JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

HYDRAULIC AND WATER RESOURCES ENGINEERING DEPARTMENT

HYDRAULIC ENGINEERING MASTER'S PROGRAM

SIMULATION AND OPTIMIZATION FOR OPERATION OF KOKA RESERVOIR

This Research submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of Requirements for the Degree of Masters of Science in Hydraulic Engineering

By

Natan Kefyalew

November, 2017

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Main advisor: Dr. Ing. Kassa Tadele

Co-advisor: Mr. Megersa Kebede, (MSc.)

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Co- Advisor	Signature	Date

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My deepest gratitude also extends to my parents without them everything had been nothing. I also thankful to my friends: Surafel Alebel, Robel Fissha, Yishak Abrham and Miliyon Bekele whose unfailing support was an important factor, during time of pressure.

ABSTRACT

Reservoirs are constructed and operated for multiple purposes and the application of simulation models are efficiently analyze these multi-purpose reservoir's operations. In Ethiopia the optimization of hydropower potential is the first problem that face the existing hydropower plants; due to poor reservoir operation policy, which leads to unwise use of available water. Unlike most other reservoir; low operating policy of Koka reservoir is critical and most common problem. The present research aims to satisfactorily simulate and optimize the operation of multipurpose reservoir of Koka hydro power plant using HEC-ResSim. The simulation approach indicates an improvement in the reservoir operation in terms of increasing storage volumes, and ensuring reliable releases.

HEC-ResSim is one of the simulation models that can simulate reservoirs these contribute a significant amount of water to the water resources system. This model search the space of possible design variable values and identify an optimal operating policy for a given system objective and set of constraints.

The input data used for the HEC-ResSim model; daily inflow, daily precipitation, water level and monthly reservoir surface evaporation and Koka dam and reservoir physical data. The Koka reservoir operation modeling has been done with inflow data of four stations of Akaki, Hombole, Melka kuntrie, and Mojo; within twenty years (1996 - 2015) time series data and the precipitation data at the reservoir surface (i.e Koka station) for twenty years (1996-2015).

In this study the optimal, maximum and minimum guide curve level is determined. The average optimal guide curve level is 107.88m, maximum guide curve level of 112.43m and minimum guide curve level is 100.4m. The maximum releases from Koka reservoir and net inflow to the reservoir; 5226.94m^3/s and 1968.07m^3/s respectively. The calibration and validation of simulated verses observed values of R^2=0.84 and 0.82 respectively and with Nash-Stucliffe model efficiency of 0.81 this value shows the model was correctly simulate the reservoir.

Key Word: HEC-ResSim, Reservoir, simulation

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ABBREVIATIONS

AVG	Average
CUM	Cumulative
DEM	Digital elevation model
DSS	Data storage system
EVA	Evaporation
GIS	Geographic information system
HEC	Hydrologic engineering center
HEC-ResSim	Hydrologic engineering center reservoir system simulation
Km^2	Kilometer square
M/S	Meter per second
CMS	Cubic meter per second
NMA	National meteorological agency
ResSim	Reservoir simulation model
SCS-CN	Soil conservation service-curve number
TMAX	Maximum temperature
TMEAN	Mean temperature
WWDSE	Water works design and supervision enterprise

1. INTRODUCTION

1.1. Background

Large manmade reservoir are constructed and operated for multiple purposes. Reservoir operation meet requirements for any needs, including flood control, power generation, recreational use of the reservoir pool, and structural stability of the dam. In a country like Ethiopia for improvement of standard of living, the development of power have vital importance; in addition to this Water resource planning and management involve the development, control, protection and beneficial use of surface and ground water resources (Tsegazeab.D, 2014).

Stream flow models are mathematical representations of a given watershed that plays significant role in water resource planning and management. From the scientist's and the researcher's perspective, the role of this models is to provide a better understanding of real world processes. From the water manager perspective, mathematical modeling is a way to generate quantitative information in support of decision making activities (Skoulikaris.C, 2008).

HEC-ResSim is specialized software to simulate water resources systems released in 2003 by the Hydrologic Engineering Center of the US Army Corps of Engineers. The software simulate reservoir operation for flood risk management, low flow augmentation, detailed reservoir regulation plan investigations, and real-time decision support (Joan D. Klipsch , Marilyn B. Hurst, 2013).

Reservoir operation is a complex problem that involves many decision variables, multiple objectives as well as considerable risk and uncertainty (Loucks, D.P. Stedinger, J.R. and Haith, D.A., 1981). In addition, the conflicting objectives lead to significant challenges for operation when making operational decisions. Reservoirs are often operated considering a number of conflicting objectives (such as different water uses) related to environmental, economic, and public services. The optimization of the reservoir operation system has attracted substantial attention over the past several decades. In many other countries, reservoir are operated according to reservoir operation rule curve which are established at the planning/design stage to provide long-term operation guidelines for reservoir management to meet expected water demands. Reservoir operation rule curve usually consists of a series of storage volume or levels at different periods.

In Ethiopia, the scarcity of energy become greater due to high rate of population growth and weak energy supply system. But not only energy shortage is the problem, the optimization of hydropower potentials is the first problem that face the existing hydropower structures.

Koka reservoir, one of the rift valley reservoir in the Awash River basin, was created for hydroelectric power generation in 1960 but later it has been also fulfilling different social and ecological needs. The original storage capacity of the reservoir at full capacity level of 1590.7m a.s.l. or 110.3m reduced level, was 1650Mm^3, and is found 81 kilometer south east of the Capital of Ethiopia, Addis Ababa. It has been for long supporting lives in the surrounding, including the Amude community (Sufiyan.A, 2014).

The reservoir has been used by different stakeholders with varying level of interest as well as degree of power to control this commonly shared resource. Some of the stakeholders are the local communities, Ethiopian Electric power (EEP), Ethiopian Environmental protection Authority (EEPA), Ministry of Trade and Industry (MoTI), and Non-Governmental Organizations (NGOs). There are about 15,000 local people who have been heavily relying on the reservoir as sources of water for drinking, animal watering, cleaning, fishing, traditional irrigation practices, etc. However, due to the present conditions of the reservoir poor operation policy, that leads to unwise use of available water.

1.2. Statement of the problem

Planning of reservoir management and optimal operations of reservoir water has always been a critical and strategic concern of all governments. The constructions of new dams have become one of the most controversial issues in this world to reduce poverty, improve human health, and strengthen regional economies. This is due to competitive potential constraints subjected on the operation of dams and reservoirs. Modifying the operations of existing dams are considered in the present modes of dam operation to meet the demands of all (for example the environmental and social benefits of healthy ecosystems, etc.) (Richter, B.D. & Thomas, G.A., 2007).

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In Ethiopia, the scarcity of energy become greater due to high rate of population growth and weak energy supply system. But not only energy shortage is the problem, the optimization of hydropower potentials is the first problem that face the existing hydropower plants; due to the present condition of the reservoir poor operation policy, which leads to unwise use of available water.

The Awash basin is the most intensively utilized basin in Ethiopia. Extensive irrigation and hydropower schemes have been functional for many years following the construction of the main Structure, Koka dam in 1960. Koka dam is one of the awash basin dam that face the reservoir optimization problem. Now the reservoir is constantly lost more than 30% of its water storage capacity (Sufiyan.A, 2014). Due to this continuing reduction in capacity, the water management of the reservoir is becoming exceedingly difficult.

1.3. Objective of the study

1.3.1 General objective

The main objective of this study is to satisfactorily simulate the operation of multipurpose reservoir of Koka hydropower plant for optimal use of water.

1.3.2 Specific objectives

- To calibrate and validate the data with digitized inputs and historical observed meteorological data.
- To construct and set up a reservoir simulation module for operation of Koka reservoir.
- To set a guide curve (operating curve) for operation of Koka reservoir.

1.4 Research questions

The research questions that this study will attempt to clarify; are as follows

1. What are the daily residual inflow and out flow from the reservoir?
2. How to improve the reservoir operation performance of Koka reservoir?
3. How construct a guide curve for operation of Koka reservoir?

1.5 Scope and limitations

The scope of the research is to determine the optimal capacity of Koka reservoir that serve the community for exactly 50 years and increasing the benefit of the community.

There are not many literatures written on this specific topic. Lack of external research opinion has narrowed the perspective of running around ideas and problems that could have been raised. Very few stream gauges exist along the Awash River with in Ethiopia, and those that do tend to have spotty or limited records, and are often not publicly available.

1.6 Organization of the chapters

This study presents the reservoir operation modeling of Koka reservoir for safe operation and optimal use of water for Hydropower, irrigation, recreation, and other purpose. The study considers Koka reservoir inflow source options and a number of interrelated activities.

The study is divided into five chapters. Following this chapter 2 review of literatures pertinent to the study under consideration is presented. Chapter 3 presents the general descriptions of the methodology followed. In chapter 4, the results of the reservoir operation simulation result analysis are presented. Chapter 5, comes up with a brief conclusion and recommendations of the study.

2. LITERATURE REVIEW

2.1 Overview of previous studies

In the past a great deal of research has been conducted into water management trends and options with in Awash, both in thesis and numerous institutional research levels. Many hydrologic models have been developed to assess hydropower and irrigation potential with in the awash basin, yet often fail to adequately address critical aspects. The limited and spotty occurrence of stream gauges in the basin is still the source of vague in the out puts of most researches. A model is only as good as the data it is supplied.

In recent years, the number of models simulating the discharge from watersheds in the Awash River has increased exponentially. An overview of the models developed for the basin show that the lack of data both for input and calibration the use of complex models utilizing daily data. For these reasons, simple water balance models, like Hec-Ressim that most efficiently utilize the available data, are the most appropriate choice for Simulation of the hydrology of the awash basin (Awlachew S.B., M. MCcartney, Tammo S., Steenhuis and Abdalla A. Ahmed., 2008).

2.2 Calibration and validation of studies

Addis Ababa University by Fanuel wondye

Control run was made to test and verify the validity of the model, based on current condition or base scenario (scenario-1), which has been configured as shown above. After first trial simulation has been done, the model has been calibrated altering the flow downstream of dams until it gives satisfactory response at certain control points. The HEC-ResSim model has been tested based on the 1960-1992 flow measured at three gauges (Bahirdar, Kessie and Border) existing on Abay main stream. Considering the complexity of the basin and that most tributaries being ungauged, the model flows are reasonably agreeing with the observed flows at the stations.

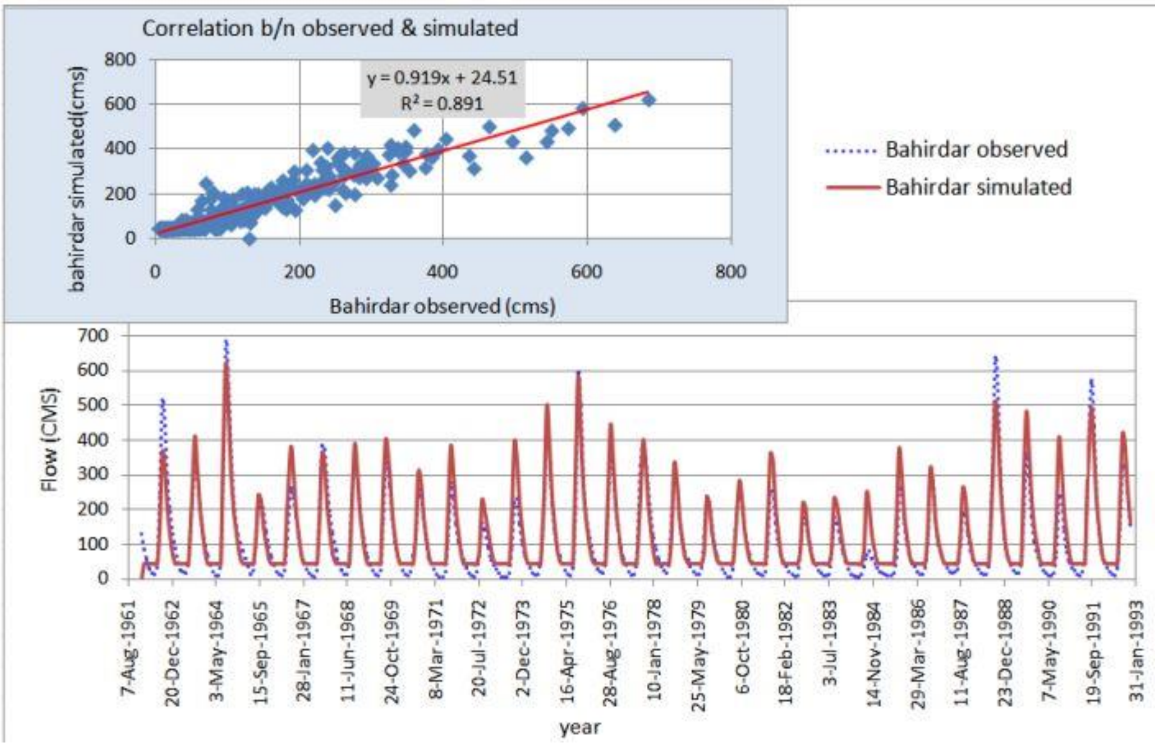

Figure 2.1 Calibration of observed verses simulated

Addis Ababa University by Shimelis Behailu

The statistical measures used in this thesis to assess the model performance, as well as highlight the strengths and weaknesses of the model, are commonly used measures referenced in literature. This measures-oriented approach to model performance assessment focuses on several different aspects of overall accuracy or skill of the streamflow model. The statistics used are intended to give a range of information (12). The correlation coefficient is used to measure how good the simulated result reproduces historical patterns. The root mean square statistics is sensitive to extreme events, such as high streamflow peaks and flooding. A low root mean square result would indicate high performance at matching the peak flows. The mean absolute error gives a performance indicator that is more equally weighted between assessing the simulation of both low and high peaks. The maximum absolute error shows the value of the largest deviation between the observation and the model, usually the largest high flow peak that was unable to be reproduced by the model. The bias statistic gives an indication if the model is systematically under or overestimating the streamflow. Because of the square of the differences in the Nash-Sutcliffe measure, it is extremely sensitive to high flow events. The range for the Nash-Sutcliffe is between one and negative infinity. If the Nash-Sutcliffe (16) result is a negative value, the mean of the observations is statistically better than the model results.

After a model is calibrated for a given calibration period, its verification by independent historical data and the calibrated model parameters need to be carried out. Model verification for the Upper Awash Basin was done for the five years daily input data set (1996-2000).

2.3 Reservoir operations of related researches

Reservoir operation is the most important method in water resource management and used to allocate water that stored in the reservoir among different upstream and downstream users. Reservoir operation takes into account the water uses for power generation, water supply, irrigation, and releases for downstream ecosystem, and the needs of aquatic habitats. These large numbers of complex and interrelated activities may create a demand conflict that requires an optimal operation rule and strong decision support system (Skoulikaris.C, 2008).

2.3.1 Reservoir rule curve

The terms rule curve or guide curve are typically used to denote operating rules which define ideal or target storage levels and provide a mechanism for release rules to be specified as a function of storage content. Rule curves are usually expressed in as water surface elevation or storage volume versus time of the year. Although the term rule curve denotes various other types of storage volume designations as well, the top of conservation pool is a common form of rule curve designation.

The top of conservation pool may be varied seasonally, particularly in regions with distinct flood seasons. The seasonal rule curve illustrated by figure 2.2 reflects a location where summer months are characterized by high water demands, low stream flows, and a low probability of flood. The top of conservation pool could also be varied as a function of watershed moisture conditions, forecasting inflow, flood plain activities, storage in other system reservoirs, or other parameters as well as season of the year. A seasonally or otherwise varying top of conservation pool elevation defines a joint use pool which is treated as part of the flood control pool at certain time and part of the conservation pool at other times. Figure 2.1 illustrates such an operating plan where upper and lower zones are used exclusively for flood control and conservation purposes, respectively, and the storage capacity in between is used for either purpose depending on seasons or other factors.

Also, either the flood control or conservation pool can be subdivided into any number of vertical zones to facilitate specifying reservoir releases as a function of amount of water in storage.

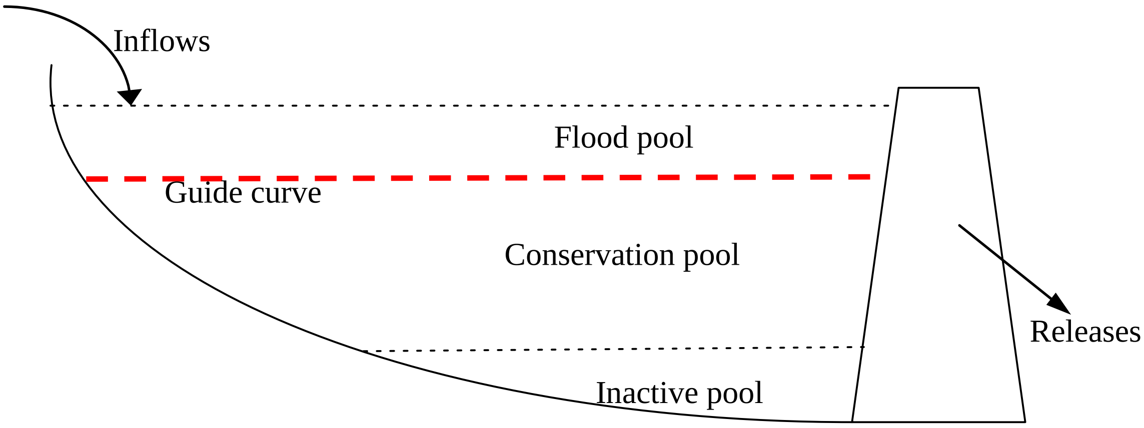

Figure 2.2 Constant zone *(Birhanu.A, 2008)*

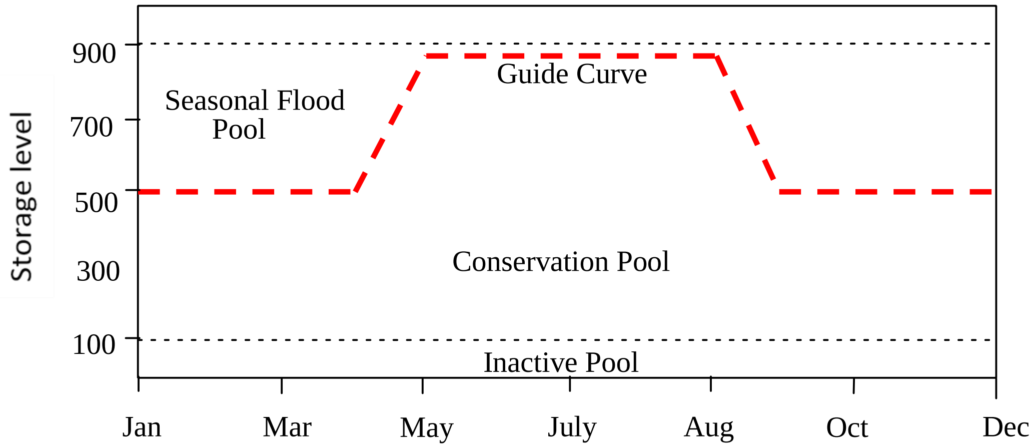

Figure 2.3 Seasonal zone *(Birhanu.A, 2008)*

2.3.2 Reservoir operation policy

A reservoir operating policy is a sequence of release decisions in operational periods (such as months), specified as a function of the state of the system. The state of the system in a period is generally defined by the reservoir storage at the beginning of a period and the inflow to the reservoir during the period.

An operating plan or release policy is a set of guidelines for determining the quantities of water to be stored and to release or withdraw from a reservoir. Operating decisions involve allocation of storage capacity and water releases between multiple reservoirs, between project purposes, between water uses, and between time periods. A release plan includes a set of quantitative criteria within which significant flexibility exists for qualitative judgment. Operating plans provide guidance to reservoir management personnel. (Tsegazeab.D, 2014)

2.4 Reservoir operation model

Reservoir operation model is the method used to allocate water stored in the reservoir among different upstream and downstream users. Reservoir operation consists of several control variables that defines the operation strategies for guiding a sequence of releases to meet a large number of demands from stakeholders with different objectives, such as flood control, hydropower generation and allocation of water to different users. Numerous researchers have developed computer models for the operation of the reservoirs and river system. Currently, the vast majority of the reservoir planning and operation is undertaken using simulation models. A brief review of the two categories of reservoir operation techniques that have been, applied to dam operation is presented below. (A., 2010)

2.4.1 Simulation techniques

Simulation models still remain the primary tool for reservoir operation studies. Simulation models represent an abstraction of reality and replicate the physical behavior of the system on a computer. Simulation is different from the mathematical programming techniques, which find an 'optimal solution' for the system operation meeting all system constraints while maximizing or minimizing some objective. (Yeh, 1985)

The simulation model enables the analyst to test the alternative scenarios (e.g. different operating rules) and examine the consequence before actually implementing them. The main drawback of simulation is that it requires prior specification of the system operation policy. In consequence, the only way to locate optimal policy is through subsequent trials. In consequence, the only way to locate optimal policy is through subsequent trials. Many researchers have employed optimization methods within simulation models. These techniques do not result in an optimal solution but rather facilitate compliance with the predefined operating rules. (Moseley, 1971)

Simulation models for the operation of reservoir have been applied for many years. Many models are customized for a particular system. However, more recently, the trend has been to develop general simulation models that can be applied to any basin or reservoir system. (McCarteny, 2007) Some of the common and the most applicable reservoir operation models are RIVERWAER, RRFM (River Release-Forecasting Model), RESOP (Reservoir Operation Study Computer Program), WEAP (Water Evaluation and Planning Model), HEC-5, and HEC-ResSim (Reservoir Simulation Model).

2.5 System simulation software

To date, software used for simulating operating rules and storage allocations has included spreadsheet programs, HEC-5, HEC-3, Stella®, and other study specific programs identified in reviews by Wurbs (1993) and Yeh (1985). The HEC- numbered codes were developed at HEC, a division of the USACE, in Davis, California. Of publicly available programs, they are the most well documented and capable for performing network systems simulation analysis, including flood management, water supply, irrigation and hydropower operations (Feldman 1981; HEC 1998). At present, HEC is replacing the HEC-5 code with HEC- Reservoir Simulation System (HEC- ResSim), a next generation reservoir systems analysis software that is object, graphically, and database oriented for real-time or planning analysis studies (Fanuel.W, 2009). For the present study, HEC- ResSim was chosen to model reservoir of Koka on monthly basis.

2.5.1 Studies using HEC-ResSim models

Hec-ResSim has been widely used since the release of the program. Reservoir operation simulation studies done on different basin of Ethiopia and other countries using ResSim model has been referred for the preparation of this study.

Addis Ababa University by (Biruk Asrat 2010)

The Awash basin is part of the Great Rift Valley in Ethiopia located from 8.5^0 N to 12^0N. It covers a total area of 110,000 km^2 of which 64,000 km^2 comprises the Western Catchment, drains to the main river or its tributaries. The remaining 46,000 km^2, most of which comprises the so called Eastern Catchment, drains into a desert area and does not contribute to the main river course. The highest sources of the Awash lie in a mountain range lying near the southern edge of the high plateau of Ethiopia near Ginchi town, some 80km west of the capital Addis Ababa, at an altitude of about 3000m above sea level. The river then flows along the rift valley into the Afar triangle, and terminates in salty Lake Abe on the border with Djibouti, being an endorheic basin. The total length of the main course is some 1,200 km.

The Awash Basin covers the central and northern part of the rift valley and is bounded to the west, southeast and south by the Blue Nile, the Rift Lakes and the Wabi Shebelle Basins respectively. The main highway from Addis Ababa to Assab traverses the entire length of the Awash Valley. The other highway runs up to Awash where it continues eastward to Dire Dawa and further across the Wabi Shebelle watershed to Harar and on to Jijiga. An alternative route linking with the Assab road at Mile runs along the western escarpment from Addis Ababa, serving the larger industrial centers of Kombolcha and Desse. Furthermore, the main railway links Addis Ababa and the port of Djibouti. (A., 2010)

WWDSE Detail Design Reports (2005)

As Awash River basin is the most intensively developed basin in Ethiopia in terms of irrigation, a number of studies have been conducted with respect to the development strategies to be followed to utilize the water resources of the basin. Survey of the Awash basin by Sogreah-FAO (1965), Feasibility study of the Lower Awash Basin by Gibb and Hunting (1975), Feasibility Study, Proposal and Estimate of Cotton Development on the area of 60,000 ha in the Lower Awash Valley by UZBEK (1985) and Master Plan for the Development of Surface Water Resources in the Awash Basin by Halcrow (1989) and the latest Tendaho Dam and Irrigation Project Detail Design Reports (2005) are among the most important ones. All these studies have tried to show the irrigation development opportunities attainable in the lower valley of the basin with the construction of Tendaho dam at Tendaho. They generally dealt with proposition of the type and features of the dam to be constructed at Tendaho and all share almost similar approaches, except the latest study conducted under the consultancy service of WWDSE. Thus, 36 in this research the study conducted by WWDSE (2005), which is related to this study, is reviewed. The Tendaho Dam Hydrology and Awash River Basin Modeling are the two most important study works which have been conducted as parts of the Tendaho Dam and Irrigation Project Design Report. The study reports included revisions of all the study works presented in earlier times. The existing situations of the Awash River basin as a whole have also been considered in the study reports. In the Awash River basin modeling, simulation was made for the whole Awash River basin to evaluate the availability of water for the Tendaho reservoir under different level of water abstractions at the upper reaches of the Awash River. The simulation was done by HEC-5 software under four irrigation development level scenarios. The simulation result showed that except the Kessem irrigation development, all the other irrigation projects necessitating abstraction of water from the Awash River, especially Wonji and Metahara sugar plantation expansions, have an impact on the amount of water flowing to the Tendaho reservoir. (WWDSE., 2005)

2.5.2 Features of HEC-ResSim

HEC-ResSim has been developed by the Hydrologic Engineering Center of the US Army Corps of Engineers to aid engineers and planners performing water resources studies in predicting the behavior of reservoirs and to help reservoir operators plan releases in real-time during day-to-day and emergency operations. The following describes the major features of HEC-ResSim:

- **Module elements**

HEC-ResSim offers three separate sets of functions called modules that provide access to specific types of data within a watershed. These modules are Watershed Setup, Reservoir Network, and Simulation. Each module has a unique purposes and an associated set of functions accessible through menus, toolbars, and schematic. (Joan D. Klipsch , Marilyn B. Hurst, 2013)

A. Watershed Setup Module

The purpose of the watershed setup module is to provide a common framework for watershed creation and definition among different modeling applications. This module is currently common to HEC-ResSim, HEC-FIA, and the CWMS CAVI.

A watershed is associated with a geographic region for which multiple models and coverages can be configured. A watershed may include all of the streams, projects (e.g., reservoirs, levees), gage locations, impact areas, time-series locations, and hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework. When a new watershed is created, ResSim generates a directory structure for all files associated with the watershed. In the Watershed Setup module, items that describe a watershed's physical arrangement are assembled. Once a new watershed is created, it is possible to import maps from external sources (e.g. Arc View-GIS), specify the units of measure for viewing the watershed, add layers containing additional information about the watershed, create a common stream alignment, and configure elements.

B. Reservoir Network Module

The purpose of the Reservoir Network module is to isolate the development of the reservoir model from the output analysis. In the Reservoir Network module, network schematic is built, the physical and operational elements of the reservoir are described and the alternatives that are required to be analyzed are developed. Using configurations that are created in the watershed setup module as a template, the basis of a reservoir network will be created. Then, routing reaches and possibly other network elements will be added to complete the connectivity of the network schematic. Once the schematic is complete, physical and operational data for each network element are defined. Also, alternatives are created that specify the reservoir network, operation set(s), initial conditions, and assignment of pathnames (time-series mapping).

C. Simulation Module

The purpose of the Simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the simulation module is used to configure the simulation. The computations are performed and results are viewed within the Simulation module. When Simulation is created a simulation time window, a computation interval, and the alternatives to be analyzed must be specified. Then, ResSim creates a directory structure within the rss folder of the watershed that represents the simulation. Within this simulation tree will be a copy of the watershed, including only those files needed by the selected alternatives. Also created in the simulation is a DSS file named simulation.dss, which will ultimately contain all the DSS records that represent the input and output for the selected alternatives. Additionally, elements can be edited and saved for subsequent simulations.

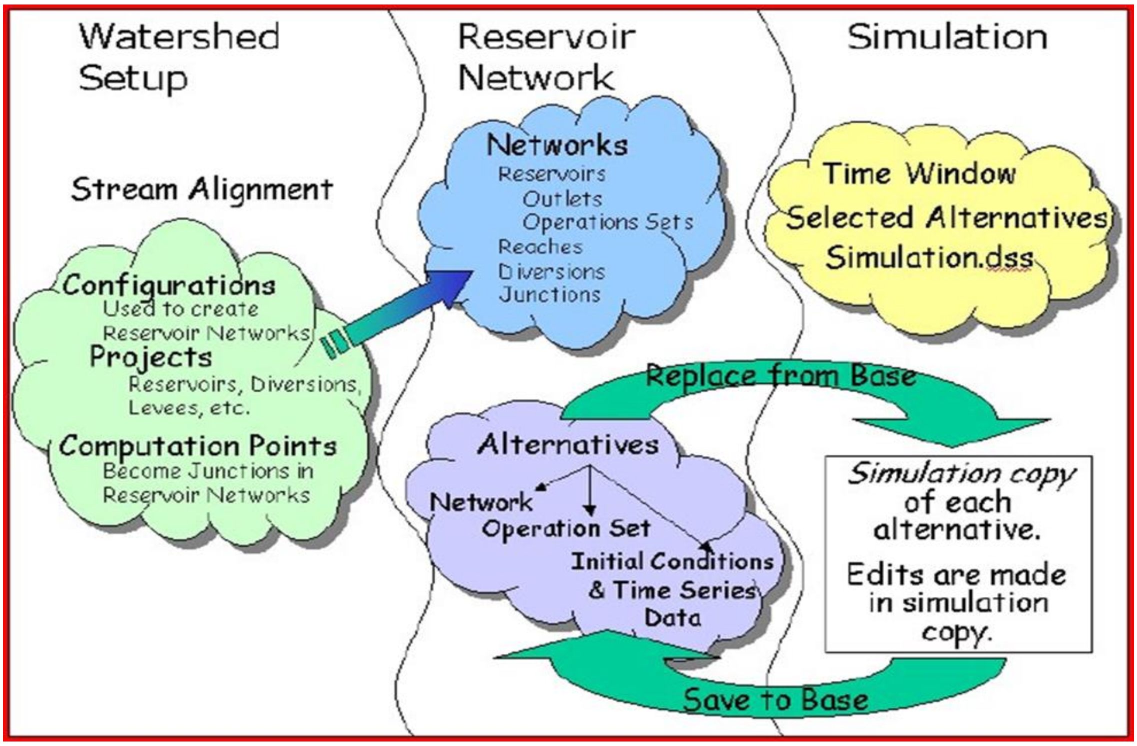

Figure 2.4 ResSim modules concepts *(Joan D. Klipsch , Marilyn B. Hurst, 2013)*

2.5.3 HEC-DSS tool

HEC-DSSVue (Hydrologic Engineering Center Data Storage System Visual Utility Engine) is a graphical user interface program for viewing, editing, and manipulating data in HEC-DSS database files. With HEC-DSSVue, you may plot, tabulate, and edit data, as well as manipulate data with over fifty mathematical functions. Along with these functions, HEC-DSSVue provides several utility functions that allow you to enter data sets into a database, rename data set names, copy data sets to other HEC-DSS database files, and delete data sets. (Joan D. Klipsch , Marilyn B. Hurst, 2013)

The tool is comprised of two visual basic executable that utilize an object library and object classes within the database structure (DSS catalogs) and contains all relevant records and descriptors to automatically transfer the time series data during simulation process. When converting time series data in to HEC-DSS format it is important that the time series be continuous, without gaps in the dates. After converting the time series data in the HEC-DSS file format it can be used in the simulation by setting the path to DSS-path for each inflow points to the reservoir in the alternative editors.

A key step in transferring a time series data from the database storage in to the DSS format is the creation of DSS catalog inside the database. DSS catalog is the object class table within the database that contains the information related to the DSS data and its pathname. The DSS pathname consists of six parts in the following format. (Joan D. Klipsch , Marilyn B. Hurst, 2013)

Where:-

A - Group name for the data such as a watershed name, study name, or any identifier which allows the records to be recognized as belonging to a group.

B - The location identifier for the data. The location identifier may be a site name or organization ID.

C - The parameter of the data such as Flow, Precipitation, Storage, Evaporation, Volume, Flow-In, Flow-Out.

D - The start date of the time series.

E - The time interval for regular data or the block length for irregular interval data.

F - An optional descriptor that can be used for additional information about the data.

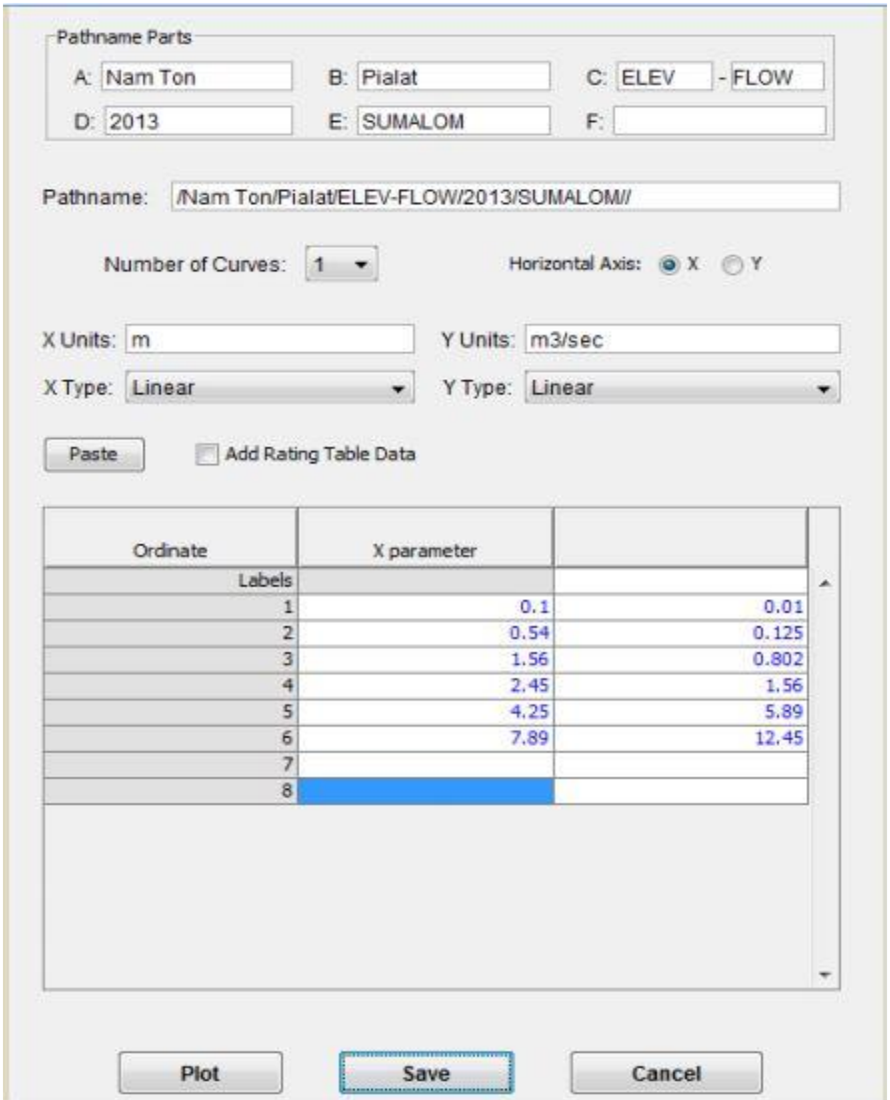

Figure 2.5 HEC-DSS editor box *(Tilman, 2013)*

3. MATERIAL AND METHODS

3.1. Description of the study area

3.1.1. Location of koka reservoir

In Ethiopia upper Awash River Basin lies upstream of Koka dam and it is located between latitude of 8^{o}16” and 9^{o}18” and longitudes of 37^{o}57” and 39^{o}17”. It has a catchment area of about 11560.48 Km^2 of 110,000km^2 of Awash Basin. The mean annual temperature at Koka reservoir is 26.21^{o} C with a maximum of 32.45^{o}C in June. The mean wind speed at Koka is 1.2 m/s with the windiest month begin June and exceed up to July with monthly value of 1.9 and 1.6 m/s respectively. The area is dominated by bimodal rainfall type with mean annual value 800mm. Koka reservoir is situated at about 81km south east of Addis Ababa in Awash basin between 39^{o}00” E and 39^{o}10” E and 8^{o}18” N and 8^{o}29” N. Koka dam is constructed on Awash River, which originates from the Ethiopian Highlands some 150 km west of Addis Ababa at an altitude of about 3000m above sea level. Koka reservoir had an original storage capacity of 1650million cubic meter at full reservoir level of 1590.7m above sea level. When the dam was made operational in 1960 the storage capacity of the reservoir at 1580.8m above sea level (minimum operating level) was 180 million cubic meters.

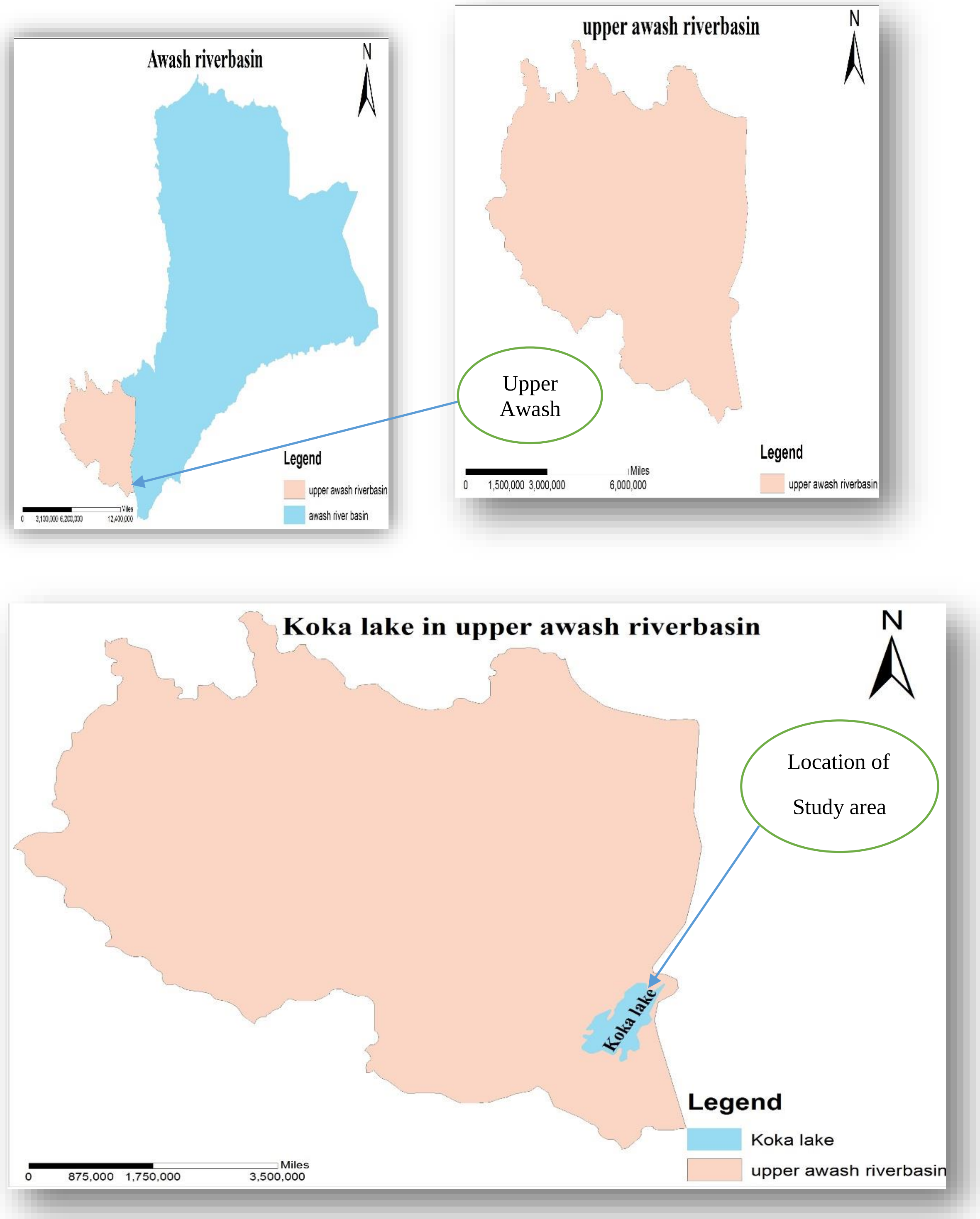

Figure 3.1 Location of the study area

The Awash Basin has been divided in to four distinct zones. These are: Upper Basin, Upper Valley, Middle Valley and Lower Valley. Table 3.1 shows the detail of these divisions.

Table 3.1 Division of awash basin by different bases. (Sufiyan.A, 2014)

Designation	From	To	Elevation	Mean annual Rainfall
Upper basin	Head water	Koka dam	Above 1500 m	>800 mm
Upper valley	Koka dam	Metehara	1500 – 1000 m	800 – 600 mm
Middle valley	Metehara	Tendaho	1000 – 500 m	600 – 200 mm
Lower valley	Tendaho	Lake Abe	500 – 300 m	Below 200 mm

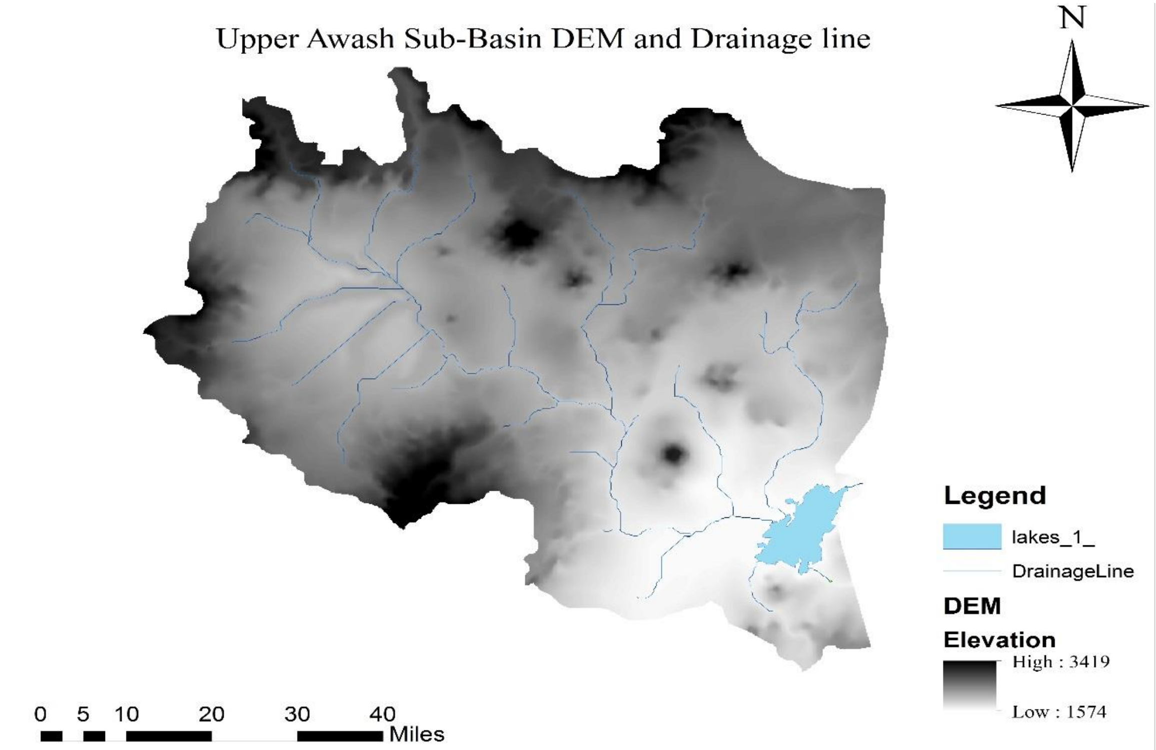

Figure 3.2 Map of upper awash sub-basin with rivers and drainage line

3.1.2. Climate

The climate of the Awash River Basin varies from humid subtropical over central Ethiopia to arid over the Afar lowlands. The climate of this basin comes under the influence of the inter-tropical convergence zone (ITCZ). The seasonal rainfall distribution with in the basin results from the annual migration of the ITCZ. In March the ITCZ advances across the Basin from the south, bringing the small or spring rains. In June and July it reaches its most northerly location beyond the Basin which then experiences the heavy or summer rains. It then returns southwards during August to October, restoring the drier easterly airstreams which prevails until the cycle repeats itself in March. Generally, in the basin, plateaus over 2,500m receive 1,400 - 1,800 mm per year, mid altitude regions (600 – 2500 m) receive

1,000 -1,400 mm per year and lowlands get less than 200mm per year. The rainfall distribution of the basin is bimodal with a short rainy season in March to April and the main rains from July to September. (Halcrow, 1989)

The annual rainfall distribution resulting from this cycle is exhibited most clearly in the two distinct rainy periods which are characteristic of the northern plains of the basin. Moving southwards the more prolonged exposure to the moist air-stream is evident in the tendency for the two dominant rainy periods to merge into a more contiguous distribution. On the high plateau to the west of Addis Ababa the rainfall distribution shows a continuous increase from the spring rains to the summer peak rainfall. The distribution of rainfall over the highland areas is modified by orographic effects and is significantly correlated with altitude.

The rainfall distribution of the Upper Awash watershed (from 1996-2015) shows that high rainfall was occurred in the months June to September and also short rainy season March to May. The mean annual minimum and maximum temperature of the watershed ranges from 10.92°C to 15.38°C and 26.21°C to 32.45°C respectively. The annual and monthly rainfalls are characterized by high variability. Mean annual wind speeds at Koka averages 1.2 m/s, the windiest months being June and July with mean monthly values of 1.9 and 1.6 m/s respectively.

3.1.3. Surface water resources

According to MoWIE, 2005 scenario the total run off generated from Awash River is 4527.1Mm^3/annum. A large amount of this is lost to seepage, evaporation and evapotranspiration from open water surfaces and wetlands. The tributaries upstream of Koka Dam as well as those flowing directly into the Koka Lake contribute a total of 1650.9 Mm^3/annum. Seepage and evaporation losses from the Koka Reservoir account for over 400 Mm^3/annum of this and the mean annual run off reduces to 1248.3 Mm^3/annum immediately downstream of the Dam. (Birhanu.A, 2008)

The mean annual runoff into Koka reservoir (upper valley) amounts to some 1,660 Mm^3 and about 90% of this runoff occurs in the period July to September. It decreases to 1,390 Mm^3 at Awash (middle valley) station being depleted largely by losses from Koka and upper valley irrigation diversions. (Y., 2011)

The main tributaries of Awash River, up stream of Koka dam, are Akaki and Mojo rivers. Akaki River starts from the mountainous areas of the northern part of Addis Ababa and join the main Awash River between Melka-Kunture and Hombole gauging stations. Mojo River, the other main tributary to Awash, originates from the high lands northeast of Addis Ababa. It drains a catchment area close to 1,900 km^2 and travels a total length of about 105 km before joining Awash. (Halcrow, 1989)

3.1.4. Elevation and slope

The peak point (highest elevation) of the study area is about 3568m, and the lowest point has an elevation of 1566m above sea level. 50% of the areas have approximately below 2200m and elevation above 2000m covers approximately 7% of the watershed and the rest of the area is between 1000 and 2000m. The majority of the slope is within the range of 0-10% that is relatively flat land scape. The rest area have moderate slope with steep inclination (i.e. slopes greater 19%).

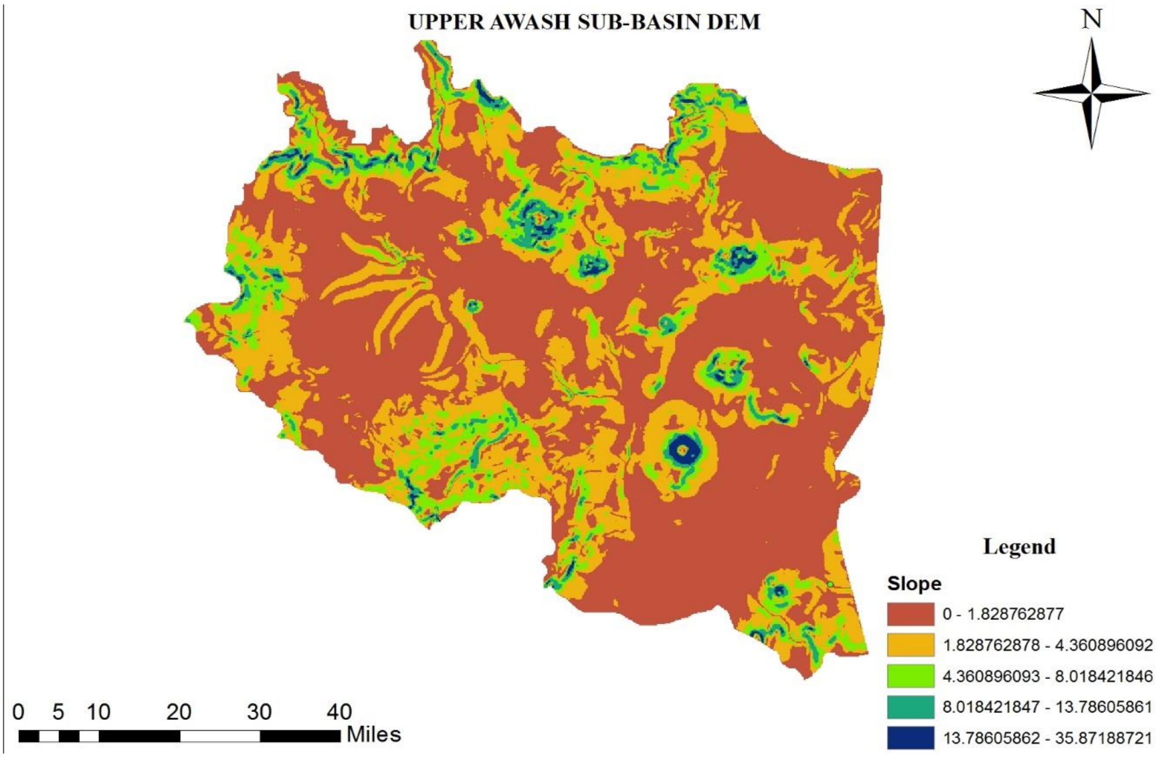

Figure 3.3 Slope map of upper awash watershed

3.2. Material used

Material used for this research ArcMap10.1 software to delineate basin of the study area and in ArcMap10.1; ArcHydro is used for drawing of drainage line and catchment polygon then HEC-ResSim 3.1 model is used for reservoir simulation and HEC-DSSVue 2.0.1 is used for organizing time series data.

3.3. Data collection and analysis

Prior to any reservoir simulation and optimization; it is mandatory to search and collect basic input data to be used for the proper simulation and optimization of the reservoir. The data used for this research can be categorized as spatial and time series data. These data was collected from different agencies and organizations. The spatial data (DEM), land use land cover and stream network layers. Meteorological and hydrological data, and the time series data were also used prediction of stream flow calibration and validation purpose.

The general frame work of the methodology is shown in figure 3.1.

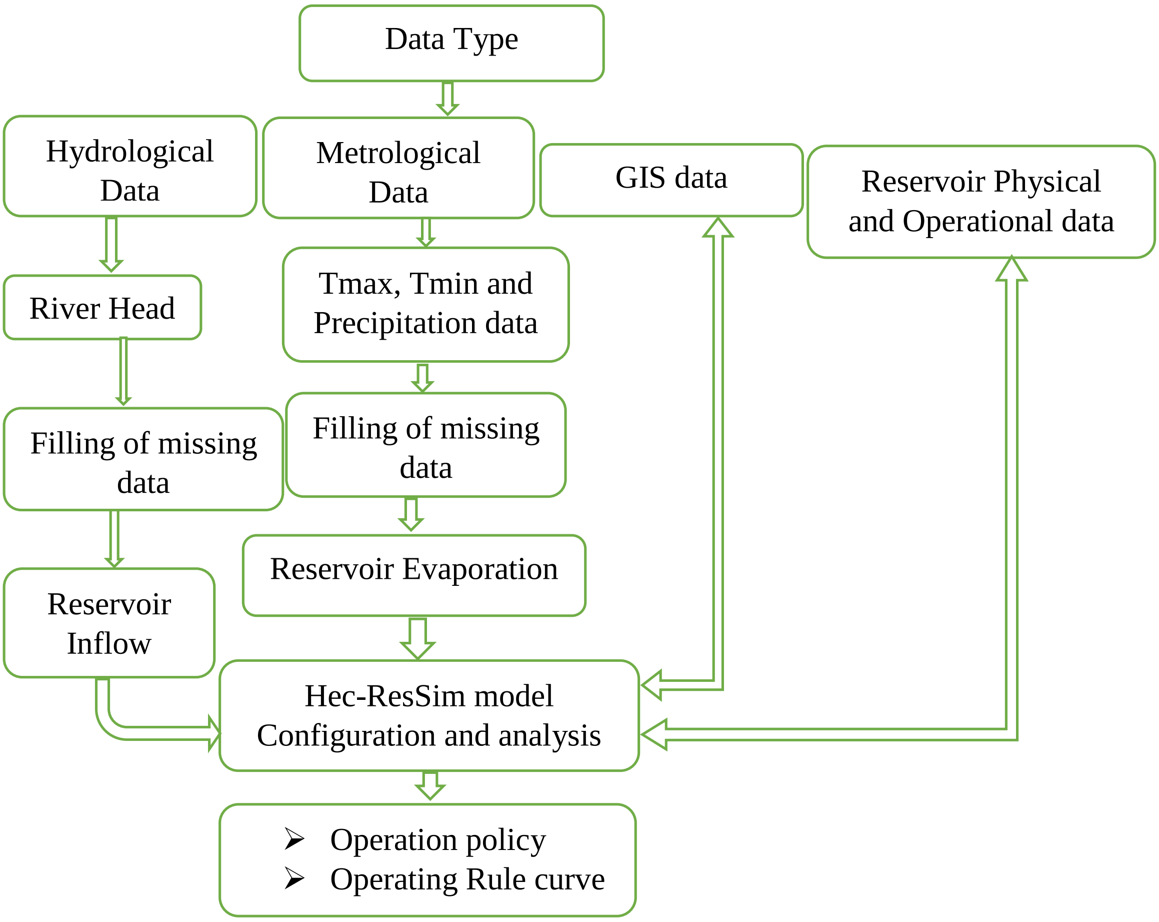

Figure 3.4 Frame work of methodology used

3.3.1. Digital elevation model (DEM)

A DEM can be represented as a raster (a grid of square, also known as a height map when representing elevation) or as a vector-based triangular irregular network (TIN). The TIN DEM dataset is also referred to as a primary (measured) DEM, whereas the Raster DEM is referred to as a secondary (computed) DEM. A 30 m by 30 m resolution DEM Figure 3.2 was obtained from Ministry of water, Irrigation and Electricity. The DEM was used to delineate the watershed and to analyze the drainage patterns of the land surface terrain, sub-basin parameters such as slope gradient, slope length of terrain, the stream network characteristics such as channel slope, length, and width were derived from the DEM.

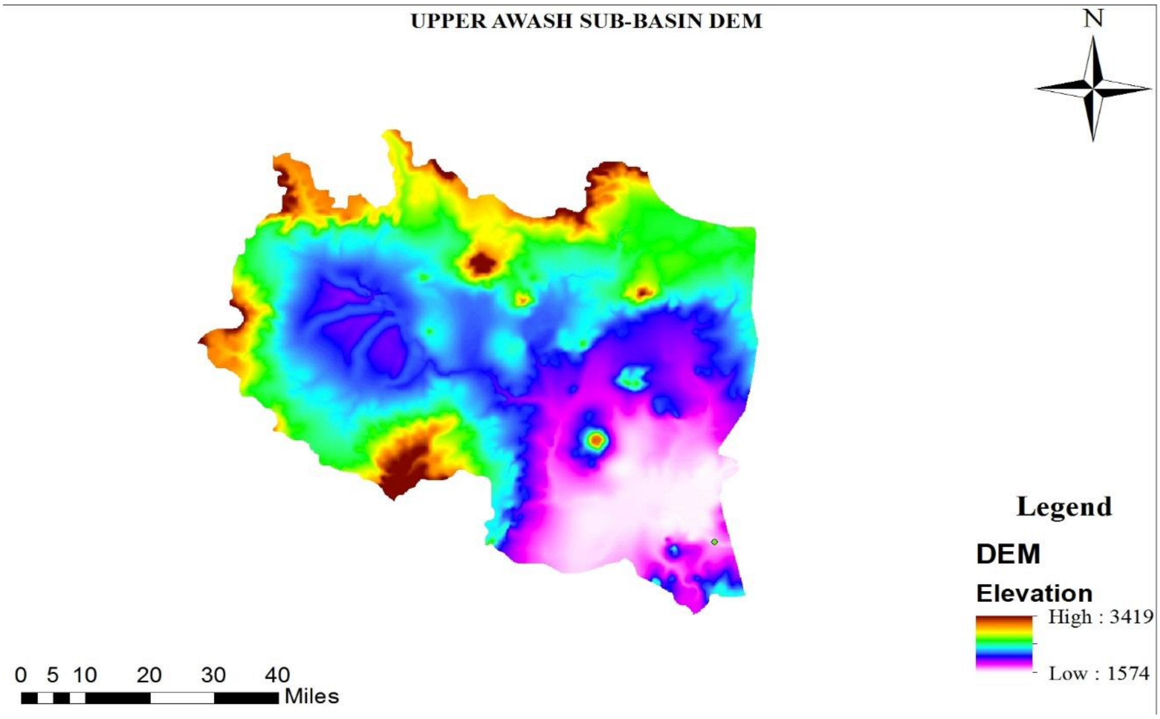

Figure 3.5 Digital elevation model of the upper awash

3.3.2. Weather data

HEC-ResSim requires daily meteorological data that can be read from a measured data set. The weather Variables used in this study are daily precipitation, minimum and maximum air temperature for the period 1996 – 2015. These data were obtained from Ethiopian National Meteorological Agency (NMA) for stations located within and around the watershed. (Mean monthly data of selected stations)

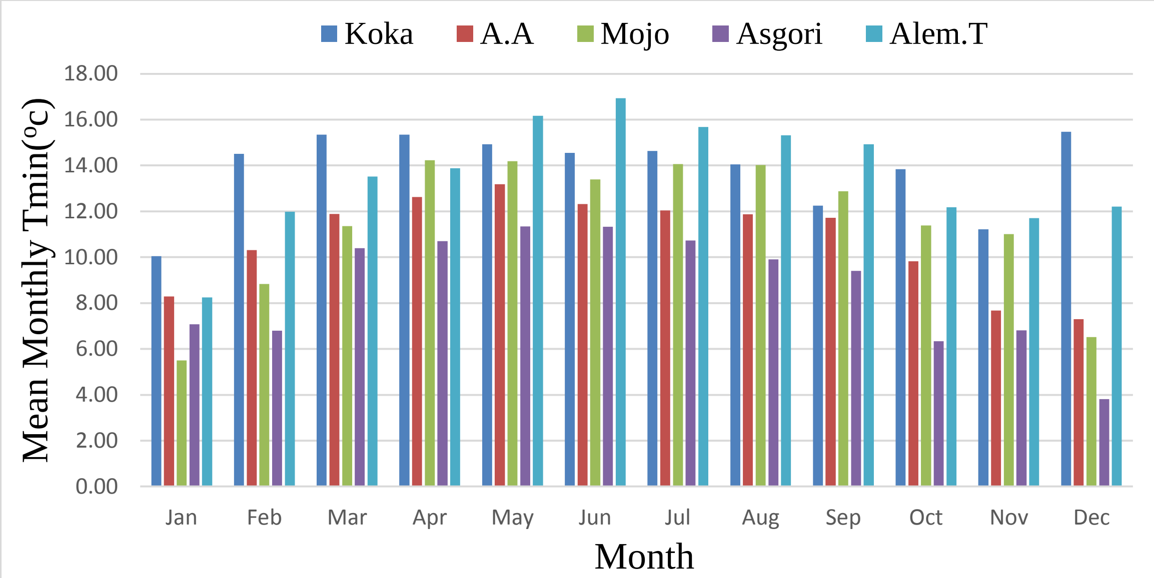

Figure 3.6 Mean monthly T Min data of selected stations

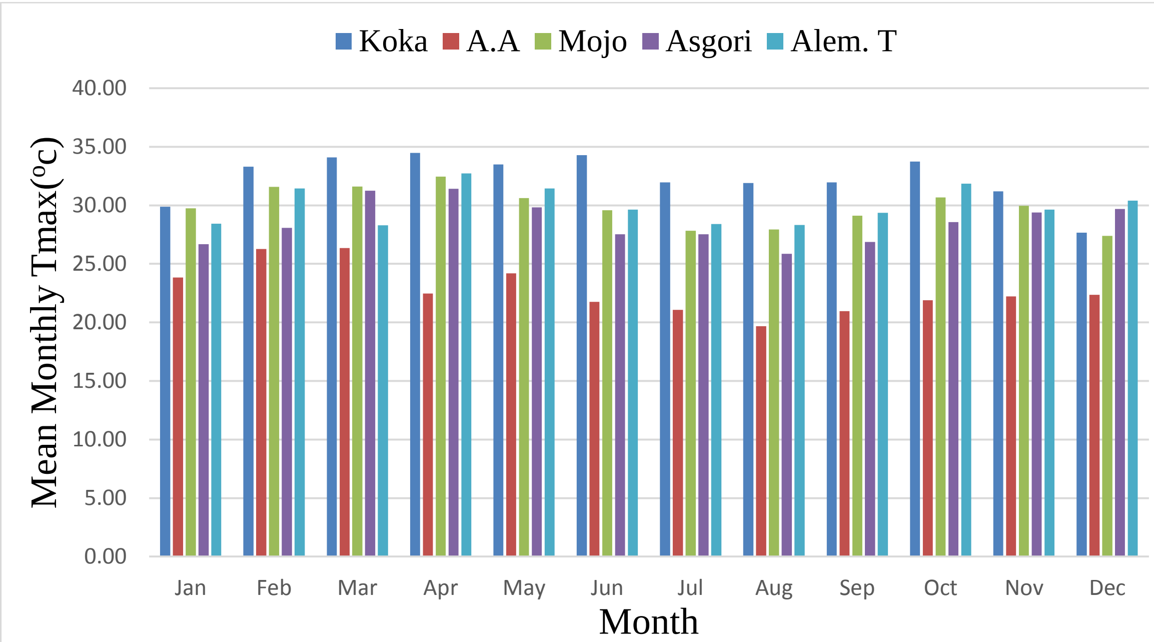

Figure 3.7 Mean monthly T Max data of selected stations

3.3.3. River discharge

The most important input data for reservoir simulation by HEC-ResSim software is inflow (river discharge) to the reservoir. To estimate the inflow to the Koka reservoir; Daily river discharge values of Akaki, Hombole, Melkakuntrie, and Mojo were considered as the main sources obtained from the Hydrological department of the Ministry of Water Irrigation and Electricity. The average monthly discharge of Akaki, Hombole, Melkakuntrie and Mojo gauging stations (Figure 3.5) was used for model calibration and validation.

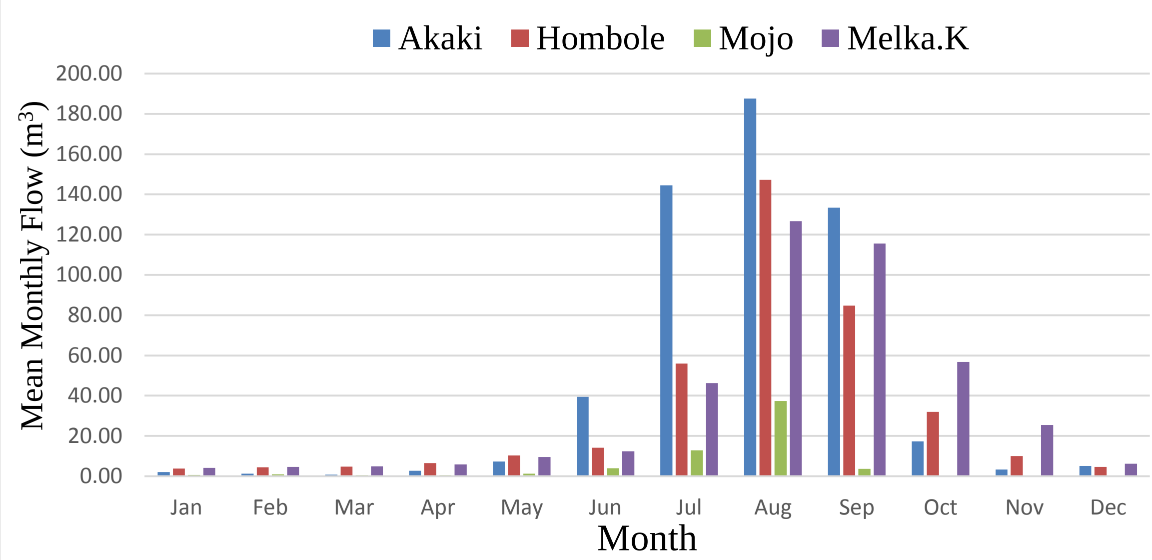

Figure 3.8 Peak flows at Hombole, Mojo and Akaki guaging stations

3.3.4. Koka reservoir

Lake Koka is actually a reservoir created by the Koka Dam, constructed in the late 1950's and opened in 1960. The creation of the Koka reservoir with an initial capacity of 1.8 billion cubic meters Provided, in addition to the primary purpose of irrigation water and the production of electric energy, flood protection to the upper and middle awash areas by retaining incoming floods.

The original storage capacity of the reservoir at full capacity level of 1590.7 m.a.s.l or 110.3m reduced level, 1650 Mm^3 and catchment area of 200 km^2. The reservoir elevation and other data related to Koka reservoir obtained from Ethiopia Electric power. The Elevation – area – capacity curve of Koka reservoir is shown below.

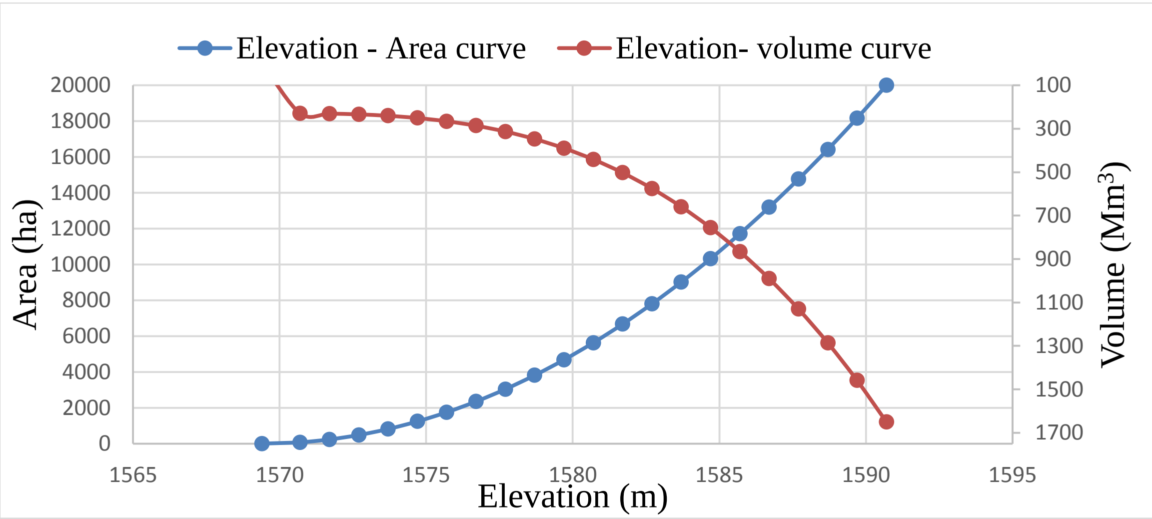

Figure 3.9 Elevation – area – volume curve of Koka reservoir

3.4. Data analysis

The studies of water resources development and management heavily depend on meteorological and hydrological data. Before starting hydrological and metrological data analysis and simulation, it is important to check whether the data are homogenous, correct, and complete with no missing data.

It is because incorrect (erroneous) data resulting from lack of appropriate recording, shifting of station location and processing are serious as they lead to inconsistency and ambiguous results that may contradict to the actual situation. (Maidment, 1992)

3.4.1. Meteorological data analysis

The daily data of Precipitation, Maximum Temperature, Minimum Temperature, and Relative humidity of the selected meteorological stations within and around the watershed were collected from the National Meteorological Agency (NMA). The availability and quality of meteorological data such as rainfall, temperature, relative humidity, and sunshine hour are vital for any water resource study.

There are number of Meteorological stations in the Upper Awash river basin, however, due to limitation of data only nine station were considered out of which only five of them are used for modeling. The criterions for the selection of the metrological data were based on the availability of data, the data quality and possibly whether the station is within the watershed or not. The data collected covers a period of 1996 – 2015. Except few of the stations most of the station data are complete.

Table 3.2 List of selected meteorological station

Number	Stations	Elevation(m)
1	Addis Ababa	2354
2	Alem Tena	1656
3	Asgori	2072
4	Mojo	1763
5	Koka Dam	1618
6	Tulu Bolo	2190
7	Kimoye	2150
8	Jeldu	2952
9	Melkasa	1550

3.4.1.1. Filling Missing Rainfall Data

The data gap that may happen due to different factors, like: failure of the observer to make the necessary visit to the gauging station, instrument failure will reduce the quality of the data. Unless these data gaps filled with the necessary procedures and methods, using these data will lead to incorrect decisions and conclusions. All metrological stations have missing daily records. Normal annual rainfall of all the stations differed by more than 10% of the missing station, therefore; normal ratio method was used to fill the missing rainfall data of the selected stations and calculated the missing data by the following equation (Equation 3.2).

$$P_x = \frac{N_x}{N}\left(\frac{P_1}{N_1} + \frac{P_1}{N_1} + \frac{P_1}{N_1} + \cdots + \frac{P_n}{N_n}\right) \ldots\ldots 3.2$$

Where:

P_x = Missing value of precipitation to be computed.

N_x = Average value of rainfall for the station in question for recording period.

N_1, N_2………N_n = Average value of rainfall for the neighboring station 1, 2…n.

P_1, P_2....P_n = Rainfall of neighboring station 1, 2…n during missing period.

N = Number of stations used in the computation.

3.4.1.2. Homogeneity test for selected stations

For a meteorological station to be selected representative to the analysis of precipitation on a reservoir of the dam sites of this research and filling of missing rainfall data, homogeneity of the group stations need to be checked.

Non dimensional of rain fall records is one of the methods to check homogeneity of the rainfall data. In this method the recorded precipitation data of the selected stations in the watershed is plotted to compare the stations with each other. Non dimensional values of the monthly precipitation of each station can be computed by:

$$P_i = \frac{P_{i.av}}{P_{av}} * 100 \ldots\ldots 3.1$$

Where: P_i – Non dimensional value of precipitation,

$P_{i.av}$ – Over year averaged monthly precipitation of the station i,

P_{av} – Over year averaged yearly precipitation of the station i.

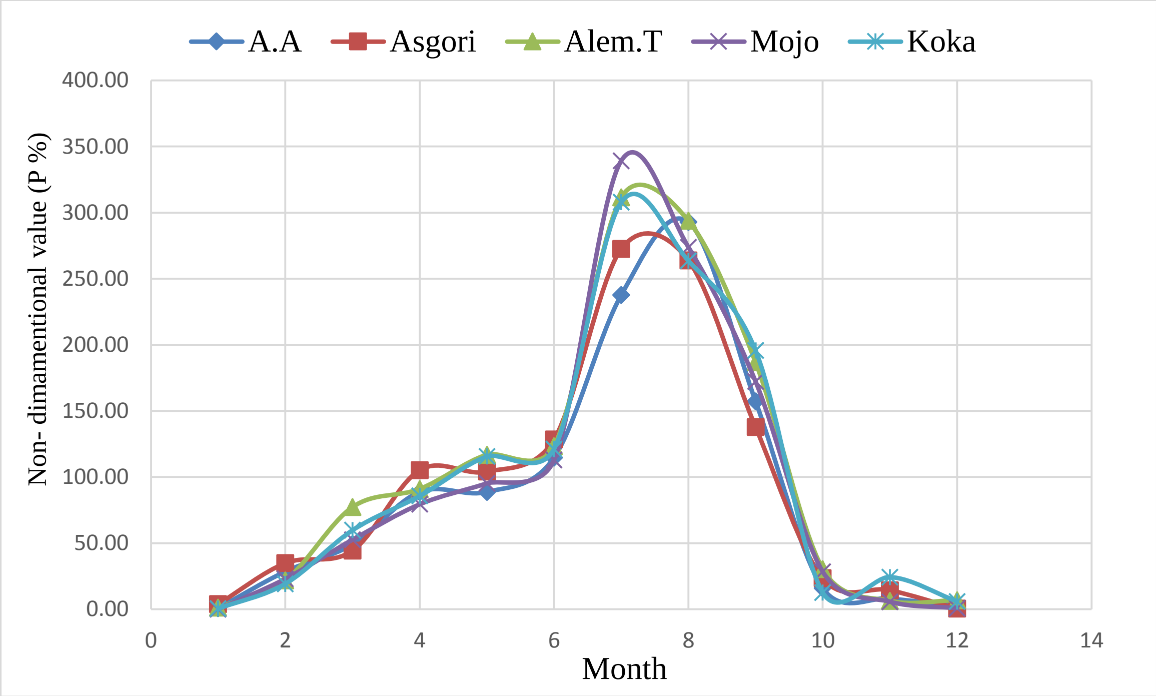

Figure 3.10 Homogeneity test for selected stations

3.4.1.3. Data consistency Check

If the condition relevant to the recording of a rain gauge station have undergone a significant change during the period of recording, inconsistency would rise in the rainfall data of that station. Shifting of rain gauge station to a new location, the neighborhood of the station undergoing a marked change, change of ecosystem due to calamity and occurrence of observational error from a certain data are some of the most common causes of inconsistency of records. The checking for inconsistency of the record is done by the double – mass curve technique. Double mass curve is graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations. (Subramanya, 1994)

In the double – mass curve analysis the graph is plotted between the cumulative rainfall of a single station as ordinate and the cumulative rainfall of the group of station as abscissa. The double mass curve analysis of these station shows that there is no significant break in the slope which implies that the data on these stations are consistent.

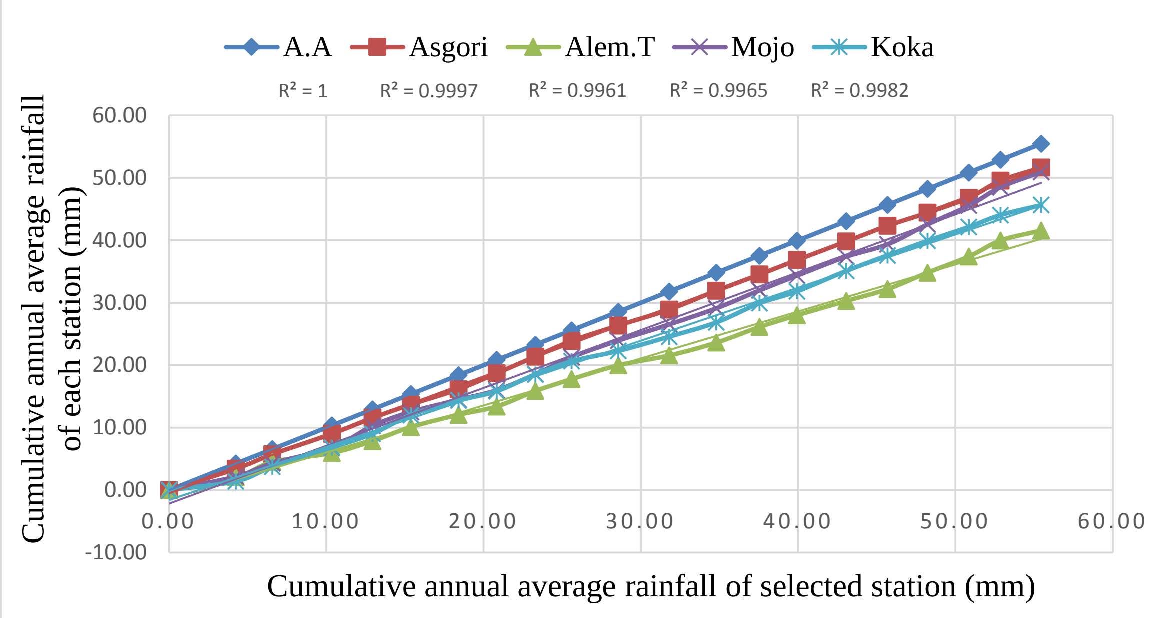

Figure 3.11 Double mass curves for selected meteorological stations

3.4.2. Hydrological data analysis

A clear understanding of the hydrological conditions of the area is one of the basic requirement of any water management study. In this study, different methods used for different type of tests for stream flow data.

3.4.2.1. Filling Missing Flow Records

Some failure of instruments, carelessness of the observers lead to missing of flow data on the station. There are different methods used for filling of missing stream flow records of a given station. Some of this are:-

- ❖ Arithmetic mean method
- ❖ Graphical correlation Method
- ❖ Normal ratio method
- ❖ Linear regression method

Unlike rainfall, stream flow shows strong Serial correlation; the value on one day is closely related to the value on the previous and following days especially during periods of low flow. The run off generated due to the small rainfall occurs from March to April and heavy rainfall from July to September is the main cause of variation of the flow in the study area. The gaging stations have good stream flow records with a small number of missing data in the study base line, especially from 1996 – 2002. Hombole sation has full data without missing, but Melkakunture, Mojo and Akaki gauging stations have some missing data; filled by arithmetic mean method.

3.4.2.2. Data Quality Check

Some manual or machine errors may exist in the stream flow observation that we collect from respective organization such as misplaced decimal numbers, very huge unrealistic numbers and negative flow records in some cases. There different method used for checking flow gauge stations. In this research plotting method is used to check the quality of the data by plotting the provided flow data verses time series. The plot stream flow observation provides an excellent visual check for period of suspect data and helps to observe treads or discontinuity in the flow data. Some daily inflow records of Melkakuntrie station were very large values compared to the normal maximum increment and hence correction was made to reduce those values in the acceptable limits. The following is the sample quality check for Melkakuntrie station.

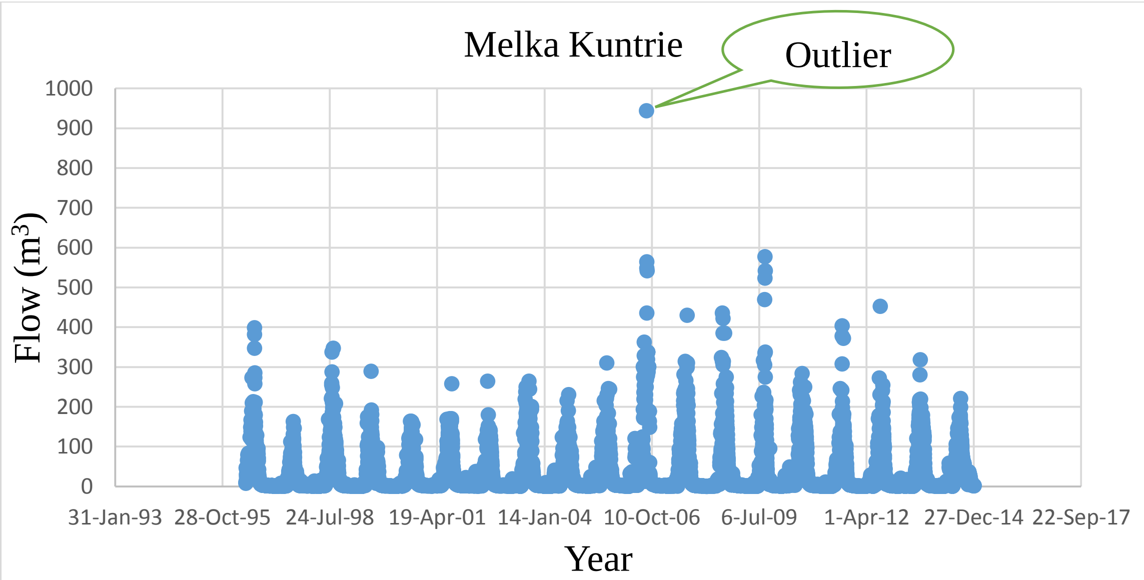

Figure 3.12 Plotting of Melka Kuntrie station for outlier test

3.4.3. Evaporation data analysis

The key parameter dependent on climatic data used in reservoir simulation studies is evaporation loss from the reservoir area. The monthly evaporation data the reservoir area is one of the basic input data of HEC-ResSim model. Among the several phases in the hydrological cycle, evaporation determination; water balance, energy balance, Aerodynamic, penman and pan evaporation methods being the most common. (Chow V.T. , Maidment M.R. , and Mays L.W., 1998)

The evaporation data calculated at Melkasa metrological station for the duration 1996 to 2015 was used to evaluate the evaporation rate from the Koka reservoir surface. The meteorological data that used to compute Koka evaporation is derived from Melkasa first class station; additionally the monthly evaporation is calculated using Energy Balance method.

$$E_r = 0.0353R_n \quad \text{.........3.3}$$

Where:

E_r = Potential Evaporation (mm/day)

R_n = Net radiation (W/m^2)

$$R_n = R_i(1-\alpha) - R_e \quad \text{.........3.4}$$

Where:

R_i = Incident radiation (W/m^2)

α = Short wave radiation reflection coefficient (Albedo) (0.06 for open deep water)

R_e = Emitted radiation (W/m^2)

$$R_e = e * T^4 * \sigma \quad \text{.........3.5}$$

Where:

e = emissivity (0.97 for water surface)

T = temperature of the surface (^{o}k)

σ = Stefan-Boltzmann constant (5.67*10^-8 W/m^2.^{o}k^4)

$$R_i = \left(0.35 + 0.61\frac{n}{N}\right) * S_0 \quad \text{.........3.6}$$

Where:

n = Bright sun hours/day (hr)

N = Total day length (hr)

S_o = Extraterrestrial radiation (W/m^2)

$\frac{n}{N}$ = Cloudiness fraction

The common and widely acceptable conversion factor of 0.7 was used to transfer the reservoir evaporation data to Pan-evaporation. (Garg, 2005)

Table 3.3 Reservoir evaporation and pan evaporation data

Month	Reservoir Evaporation (mm)	Pan Evaporation (mm)
Jan	282.765	403.950
Feb	261.333	373.333
Mar	279.213	398.876
Apr	253.920	362.743
May	257.997	368.567
Jun	231.009	330.141
Jul	227.624	325.178
Aug	232.305	331.864
Sep	252.156	360.223
Oct	285.170	407.385
Nov	287.045	410.064
Dec	296.911	424.159

3.4 Calibration and validation

Calibration is a process of standardizing estimated values, using deviations from observed values for a particular area to drive correction factor. Such empirical corrections are common in modeling, and it is understood that every hydrologic model should be tested against observed data, to understand the level of reliability of the model. The calibration process can provide important insight to both local condition and model performance.

The Nash-Sutcliffe efficiency is used for this study to quantitatively describe the accuracy of model outputs other than discharge. This can be used to describe the predictive accuracy of other models as long as there is observed data to compare the model results to. It is defined as

$$E = 1 - \frac{\sum_{t=1}^{T}(Q_m^t - Q_o^t)^2}{\sum_{t=1}^{T}(Q_o^t - \overline{Q_o})^2} \quad \text{.....................................3.7}$$

Where:

$\overline{Q_o}$ = Mean of observed discharge.

Q_m^t = Modeled discharge at time t.

Q_m^t = Observed discharge at time t.

Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. The process continued (calibration process) till simulation of validation-period stream flows confirmed that the model performs satisfactorily. Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals. (Refsgaard, 1997)

3.5. Modeling

When a new watershed is created, HEC-ResSim generate a directory structure and stores all files associated with the watershed inside that structure. HEC-ResSim is a planning and real time decision-support tool for single and multi-reservoir system management. This software performs hydrologic routing and determines releases based on a rule curve approach plus user-specified operating rules to meet multipurpose, seasonal, at-site and downstream operational goals, including flood reduction, water supply, hydropower generation and stream flow generation. Hec-ResSim comprises three separate set of functions called Modules. These modules are Watershed Setup, Reservoir Network, and Simulation.

HEC-ResSim creates a new watershed directory in the base directory. The watershed directory is named according to the name given to the watershed. The watershed directory stores all of the base data for the watershed, including maps, schematic elements, base model data, and simulation data and results. (Joan D. Klipsch , Marilyn B. Hurst, 2013)

3.5.1. Koka reservoir watershed setup

The background image that describes the Geo-referenced area of the watershed was imported from Arc View (GIS) (figure 4.1). This helps to draw the stream alignment properly following the background map and put the reservoir dams and its computation points at the appropriate positions. The unit to be used in the system is SI unit and the international time zone of the area was set to be GMT+3. Items that describe the watershed’s physical arrangement are computation points, streams, and reservoir; were drawn using their mouse tools provided in the watershed setup window.

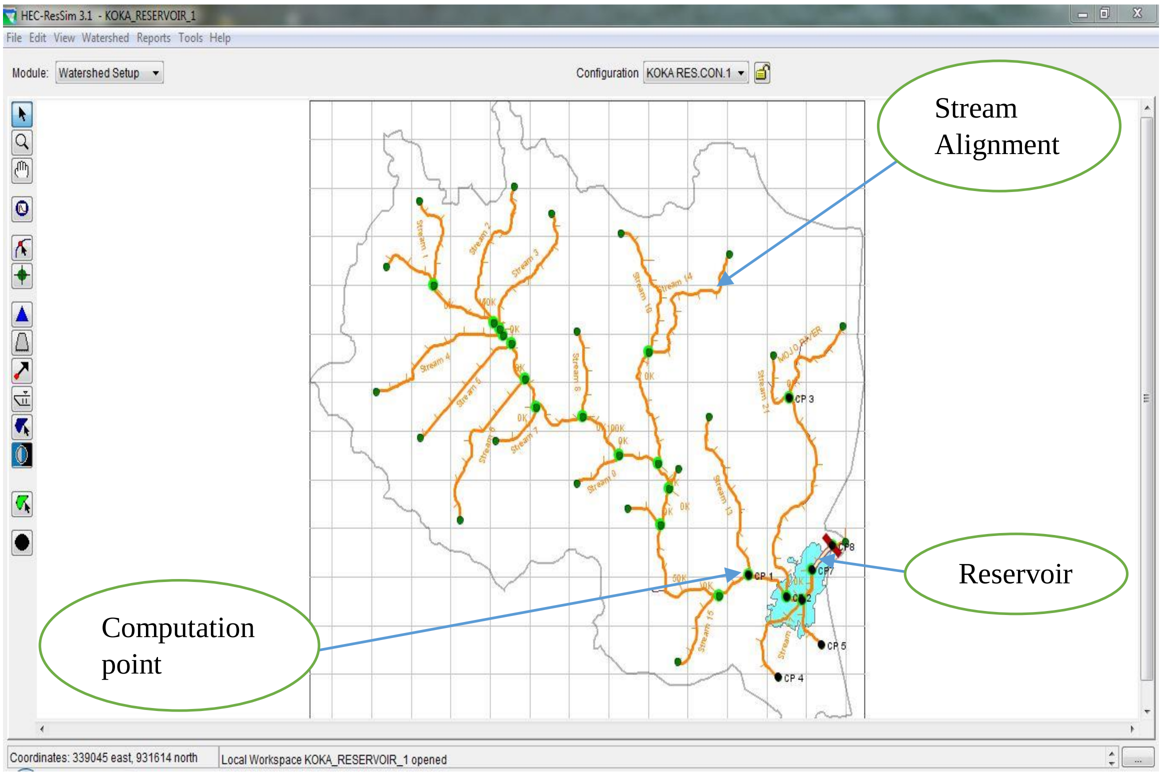

Figure 3.13 Koka reservoir watershed setup

3.5.2. Koka reservoir network setup

After the watershed setup is complete, building of the river system schematic, describe the physical and operational data for each network element are incorporated. Using configurations that are created in the Watershed Setup Module as a template, the basis of a Reservoir Network has been created. The network components that are represented by HEC-ResSim for Upper Awash river basin are: junctions, routing reaches and reservoirs. Each element is defined with enough information to be physically realistic without requiring excessive detail that would bog down computation time. Alternative were also created that specify the Reservoir Network, operation set, initial conditions and assignment of DSS pathnames (time-series mapping).

- ✓ River nodes (CP1 to CP7): are the points used to add the daily flow records within 1996 – 2015 of the gauged rivers.
- ✓ Koka reservoir outlet (CP8): was the node that used to add the out let physical and operational values.
- ✓ Koka reservoir physical component: was used to add the mean monthly rate of evaporation and the characteristics curves of the reservoir.

- ✓ Koka dam physical components: was the control points used to add the dam component like, hydropower outlet and spillway capacity curves, dam crest length and elevation of top of the dam.

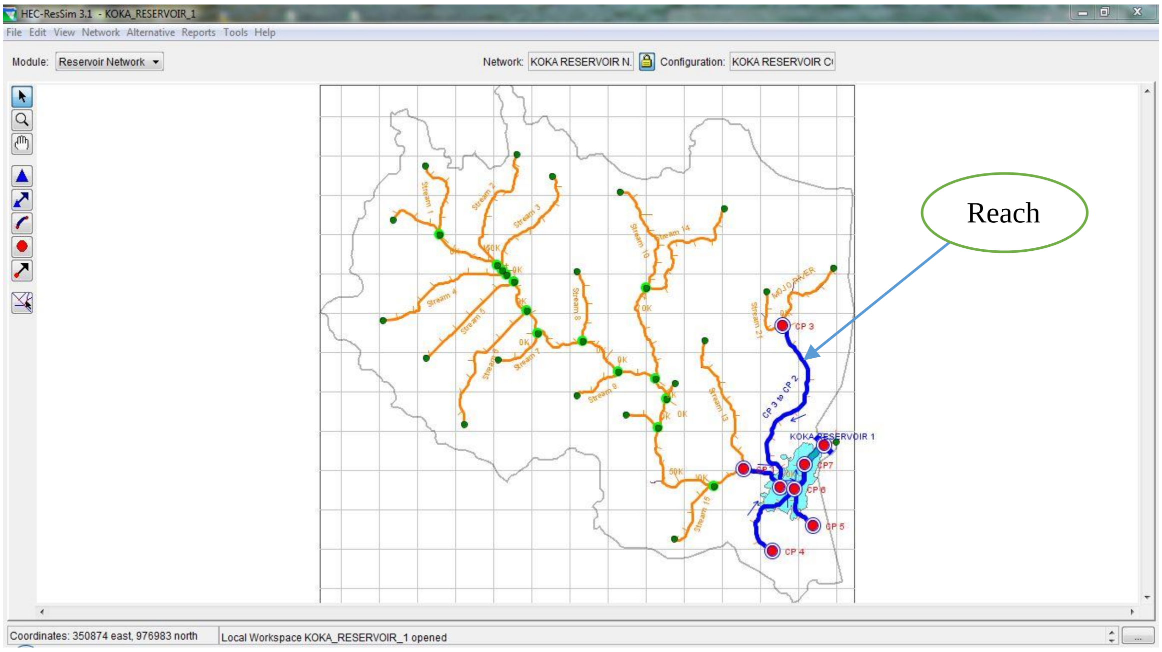

Figure 3.14 Koka reservoir network setup

3.5.3. River junction

The junction element link model elements together, they are the means by which enters the network, combine flow, and the outflow of a junction is the sum of the inflows to the junction.

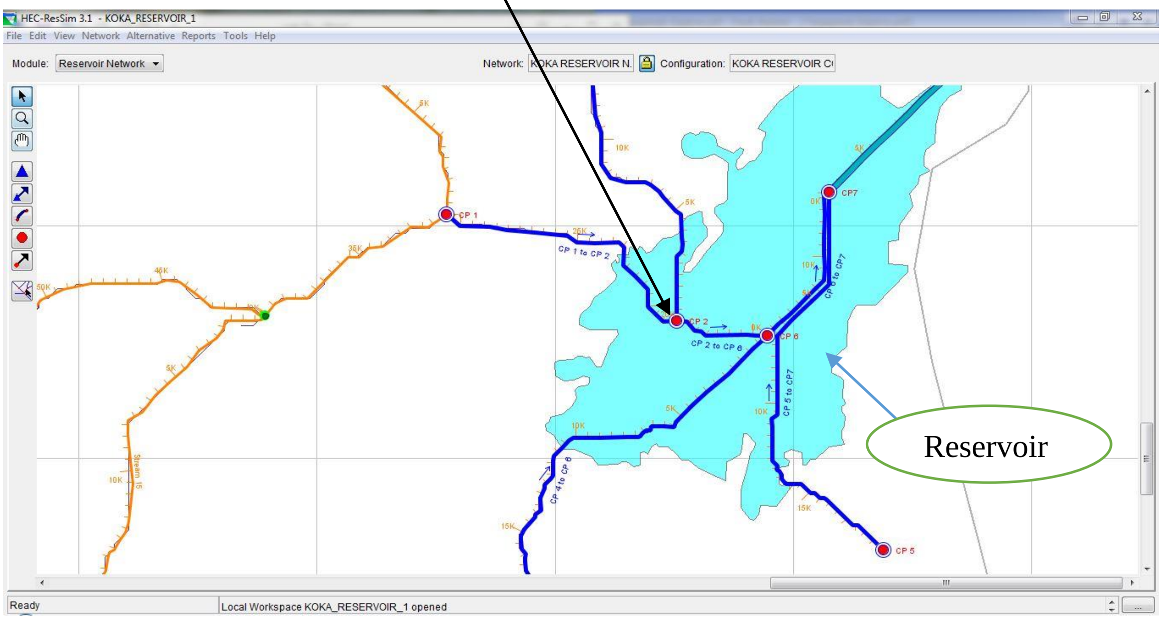

Figure 3.15 Koka reservoir junctions

3.5.4. River reaches

Routing reaches represent the natural stream in the system that route water from one junction to another in the network. Routing is performed in HEC-ResSim using one of a handful of hydrologic routing methods. The routing reaches parameters computed using Kirpich's formula for the river channels conveying flows from remote distances to the reservoir inlet to be used as inputs for Muskingum method.

The Muskingum method is used for this study the Muskingum routing method requires three parameters, the Muskingum K, Muskingum X, and the number of sub-reaches. The K parameter is the travel time of the flood wave through the reach, the X parameter is used to model the attenuation of the flood wave due to channel and overbank storage, and the number of sub-reaches is an additional parameter that affect the amount of attenuation through the reach. The X parameter is dimensionless and can vary from 0.0-0.5. A value of 0.0 maximizes attenuation of the flood wave and a value of 0.5 does not attenuate the flood wave indicates a "direct translation" of the hydrograph through the reach. K is approximated using Kirpich's formula:

$$K = 0.0078L * S^{-0.385} \qquad \text{.......................................3.8}$$

Where:

K = Travel time for drop of water to travel from the remotest point outlet (minute)

L = Length of channel/ditch from head water to outlet (ft)

S = Average watershed slope (ft/ft).

The computed (K) in hr, X and the number of sub-reach values have been entered as an inputs to reach editor of the reservoir network model as shown in the table below.

Table 3.4 Reach values in the reservoir network

Computation points	Reach length (ft)	Reach slope	X	K (hr)
CP 1 – CP 2	101,082.68	0.0257	0.3	3.79
CP 4 – CP 6	80,282.15	0.0133	0.3	4.10
CP 3 – CP 2	167,322.83	0.0432	0.3	4.58
CP 5 – CP 7	62,664.04	0.0411	0.3	2.19
CP 2 – CP 6	60,498.69	0.0242	0.3	2.62
CP 6 – CP 7	47,211.29	0.0231	0.3	2.2

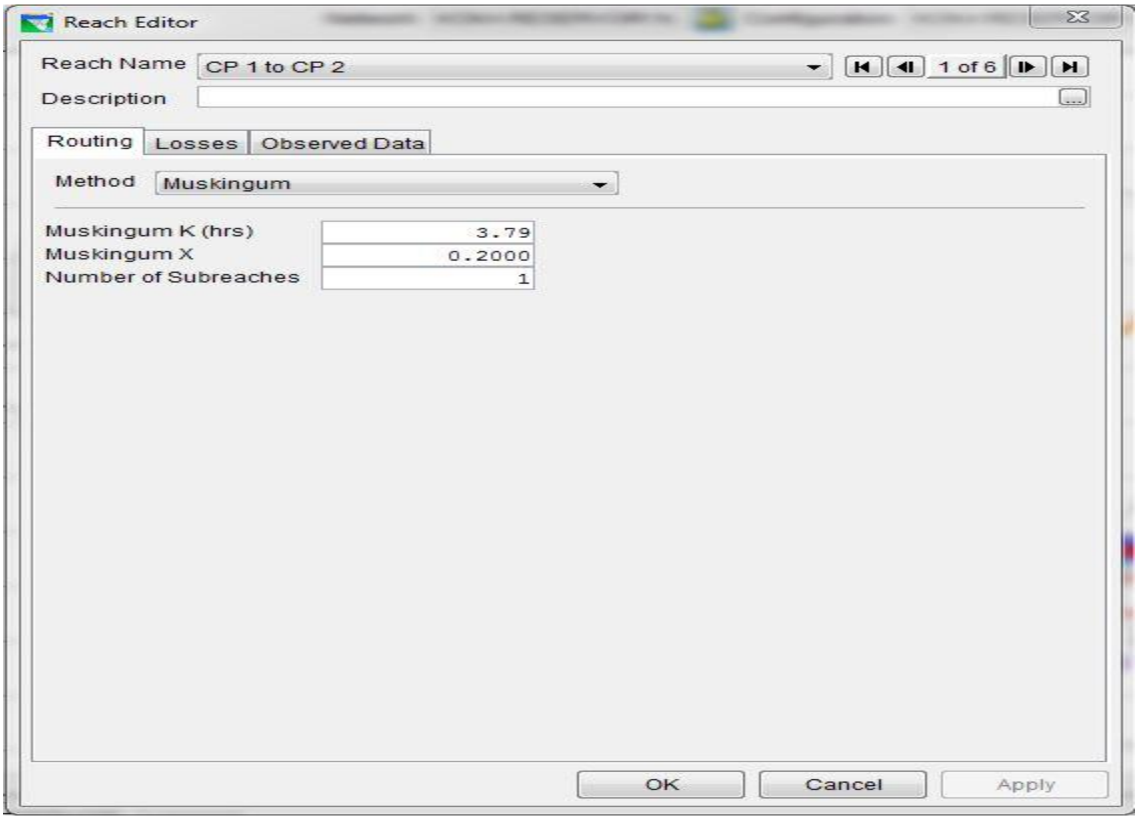

Figure 3.16 Routing reach input data

3.5.5. Reservoir

A reservoir is the most complex element of the reservoir network and is composed of a pool and a dam. HEC-ResSim assumes that the pool level and its hydraulic behavior is partly defined by an elevation – storage – area table.

The pool is described by the reservoir's elevation – storage – area relationship and can optionally include evaporation and seepage losses. The dam represents both uncontrolled outlet and an outlet group – the top of dam elevation and length specifies the minimum parameter for uncontrolled spillway and the dam may contain one or more controlled or uncontrolled outlets. The advanced outlet types are power plant and pump, both of which are controlled outlets with additional features to represent their special purposes. The power plant add the ability to compute energy production to the standard controlled outlet. Reservoir elements also hold the operational data for a reservoir. The operational data represents the goals and constraints that guide the release decision process. The operation data is grouped as a unit called an operation set. A reservoir can hold multiple operation sets, but only one operation set per reservoir may be used in an alternative.

Once the reservoir Network elements are added to the watershed setup, the reservoir network is developed. Each reservoir characteristics has to be carefully provided with the appropriate physical and operation data for the proper and realistic simulation of the Reservoir system.

Physical Components

Definition of physical parts is one of the most important parts in HEC model. Even small changes affect significantly the system behavior and the impacts deteriorate or meliorate the result in the simulation part. Input that should be considered for the physical part consists of the reservoir pool characteristics which are defined by the storage – elevation – area curve and the dam properties that consist of uncontrolled and controlled outlets along with tail water elevation and the downstream control.

i. Storage-Elevation-Area

The elevation storage area curve is the main characteristics of the reservoir pool defining the surface area and the volume of storage at the respective elevation. Elevation – Storage – Area curves are shown in section 3.1.4. However, the input of elevation storage area from a spread sheet for shown for the Koka Reservoir in ResSim in shown in figure 3.17.

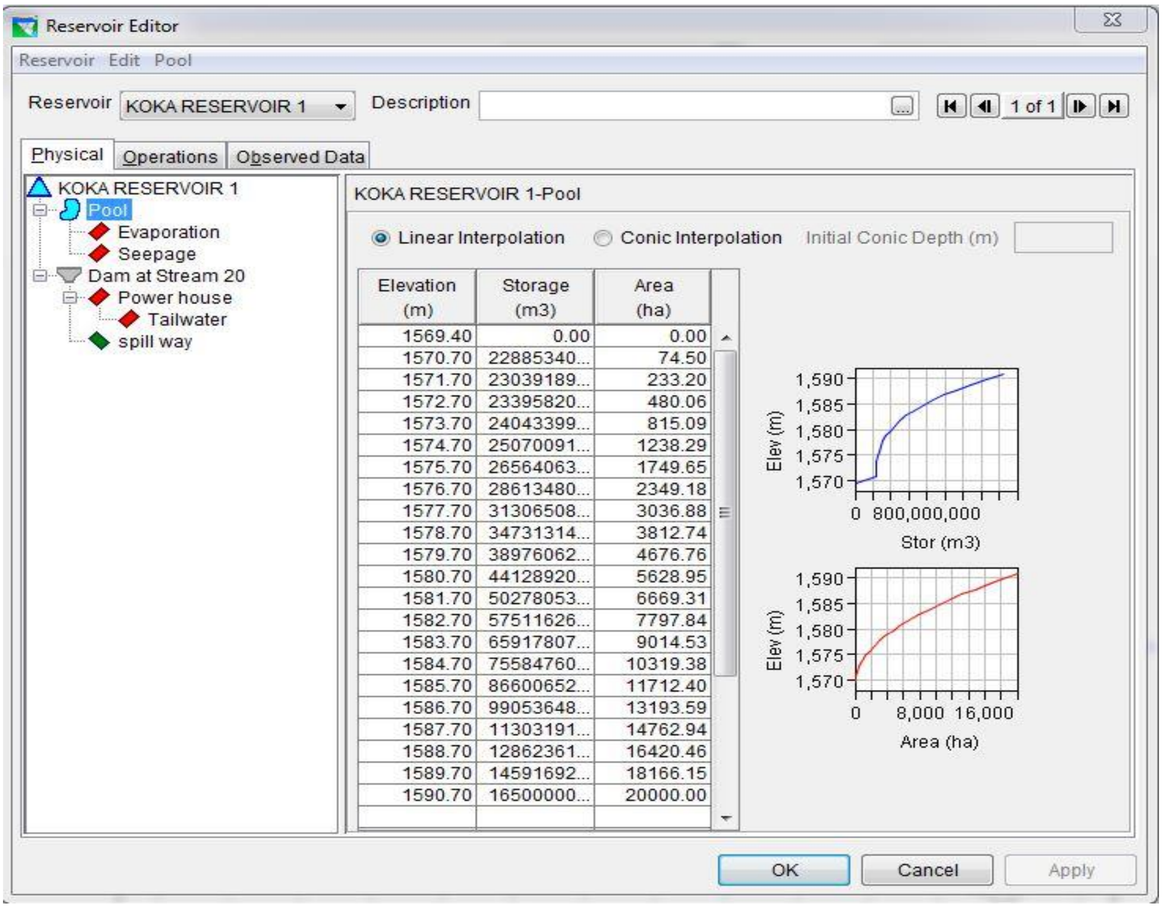

Figure 3.17 Koka reservoir pool elevation area volume data

The evaporation data for Koka reservoir pool is inserted from Excel spread sheet calculated by energy balance method as discussed above section 3.2.3. The pool seepage referred from previous feasibility study (i.e seepage for Koka reservoir pool 8.68cms).

ii. Power house

In the case of Koka the power house is constructed below the dam with runner center elevation of 67.5 m.a.s.l. and the installed capacity of 14.4 MW/unit; there are three unites in the power house with combined installed capacity of 42.3 MW. The hydraulic loss calculated for three different types of conveyance structures; these are Pressure tunnel, Concrete pipe, and Penstock. The elevation versus maximum capacity relation for the power house outlet will be computed for the various elevations is calculated using outlet formula, equation 3.8.

$$Q = C_d * A * \sqrt{2 * g * H} \qquad \text{.....3.9}$$

Where:

C_d = Coefficient of discharge (0.98)

A = Area of pressure tunnel (m^2)

g = Gravitational acceleration (m/s^2)

H = Elevation (m)

Tail water arises both due to hydropower outlets and spillway but in a different elevation and location according to dam topography. It can be natural channel or concert channels. Design of the tail water is important because of the risk for cavitation that can damage the system when sub critical water condition arises. The tail water elevations are adopted from the adopted from the physical data obtained from Koka hydropower plant generation supervisor (Mr. Alemu).

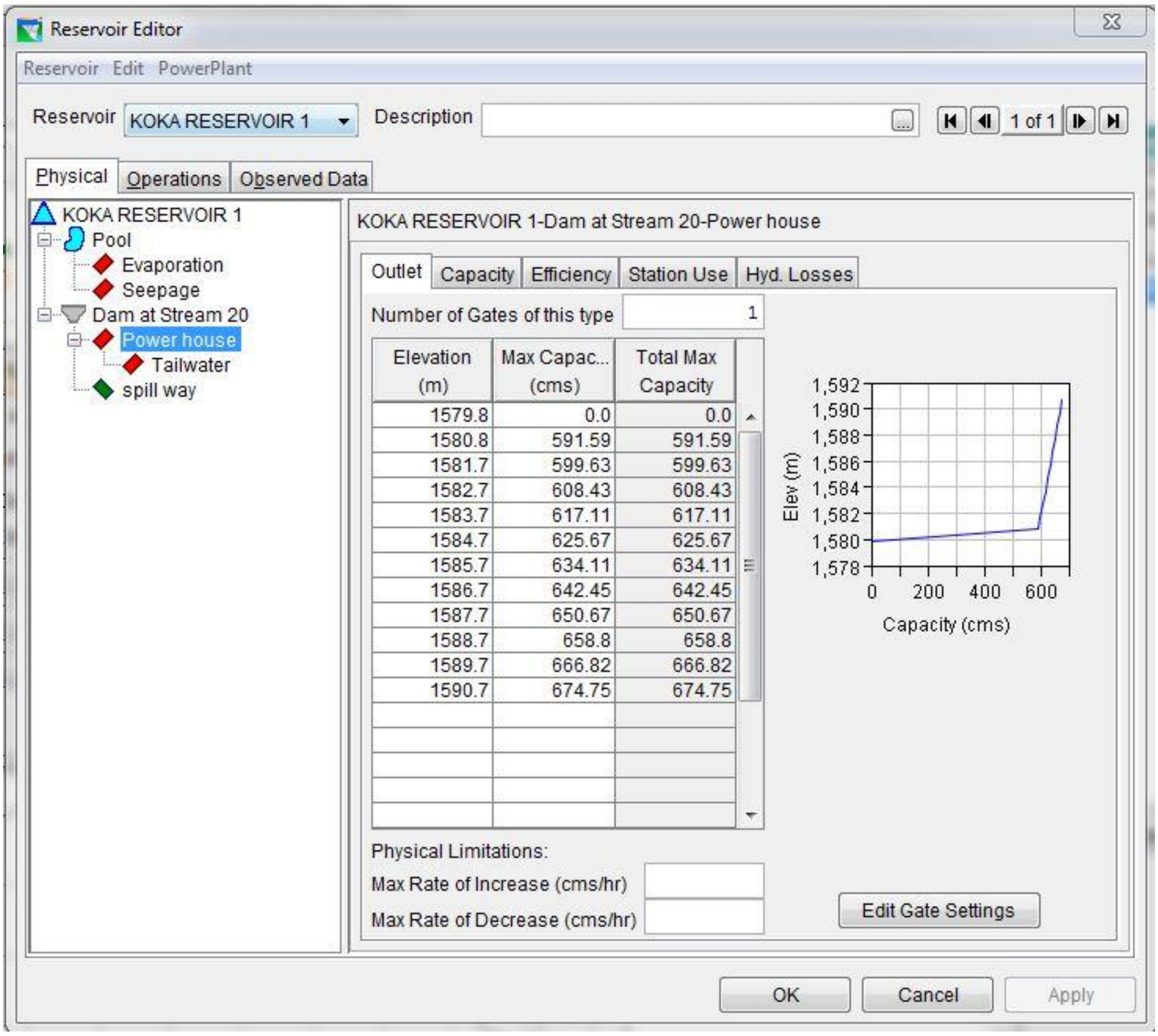

Figure 3.18 Koka reservoir power house editor

iii. Spillway

Spillway are structures constructed to provide safe release of the floods pass a dam to a downstream river stretches. Every reservoir has a certain capacity to store water. If the reservoir is full and high flows enter the same, the reservoir level increases and may eventually result in over – topping of the dam. To avoid this situation, the flood has to be passed to the downstream side and this is done either through the spillway or turbine intakes. A spillway can be a part of a concrete or connected to an embankment dam. The elevation versus maximum capacity relation for the spillway of reservoir will be computed for the various elevations above the spillway crest from the well-known broad crest weir formula, equation 3.9.

$$Q = C * L_e * H^{3/2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.9$$

Where:

Q = Discharge in the spillway (m^3/sec)

C = Coefficient of discharge which is taken as 2.05

L_e = Effective length of spillway (m)

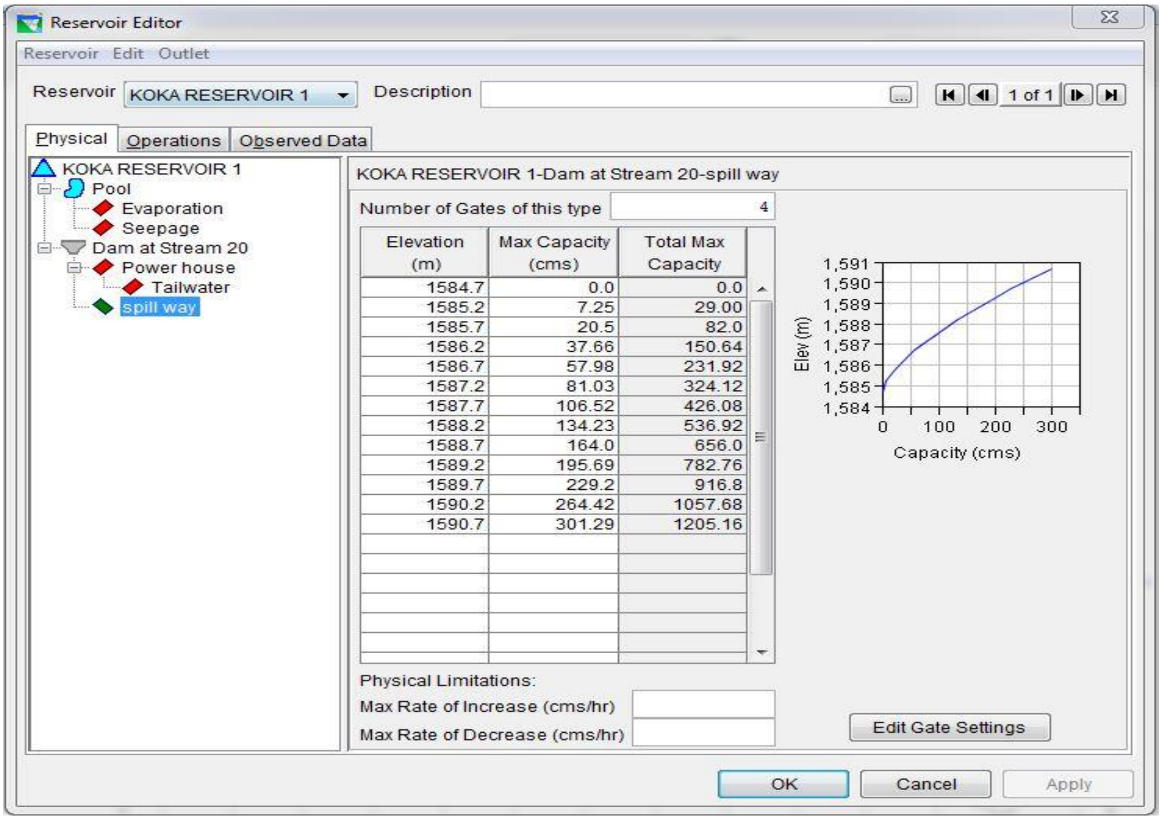

Figure 3.19 Koka reservoir spillway maximum capacity

3.6. Operation of koka reservoir

After HEC-ResSim elements are geographically placed including main stream segments, inflow points, and the dam with its connectons to the main river stream as well as dam outlet for power house and physical parameters are added for elements listed above; the next step of the HEC-ResSim setup is the definition of the operation parameters of the dam. These parameters are geometric properties of the pool, the capability of the dam spillway and the operation in conditions of flooding.

There are three reservoir storage zones defined in the Koka reservoir operation modeling: Flood control zone, Conservation zone, and Inactive zone. For each of the zones generated in the operation set, operation rules are provided.

I. Flood control zone

One rule were used in order to define the Flood control mode which is triggered when the reservoir pool just exceeds 1590.7 m.a.s.l. The first rule which was called “SPILLWAY” simply states that the spillway for reservoir dam continues to operate with maximum spill capacity of 301.29 m^3/s to relief the reservoir.

II. Conservation (Normal) zone

For the normal (Conservation) mode of operation, the only rule provided is “FIRM POWER” which reveals that the outlet for power generation is operated throughout the year. This rule gives the option to set the load factor of the power house (i.e for Koka reservoir 0.72) and power generation pattern for specific week or day.

The Conservation mode is triggered when the level of the reservoir situated between the top of conservation zone of 1590.7 m.a.s.l. and the top of Inactive zone of 1580.8 m.a.s.l.

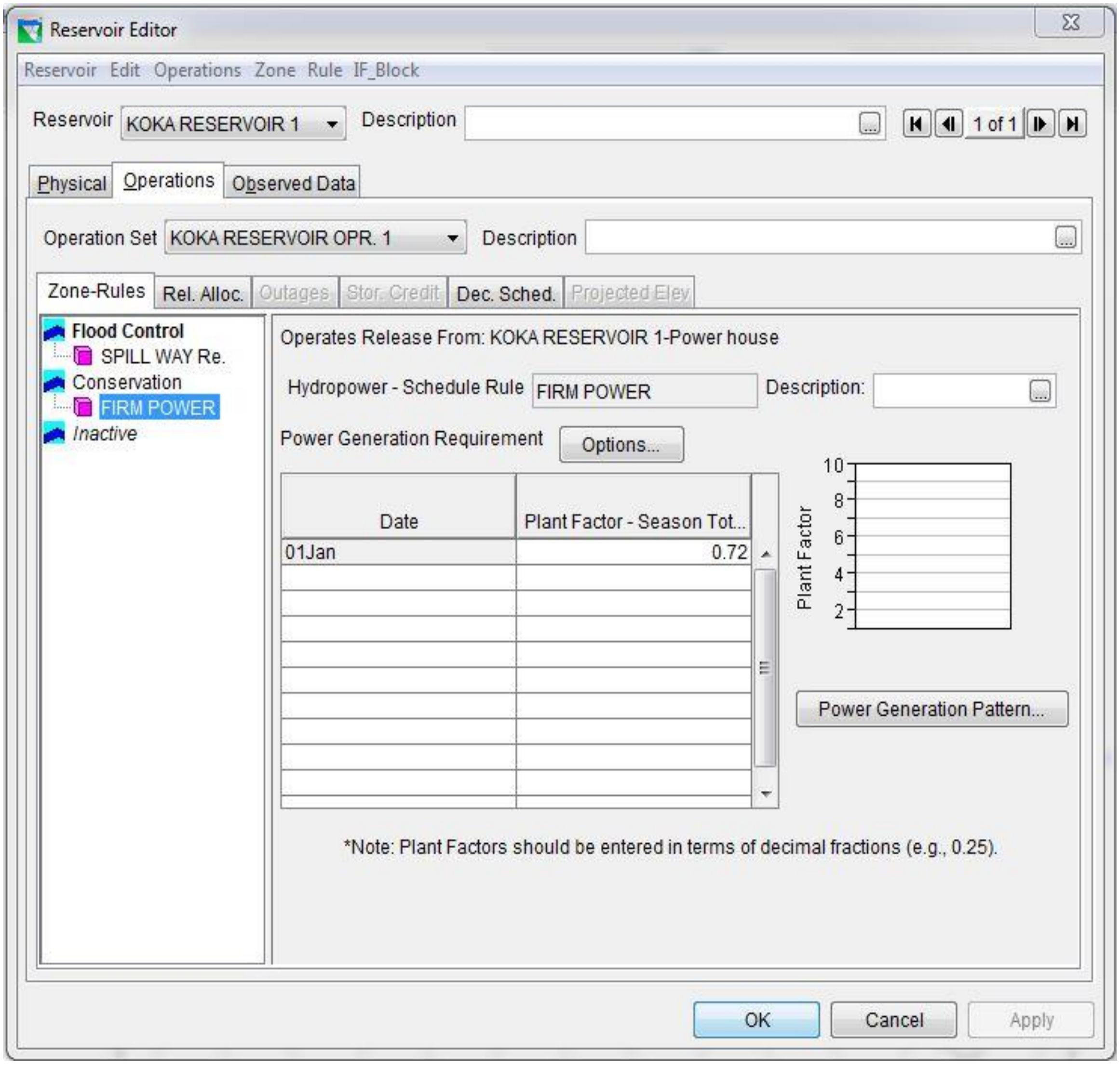

Figure 3.20 Koka reservoir operation setup

3.7. Guide curve

A reservoir in HEC-ResSim must have a target elevation. A reservoir's target elevation, represented as a function of time, is called its Guide Curve. It is the dividing line between the upper zones of the reservoir (the flood – control pool) and the lower zones (typically called the conservation pool).

Guide Curve specifies the reservoir level between the flood and hydropower pools. Guide curve operation oversees releases to maintain that storage level. The general release operation is to; release water as quickly as possible when high inflows encroach into the flood pool and raise storage above the guide curve, or curtail releases to the minimum required amounts necessary to satisfy conservation, or hydropower requirements when inflows are low and storage level is drawn-down below the guide curve.

3.8. Transferring time series data to HEC-DSS tools

The only time series data required storing in HEC-DSS file for this study were the daily in flows and water level of the reservoir, from the year 1996 to 2015. Once the time series data are converted in to HEC-DSS file format, it can be used in the simulation module of HEC-ResSim by setting the path to DSS-path for each inflow points to the reservoir in the alternative editors.

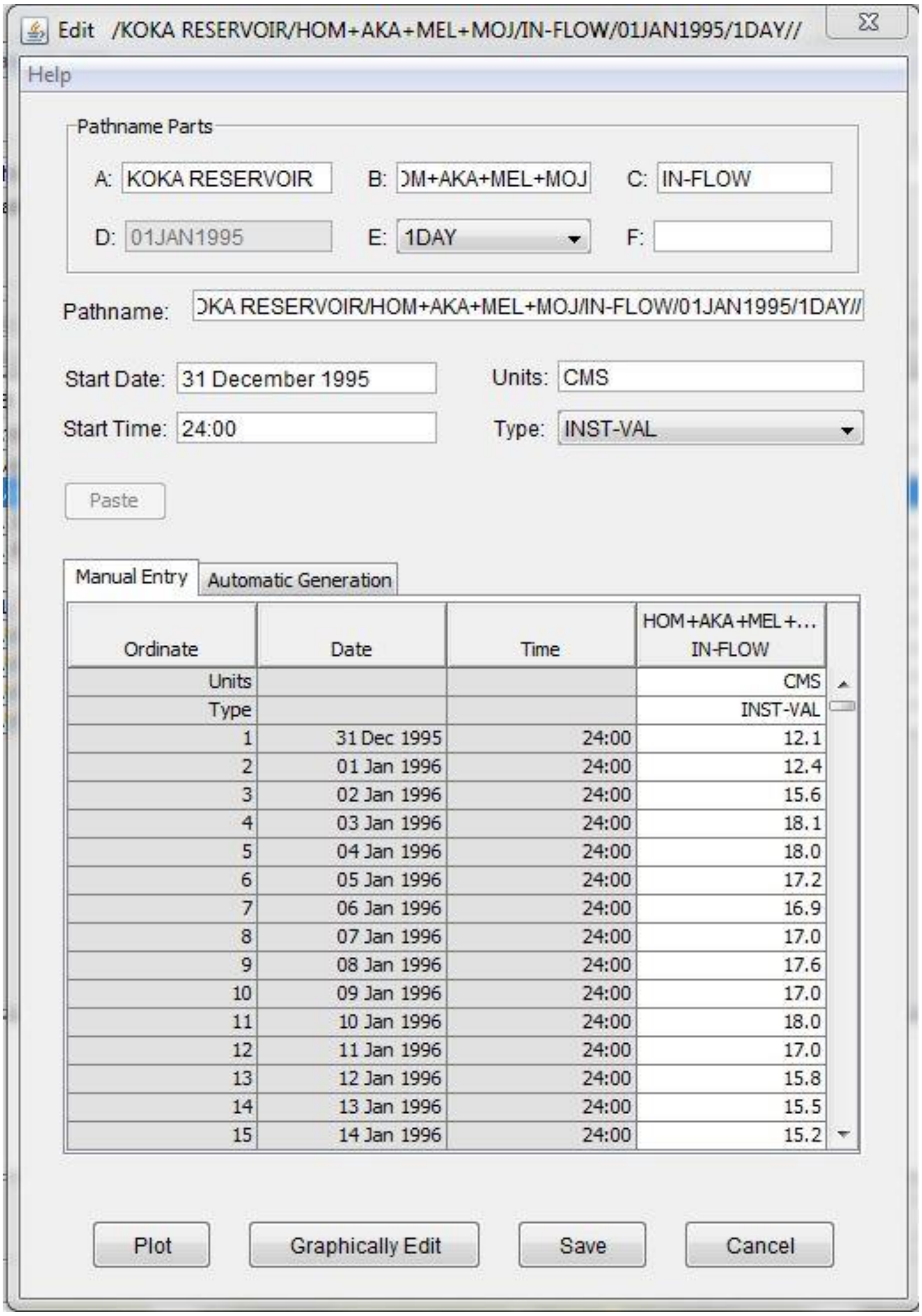

Figure 3.21 HEC-DSS pathname parts editor

3.9. Simulation procedure

The purpose of the Simulation module is to separate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the Simulation module is used to configure the simulation. The computations are performed and results are viewed within the Simulation module. During the creation of the simulation model it was a must to specify a simulation time window, a computation interval, and the alternatives to be analyzed. The time widows given for present case was starting, lock back, and end time of the simulation. Then, ResSim creates a directory structure within the rss folder of the watershed that represents the “simulation”. Also created in the simulation is a DSS file called simulation.dss, which will ultimately contain all the DSS records that represent the input and output for the selected alternatives.

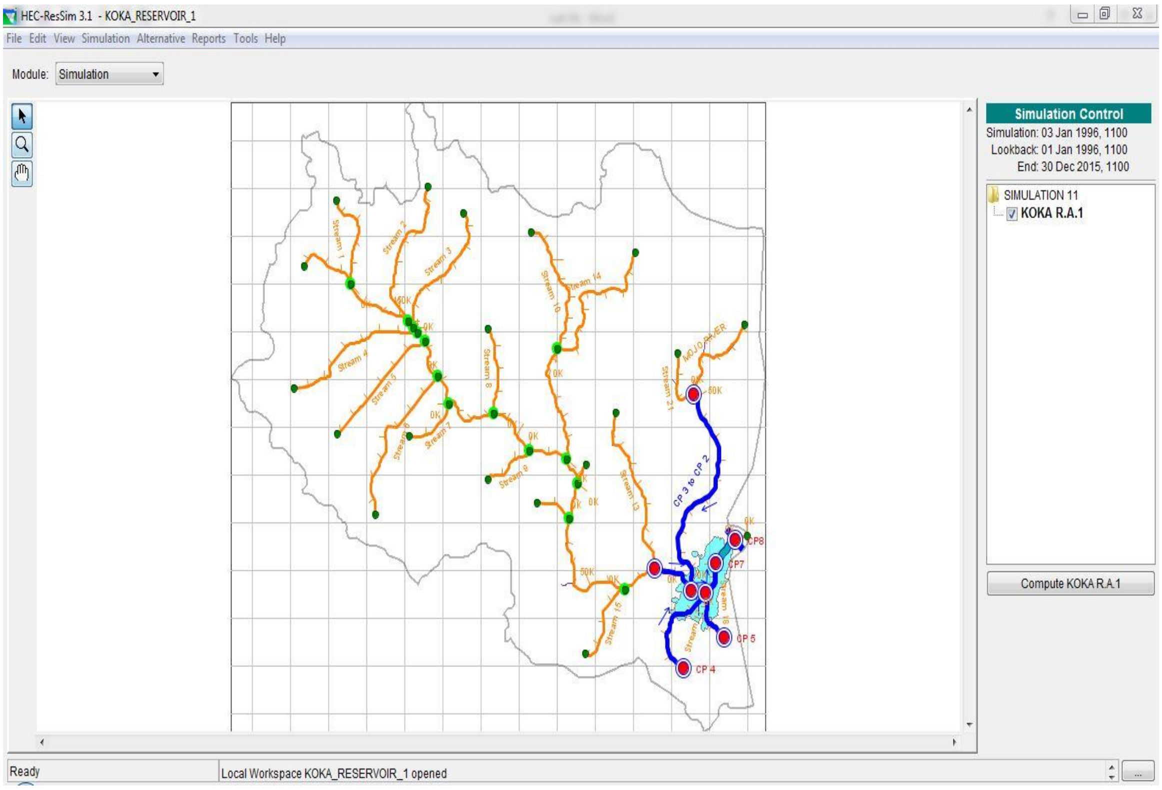

Figure 3.22 Koka reservoir simulation module

4. RESULT AND DISCUSSION

4.1 General

As mentioned previously, main objective of the study is to simulate and get optimal power generation for the Koka reservoir and prepare a rule curve to attain the optimized power and energy. After the watershed setup and reservoir network is completed different decision rules has been used. Hence, from the three modules of Hec-ResSim; simulation module is the one where the simulation results are viewed with a number of trial and error iteration.

4.2 Calibration and validation

In this study the calibration process was done by using two third of the daily time series data of stream flow (i.e. Jan 1, 1996 – Dec 31, 2005) and the validation was done for one third of the daily time series data of stream flow (i.e Jan 1, 2006 – Dec 31, 2010).

On the figure shown below the graph of the measured and simulated average monthly flow of the Mojo gauging station from 1996 to 2005 for calibration. The graph indicates that the model was correctly simulates the average stream flows on the monthly time steps.

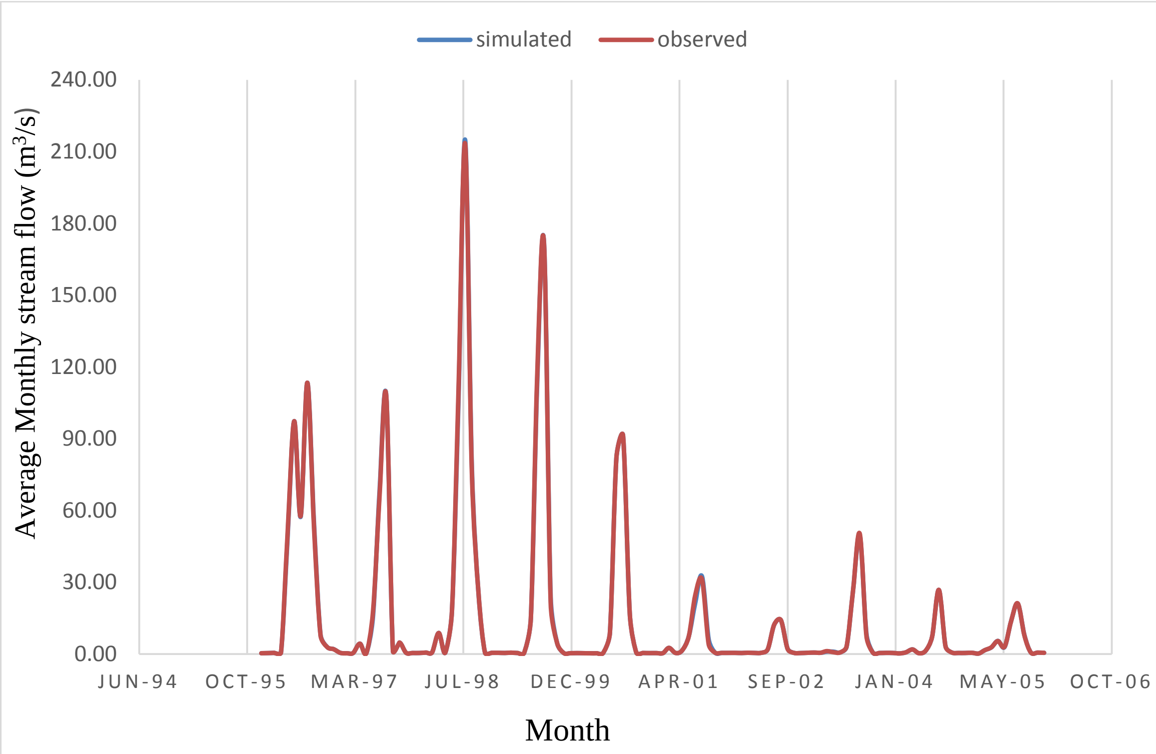

Figure 4.1 Observed and simulated monthly flow hydrograph of calibration

Validation of the model results is necessary to increase user confidence in model predictive capabilities. Thus, the model was validated with observed flow data at the same location, but different time period from January 1, 2006 to December 31, 2010. The validation graph show the model was correctly simulates the average stream flows on the monthly time steps.

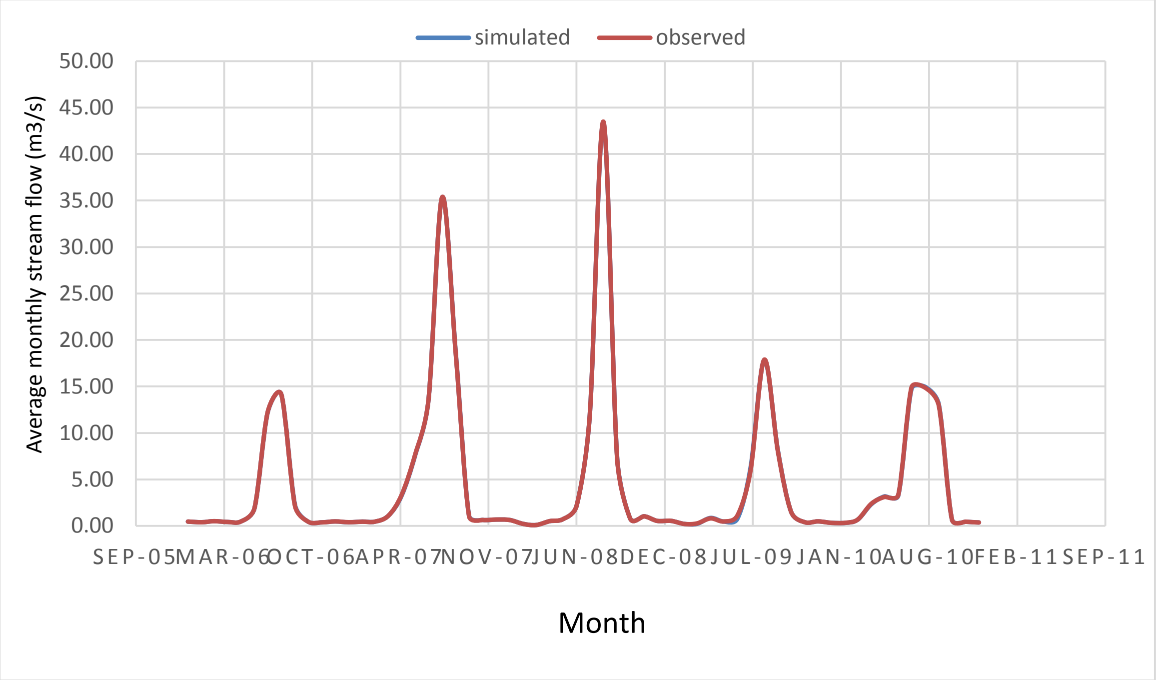

Figure 4.2 Observed and simulated monthly flow hydrograph of validation period

The Nash-Stucliffe is used in this study to assess the model performance, as well as highlight the strengths and weaknesses of the model. Nash-Stucliffe efficiency can range from -∞ to 1. An efficiency of 1(E=1) corresponds to a perfect match of modeled discharge to observed data. An efficiency of 0 (E=0) indicates that the model predictions are as accurate as the mean of the observed data. Whereas an efficiency less than zero (E < 0) occurs when the observed mean is a better predictor than the model.

Table 4.1 Calibration and validation values of koka reservoir

Location	Coefficient of determination		Nash-Stucliffe (R^2)
	Calibration	Validation	
Koka reservoir	0.84	0.82	0.81

This value shows the efficiency of model is moderate (i.e the modeled discharge is moderately match with observed data)

4.3 Inflow to and outflow from koka reservoir

Operation modeling of the reservoir has been done considering four inflow sources. Those inflow sources are Mojo, Hombole, Akaki, and Melkakuntrie. In the first case HEC-ResSim has computed the total inflows by Muskingum routing method the flow data at considerably remote distances from the reservoir inlet and finally adding all the flow time series data defined in the alternative editor.

Table 4.2 Inflow report of koka reservoir by HEC-ResSim.

Location/Parameter	Average	Maximum	Minimum
CP 1 to CP 2			
Cumulative Local Flow (cms)	96.09	1542.61	2.25
CP 2 to CP 6			
Cumulative Local Flow (cms)	212.65	3233.18	3.96
CP 3 to CP 2			
Cumulative Local Flow (cms)	10.24	311.89	0
CP 4 to CP 6			
Cumulative Local Flow (cms)	10.24	311.69	0
CP 5 to CP7			
Cumulative Local Flow (cms)	10.23	308.74	0
CP 6 to CP7			
Cumulative Local Flow (cms)	349.65	5790.28	0
KOKA RESERVOIR 1			
Regulated Flow (cms)	455.66	7382.07	0

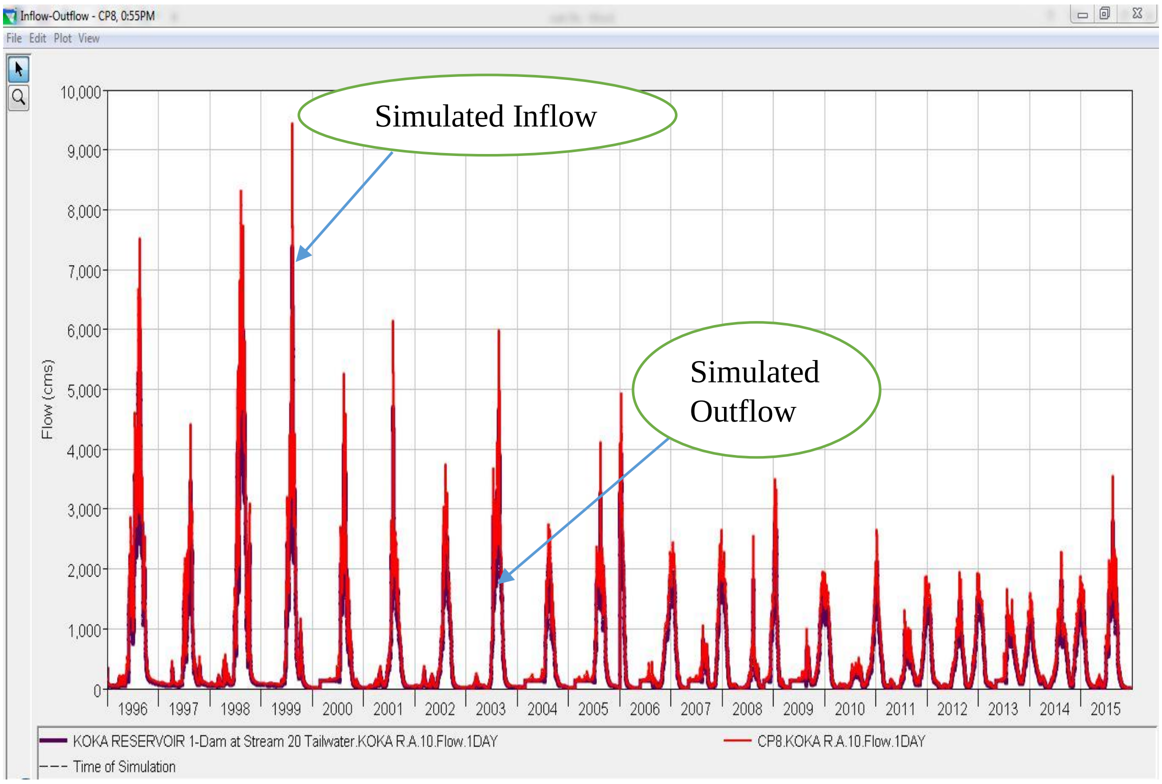

Figure 4.3 Inflow – Outflow of koka reservoir

The simulated inflow to Koka reservoir and the outflow from Koka reservoir well regulated and the outflow is through the outlet to the power house.

4.4 Koka reservoir releases

For the four inflow options considered in this study, the minimum and maximum and average releases through the outlet for power house and reservoir spillway are calculated by taking twenty year time series data. The average, maximum and minimum values shown in the table below.

Table 4.3 Summary of power house and spillway release

Location	Maximum release (m^3/s)	Average release (m^3/s)	Minimum release (m^3/s)
Power house	674.75	66.55	0
Spill way	1205.20	1.70	0

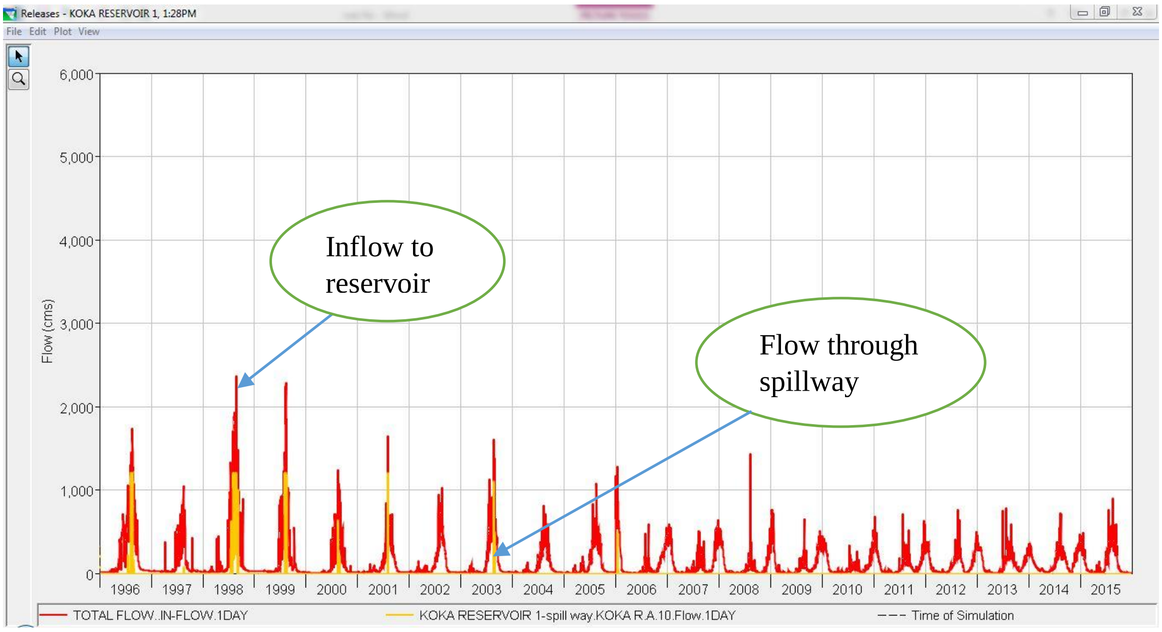

Figure 4.4 Spillway releases

The above graph shows the simulated value of the spillway release from 2006 – 2015 almost zero but from 1996 - 2005 the spillway of Koka reservoir spills water mostly in the rainy season of upper awash basin (i.e from June to September) with maximum discharge of 1205m^3/s.

4.5 Power verses release plots of koka reservoir power house

All the output results of the simulation can be retrieved from the Hec-DSSVue found under the tool command on the menu bar of the simulation window. The results can be viewed in tabular form and as plots. Since it is easy to see and understand than the tabular output some of the plots of the results are discussed in this section.

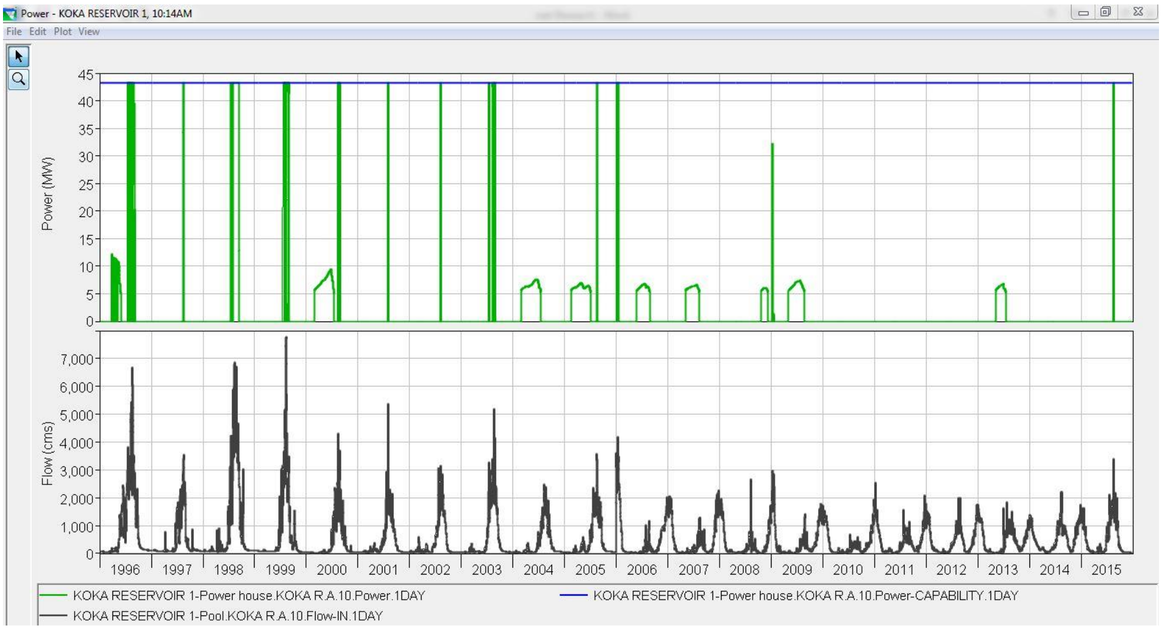

Figure 4.5 Power generated

The power house of Koka dam is mostly generating low power that compared to the design capacity and a firm power of 31.10.

4.6 Koka reservoir operation guide curve

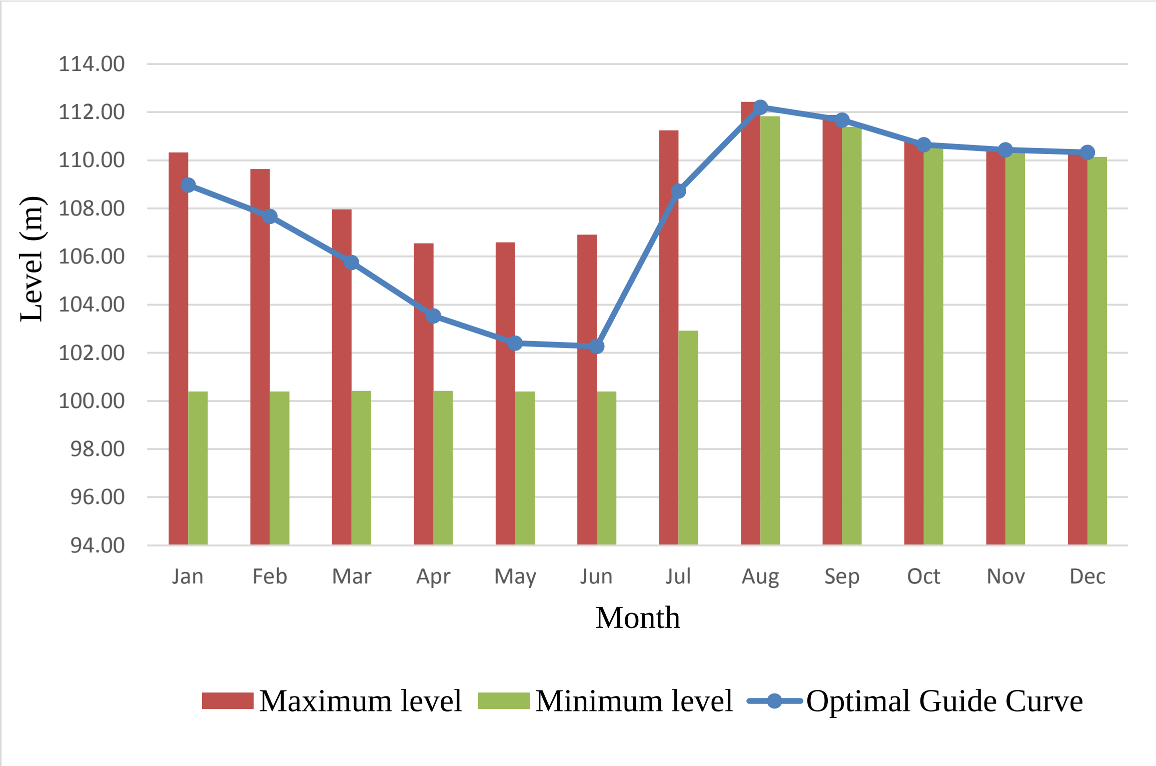

Figure 4.6 Guide curve for koka reservoir

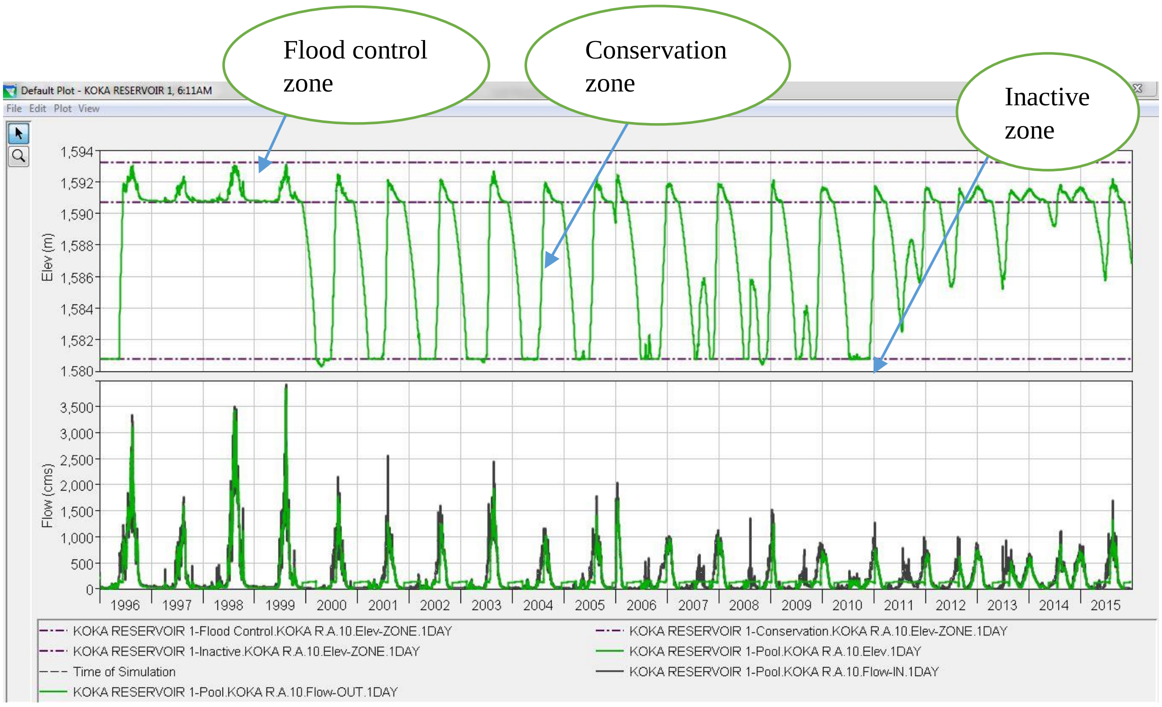

Figure 4.7 Koka reservoir pool level, inflow and outflow

The above figure shows the guide curve output plot of Hec-ResSim model for Koka reservoir. This plot shows that the level of water in Koka Reservoir is mostly in the conservation zone. The conservation zone is safe zone for power generation and low flood risk for downstream users.

4.7. Koka reservoir area

The simulated area of Koka reservoir is calculated by using taking the inflow as input data and water level of the reservoir.

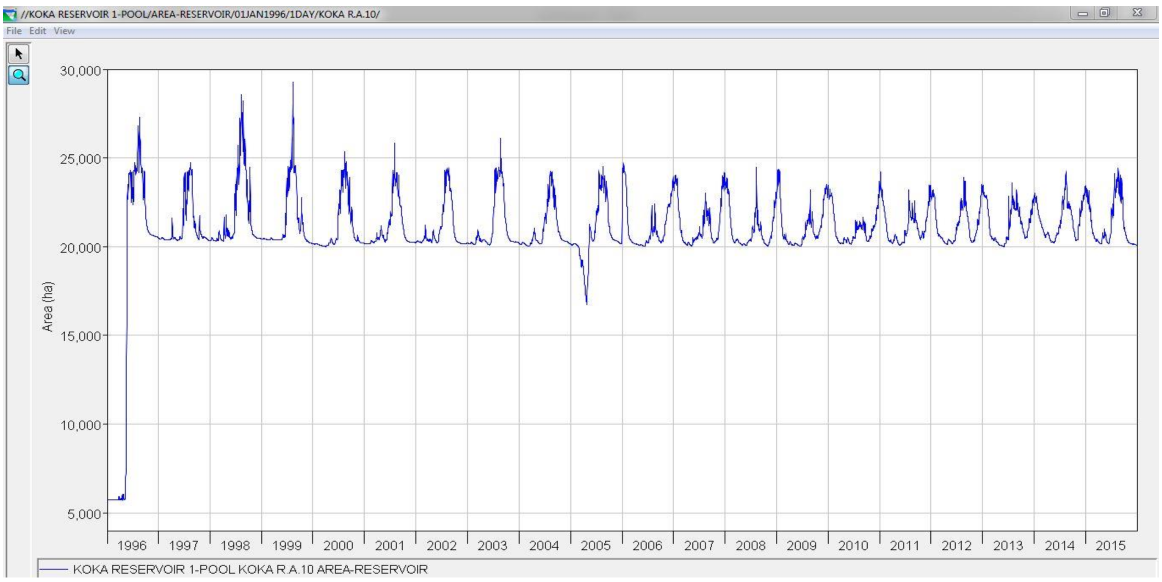

Figure 4.8 Simulated koka reservoir area

The reservoir area of the dam is varied during rainy season of the reservoir and the area exceed up to 28,000 ha from the dam to the upstream side. During the dry season the reservoir area drawdown to 17,000 ha. When the reservoir area of Koka is increased; also the evaporation and seepage from the reservoir also increased.

4.8. Koka reservoir evaporation

The evaporation data calculated at Melkasa metrological station for the duration 1996 to 2015 was used to evaluate the evaporation rate from the Koka reservoir surface. HEC-ResSim also simulate the evaporation from the reservoir.

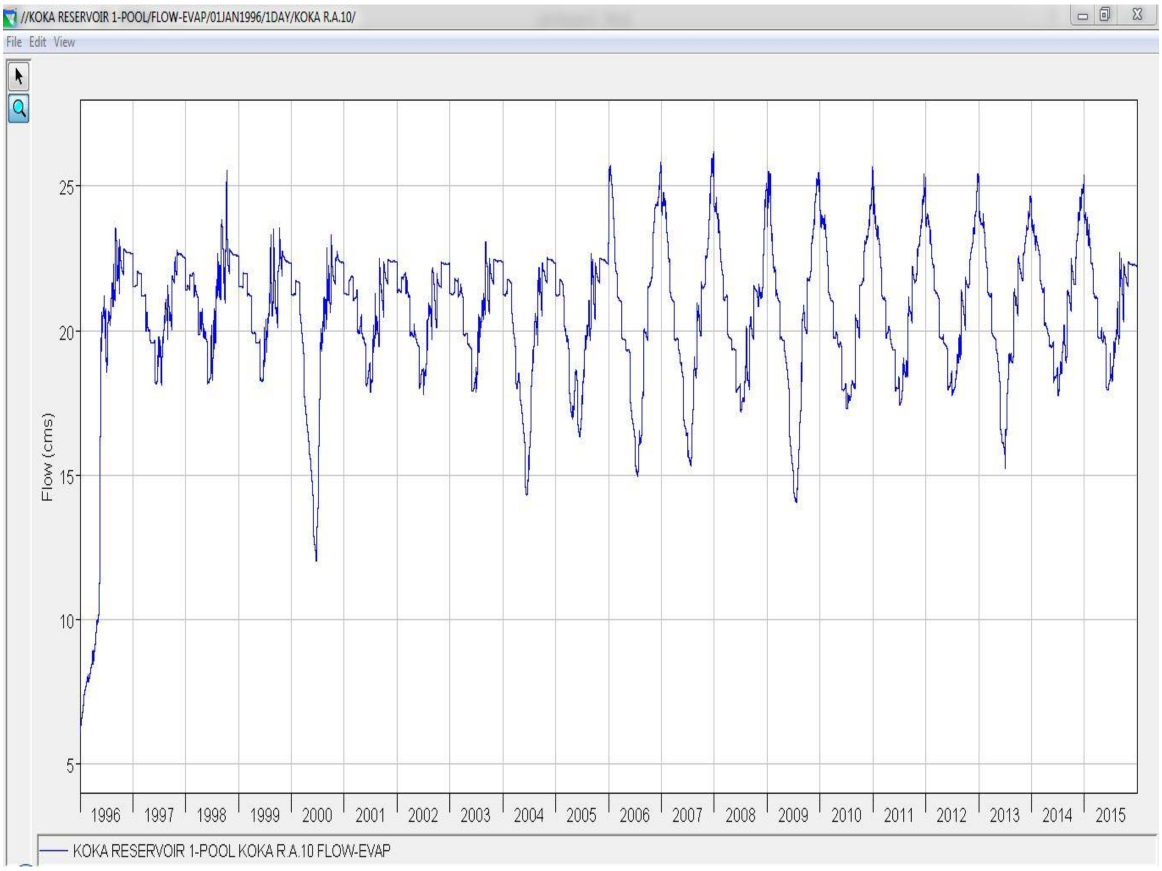

Figure 4.9 Simulated koka reservoir evaporation

A large amount of water is lost due to evaporation because of the reservoir area is very wide and the climate of upper awash is hot and with maximum evaporation of 26 m^3/s and minimum of $6m^3/s$ from open water surfaces.

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The principal aim of the study is to increase the performance of Koka hydropower plant by operating the reservoir using new Hec-ResSim3.1. Model, considering annual and seasonal hydrological variations contained in the inflow series, reservoir characteristics and operation rules, evaporation losses and downstream water requirements. All the physical and operation data has been taken from concerned governmental offices and the feasibility study of Koka reservoir.

The model calibration and validation results show as the model is sufficiently efficient to simulate. This is proved by determination of correction coefficient and Nash-Stucliffe model efficiency checking methods. Therefore the observed data is accurately simulated.

Application of whichever the Operation Guide Curve developed depends on the in-flow condition. For wettest seasons (June to September), using the Upper Guide Curve is of advantageous and for driest seasons (February to May) it is wise applying the Lower Guide Curve. For moderate seasons (October to January) applying the Average Guide Curve is advantageous. In following any of the Guide Rules developed, the purposes for which the dam has been constructed are entirely satisfied. The only difference is the amount of floods stored in the flood control zone of the reservoir for the Upper Guide Curve. The maximum and minimum releases through the outlet for the power house is 674.75 m^3/s and 0 m^3/s respectively; maximum and minimum release value for the spillway 1205.20 m^3/s and 0 m^3/s.

Finally, the operation rule curves developed for Koka reservoir can be used as a guide to determine the amount of releases through the outlet and over the spillway on daily basis operations. The Guide Curves developed are dependent on the inflows and water level. The most important inflow sources of Koka reservoir are Awash and mojo rivers.

5.2 Recommendations

The study has recommended the following points to be included in the future reservoir operation and studies for better water based development plan in the basin.

The Reservoir Operation Guide Curves developed can be deviated depending on the inflow conditions to return the reservoir pool level back to the Guide Curves. The quality and continuity of the flow recordings at Mojo and Melka kuntrie gauging stations have to be seriously maintained so that whether the Upper Guide Curve or the Lower Guide Curve has to be chosen can be decided accordingly. As the applicability of the developed operation rule entirely depends on the functionality of the outlet and the spillway, there need to be a timely follow up of the proper functioning of these structures.

The work conducted in this thesis was by employing HEC-ResSim 3.1 which still does not have ability to simulate the rainfall runoff process in the catchment, as a result outputs for reservoir and power plant simulation was dependent on the discharge inflow into the reservoirs. Hence, it is recommendable to use a stochastically generated time series of rainfall and stream flow instead observed historic hydrological data.

The Hec-ResSim optimal result is based on a successive trial and error procedure that is not fully guaranteed for the optimal value. Hence it is recommendable to recheck using optimization models.

Nowadays climate change and its impact is becoming a hot issue on different natural and manmade systems in different ways. Therefore, it is recommended to include further refinement of scenarios considering climate change impact for further analysis.

REFERENCES

1. A., B., 2010. Operation modeling for Tendaho Reservoir using HEC-ResSim., Addis Ababa: s.n.
2. Awlachew S.B., M. MCcartney, Tammo S., Steenhuis and Abdalla A. Ahmed., 2008. A review of hydrology, sediment and water resource use in the Awash basin, Addis Ababa, Ethiopia: s.n.
3. Birhanu.A, 2008. Water Allocation Study of Upper Awash Valley for existing and future demand., Addis Ababa: s.n.
4. Chow V.T. , Maidment M.R. , and Mays L.W., 1998. Applied Hydrology. New York: McGrew-Hill.
5. Engineers, U. A. C. o., 2010. HEC-DSSVue, Hydrologic Engineering center Data Storage System, C.A: s.n.
6. Fanuel.W, 2009. Abay basin water allocation modeling using HEC-ResSim. Addis Ababa: Hydraulic Engineering department.
7. Garg, S. K., 2005. Irrigation Engineering and Hydraulic Structures. Delhi: Khanna.
8. Halcrow, 1989. Awash River Basin Master Plan, Addis Ababa: s.n.
9. Halcrow, 2005. Awash River Basin flood control and Watershed Management, Addis Ababa: s.n.
10. Joan D. Klipsch , Marilyn B. Hurst, 2013. HEC-ResSim, Reservoir system Simulation, Davis: U.S Army corps of Engineers.
11. Loucks, D.P. Stedinger, J.R. and Haith, D.A., 1981. Water resources systems planning and analysis. Engle wood Cliff(New Jersey): Pentic-Hall, Inc.
12. Lund, J. R., 1996. Developing Seasonal and Long-Term Reservoir System OperationPlans Using HEC-PRM, s.l.: U.S. Army Corps of Engineers Hydrologic Engineering Center,U.S.A.
13. Maidment, D., 1992. Hand book of Hydrology. s.l.:Mc Grew-Hill Inc.
14. McCarteny, M., 2007. Decision support systems for large dam planning and operation in Africa.. s.l.:International Water Management Institute colombo.
15. Moseley, D. E. a. J., 1971. Simulation/optimization Technique for multi-basin Water resources planning.. Water Resources Bulletin.
16. Refsgaard, J. C., 1997. Parameterisation, calibration, and validation of distributed hydrological models. J. Hydrol.198(1), pp. 69-97.
17. Richter, B.D. & Thomas, G.A., 2007. Restoring Environmental Flows By Modifying Dam Operations. Ecology and Society. [Online]
18. S., P., 1998. Establishing Water Release Rules for Koka Reservoir for wet Seasons, Addis Ababa: s.n.
19. Skoulikaris.C, 2008. Mathematical modeling applied to the sustainable management of water resources projects at a river basin scale-the case of the Mesta-Nestos., Greece: s.n.
20. Subramanya, K., 1994. Engineering Hydrology. Tata: McGraw-Hill Education.

21. Sufiyan.A, 2014. Seiment yield Estimation from upper Awash Watershed: Sedimentation in Koka Reserovir Ethiopia., Arbaminch: s.n.

22. Tsegazeab.D, 2014. Tandem Reservoir operation of cacade Hydropower plant case of Genale - Dawa River Basin, Addis Ababa: s.n.

23. WWDSE., 2005. Tendaho Dam and Irrigation Project Design Reports, Addis Ababa: MoWR.

24. Y., Z., 2011. Estimation of Sediment Yield of mille Watershed in to Tendaho dam, Arba minch: s.n.

25. Yeh, W., 1985. Reservoir Management and operation models. Water Resources research.

APPENDICES

Appendix-1 Summary report of HEC-ResSim Simulation Module

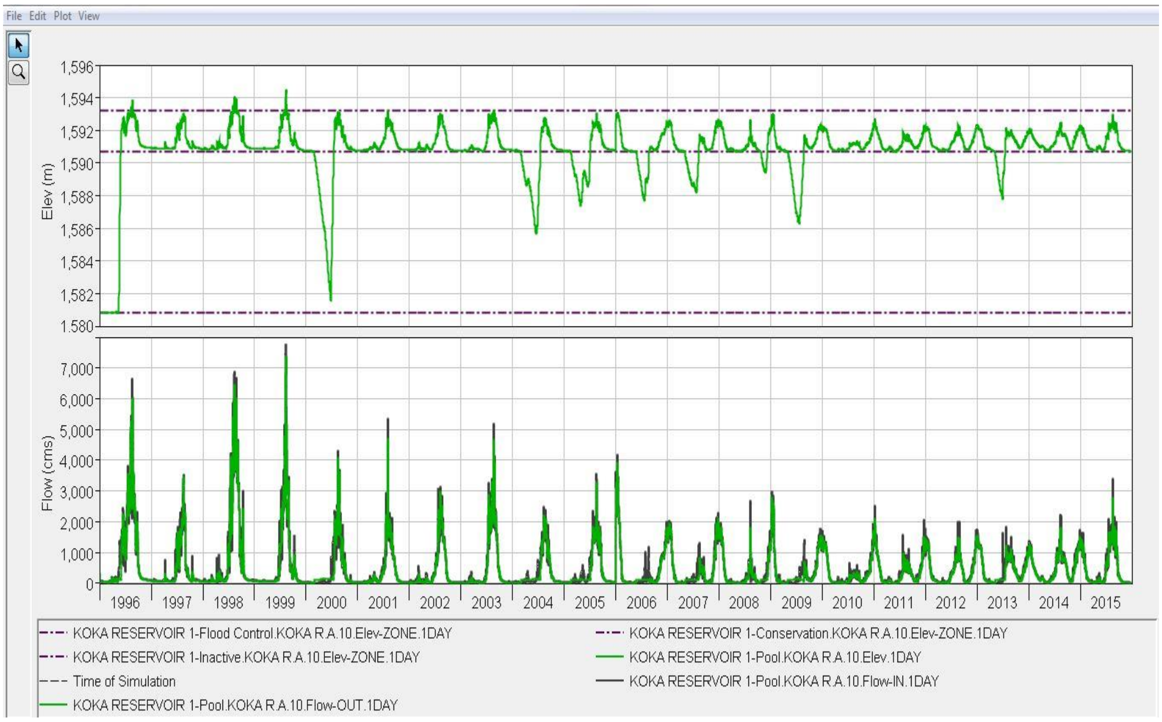

Fig 1.1 Koka reservoir storage and elevation curve

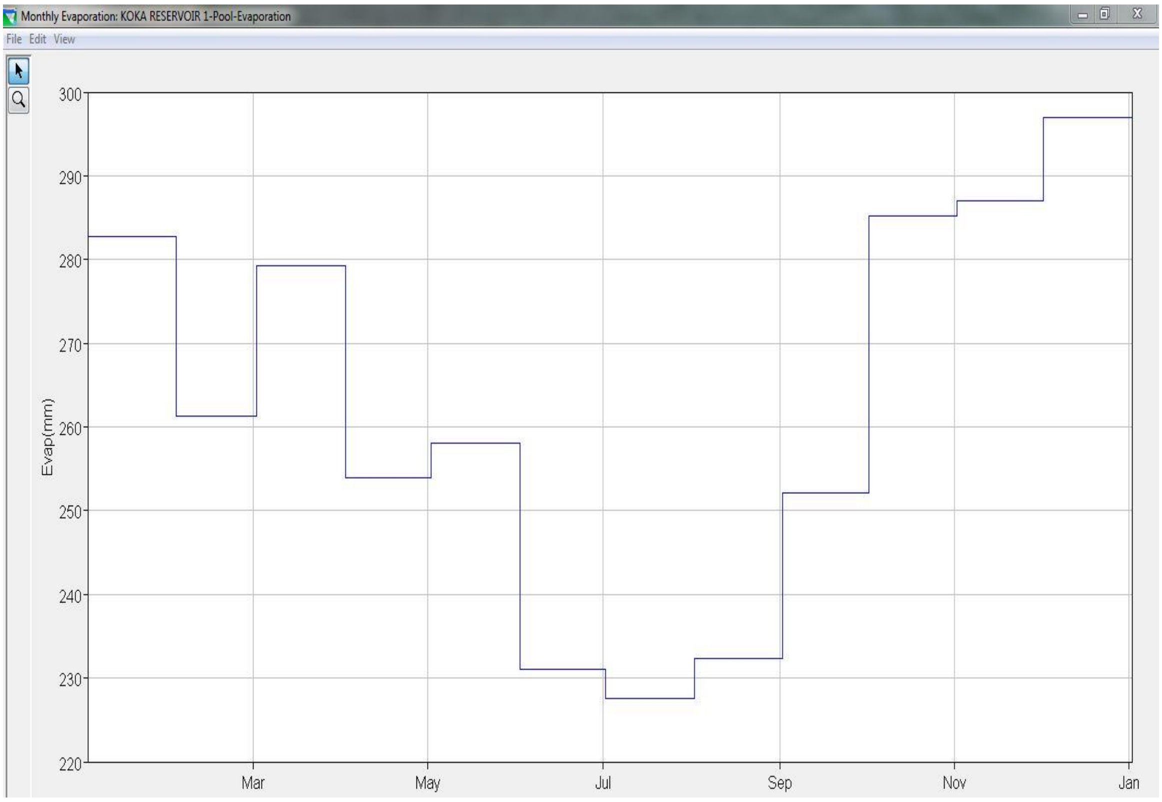

Fig 1.2 Koka reservoir monthly Evaporation

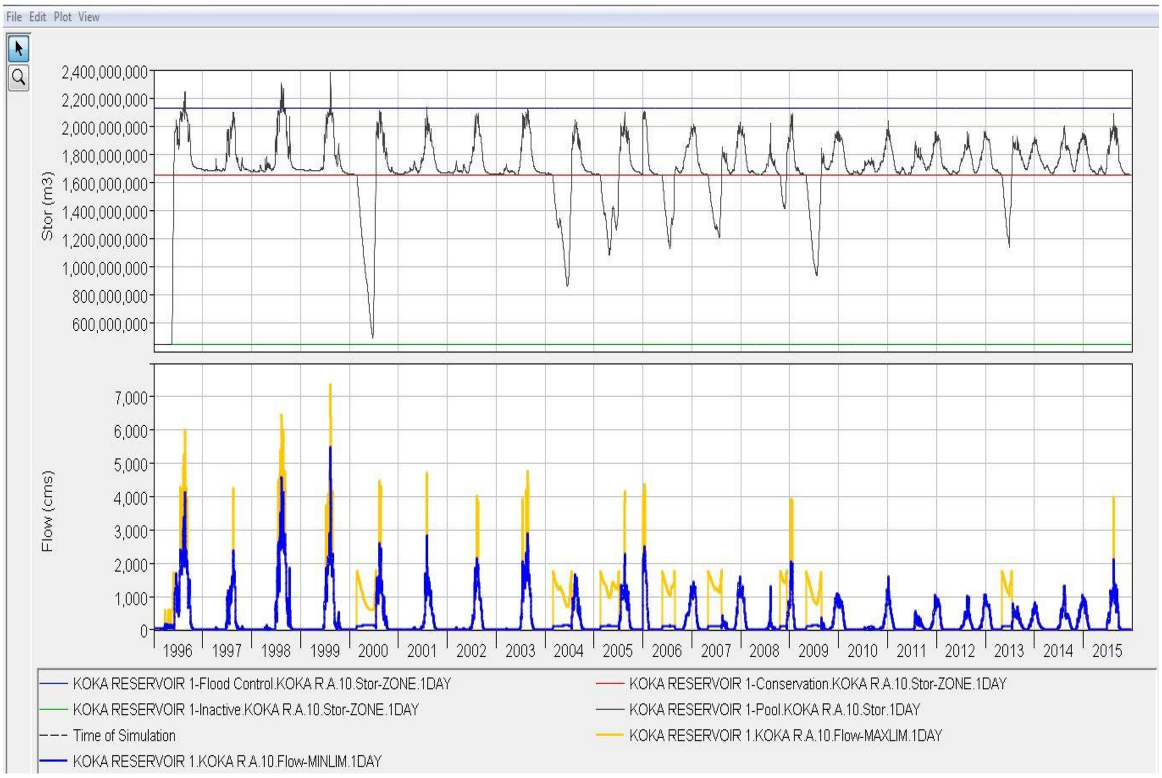

Fig 1.3 Operation curve of Koka Reservoir

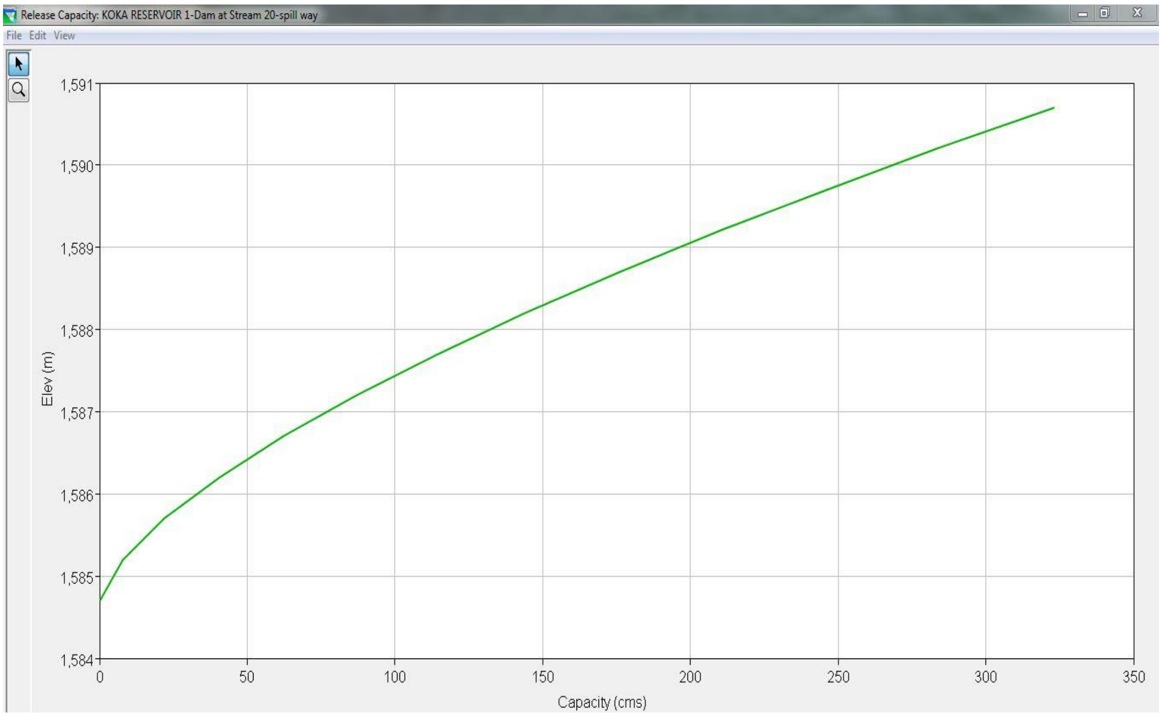

Fig 1.4 Release capacity of Koka dam spillway

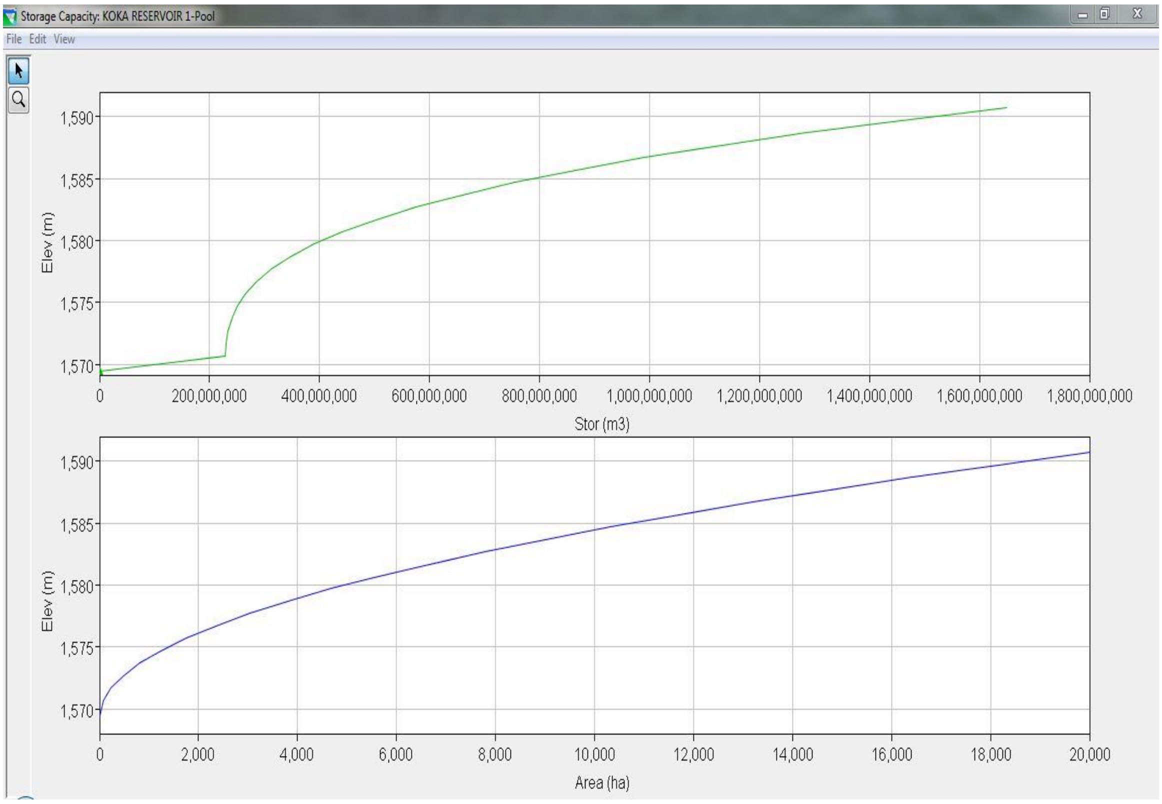

Fig 1.5 Elevation – Area- Storage curve of Koka Reservoir pool

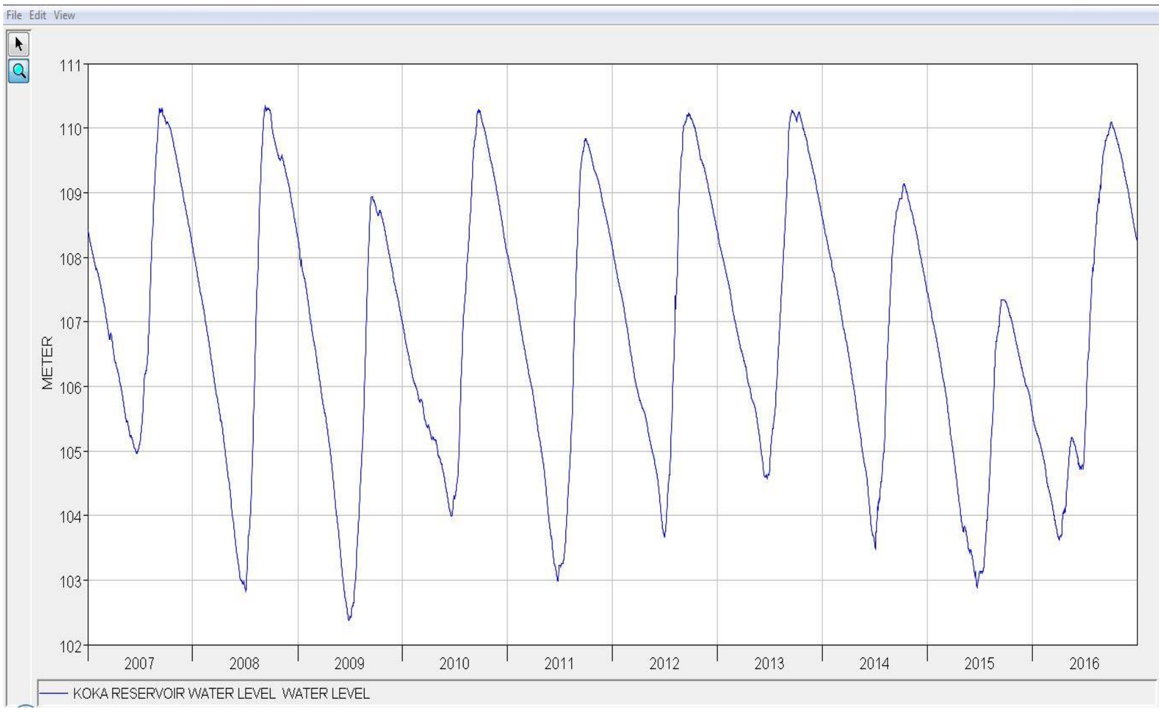

Fig 1.6 Koka reservoir water level

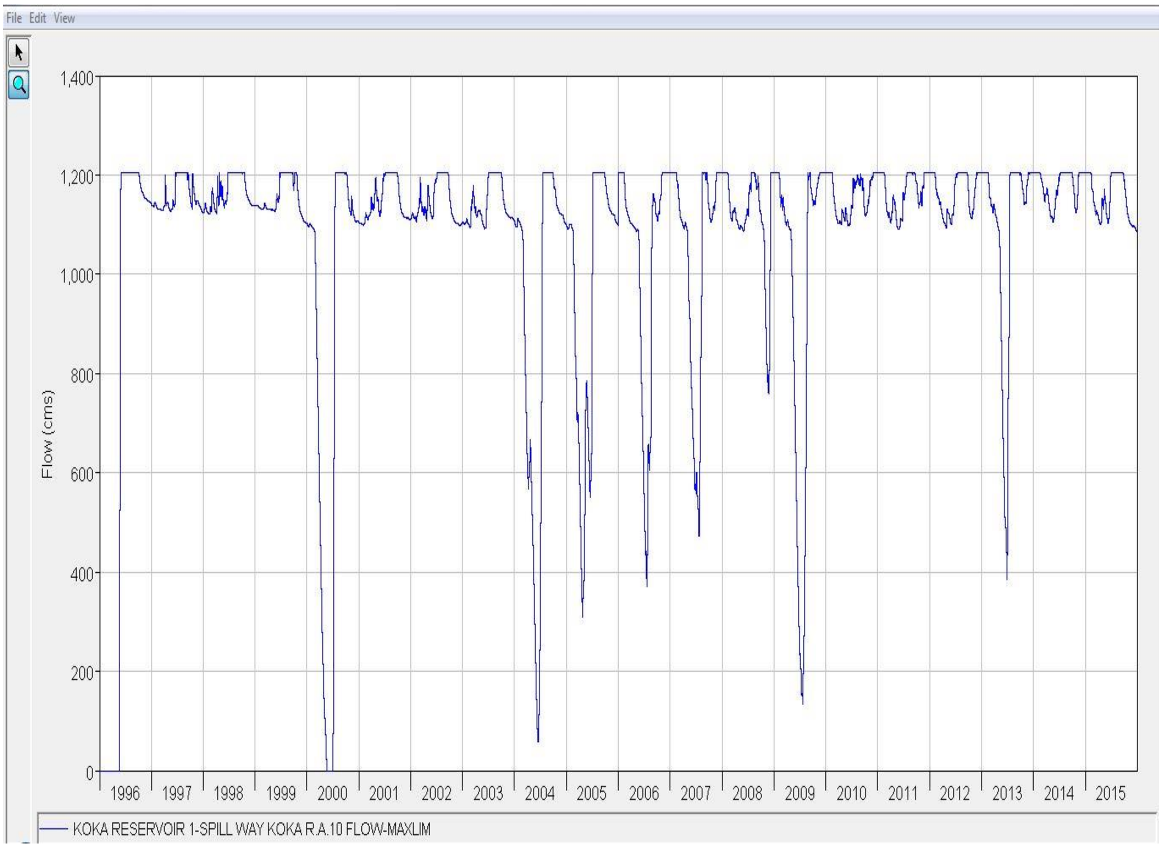

Fig 1.7 Koka reservoir maximum spillway capacity

Appendix-2 Summary of different computation points upstream of Koka reservoir

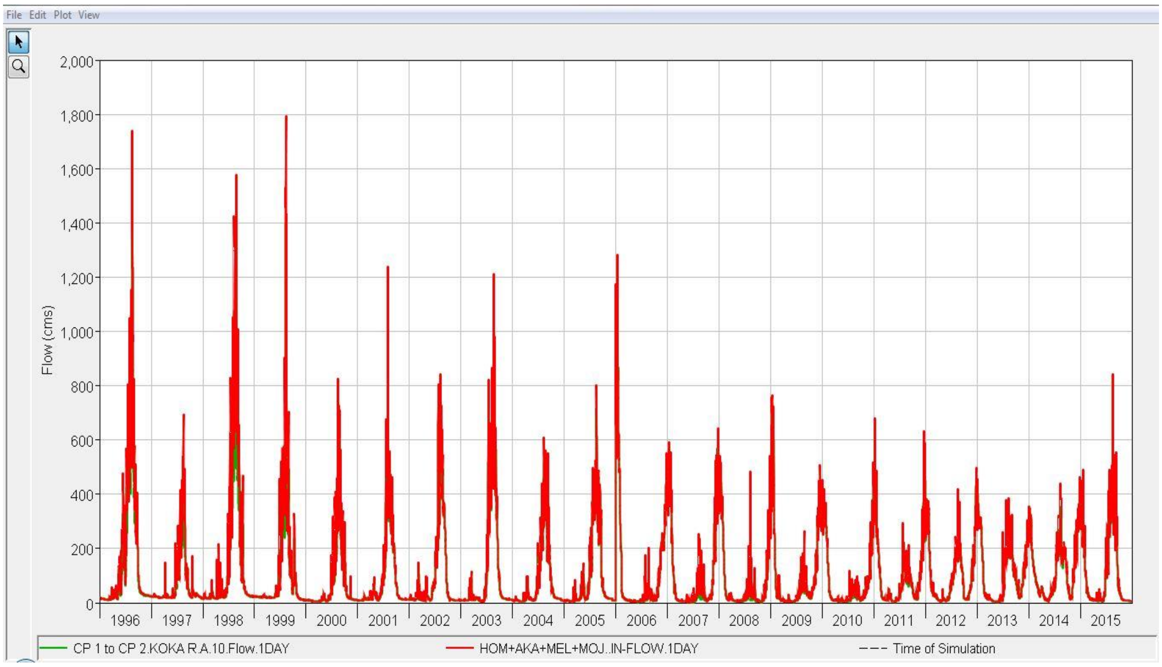

Fig 2.1 Flow through CP1 – CP2

Appendix-3 Monthly Evaporation of Koka reservoir

Table 3.1 Monthly evaporation of Koka Reservoir

Year	Month	n	N	n/N	Ri	Re	Rn (W/m^2)	Er (mm/day)	Er (mm)	Pan Evapo.
1996	Jan	8.668	10	0.867	263.492	0.039	247.643	8.841	274.067	391.524
	Feb	10.352	11	0.941	288.942	0.039	271.566	9.695	281.153	401.647
	Mar	8.352	12	0.696	264.404	0.039	248.501	8.871	275.016	392.880
	Apr	8.213	13	0.632	250.191	0.039	235.140	8.395	251.835	359.765
	May	8.161	14	0.583	238.014	0.039	223.694	7.986	247.562	353.661
	Jun	6.887	15	0.459	209.982	0.039	197.344	7.045	211.356	301.937
	Jul	7.387	14	0.528	225.237	0.039	211.684	7.557	234.270	334.672
	Aug	7.732	13	0.595	235.092	0.039	220.948	7.888	244.523	349.318
	Sep	7.413	12	0.618	248.795	0.039	233.828	8.348	250.430	357.757
	Oct	10.029	11	0.912	296.445	0.039	278.619	9.947	308.348	440.497
	Nov	9.363	10	0.936	279.624	0.039	262.807	9.382	281.467	402.095
	Dec	10.461	9	1.162	303.598	0.039	285.343	10.187	315.789	451.127
1997	Jan	7.803	10	0.780	247.679	0.039	232.779	8.310	257.617	368.024
	Feb	10.739	11	0.976	295.662	0.039	277.883	9.920	277.772	396.818
	Mar	9.345	12	0.779	281.645	0.039	264.708	9.450	292.952	418.503
	Apr	7.640	13	0.588	241.038	0.039	226.537	8.087	242.621	346.602
	May	10.094	14	0.721	266.414	0.039	250.390	8.939	277.106	395.866
	Jun	8.623	15	0.575	233.520	0.039	219.469	7.835	235.052	335.788
	Jul	7.335	14	0.524	224.483	0.039	210.975	7.532	233.486	333.551
	Aug	8.019	13	0.617	239.535	0.039	225.124	8.037	249.145	355.921
	Sep	8.933	12	0.744	275.243	0.039	258.689	9.235	277.056	395.795
	Oct	7.503	11	0.682	250.622	0.039	235.546	8.409	260.679	372.398
	Nov	8.947	10	0.895	271.908	0.039	255.555	9.123	273.699	390.999
	Dec	10.023	9	1.114	295.073	0.039	277.330	9.901	306.921	438.459
1998	Jan	7.497	10	0.750	242.074	0.039	227.510	8.122	251.786	359.694
	Feb	8.114	11	0.738	250.144	0.039	235.097	8.393	235.003	335.718
	Mar	7.939	12	0.662	257.239	0.039	241.766	8.631	267.562	382.232
	Apr	9.177	13	0.706	265.569	0.039	249.596	8.911	267.318	381.882
	May	8.926	14	0.638	249.251	0.039	234.257	8.363	259.252	370.360
	Jun	9.587	15	0.639	246.576	0.039	231.742	8.273	248.196	354.566
	Jul	7.281	14	0.520	223.682	0.039	210.222	7.505	232.653	332.361
	Aug	6.861	13	0.528	221.614	0.039	208.278	7.436	230.501	329.287
	Sep	7.413	12	0.618	248.795	0.039	233.828	8.348	250.430	357.757
	Oct	8.368	11	0.761	266.306	0.039	250.289	8.935	276.995	395.707
	Nov	10.563	10	1.056	301.844	0.039	283.694	10.128	303.837	434.052
	Dec	10.584	9	1.176	305.979	0.039	287.582	10.267	318.267	454.666
1999	Jan	9.516	10	0.952	279.010	0.039	262.230	9.362	290.210	414.586
	Feb	10.711	11	0.974	295.167	0.039	277.418	9.904	277.307	396.153
	Mar	7.397	12	0.616	247.835	0.039	232.926	8.315	257.779	368.256
	Apr	9.593	13	0.738	229.380	0.039	215.578	7.696	230.884	329.835
	May	9.181	14	0.656	215.008	0.039	202.068	7.214	223.629	319.470

	Jun	9.147	15	0.610	206.967	0.039	194.510	6.944	208.320	297.600
	Jul	6.587	14	0.471	182.612	0.039	171.617	6.127	189.928	271.326
	Aug	8.084	13	0.622	209.075	0.039	196.492	7.015	217.458	310.654
	Sep	8.127	12	0.677	218.761	0.039	205.596	7.340	220.193	314.562
	Oct	7.635	11	0.694	221.718	0.039	208.376	7.439	230.610	329.443
	Nov	9.897	10	0.990	273.398	0.039	256.955	9.173	275.199	393.141
	Dec	10.406	9	1.156	302.532	0.039	284.341	10.151	314.680	449.543
2000	Jan	10.587	10	1.059	285.471	0.039	268.304	9.578	296.932	424.189
	Feb	10.217	11	0.929	262.761	0.039	246.956	8.816	255.674	365.249
	Mar	9.842	12	0.820	243.756	0.039	229.092	8.179	253.536	362.195
	Apr	8.793	13	0.676	218.619	0.039	205.463	7.335	220.050	314.358
	May	8.942	14	0.639	212.026	0.039	199.266	7.114	220.527	315.039
	Jun	8.380	15	0.559	198.029	0.039	186.108	6.644	199.322	284.746
	Jul	6.803	14	0.486	185.312	0.039	174.154	6.217	192.737	275.338
	Aug	7.316	13	0.563	198.748	0.039	186.784	6.668	206.714	295.306
	Sep	6.797	12	0.566	199.379	0.039	187.378	6.689	200.681	286.688
	Oct	7.968	11	0.724	227.000	0.039	213.341	7.616	236.105	337.292
	Nov	9.377	10	0.938	264.304	0.039	248.407	8.868	266.044	380.063
	Dec	9.771	9	1.086	290.185	0.039	272.735	9.737	301.835	431.193
2001	Jan	9.319	10	0.932	263.302	0.039	247.465	8.835	273.870	391.243
	Feb	9.861	11	0.896	257.093	0.039	241.629	8.626	241.532	345.046
	Mar	6.755	12	0.563	198.770	0.039	186.805	6.669	206.737	295.338
	Apr	9.980	13	0.768	234.581	0.039	220.467	7.871	236.121	337.315
	May	8.965	14	0.640	212.308	0.039	199.531	7.123	220.821	315.458
	Jun	8.717	15	0.581	201.954	0.039	189.798	6.776	203.273	290.390
	Jul	7.758	14	0.554	197.239	0.039	185.365	6.618	205.144	293.063
	Aug	6.265	13	0.482	184.602	0.039	173.487	6.193	191.998	274.283
	Sep	8.877	12	0.740	229.690	0.039	215.870	7.707	231.196	330.281
	Oct	8.555	11	0.778	236.333	0.039	222.114	7.929	245.814	351.163
	Nov	10.110	10	1.011	277.128	0.039	260.462	9.298	278.954	398.506
	Dec	9.603	9	1.067	286.925	0.039	269.671	9.627	298.445	426.350
2002	Jan	8.377	10	0.838	246.831	0.039	231.982	8.282	256.734	366.763
	Feb	9.936	11	0.903	258.285	0.039	242.749	8.666	242.652	346.646
	Mar	7.755	12	0.646	213.342	0.039	200.503	7.158	221.896	316.995
	Apr	8.863	13	0.682	219.560	0.039	206.348	7.367	220.998	315.712
	May	9.452	14	0.675	218.392	0.039	205.250	7.327	227.150	324.500
	Jun	9.007	15	0.600	205.335	0.039	192.976	6.889	206.677	295.253
	Jul	8.290	14	0.592	203.887	0.039	191.615	6.841	212.060	302.943
	Aug	7.065	13	0.543	195.363	0.039	183.603	6.555	203.193	290.276
	Sep	7.297	12	0.608	206.666	0.039	194.227	6.934	208.017	297.167
	Oct	9.200	11	0.836	246.590	0.039	231.755	8.274	256.484	366.405
	Nov	10.173	10	1.017	278.236	0.039	261.503	9.336	280.069	400.099
	Dec	7.013	9	0.779	236.595	0.039	222.361	7.938	246.087	351.552
2003	Jan	8.800	10	0.880	254.220	0.039	238.928	8.530	264.422	377.745
	Feb	9.375	11	0.852	249.372	0.039	234.370	8.367	234.277	334.681
	Mar	8.223	12	0.685	220.158	0.039	206.910	7.387	228.987	327.125

	Apr	7.717	13	0.594	204.136	0.039	191.849	6.849	205.470	293.529
	May	9.648	14	0.689	220.850	0.039	207.560	7.410	229.707	328.153
	Jun	8.360	15	0.557	197.796	0.039	185.889	6.636	199.087	284.410
	Jul	6.045	14	0.432	175.843	0.039	165.254	5.900	182.886	261.266
	Aug	5.648	13	0.434	176.314	0.039	165.697	5.915	183.376	261.966
	Sep	7.167	12	0.597	204.771	0.039	192.446	6.870	206.110	294.442
	Oct	9.810	11	0.892	256.282	0.039	240.866	8.599	257.968	368.525
	Nov	9.687	10	0.969	269.725	0.039	253.503	9.050	271.502	387.860
	Dec	9.381	9	1.042	282.601	0.039	265.606	9.482	293.946	419.923
2004	Jan	8.332	10	0.833	246.041	0.039	231.240	8.255	255.913	365.590
	Feb	9.297	11	0.845	248.125	0.039	233.198	8.325	241.430	344.900
	Mar	8.203	12	0.684	219.876	0.039	206.645	7.377	228.694	326.705
	Apr	8.173	13	0.629	210.279	0.039	197.623	7.055	211.654	302.363
	May	9.819	14	0.701	222.986	0.039	209.568	7.482	231.928	331.326
	Jun	7.666	15	0.511	189.699	0.039	178.279	6.365	190.936	272.766
	Jul	7.142	14	0.510	189.543	0.039	178.131	6.359	197.138	281.626
	Aug	7.161	13	0.551	196.665	0.039	184.826	6.598	204.547	292.211
	Sep	7.877	12	0.656	215.118	0.039	202.172	7.218	216.526	309.323
	Oct	8.790	11	0.799	240.077	0.039	225.633	8.055	249.708	356.726
	Nov	10.067	10	1.007	276.370	0.039	259.749	9.273	278.192	397.417
	Dec	9.087	9	1.010	276.897	0.039	260.244	9.291	288.012	411.446
2005	Jan	8.790	10	0.879	254.051	0.039	238.769	8.524	264.246	377.494
	Feb	9.982	11	0.907	259.024	0.039	243.443	8.691	243.346	347.637
	Mar	8.839	12	0.737	229.137	0.039	215.350	7.688	238.328	340.468
	Apr	8.883	13	0.683	219.829	0.039	206.601	7.376	221.269	316.099
	May	7.329	14	0.524	191.880	0.039	180.328	6.438	199.569	285.099
	Jun	8.077	15	0.538	194.493	0.039	182.784	6.525	195.762	279.660
	Jul	6.639	14	0.474	183.257	0.039	172.223	6.148	190.599	272.284
	Aug	8.432	13	0.649	213.762	0.039	200.897	7.172	222.333	317.618
	Sep	7.113	12	0.593	203.994	0.039	191.715	6.844	205.327	293.324
	Oct	9.377	11	0.852	249.410	0.039	234.407	8.368	259.418	370.597
	Nov	9.460	10	0.946	265.762	0.039	249.777	8.917	267.511	382.159
	Dec	10.271	9	1.141	299.900	0.039	281.867	10.063	311.942	445.631
2006	Jan	9.587	10	0.959	267.984	0.039	251.866	8.992	278.740	398.201
	Feb	9.179	11	0.834	246.249	0.039	231.435	8.262	231.343	330.489
	Mar	8.000	12	0.667	216.915	0.039	203.861	7.278	225.613	322.304
	Apr	7.587	13	0.584	202.387	0.039	190.205	6.790	203.710	291.014
	May	8.926	14	0.638	211.825	0.039	199.076	7.107	220.318	314.739
	Jun	7.853	15	0.524	191.889	0.039	180.337	6.438	193.141	275.915
	Jul	6.755	14	0.482	184.708	0.039	173.586	6.197	192.108	274.440
	Aug	5.606	13	0.431	175.750	0.039	165.166	5.896	182.790	261.128
	Sep	7.170	12	0.598	204.820	0.039	192.492	6.872	206.158	294.512
	Oct	7.474	11	0.679	219.154	0.039	205.966	7.353	227.943	325.632
	Nov	9.987	10	0.999	274.972	0.039	258.434	9.226	276.783	395.405
	Dec	8.348	9	0.928	262.544	0.039	246.752	8.809	273.081	390.115
2007	Jan	8.903	10	0.890	256.025	0.039	240.625	8.590	266.300	380.428

	Feb	9.036	11	0.821	243.978	0.039	229.300	8.186	229.209	327.441
	Mar	10.032	12	0.836	246.530	0.039	231.699	8.272	256.421	366.316
	Apr	8.357	13	0.643	212.745	0.039	199.941	7.138	214.137	305.910
	May	8.903	14	0.636	211.542	0.039	198.811	7.098	220.024	314.320
	Jun	7.843	15	0.523	191.772	0.039	180.227	6.434	193.023	275.748
	Jul	6.752	14	0.482	184.667	0.039	173.548	6.196	192.066	274.380
	Aug	5.906	13	0.454	179.786	0.039	168.960	6.032	186.988	267.125
	Sep	6.890	12	0.574	200.739	0.039	188.656	6.735	202.051	288.644
	Oct	8.945	11	0.813	242.538	0.039	227.947	8.138	252.269	360.385
	Nov	9.643	10	0.964	268.968	0.039	252.791	9.025	270.739	386.770
	Dec	10.329	9	1.148	301.028	0.039	282.927	10.100	313.115	447.308
2008	Jan	9.555	10	0.955	267.420	0.039	251.336	8.973	278.154	397.362
	Feb	9.672	11	0.879	254.100	0.039	238.815	8.526	247.245	353.207
	Mar	10.197	12	0.850	248.927	0.039	233.953	8.352	258.915	369.879
	Apr	8.427	13	0.648	213.686	0.039	200.826	7.170	215.085	307.264
	May	7.971	14	0.569	199.898	0.039	187.865	6.707	207.910	297.015
	Jun	8.533	15	0.569	199.816	0.039	187.789	6.704	201.122	287.316
	Jul	7.223	14	0.516	190.550	0.039	179.078	6.393	198.186	283.123
	Aug	6.845	13	0.527	192.413	0.039	180.829	6.456	200.124	285.891
	Sep	7.947	12	0.662	216.138	0.039	203.130	7.252	217.553	310.790
	Oct	8.268	11	0.752	231.769	0.039	217.824	7.776	241.066	344.380
	Nov	9.147	10	0.915	260.282	0.039	244.627	8.733	261.995	374.279
	Dec	10.058	9	1.118	295.763	0.039	277.978	9.924	307.638	439.483
2009	Jan	8.448	10	0.845	248.072	0.039	233.148	8.323	258.025	368.608
	Feb	10.132	11	0.921	261.408	0.039	245.685	8.771	245.586	350.838
	Mar	9.600	12	0.800	240.231	0.039	225.778	8.060	249.869	356.955
	Apr	8.360	13	0.643	212.790	0.039	199.983	7.139	214.182	305.975
	May	9.377	14	0.670	217.465	0.039	204.379	7.296	226.186	323.123
	Jun	9.153	15	0.610	207.044	0.039	194.583	6.947	208.398	297.712
	Jul	7.303	14	0.522	191.557	0.039	180.025	6.427	199.234	284.620
	Aug	7.384	13	0.568	199.659	0.039	187.641	6.699	207.662	296.660
	Sep	8.127	12	0.677	218.761	0.039	205.596	7.340	220.193	314.562
	Oct	8.232	11	0.748	231.205	0.039	217.294	7.757	240.479	343.542
	Nov	9.690	10	0.969	269.784	0.039	253.558	9.052	271.560	387.943
	Dec	7.094	9	0.788	238.162	0.039	223.834	7.991	247.717	353.881
2010	Jan	9.200	10	0.920	261.215	0.039	245.503	8.764	271.699	388.141
	Feb	6.386	11	0.581	201.850	0.039	189.700	6.772	189.624	270.892
	Mar	7.758	12	0.647	213.389	0.039	200.547	7.160	221.945	317.065
	Apr	7.410	13	0.570	200.011	0.039	187.971	6.711	201.317	287.596
	May	7.519	14	0.537	194.257	0.039	182.563	6.517	202.042	288.632
	Jun	8.263	15	0.551	196.669	0.039	184.830	6.598	197.953	282.790
	Jul	6.300	14	0.450	179.026	0.039	168.246	6.006	186.198	265.997
	Aug	6.303	13	0.485	185.123	0.039	173.977	6.211	186.329	266.184
	Sep	7.303	12	0.609	206.763	0.039	194.318	6.937	208.115	297.307
	Oct	9.894	11	0.899	257.615	0.039	242.119	8.644	267.953	382.791
	Nov	9.067	10	0.907	258.884	0.039	243.312	8.686	260.587	372.267

	Dec	8.768	9	0.974	270.692	0.039	254.412	9.082	281.557	402.225
2011	Jan	9.761	10	0.976	271.030	0.039	254.730	9.094	281.909	402.728
	Feb	10.121	11	0.920	261.238	0.039	245.525	8.765	245.426	350.609
	Mar	8.626	12	0.719	226.034	0.039	212.433	7.584	235.100	335.857
	Apr	8.840	13	0.680	219.246	0.039	206.053	7.356	220.682	315.261
	May	7.997	14	0.571	200.220	0.039	188.168	6.718	208.246	297.494
	Jun	8.133	15	0.542	195.153	0.039	183.405	6.548	196.427	280.610
	Jul	7.181	14	0.513	190.026	0.039	178.586	6.376	197.641	282.344
	Aug	6.542	13	0.503	188.334	0.039	176.995	6.319	195.880	279.829
	Sep	6.597	12	0.550	196.465	0.039	184.638	6.592	197.747	282.496
	Oct	9.971	11	0.906	258.846	0.039	243.276	8.685	269.234	384.620
	Nov	8.490	10	0.849	248.799	0.039	233.833	8.348	250.435	357.764
	Dec	10.087	9	1.121	296.327	0.039	278.508	9.943	308.225	440.322
2012	Jan	9.913	10	0.991	273.682	0.039	257.222	9.183	284.667	406.668
	Feb	9.831	11	0.894	256.621	0.039	241.185	8.610	249.699	356.713
	Mar	9.258	12	0.772	235.248	0.039	221.094	7.893	244.685	349.550
	Apr	7.303	13	0.562	198.576	0.039	186.622	6.662	199.873	285.532
	May	8.903	14	0.636	211.542	0.039	198.811	7.098	220.024	314.320
	Jun	7.463	15	0.498	187.342	0.039	176.063	6.285	188.563	269.376
	Jul	5.906	14	0.422	174.111	0.039	163.625	5.841	181.084	258.691
	Aug	5.471	13	0.421	173.928	0.039	163.453	5.835	180.894	258.420
	Sep	6.983	12	0.582	202.099	0.039	189.935	6.781	203.420	290.600
	Oct	8.861	11	0.806	241.205	0.039	226.694	8.093	250.882	358.403
	Nov	10.180	10	1.018	278.352	0.039	261.612	9.340	280.187	400.267
	Dec	9.658	9	1.073	287.991	0.039	270.672	9.663	299.553	427.933
2013	Jan	8.968	10	0.897	257.154	0.039	241.686	8.628	267.473	382.105
	Feb	9.918	11	0.902	258.002	0.039	242.483	8.657	242.386	346.265
	Mar	8.529	12	0.711	224.624	0.039	211.108	7.537	233.633	333.761
	Apr	8.279	13	0.637	211.704	0.039	198.963	7.103	213.089	304.414
	May	8.055	14	0.575	200.946	0.039	188.850	6.742	209.000	298.572
	Jun	7.823	15	0.522	191.539	0.039	180.008	6.426	192.789	275.412
	Jul	6.765	14	0.483	184.829	0.039	173.700	6.201	192.234	274.620
	Aug	7.729	13	0.595	204.302	0.039	192.005	6.855	212.492	303.560
	Sep	7.107	12	0.592	203.897	0.039	191.624	6.841	205.229	293.185
	Oct	8.123	11	0.738	229.462	0.039	215.655	7.699	238.665	340.951
	Nov	10.220	10	1.022	279.052	0.039	262.270	9.363	280.891	401.273
	Dec	9.939	9	1.104	293.444	0.039	275.798	9.846	305.226	436.037
2014	Jan	10.119	10	1.012	277.292	0.039	260.615	9.304	288.423	412.033
	Feb	9.754	11	0.887	255.390	0.039	240.028	8.569	239.932	342.759
	Mar	8.723	12	0.727	227.445	0.039	213.759	7.631	236.567	337.953
	Apr	7.947	13	0.611	207.230	0.039	194.757	6.953	208.585	297.978
	May	9.413	14	0.672	217.909	0.039	204.795	7.311	226.647	323.781
	Jun	7.500	15	0.500	187.770	0.039	176.465	6.300	188.994	269.991
	Jul	6.648	14	0.475	183.378	0.039	172.336	6.152	190.725	272.464
	Aug	6.771	13	0.521	191.415	0.039	179.891	6.422	199.085	284.408
	Sep	7.683	12	0.640	212.300	0.039	199.523	7.123	213.689	305.271

	Oct	9.916	11	0.901	257.974	0.039	242.457	8.656	268.327	383.324
	Nov	8.877	10	0.888	255.561	0.039	240.188	8.575	257.242	367.488
	Dec	10.068	9	1.119	295.951	0.039	278.155	9.930	307.834	439.763
2015	Jan	10.410	10	1.041	282.369	0.039	265.388	9.474	293.705	419.578
	Feb	9.168	11	0.833	246.079	0.039	231.275	8.257	231.183	330.261
	Mar	8.371	12	0.698	222.321	0.039	208.943	7.459	231.237	330.338
	Apr	7.376	13	0.567	199.552	0.039	187.540	6.695	200.855	286.935
	May	9.355	14	0.668	217.183	0.039	204.114	7.287	225.892	322.703
	Jun	9.713	15	0.648	213.573	0.039	200.720	7.166	214.971	307.101
	Jul	6.942	14	0.496	187.045	0.039	175.783	6.275	194.539	277.913
	Aug	8.371	13	0.644	212.937	0.039	200.122	7.144	221.475	316.393
	Sep	7.470	12	0.623	209.191	0.039	196.601	7.019	210.560	300.800
	Oct	9.158	11	0.833	245.923	0.039	231.129	8.251	255.790	365.414
	Nov	10.370	10	1.037	281.675	0.039	264.735	9.451	283.532	405.045
	Dec	9.658	9	1.073	287.991	0.039	270.672	9.663	299.553	427.933

Appendix- 4 Summary of computation points

Table 4.1 Summary of computation points

Location/Parameter	Average	Maximum	Minimum
CP 1			
Regulated Flow (cms)	94.14	1512.92	1.27
Cumulative Local Flow (cms)	94.14	1512.92	1.27
CP 1 to CP 2			
Regulated Flow (cms)	94.14	1572.82	1.29
Cumulative Local Flow (cms)	94.14	1572.82	1.29
CP 2			
Regulated Flow (cms)	205.6	2787.47	5.35
Cumulative Local Flow (cms)	205.6	2787.47	5.35
CP 2 to CP 6			
Regulated Flow (cms)	205.6	2802.42	5.38
Cumulative Local Flow (cms)	205.6	2802.42	5.38
CP 3			
Regulated Flow (cms)	4.6	245.21	0
Cumulative Local Flow (cms)	4.6	245.21	0
CP 3 to CP 2			
Regulated Flow (cms)	4.61	275.1	0
Cumulative Local Flow (cms)	4.61	275.1	0
CP 4			
Regulated Flow (cms)	4.6	245.21	0
Cumulative Local Flow (cms)	4.6	245.21	0
CP 4 to CP 6			
Regulated Flow (cms)	4.61	275.22	0
Cumulative Local Flow (cms)	4.61	275.22	0
CP 5			
Regulated Flow (cms)	4.6	245.21	0
Cumulative Local Flow (cms)	4.6	245.21	0
CP 5 to CP7			
Regulated Flow (cms)	4.6	270.4	0
Cumulative Local Flow (cms)	4.6	270.4	0
CP 6			
Regulated Flow (cms)	326.25	4035.35	9.59
Cumulative Local Flow (cms)	326.25	4035.35	9.59
CP 6 to CP7			
Regulated Flow (cms)	326.25	4029.31	9.62
Cumulative Local Flow (cms)	326.25	4029.31	9.62
CP7			
Regulated Flow (cms)	446.9	5260.82	13.84
Cumulative Local Flow (cms)	446.9	5260.82	13.84
CP8			
Regulated Flow (cms)	528.63	6064.69	5.25

Cumulative Local Flow (cms)	116.05	1219.35	4.14
KOKA RESERVOIR 1			
Regulated Flow (cms)	412.59	4845.35	0