRRdystric .676E+03	55.00	124.00	3.93	0.00	193.01	0.00	0.20	1333.71	18.47	642.25	613.87	12.83	20.26	22.63	21.24	8.22
102	8	AGRRPellic v.135E+04	55.00	4.80	4.23	0.00	130.98	1.67	0.20	1333.71	0.56	790.52	364.98	0.91	22.23	1.40	3.75	1.40
103	8	AGRRPellic v.406E+03	55.00	4.80	1.95	0.00	252.94	2.43	0.20	1333.71	0.58	86.76	388.46	0.40	3.56	0.75	4.71	1.77
104	8	AGRRPellic v.277E+03	55.00	4.80	0.44	0.00	234.67	1.97	0.20	1333.71	0.59	18.54	389.20	0.08	0.71	0.22	4.08	1.53
105	8	AGRRPellic v.326E+03	55.00	4.80	11.96	0.00	112.41	1.15	0.20	1333.71	0.56	828.48	361.97	2.58	21.53	3.00	3.00	1.11
106	8	PASTdystric .583E+03	55.00	124.00	0.48	0.00	0.00	0.00	0.20	1333.71	72.76	116.00	593.29	0.06	0.55	0.27	2.45	0.00
107	8	PASTdystric .125E+04	55.00	124.00	1.95	0.00	0.00	0.00	0.20	1333.71	52.82	395.32	567.63	0.18	1.44	0.83	2.64	0.00
108	8	PASTdystric .124E+04	55.00	124.00	2.99	0.00	0.00	0.00	0.20	1333.71	21.27	696.86	534.47	0.11	2.40	0.52	2.83	0.00
109	8	PASTEutric c.224E+04	55.00	56.70	3.82	0.00	0.00	0.00	0.20	1333.71	14.52	503.77	580.39	0.13	1.60	0.34	1.27	0.00
110	8	PASTEutric c.768E+03	55.00	56.70	2.14	0.00	0.00	0.00	0.20	1333.71	14.96	45.35	614.91	0.08	0.17	0.21	1.15	0.00
111	8	PASTPellic v.137E+04	55.00	4.80	4.05	0.00	0.00	0.00	0.20	1333.71	1.18	788.83	346.12	0.01	2.08	0.05	0.50	0.00
112	8	PASTPellic v.271E+03	55.00	4.80	11.82	0.00	0.00	0.00	0.20	1333.71	1.20	835.35	342.06	0.03	2.25	0.13	0.52	0.00
113	8	PASTPellic v.310E+03	55.00	4.80	2.24	0.00	0.00	0.00	0.20	1333.71	0.88	93.98	389.39	0.01	0.23	0.03	0.26	0.00
114	9	AGRCdystric .265E+03	55.00	124.00	2.99	0.00	159.73	0.00	0.20	1693.53	18.19	849.85	725.45	1.13	17.46	4.80	12.07	3.73
115	9	AGRCdystric .217E+03	55.00	124.00	2.14	0.00	172.87	0.00	0.20	1693.53	52.38	502.78	763.15	2.29	10.16	9.60	12.11	3.75
116	9	AGRCDystric .218E+02	55.00	124.00	0.48	0.00	172.11	0.00	0.20	1693.53	79.73	143.23	779.32	0.69	3.07	3.67	11.72	3.63
117	9	AGRCDystric .549E+02	55.00	124.00	1.88	0.00	173.28	0.00	0.20	1693.53	54.81	476.54	764.92	1.92	9.65	8.55	12.10	3.74
118	9	AGRCDystric .254E+02	55.00	124.00	3.50	0.00	159.73	0.00	0.20	1693.53	18.33	847.33	725.46	1.10	17.22	4.70	12.07	3.73
119	9	AGRRdystric .356E+03	55.00	124.00	2.21	0.00	223.30	0.00	0.20	1693.53	53.66	519.63	729.96	10.60	14.30	25.89	20.15	7.80
120	9	AGRRdystric .499E+03	55.00	124.00	3.03	0.00	190.67	0.00	0.20	1693.53	21.36	862.73	696.61	5.57	20.14	16.03	21.23	8.22
121	9	AGRRDystric .879E+02	55.00	124.00	1.76	0.00	224.15	0.00	0.20	1693.53	57.52	472.55	733.17	8.74	13.01	23.56	19.95	7.73
122	9	AGRRDystric .603E+02	55.00	124.00	0.40	0.00	254.48	0.00	0.20	1693.53	80.55	128.84	752.24	2.78	4.45	12.60	18.70	7.24
123	9	AGRRDystric .197E+02	55.00	124.00	3.52	0.00	190.67	0.00	0.20	1693.53	21.53	859.86	696.64	5.44	19.96	15.83	21.22	8.22
124	9	PASTChromic .650E+03	55.00	119.00	0.35	0.00	0.00	0.00	0.20	1693.53	21.41	8.93	821.87	0.33	0.06	0.27	2.42	1.69
125	9	PASTChromic .204E+03	55.00	119.00	1.56	0.00	0.00	0.00	0.20	1693.53	21.24	44.73	821.36	1.77	0.14	0.94	2.43	1.69
126	9	PASTdystric .677E+03	55.00	124.00	2.17	0.00	0.00	0.00	0.20	1693.53	42.04	496.21	829.88	1.87	1.11	4.96	3.99	2.79
127	9	PASTdystric .898E+03	55.00	124.00	3.17	0.00	0.00	0.00	0.20	1693.53	13.01	820.85	789.14	0.88	1.55	2.29	4.33	3.03
128	10	PASTChromic .229E+02	55.00	119.00	1.64	0.00	0.00	0.00	0.20	1300.51	36.09	35.67	631.92	0.47	0.18	0.30	1.27	0.00
129	10	PASTChromic .940E+01	55.00	119.00	3.35	0.00	0.00	0.00	0.20	1300.51	33.60	290.60	618.31	0.83	0.93	0.47	1.37	0.00
130	10	PASTChromic .570E+02	55.00	119.00	0.33	0.00	0.00	0.00	0.20	1300.51	36.34	6.59	633.03	0.10	0.10	0.08	1.26	0.00
131	10	PASTdystric .302E+02	55.00	124.00	2.27	0.00	0.00	0.00	0.20	1300.51	69.04	398.90	569.73	0.91	1.55	2.13	2.30	0.00
132	10	PASTdystric .910E+02	55.00	124.00	3.60	0.00	0.00	0.00	0.20	1300.51	33.92	675.41	518.43	0.59	2.44	1.42	2.60	0.00
133	10	PASTEutric c.546E+02	55.00	56.70	0.36	0.00	0.00	0.00	0.20	1300.51	24.35	7.56	589.38	0.06	0.08	0.13	0.97	0.00
134	10	PASTEutric c.394E+02	55.00	56.70	1.79	0.00	0.00	0.00	0.20	1300.51	24.31	39.73	588.14	0.31	0.18	0.50	0.98	0.00
135	10	PASTEutric c.297E+02	55.00	56.70	3.07	0.00	0.00	0.00	0.20	1300.51	22.65	457.76	563.10	0.52	1.56	0.75	1.07	0.00
136	10	PASTEutric f.342E+02	55.00	88.42	1.67	0.00	0.00	0.00	0.20	1300.51	50.13	6.36	573.50	0.61	0.14	1.19	2.10	0.00
137	10	PASTEutric f.220E+02	55.00	88.42	3.91	0.00	0.00	0.00	0.20	1300.51	48.58	70.07	572.02	1.36	0.42	2.24	2.11	0.00
138	10	PASTEutric f.103E+03	55.00	88.42	0.35	0.00	0.00	0.00	0.20	1300.51	50.30	1.18	573.50	0.13	0.12	0.34	2.10	0.00
139	10	PASTPellic v.329E+02	55.00	4.80	1.92	0.00	0.00	0.00	0.20	1300.51	1.74	85.39	341.50	0.03	0.21	0.12	0.19	0.00
140	10	PASTPellic v.521E+02	55.00	4.80	3.39	0.00	0.00	0.00	0.20	1300.51	1.94	756.46	307.31	0.03	1.98	0.10	0.41	0.00
141	10	PASTPellic v.287E+02	55.00	4.80	0.48	0.00	0.00	0.00	0.20	1300.51	1.75	19.68	342.16	0.01	0.05	0.04	0.17	0.00
142	11	PASTChromic .152E+03	55.00	119.00	1.58	0.00	0.00	0.00	0.20	1299.01	27.23	38.22	528.91	0.09	0.16	0.10	1.48	0.00
143	11	PASTChromic .532E+03	55.00	119.00	0.30	0.00	0.00	0.00	0.20	1299.01	27.49	6.60	529.65	0.02	0.08	0.02	1.48	0.00
144	11	PASTEutric c.232E+03	55.00	56.70	0.36	0.00	0.00	0.00	0.20	1299.01	19.39	8.27	481.84	0.02	0.06	0.04	1.02	0.00
145	11	PASTEutric c.138E+03	55.00	56.70	3.23	0.00	0.00	0.00	0.20	1299.01	18.62	510.39	462.54	0.14	1.60	0.38	1.06	0.00
146	11	PASTEutric c.165E+03	55.00	56.70	1.76	0.00	0.00	0.00	0.20	1299.01	19.35	43.00	480.94	0.08	0.16	0.22	1.02	0.00
147	11	PASTEutric f.143E+03	55.00	88.42	1.58	0.00	0.00	0.00	0.20	1299.01	41.58	6.83	469.21	0.09	0.12	0.36	2.09	0.00
148	11	PASTEutric f.779E+03	55.00	88.42	0.30	0.00	0.00	0.00	0.20	1299.01	41.78	1.15	469.30	0.02	0.10	0.06	2.09	0.00
149	11	PASTPellic v.101E+03	55.00	4.80	11.82	0.00	0.00	0.00	0.20	1299.01	1.69	848.16	278.86	0.05	2.35	0.19	0.36	0.00
150	11	PASTPellic v.217E+03	55.00	4.80	2.27	0.00	0.00	0.00	0.20	1299.01	1.66	96.54	307.67	0.02	0.23	0.11	0.16	0.00
151	11	PASTPellic v.611E+03	55.00	4.80	3.79	0.00	0.00	0.00	0.20	1299.01	1.70	788.75	282.56	0.02	2.12	0.07	0.35	0.00
152	12	AGRCChromic .362E+03	55.00	119.00	0.17	0.00	154.35	0.00	0.20	1299.01	26.67	2.49	575.26	0.36	0.17	0.70	8.81	2.73
153	12	PASTChromic .300E+04	55.00	119.00	0.20	0.00	0.00	0.00	0.20	1299.01	27.61	3.08	526.83	0.01	0.07	0.01	1.48	0.00
154	12	PASTdystric .531E+03	55.00	124.00	3.27	0.00	0.00	0.00	0.20	1299.01	38.98	718.75	440.51	0.20	2.51	0.92	2.42	0.00
155	12	PASTdystric .357E+03	55.00	124.00	2.24	0.00	0.00	0.00	0.20	1299.01	86.54	422.21	465.99	0.30	1.58	1.37	2.36	0.00
156	12	PASTEutric f.233E+04	55.00	88.42	0.29	0.00	0.00	0.00	0.20	1299.01	41.88	0.78	466.68	0.01	0.09	0.05	2.09	0.00
157	12	PASTEutric f.433E+03	55.00	88.42	1.47	0.00	0.00	0.00	0.20	1299.01	41.68	6.51	466.60	0.09	0.12	0.35	2.09	0.00
158	13	PASTChromic .610E+03	55.00	279.00	1.20	0.00	0.00	0.00	0.20	1299.01	78.15	11.65	504.13	0.15	0.23	0.70	3.33	0.00
159	13	PASTChromic .203E+04	55.00	279.00	0.46	0.00	0.00	0.00	0.20	1299.01	78.96	3.38	504.33	0.05	0.20	0.23	3.33	0.00
160	13	PASTEutric f.392E+04	55.00	88.42	0.21	0.00	0.00	0.00	0.20	1299.01	41.76	0.57	470.42	0.01	0.09	0.03	2.09	0.00
161	13	PASTLeptosol.518E+03	55.00	279.00	0.54	0.00	0.00	0.00	0.20	1299.01	78.92	3.83	504.32	0.06	0.20	0.31	3.33	0.00
162	13	PASTLeptosol.859E+03	55.00	279.00	1.73	0.00	0.00	0.00	0.20	1299.01	77.83	14.83	504.05	0.21	0.24	0.99	3.33	0.00
163	13	PASTLeptosol.581E+03	55.00	279.00	3.23	0.00	0.00	0.00	0.20	1299.01	58.09	246.47	496.12	0.31	1.05	1.43	3.36	0.00

FigureA1 Lower Omo Gibe Basin Runoff Map (runoff in mm) extracted from HRU areas.

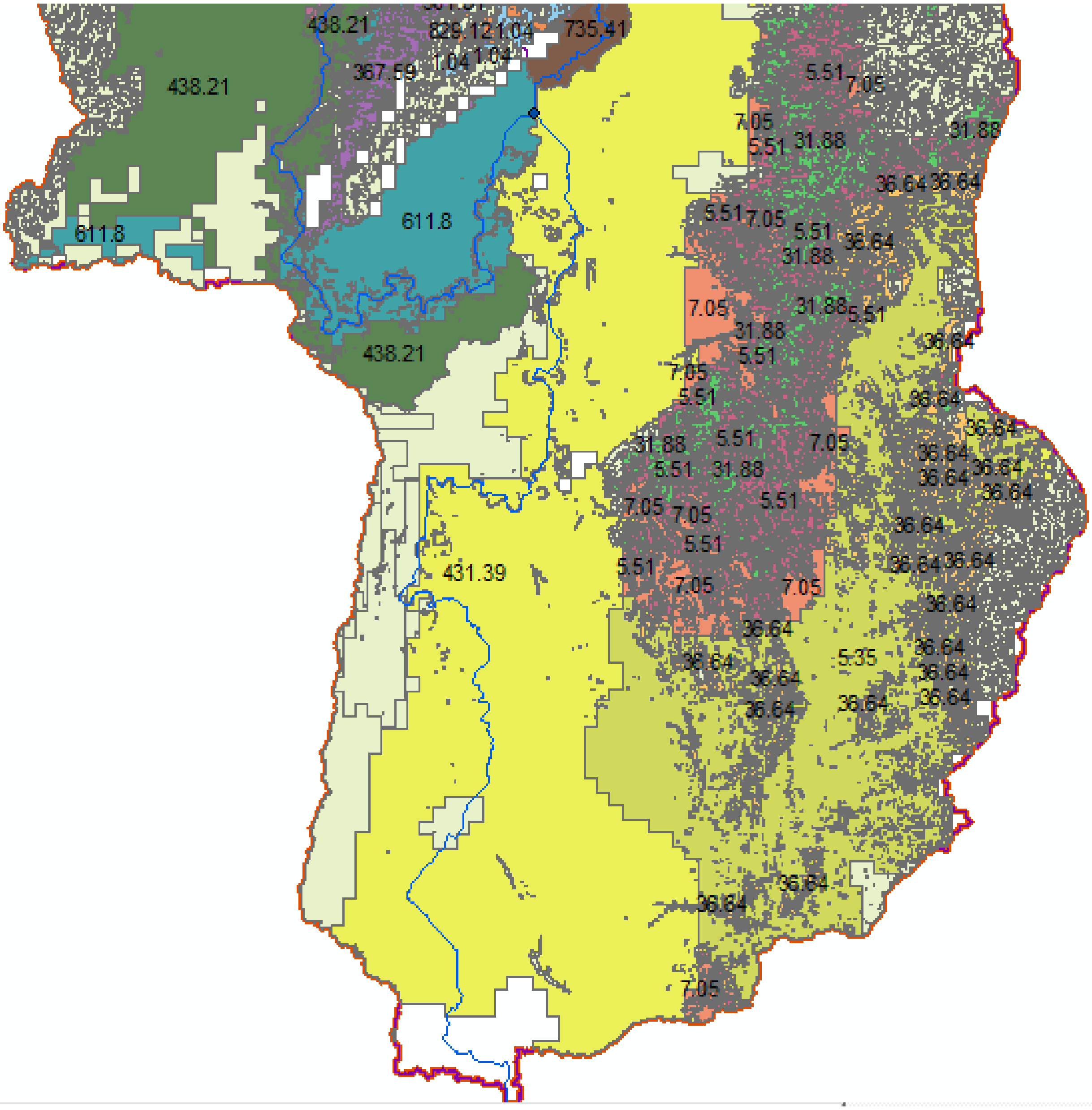


Figure A2 Runoff from each 163 HRU areas in Omo Gibe river basin

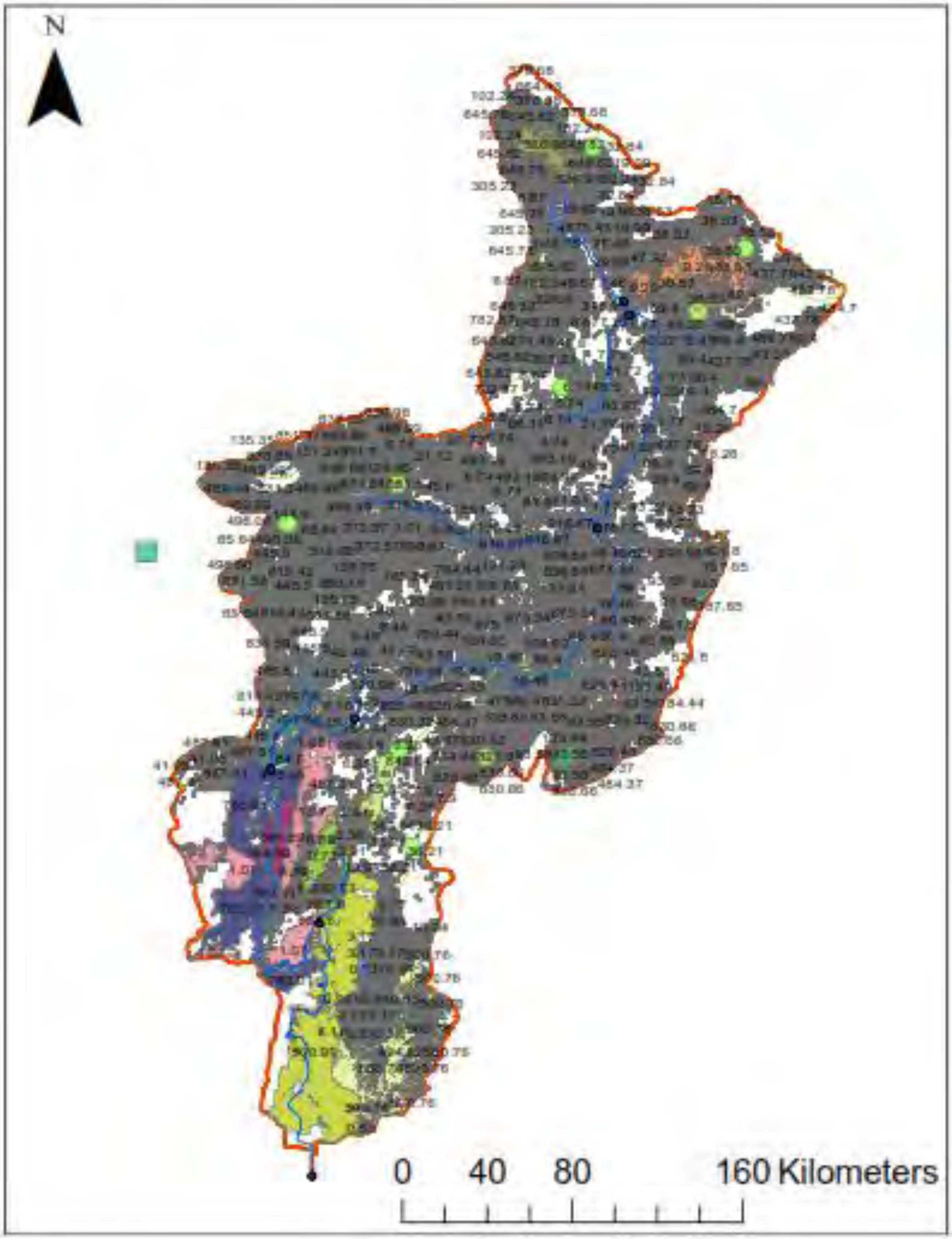


Figure A3 Sub-basin runoff contribution in Omo Gibe River basin

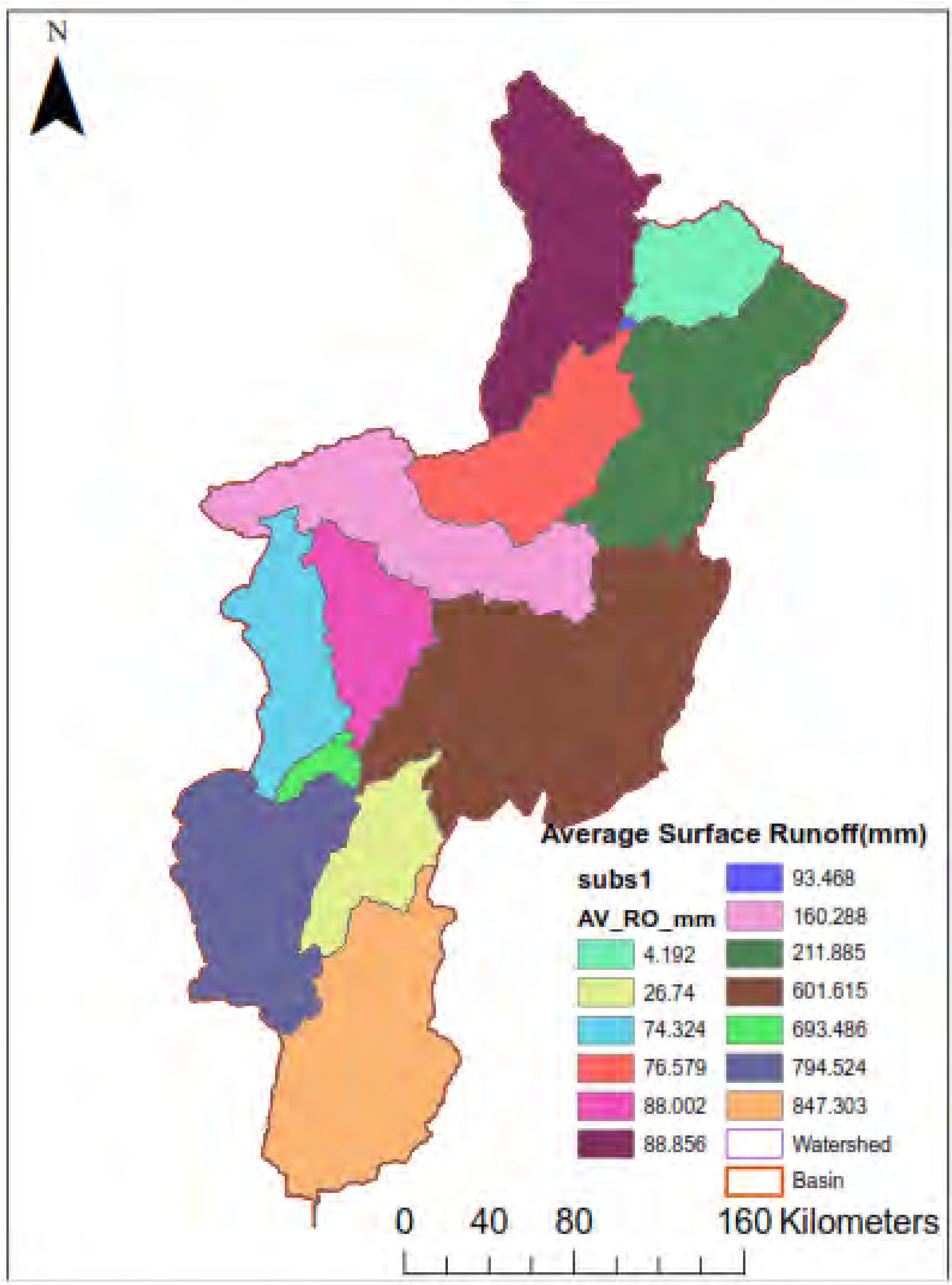
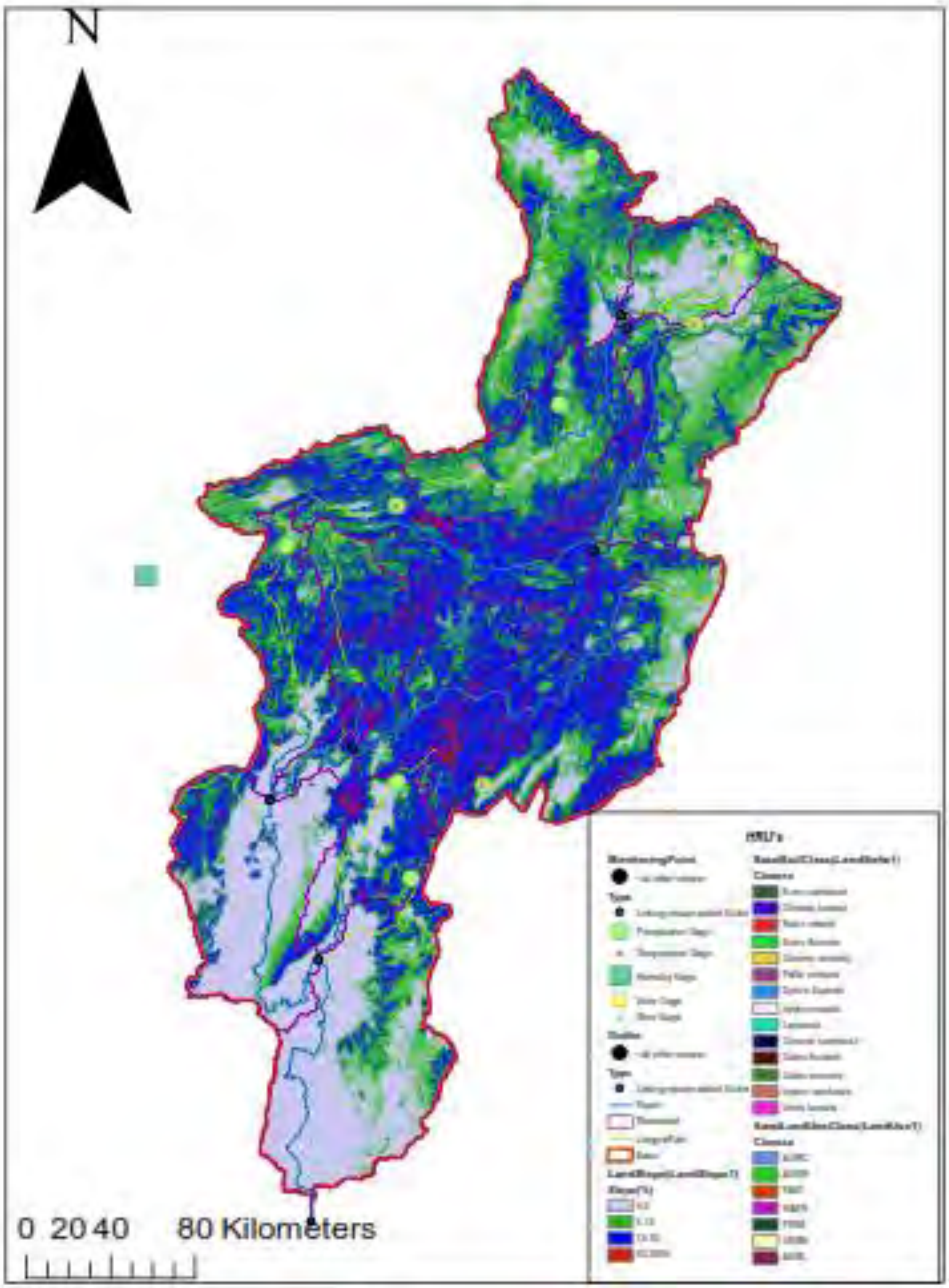


Figure A5 Hydrologic Response Unit Areas created in Arc GIS SWAT extension



APPENDEX B

WEAP Data Expression Report and additional results

```
WEAP Data Expressions Report

Area: omo
Current Accounts
Date: 5/14/2015


Key Assumptions
  Population Grouth rate          (%)                                    2.9
  Unit irrigation requirment      (m^3)                                  3423
  Irrigation Efficency            (%)                                    55
  Environmental flow
  Irrigation potential            (ha)                                   253843
  Irrigation projection
Demand Sites and Catchments
  Bako                            Land Use         Area (ha)                                 1933
                                                      Crops
CropLibrary("Seseame (Arid Region. Afica)", Jan 10, "Sorghum (Arid Region)", Sep 1)
                                                      Soil Water Capacity (%)
SoilProperties(51, 32, 20, 0)

                                   Climate
Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA 2.csv, 24, 1990)
                                                      ETref (mm)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 2, 1990)
                                                      Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 4, 1990, , , Replace)
                                                      Wind (m/s)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 3, 1990)
                                                      Sunshine Hours (hr)                12
                                   Irrigation          Irrigation Schedule
Irrigation Schedule (1, Jan 10, Jul 18, % of RAW, 100, % Depletion, 100)
                                                      Irrigation Efficiency (%)          55
                                                      Loss to Groundwater (%)            10
                                                      Loss to Runoff (%)                 35
                                   Advanced           Method                             MABIA
(FAO 56, dual KC, daily)

  Tunjo                            Land Use         Area (ha)                                 1400
                                                      Crops
CropLibrary("Seseame (Arid Region. Afica)", Jan 15, "Sorghum (Arid Region)", Sep 2)
                                                      Soil Water Capacity (%)
SoilProperties(45, 31, 18, 0)
                                   Climate              Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 19, 1990)
                                                      ETref (mm)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 2, 1990)
                                                      Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 4, 1990, , , Replace)
                                                      Wind (m/s)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 3, 1990)
                                                      Sunshine Hours (hr)                10
                                   Irrigation         Irrigation Schedule
IrrigationSchedule(1, Jan 15, Jul 23, % of RAW, 100, % Depletion, 100)
                                                      Irrigation Efficiency (%)          55
                                                      Loss to Groundwater (%)            10
                                                      Loss to Runoff (%)                 35
                                   Advanced           Method                             MABIA
(FAO 56, dual KC, daily)

  Kulti Darge                      Land Use         Area (ha)                                 1600
                                                      Crops
CropLibrary("Seseame (Arid Region. Afica)", Jan 1, "Beans (green) (Calif., Egypt, Lebanon)", Sep 15)
                                                      Soil Water Capacity (%)
SoilProperties(49, 35, 15, 0)
```

```
                                  Climate            Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 20, 1990, , , Replace)
                                                     ETref (mm)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 2, 1990)
                                                     Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 4, 1990, , , Replace)
                                                     Wind (m/s)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 3, 1990)
                                                     Sunshine Hours (hr)            10
                                  Irrigation           Irrigation Schedule
IrrigationSchedule(1, Jan 1, Jul 9, % of RAW, 100, % Depletion, 100)
                                                     Irrigation Efficiency (%)      55
                                                     Loss to Groundwater (%)        10
                                                     Loss to Runoff (%)             35
                                  Advanced           Method                         MABIA
(FAO 56, dual KC, daily)
 Walga                             Land Use        Area (ha)                      5300
                                                     Crops
CropLibrary("Maize (grain) (East Africa (alt.))", Apr 15)
                                                     Soil Water Capacity (%)
SoilProperties(45, 35, 25, 0)
                                  Climate            Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 5, 1990)
                                                     ETref (mm)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 2, 1990)
                                                     Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 4, 1990, , , Replace)
                                                     Wind (m/s)
ReadFromFile(E:\WEAP DATA\Midel basin.csv, 3, 1990)
                                                     Sunshine Hours (hr)            10
                                  Irrigation           Irrigation Schedule
IrrigationSchedule(1, Apr 15, Oct 11, % of RAW, 100, % Depletion, 100)
                                                     Irrigation Efficiency (%)      55
                                                     Loss to Groundwater (%)        10
                                                     Loss to Runoff (%)             35
                                  Advanced           Method                         MABIA
(FAO 56, dual KC, daily)

 Dana Plain                         Land Use       Area (ha)                      900
                                                     Crops
CropLibrary("Seseame (Arid Region. Afica)", Jan 1, "Barley/Oats/Wheat (East Africa)", Jul 31)
                                                     Soil Water Capacity (%)
SoilProperties(54, 25, 15, 0)
                                  Climate            Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 15, 1990)
                                                     ETref (mm)
ReadFromFile(E:\WEAP DATA\Midel basin.csv, 2, 1990)
                                                     Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 4, 1990, , , Replace)
                                                     Wind (m/s)
ReadFromFile(E:\WEAP DATA\Midel basin.csv, 3, 1990)
                                                     Sunshine Hours (hr)            10
                                  Irrigation             Irrigation Schedule
IrrigationSchedule(1, Jan 1, Jul 9, % of RAW, 100, % Depletion, 100)
                                                     Irrigation Efficiency (%)      55
                                                     Loss to Groundwater (%)        10
                                                     Loss to Runoff (%)             35
                                  Advanced           Method                         MABIA
(FAO 56, dual KC, daily)

 Gura Usno                         Land Use         Area (ha)                      710
                                                     Crops
CropLibrary("Beans (green) (Calif., Egypt, Lebanon)", Aug 1, "Cotton (East Africa)", Dec 15)
                                                     Soil Water Capacity (%)
SoilProperties(56, 36, 14, 0)
                                  Climate             Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 10, 1990)
                                                     ETref (mm)
ReadFromFile(E:\WEAP DATA\Midel basin.csv, 2, 1990)
                                                     Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 4, 1990, , , Replace)
```

```
                                      Wind (m/s)
ReadFromFile(E:\WEAP DATA\Upper basinn.csv, 3, 1990)
                                      Sunshine Hours (hr)                 10
                  Irrigation            Irrigation Schedule
IrrigationSchedule(1, Aug 1, Oct 14, % of RAW, 100, % Depletion, 100)
                                      Irrigation Efficiency (%)           55
                                      Loss to Groundwater (%)             10
                                      Loss to Runoff (%)                  35
                  Advanced            Method                              MABIA
(FAO 56, dual KC, daily)
 KURAZ B1         Land Use          Area (ha)                          75000
                                      Crops
CropLibrary("Beans (green) (Calif., Egypt, Lebanon)", Aug 1, "Sugarcan (East Africa. Desert,)", Nov
1)
                                      Soil Water Capacity (%)
SoilProperties(55, 35, 15, 0)
                  Climate              Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 23, 1990)
                                      ETref (mm)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 2, 1990)
                                      Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 4, 1990)
                                      Wind (m/s)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 3, 1990)
                                      Sunshine Hours (hr)                 10
                  Irrigation            Irrigation Schedule
IrrigationSchedule(1, Aug 1, Oct 14, % of RAW, 100, % Depletion, 100)
                                      Irrigation Efficiency (%)           55
                                      Loss to Groundwater (%)             10
                                      Loss to Runoff (%)                  35
                  Advanced            Method                              MABIA
(FAO 56, dual KC, daily)
 KURAZ B2         Land Use          Area (ha)                          50000
                                      Crops
CropLibrary("Sugarcan (East Africa. Desert,)", Jan 3, "Beans (green) (Calif., Egypt, Lebanon)", Sep
20)
                                      Soil Water Capacity (%)
SoilProperties(45, 25, 10, 0)
                  Climate              Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 1, 1990, , , Replace)
                                      ETref (mm)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 2, 1990)
                                      Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 4, 1990)
                                      Wind (m/s)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 3, 1990)
                                      Sunshine Hours (hr)                 10
                  Irrigation            Irrigation Schedule
IrrigationSchedule(1, Jan 3, Sep 14, % of RAW, 100, % Depletion, 100)
                                      Irrigation Efficiency (%)           55
                                      Loss to Groundwater (%)             10
                                      Loss to Runoff (%)                  35
                  Advanced            Method                              MABIA
(FAO 56, dual KC, daily)
 KURAZ B3         Land Use          Area (ha)                          50000
                                      Crops
CropLibrary("Cotton (Yemen)", Sep 1)
                                      Soil Water Capacity (%)
SoilProperties(49, 31, 14, 0)
                  Climate              Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 1, 1990, , , Replace)
                                      ETref (mm)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 2, 1990)
                                      Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 4, 1990)
                                      Wind (m/s)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 3, 1990)
                                      Sunshine Hours (hr)                 10
                  Irrigation            Irrigation Schedule
IrrigationSchedule(1, Sep 1, Mar 14, % of RAW, 100, % Depletion, 100)
                                      Irrigation Efficiency (%)           55
```

```
                                                        Loss to Groundwater (%)              10
                                                        Loss to Runoff (%)                   35
                                   Advanced             Method                               MABIA
(FAO 56, dual KC, daily)
  Lower Omo                        Land Use          Area (ha)                            67000
                                                        Crops
CropLibrary("Maize (sweet) (Calif. Desert, USA)", Jan 10, "Sorghum (Arid Region)", Sep 1)
                                                        Soil Water Capacity (%)
SoilProperties(41, 35, 21, 0)
                                   Climate                Precipitation (mm)
ReadFromFile(C:\Users\User\Desktop\WEAP DATA.csv, 1, 1990, , , Replace)
                                                        ETref (mm)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 2, 1990)
                                                        Min Humidity (%)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 4, 1990)
                                                        Wind (m/s)
ReadFromFile(E:\WEAP DATA\Lower Basin.csv, 3, 1990)
                                                        Sunshine Hours (hr)                  10
                                   Irrigation             Irrigation Schedule
IrrigationSchedule(1, Jan 10, May 29, % of RAW, 100, % Depletion, 100)
                                                        Irrigation Efficiency (%)            55
                                                        Loss to Groundwater (%)              10
                                                        Loss to Runoff (%)                   35
                                   Advanced             Method                               MABIA
(FAO 56, dual KC, daily)
  Urban                            Water Use      Annual Activity Level (cap)          9567123
                                                  Annual Water Use Rate (m^3/cap)        14.6
                                   Advanced       Method                                 Specify
yearly demand and monthly variation
  Rural                            Water Use      Annual Activity Level (cap)            13956345
                                                  Annual Water Use Rate (m^3/cap)        5.475
                                   Advanced       Method                                 Specify
yearly demand and monthly variation
  Livestoc                         Water Use      Annual Activity Level (cap)            29567890
                                                  Annual Water Use Rate (m^3/cap)        1.093
                                   Advanced       Method                                 Specify
yearly demand and monthly variation
Hydrology
    Water Year Method                Current Accounts                        Normal
    Read from File                   Read from File                          Not Specified
Supply and Resources
  River
    Omo River                        Inflows and Outflows Headflow (CMS)
MonthlyValues( Jan, 137.14,  Feb, 110.55,  Mar, 165.01,  Apr, 183.62,  May, 390.38,  Jun, 428.95,
Jul, 930.38,  Aug, 1494.62,  Sep, 1268.03,  Oct, 733.11,  Nov, 353.39,  Dec, 148.59 )
                                     Water Quality       Model Water Quality?                    No
      Flow Requirements
        EV FLOW
      Reaches
        Below Omo River Headflow
        Below Gibe River Inflow
        Below Withdrawal Node 7
        Below Catchment Inflow Node 6
        Below Withdrawal Node 8
        Below Catchment Inflow Node 7
        Below Withdrawal Node 9
        Below Catchment Inflow Node 8
        Below Withdrawal Node 10
        Below Catchment Inflow Node 9
        Below EV FLOW
    Gibe River                       Inflows and Outflows Headflow (CMS)                          ;
Inflow from Catchment Bako (values not shown in Data View)
                                     Water Quality       Model Water Quality?                    No
      Flow Requirements
        E Flow
      Reaches
        Below Gibe River Headflow
        Below Withdrawal Node 1
        Below Catchment Inflow Node 10
        Below Withdrawal Node 2
        Below Catchment Inflow Node 1
        Below Withdrawal Node 3
```

```
      to AG 3
    from Lower Omo
      to Catchment Inflow Node 9
      to AG4
Water Quality
  Pollutant Decrease in Return Flows
    from Bako
      to GW A
      to Catchment Inflow Node 10
    from Tunjo
      to GW A
      to Catchment Inflow Node 1
    from Kulti Darge
      to Catchment Inflow Node 2
      to GW A
    from Walga
      to Catchment Inflow Node 3
      to GW A
    from Dana Plain
      to Catchment Inflow Node 4
      to AG 2
    from Gura Usno
      to Catchment Inflow Node 5
      to AG 3
    from KURAZ B1
      to Catchment Inflow Node 6
      to AG 3
    from KURAZ B2
      to Catchment Inflow Node 7
      to AG 3
    from KURAZ B3
      to Catchment Inflow Node 8
      to AG 3
    from Lower Omo
      to Catchment Inflow Node 9
      to AG4
Other Assumptions
```

Figure B61 Additional WEAP Results

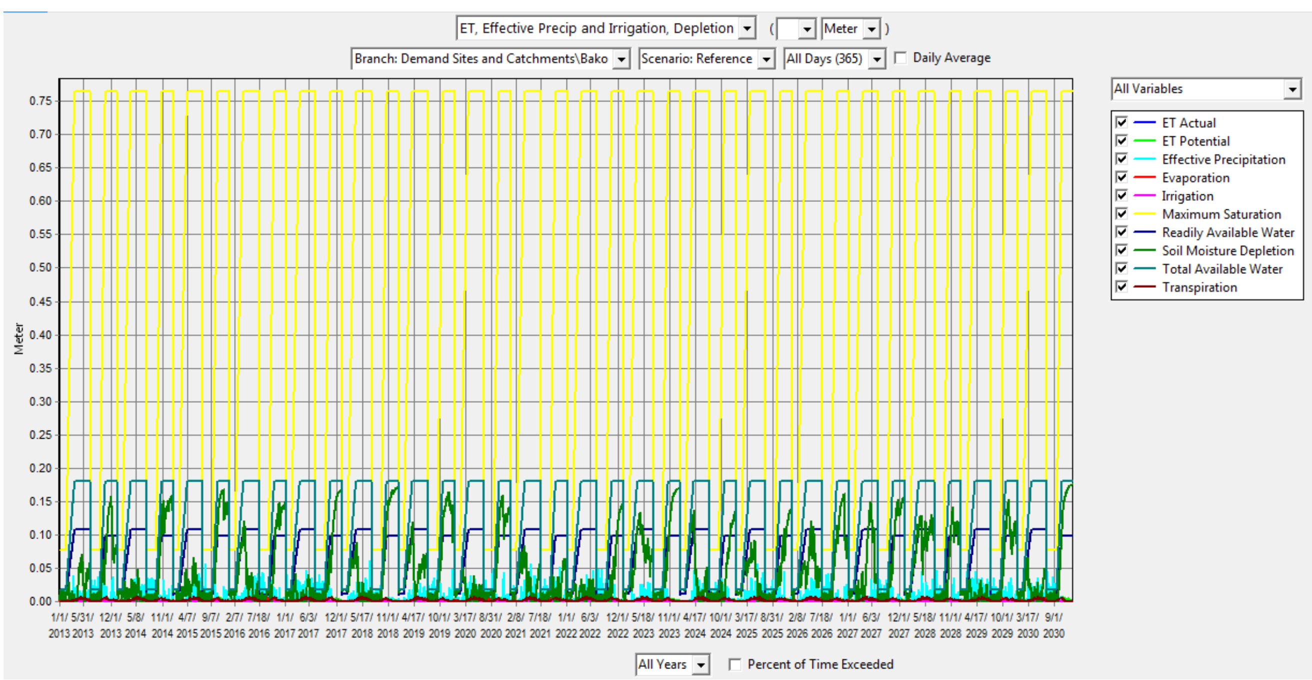


Figure B62 Effective precipitation Used

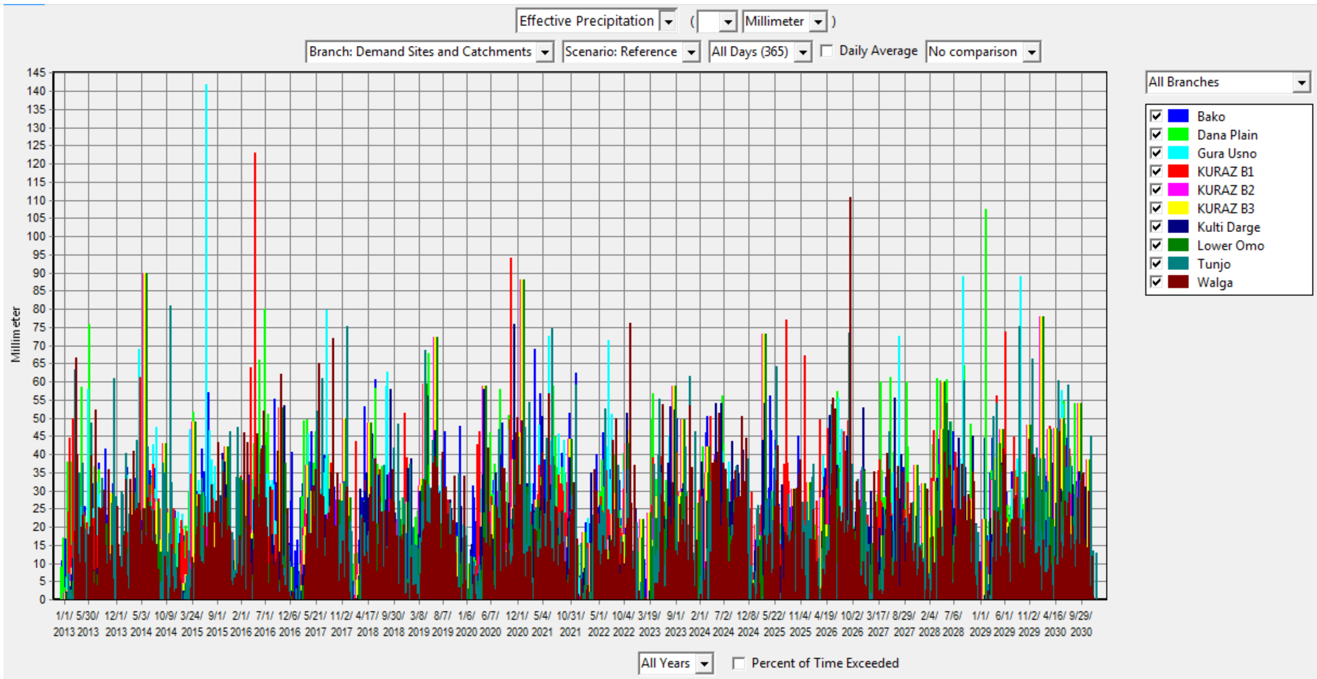


Figure B63 Evaporation result in Omo Gibe River Basin

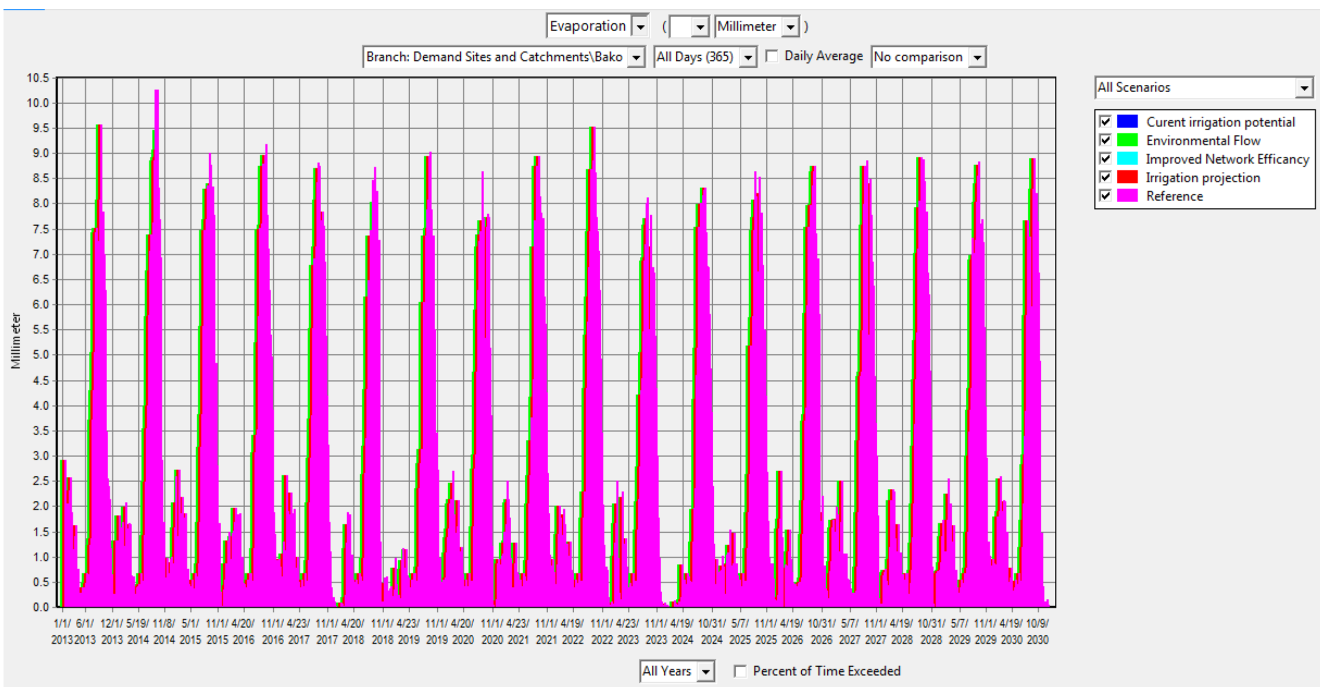


Figure B64 Demand site Reliability for water

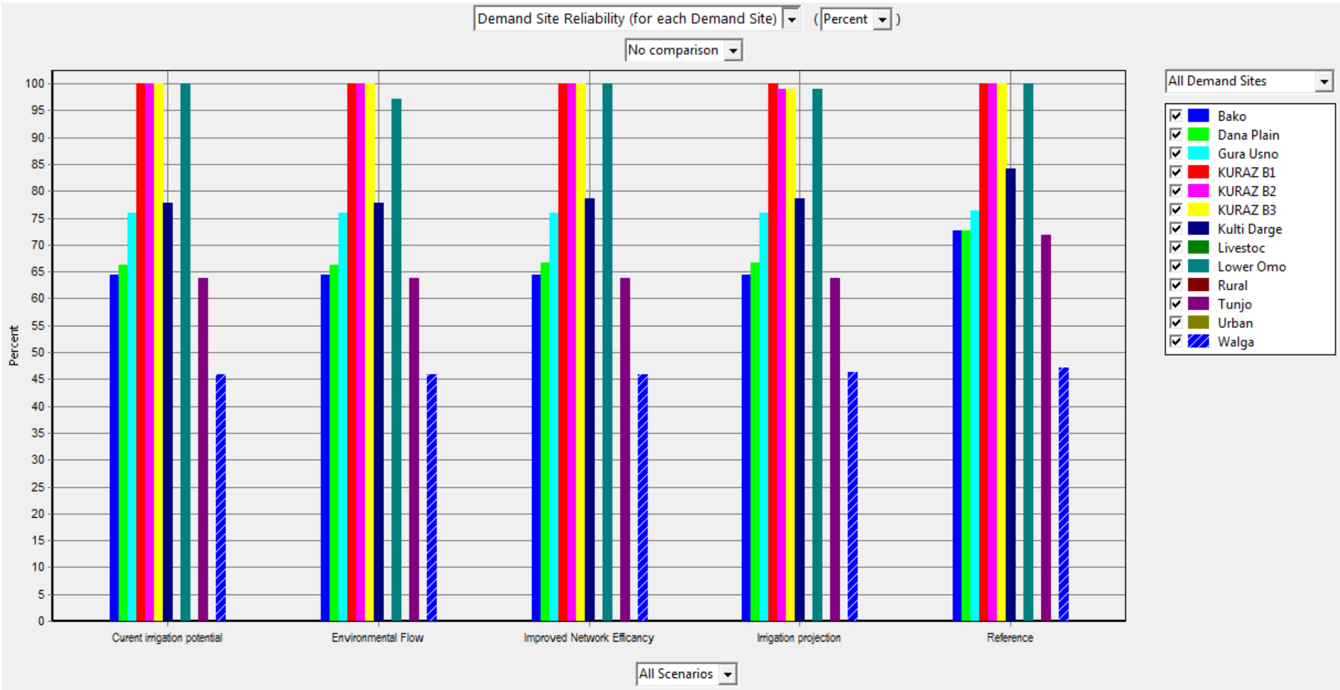


Figure B65 All scenario effect on water demand

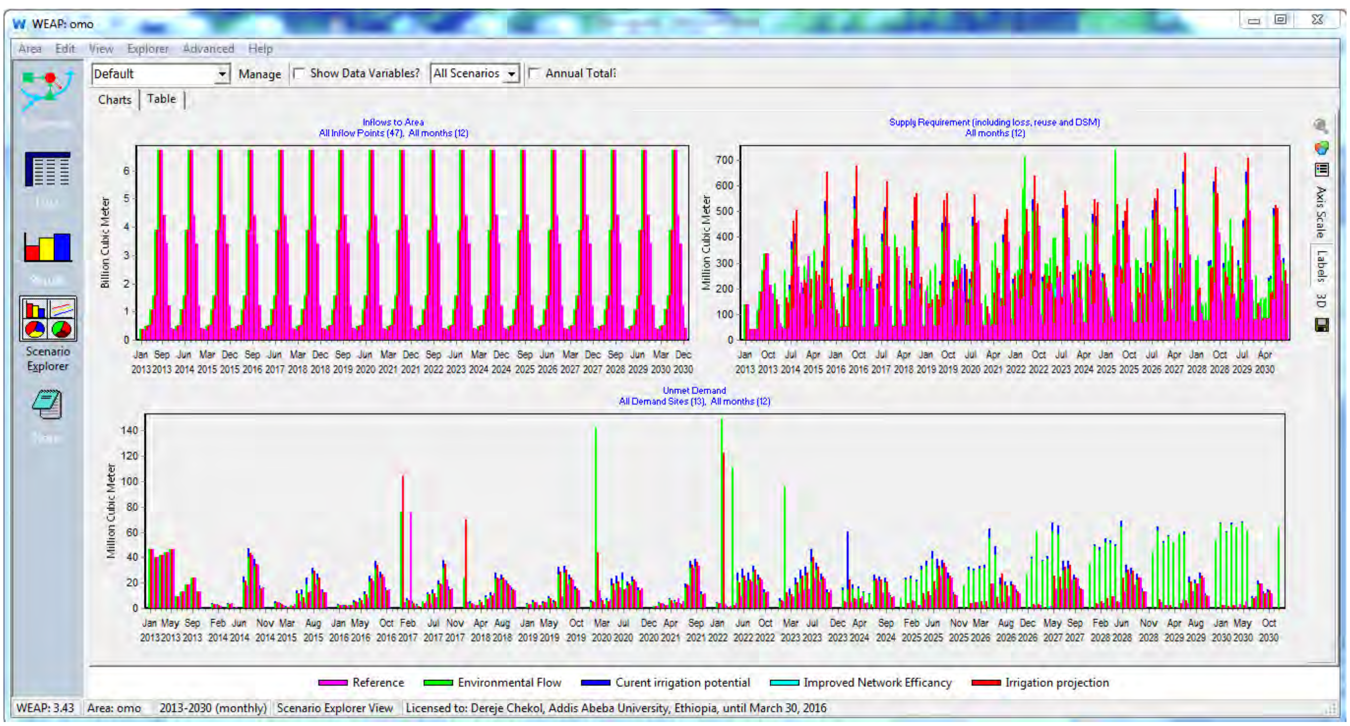


Figure B66 Reference Scenario effect

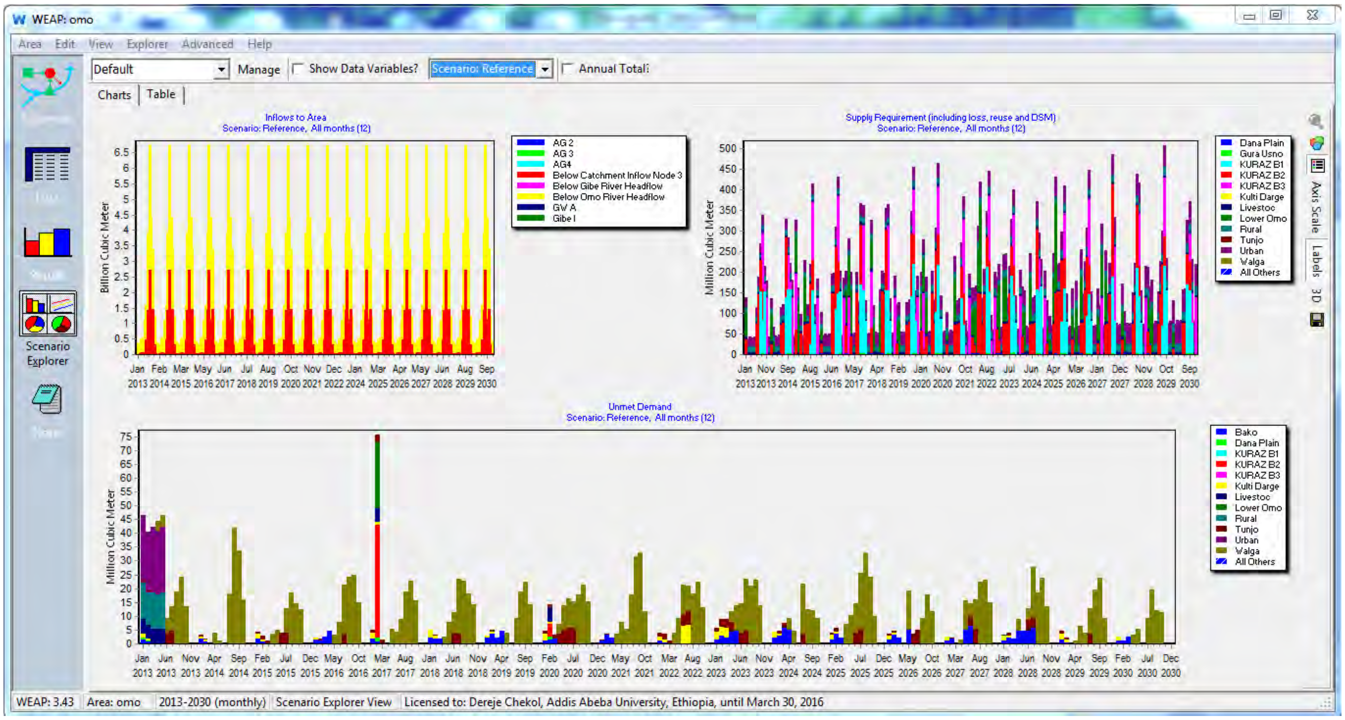
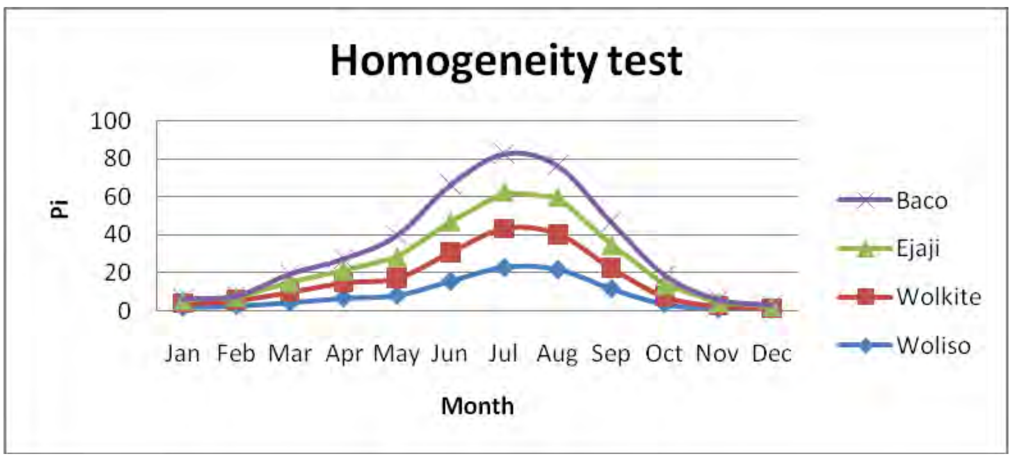
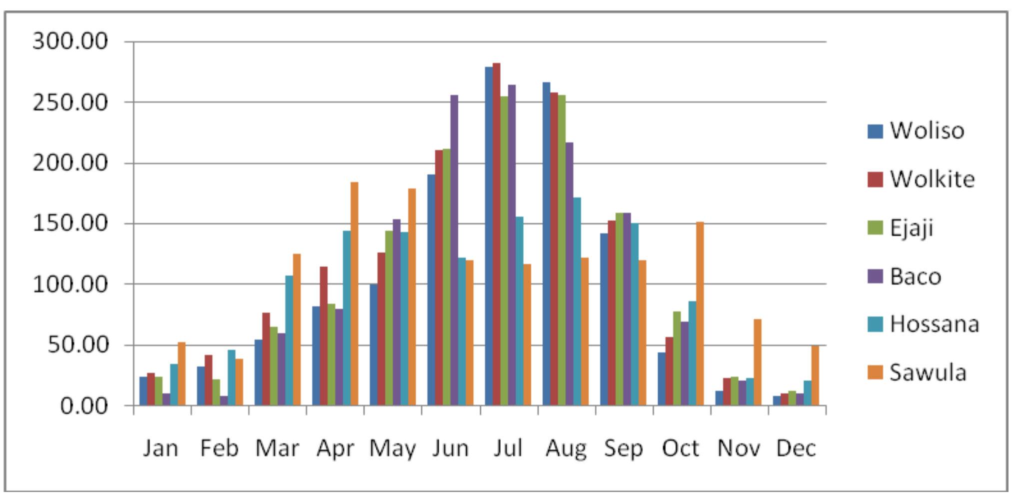


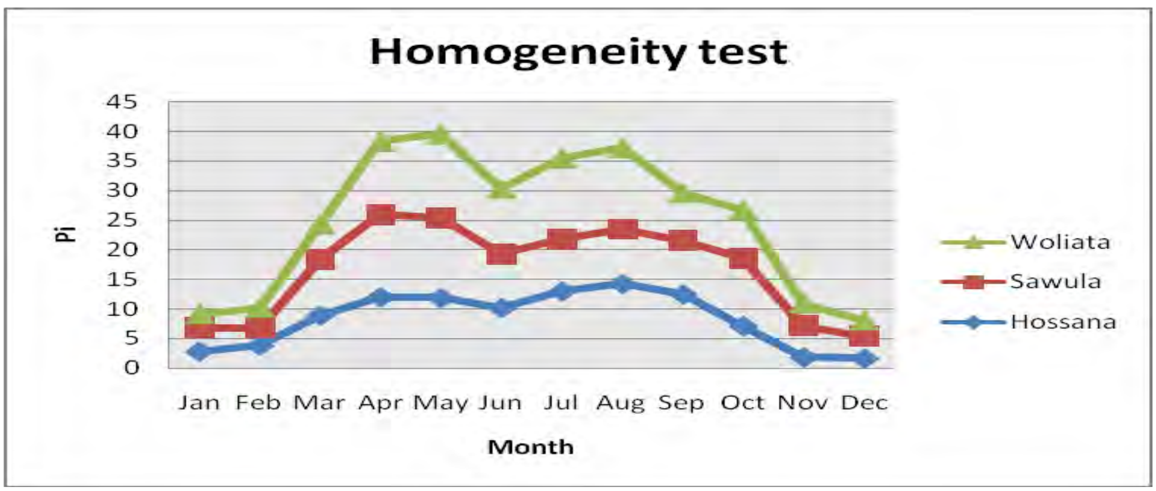
Table B1 Homogeneity test on Metrological stations(precipitation).

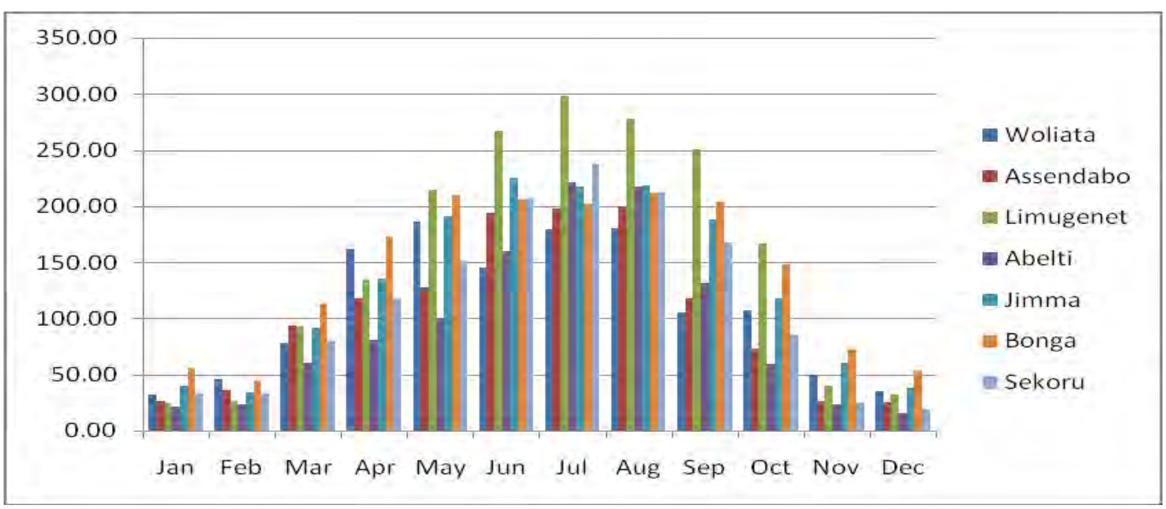
	Woliso			Wolkite			Ejaji			Baco		
	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi
Jan	22.74	1227.63	2	26.17	1374.56	2	22.98	1326.78	2	10.01	1302.16	1
Feb	31.92	1227.63	3	41.54	1374.56	3	20.67	1326.78	2	7.23	1302.16	1
Mar	53.83	1227.63	4	76.11	1374.56	6	64.81	1326.78	5	59.67	1302.16	5
Apr	81.28	1227.63	7	113.90	1374.56	8	83.24	1326.78	6	79.71	1302.16	6
May	99.22	1227.63	8	125.63	1374.56	9	143.53	1326.78	11	152.68	1302.16	12
Jun	190.47	1227.63	16	210.73	1374.56	15	211.08	1326.78	16	255.43	1302.16	20
Jul	279.02	1227.63	23	282.16	1374.56	21	254.64	1326.78	19	263.87	1302.16	20
Aug	266.33	1227.63	22	258.24	1374.56	19	255.29	1326.78	19	217.07	1302.16	17
Sep	141.25	1227.63	12	151.90	1374.56	11	158.33	1326.78	12	158.72	1302.16	12
Oct	42.96	1227.63	3	56.33	1374.56	4	76.91	1326.78	6	69.00	1302.16	5
Nov	11.27	1227.63	1	22.55	1374.56	2	23.67	1326.78	2	19.58	1302.16	2
Dec	7.35	1227.63	1	9.29	1374.56	1	11.64	1326.78	1	9.65	1302.16	1



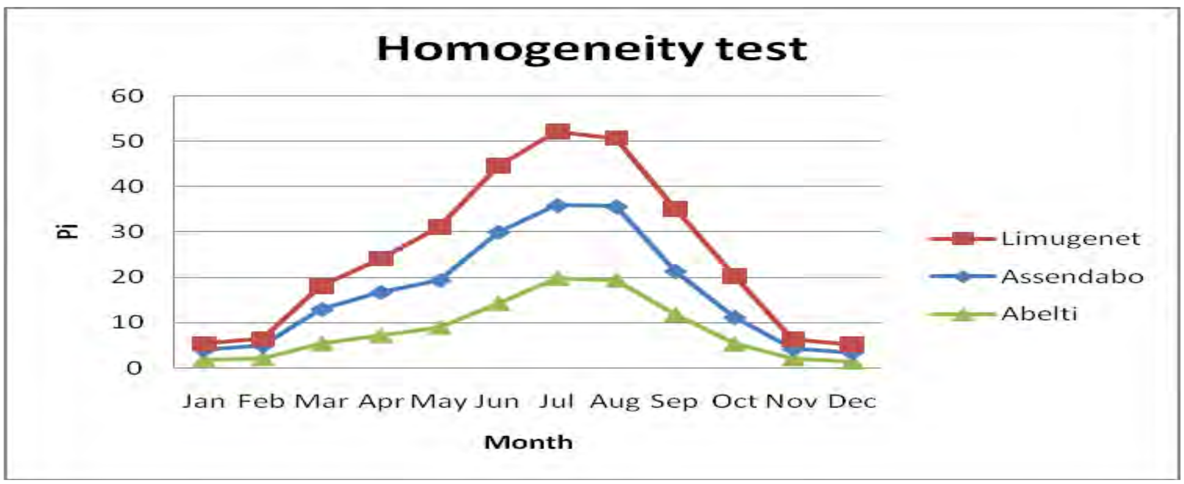


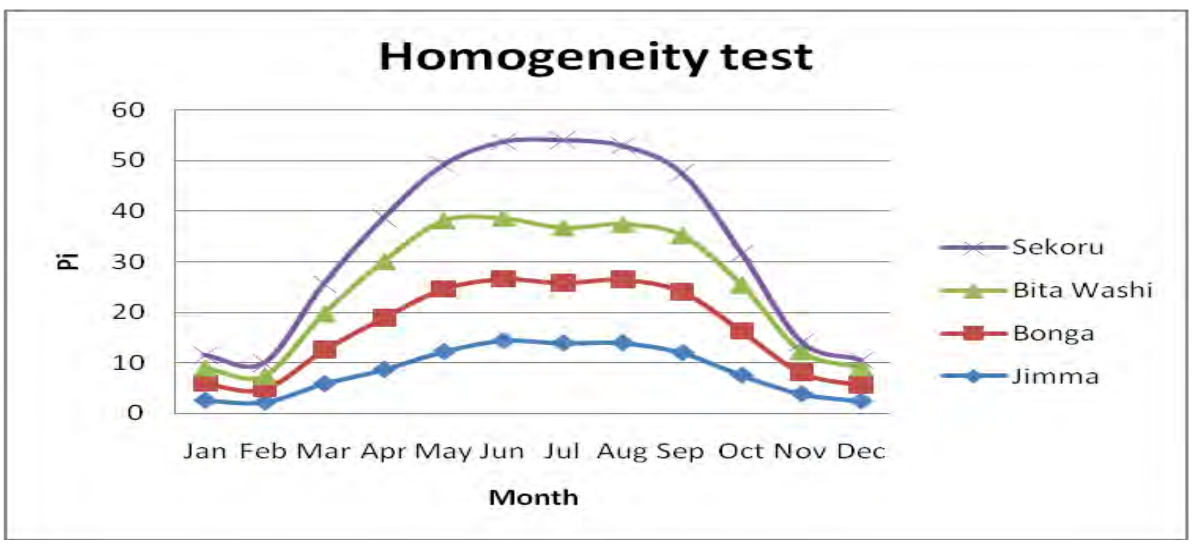
	Hossana Av Monthly RF	Av Annual Rf	Pi	Sawula Av Monthly RF	Av Annual Rf	Pi	Woliata Av Monthly RF	Av Annual Rf	Pi
Jan	33.65	1198.27	3	51.77	1323.507	4	32.06	1305.023	2
Feb	45.92	1198.27	4	38.09	1323.507	3	45.68	1305.023	4
Mar	106.97	1198.27	9	124.96	1323.507	9	77.63	1305.023	6
Apr	143.92	1198.27	12	183.99	1323.507	14	161.80	1305.023	12
May	142.32	1198.27	12	178.55	1323.507	13	185.77	1305.023	14
Jun	121.96	1198.27	10	119.88	1323.507	9	144.81	1305.023	11
Jul	155.80	1198.27	13	115.80	1323.507	9	179.23	1305.023	14
Aug	171.02	1198.27	14	121.56	1323.507	9	180.25	1305.023	14
Sep	149.71	1198.27	12	119.35	1323.507	9	105.72	1305.023	8
Oct	85.38	1198.27	7	150.66	1323.507	11	107.11	1305.023	8
Nov	21.89	1198.27	2	70.43	1323.507	5	49.52	1305.023	4
Dec	19.74	1198.27	2	48.47	1323.507	4	35.44	1305.023	3





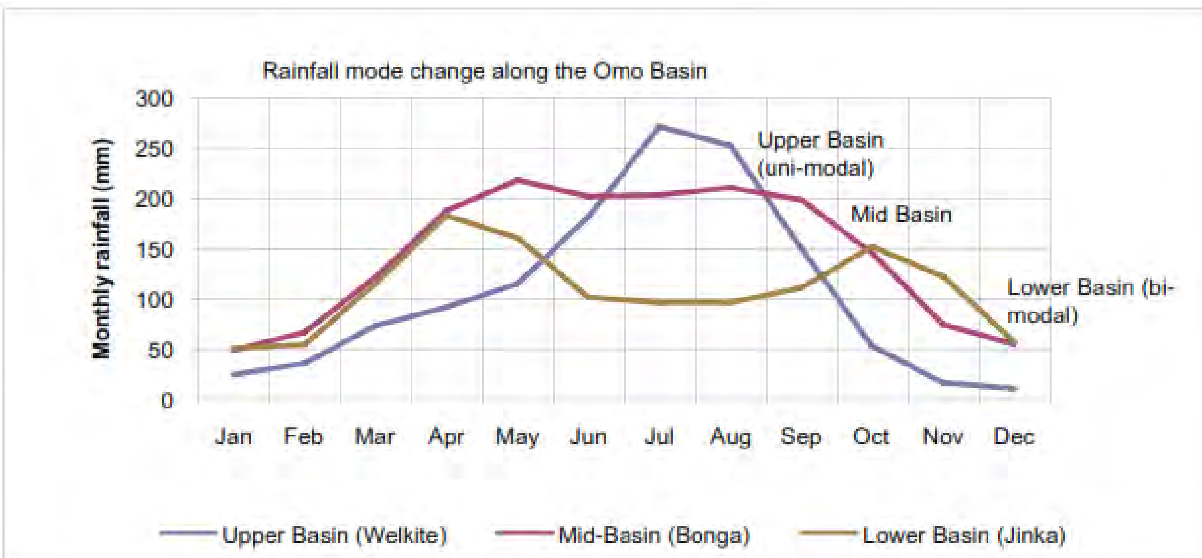
	Assendabo			Limugenet			Abelti		
	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi
Jan	26.45	1236.14	2	24.55	1825.51	1	21.11	1113.754	2
Feb	35.61	1236.14	3	26.54	1825.51	1	23.22	1113.754	2
Mar	93.43	1236.14	8	92.85	1825.51	5	60.37	1113.754	5
Apr	117.66	1236.14	10	134.71	1825.51	7	80.65	1113.754	7
May	127.96	1236.14	10	214.49	1825.51	12	100.51	1113.754	9
Jun	194.27	1236.14	16	267.20	1825.51	15	159.71	1113.754	14
Jul	197.95	1236.14	16	298.76	1825.51	16	221.65	1113.754	20
Aug	199.61	1236.14	16	277.43	1825.51	15	216.95	1113.754	19
Sep	118.39	1236.14	10	250.91	1825.51	14	131.82	1113.754	12
Oct	72.81	1236.14	6	166.54	1825.51	9	59.41	1113.754	5
Nov	26.42	1236.14	2	39.53	1825.51	2	23.21	1113.754	2
Dec	25.59	1236.14	2	32.00	1825.51	2	15.12	1113.754	1





	Jimma			Bonga			Bita washi			Sekoru		
	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi	Av Monthly RF	Av Annual Rf	Pi
Jan	40.30	1559.64	3	56.04	1692.37	3	54.19	1693.42	3	33.30	1369.967	2
Feb	34.45	1559.64	2	44.87	1692.37	3	45.15	1693.42	3	33.37	1369.967	2
Mar	91.75	1559.64	6	112.65	1692.37	7	122.88	1693.42	7	79.94	1369.967	6
Apr	135.40	1559.64	9	173.04	1692.37	10	189.86	1693.42	11	117.64	1369.967	9
May	191.20	1559.64	12	209.68	1692.37	12	229.00	1693.42	14	150.97	1369.967	11
Jun	225.66	1559.64	14	205.64	1692.37	12	204.57	1693.42	12	206.83	1369.967	15
Jul	217.84	1559.64	14	201.41	1692.37	12	185.06	1693.42	11	237.54	1369.967	17
Aug	218.53	1559.64	14	211.56	1692.37	13	185.84	1693.42	11	212.63	1369.967	16
Sep	188.00	1559.64	12	203.90	1692.37	12	189.35	1693.42	11	168.13	1369.967	12
Oct	118.25	1559.64	8	147.91	1692.37	9	155.75	1693.42	9	85.39	1369.967	6
Nov	60.18	1559.64	4	72.19	1692.37	4	71.74	1693.42	4	24.90	1369.967	2
Dec	38.09	1559.64	2	53.48	1692.37	3	60.02	1693.42	4	19.34	1369.967	1

Table B2 Rainfall Mode change along the basin



Daily calibration test at Rati