ADDIS ABABA UNIVERSITY

SCHOOL OF GRAGUATE STUDIES

ABAY BASIN WATER ALLOCATION MODELLING USING HEC – RESSIM

BY

FANUEL WONDYE

ADVISOR- Dr. YILMA SELESHI

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THESIS

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Certification

I, the undersigned, certify that I read and here by recommend for acceptance by Addis Ababa University a dissertation entitled **“ABAY BASIN WATER ALLOCATION MODELLING USING HEC-RESSIM”** in partial fulfillment of the requirements for the degree of masters of Science in civil engineering major in hydraulic engineering.

Dr. Yilma Seleshi

Supervisor

Declaration and Copy right

Fanuel Wondye Tefera, declares that this thesis is my own original work that has not been presented and will not be presented by me to any other University for similar or any other degree award.

Signature

Acknowledgement

Honor for his intimacy, **GOD** who ultimately enabled me from the very beginning of my studies up to the end page of this report.

I would like to take this opportunity to sincerely forward my respect and thank for the Head, civil engineering department and my advisor indeed Dr. Yilma Seleshi for his valuable advice and assistance while being in a great burden post. I also have a great admiration for my advisor's effort in making my thesis funded by 'International water management institute (IWMI)'.

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I am very much respectful and honest for my organization Water Works Design & Supervision Enterprise, all my bosses and employees of the organization who owe undeniable share of this study. Ministry of water resources' division heads and library staffs contributed me significant. Hard to mention in name, all my friends thank u very much for the lots u have done to help me.

My families possess not less than I do out of this effort. THANK YOU

Dedication

This piece of work is dedicated to my families.

Abstract

Despite Ethiopia possesses abundant water resources potential, second only to Congo in all of Africa, the country is at critical cross roads with large and increasing population, a depressed national economy, insufficient agricultural production and low no of developed energy sources. 83% of Ethiopians lack access to electricity; only 5 percent of irrigable land and 3% of the hydropower potential in the Blue Nile basin has been developed so far. Nowadays persisting drought and increasing competition for water have left Ethiopia with no more chance other than seeking solutions and assure sustainability of the resource.

Even though Ethiopian portion of Blue Nile, Abay possesses a great potential of irrigation and hydropower developments, the financial and political constraints have long hindered the country's development. This study aims at analyzing the effects of implementing the potential irrigation and hydropower projects that are contemplated in the country.

Reservoir system simulation (Hec-ResSim) software has been used to study the out puts of executing different developments in the basin. This has been done by setting up the model and simulating for four scenarios including the base scenario referring to the current situation in the basin. After a curious filtering of all projects mentioned in the basin's master plan and other project specific reports, 315,431ha (38.7% of total 815,581ha potential) of irrigation and 7,026Mw (89.6% of total 7845Mw potential) of hydropower potential; overall comprising 23 dams having a combined maximum storage capacity of 170.15Bm^3 have been preferred to be analyzed and assessed using the model. After categorizing these projects under four scenarios; the simulation has been done based on 33 years (1960-1992) of monthly hydrologic flow series.

This study under has indicated that If Ethiopia is to develop 315,431ha and 7,029Mw, the resulting decline in the cross border flow will be only 3,382.93Mm^3 which is only 7.29% of the currently simulated (under current condition scenario,scenario-1) Abay discharge to Sudan which is 46,396.99 Mm^3. Under this condition both Ethiopia and Sudan benefit from regulation of Abay by Ethiopian dams, in that it results in increasing of low flows, giving the whole system uniformity of balance, decreasing water escaping during flood seasons.

As concluded from this study regulation works upstream in Ethiopia have resulted in a uniform monthly average flow of 3,584.51Mm^3 throughout the year to Sudan. Currently as the base case simulation indicated, Sudan receives monthly average low flow of 1,233.54Mm^3 through November to June which then turns to be increasing; August being flood month when 13,456.27Mm^3 has been observed.

In addition if Ethiopia is to develop 7,029Mw including hydropower projects on the tributaries, then some 38,385.81Gwh/annum of electricity will be produced. Even though Tana-Beles project imposes a big deal of inflow and power out put decline on the main stream hydropower plants, this power decrease was exceeded by the power generated at Tana-Beles power plant. Prior to Tana-Beles project Power output from main stream plants has been 34,284.23 Gwh/annum then increased to 34,736.14 Gwh/annum despite power decrease at Karadobi, Mabil, Mandaya and Border.

Chapter-1. Introduction

1.1 Background

The Nile is the major north flowing river in Africa, generally regarded as the longest river in the world. The Nile has two major tributaries, the White Nile and Blue Nile (known as the Abay in Ethiopia) (Fig 1.1).The latter being the source of most of the Nile water and fertile soil, but the former being the longer of the two. This river has always been the sole source of life and development for countries and millions of livelihoods residing its edge. It is in fact historic pride and staring spot for countries through which is maneuvers.

The White Nile rises in the Great Lakes region of Central Africa, with the most distant source in southern Rwanda and flows north from there through Tanzania, Lake Victoria, Uganda and southern Sudan. The Blue Nile head-waters emanate at the outlet of Lake Tana in the Ethiopian highlands, becoming a mighty river long before it reaches the lowlands and crosses into Sudan. The two rivers meet near the Sudanese capital, Khartoum, and flow north through Sudan and Egypt to drain into the Mediterranean Sea. The drainage area is officially described by the Nile Basin Initiative (NBI 2007) as 3 million km2. The ten countries that share the Nile River Basin are: Burundi, Democratic Republic of Congo (DRC), Egypt, Eritrea, Ethiopia, Kenya, Rwanda, Sudan, Tanzania and Uganda. The Nile River Basin is home to approximately 180 million people, while over 350 million (based on World Bank 2006) live within the 10 riparian states. According to the World Bank (2006) data, the Nile region is characterized by high population growth and considerable development challenges. Five of the ten countries are among the poorest in the world with gross national per capita incomes of $90 (Burundi), $110 (DRC and Ethiopia), $190 (Eritrea) and $210 (Rwanda). Life expectancy varies from 42 in Ethiopia to 70 in Egypt. Most of the population in the Nile Basin live in rural areas and are dependent on agriculture. (Awlachew et al, 2008)

Fig 1.1 Nile River;

The Blue Nile Basin covers an area of 311,548 km2 (Hydrosult Inc et al. 2006b). It provides 62% of the flow reaching Aswan (World Bank 2006). The river and its tributaries drain a large proportion of the central, western and south-western highlands of Ethiopia before dropping to the plains of Sudan. The confluence of the Blue Nile and the White Nile is at Khartoum. The basin is characterized by a highly rugged topography and considerable variation of altitude ranging from about 350 meters(m) at Khartoum to over 4,250 meters above sea level (masl) in the Ethiopian highlands. The Dinder and Rahad rise to the west of Lake Tana and flow westwards across the border joining the Blue Nile below Sennar dam in Sudan. (Awlachew et al, 2008).

The Abay's source is Gish Abay in West Gojam. From here it flows northward as the Gilgel Abay1 into Lake Tana. Lake Tana is the biggest lake in Ethiopia and is some 73 km long and 68 km wide. It is located at 1,786 masl and has a surface area of 3,042 km2, accounting for 50% of the total inland water of Ethiopia (Hydrosult Inc et al. 2006b). Little of the 13,750 km2 catchment draining into the lake is above 2,400 masl, though it rises to approximately 4,000 masl to the northeast, in the Simien Mountains. There are approximately 40 rivers draining into the lake, many of which have catchment areas of less than 1,000 km2 and are ephemeral (Kebede et al. 2006). In addition to the Gilgel Abay, three other major rivers, Gumera, Ribb and Megech flow into the lake. The lake stores 29.175 km3 of water which fluctuates seasonally between 1,785 and 1,787 masl. The lake is shallow and has a mean depth of 9.53 m, while the deepest part is 14 m. (Awlachew et al, 2008)

The Abay leaves the lake close to the city of Bahir-Dar at the southeastern corner of the lake and cuts a deep gorge first south then westwards, through a series of cataracts. Approximately 40km downstream it drops 50 m over the Tiss Issat Falls (Fig 1.2) into the Blue Nile gorge. The river then follows a deep and circuitous, 900 km,

Fig 1.2 Tiss Issat Fall (photo credit: Fanuel Wondye)

course, through the Ethiopian Highlands. It first flows southeast, before looping back on itself, flowing west and then turning northwest and traversing through Sudan (Fig 1.3). In the highlands, the basin is composed mainly of volcanic and Pre-Cambrian basement rocks with small areas of sedimentary rocks. The catchment is cut by deep ravines in which the major tributaries flow. The valley of the Blue Nile itself is 1,300 m deep in places .The whole area is intersected by streams, many of which are perennial though highly seasonal in their flow. The primary tributaries of the Blue Nile in Ethiopia are the Beshio, Jema, Muger,Guder, Finchaa, Anger, Dedessa and Dabus on the left bank, and Beles, north Gojam and south Gojam on the right bank (table 1.1). (Awlachew et al, 2008)

The Blue Nile enters Sudan at an altitude of 490 meters amsl and just before crossing the frontier, the river enters the clay plain, through which it flows over a distance of about 630 km to Khartoum. At Khartoum the Blue Nile joins the White Nile to form the main stem of the Nile River. Below the Damzain rapids at Rosieres, where the main reservoir storing Blue Nile waters for irrigation in Sudan was built. The character of the Blue Nile changes in response to the change of gradient. Here the river is only just below the level of the surrounding plain and some areas are flooded during the rainy season. The average slope of the river from the Ethiopian frontier to Khartoum is only about 15 cm km-1. Within Sudan, the Blue Nile receives water from two major tributaries draining from the north, the Dinder and the Rahad . These drain both countries and join the main Blue Nile upstream of Khartoum. Both are highly seasonal, with no flow in the dry season (January to May). They are nearly equally long, about 750 to 800 km. The Blue Nile joins the White Nile at an elevation of approximately 400 masl, but still 2,800 km upstream of its Mediterranean delta. The total area of the Blue Nile Basin at this point is 311,548 km2. (Awlachew et al, 2008)

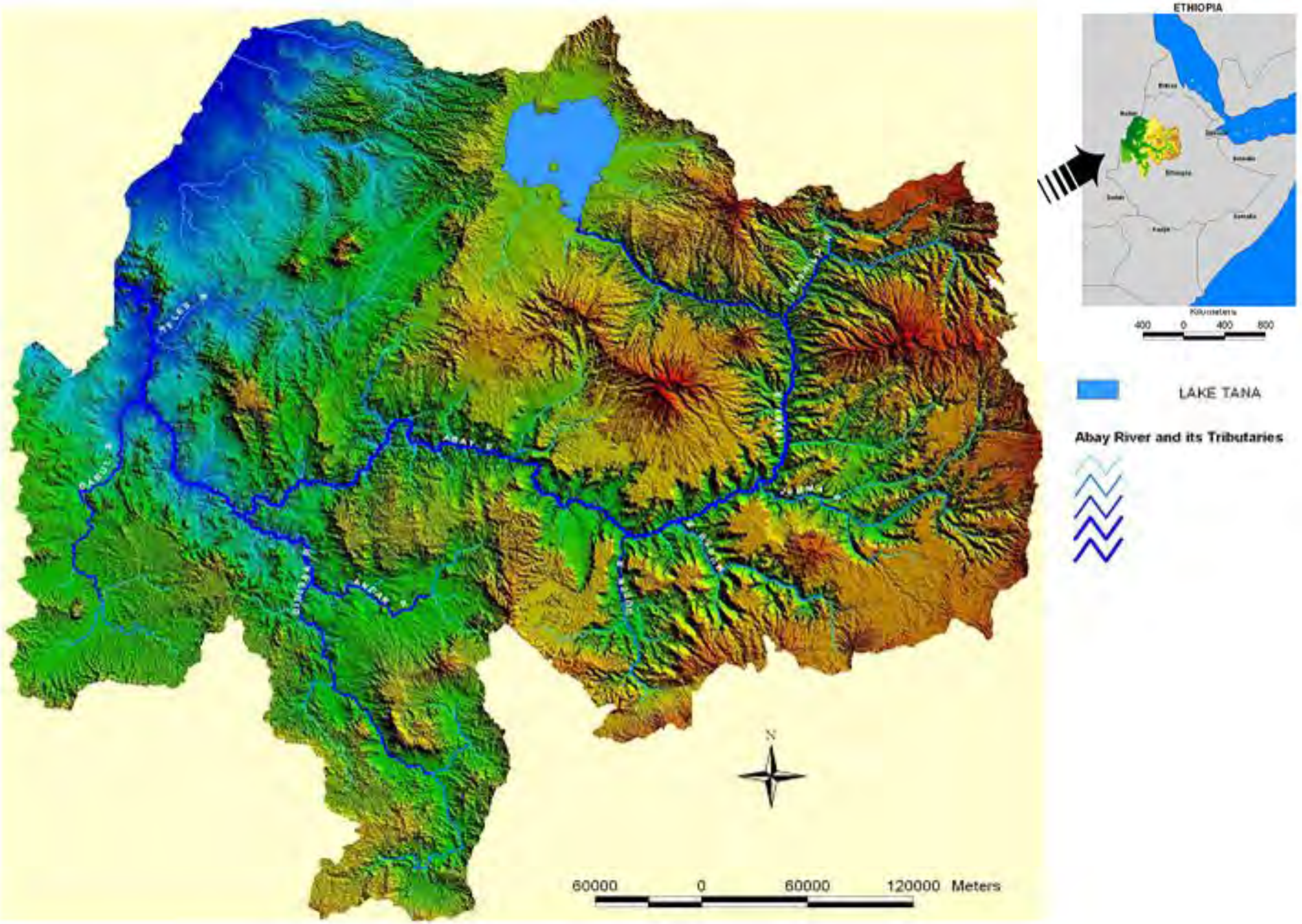


Fig 1.3 Abay basin and its main tributaries

Table 1.1 List of main tributaries of Blue Nile, emerging from Ethiopia;

No	Sub-basin	Catchment area (km^2)	Mean annual rain fall (mm)	Mean annual flow (Mm^3)
1	Lake tana	15054	1313	3809
2	Beshilo	13242	982	3920
3	Weleka	6415	1072	2072
4	Jemma	15782	1105	4798
5	Muger	8188	1347	2440
6	Guder	7011	910	2187
7	Fincha	4089	1766	1719
8	Dedessa	27531	1308	8028
9	Dabus	21030	2276	6246
10	Beles	14200	1655	4345
11	South Gojam	16762	1633	5012
12	Norht Gojam	14389	1336	4389
13	wonbera	12957	1160	3874
14	Dinder	14891	n/a	2797
15	Rahad	8269	n/a	1102

1.1.1 Climate

Rainfall varies significantly with altitude and is considerably greater in the Ethiopian highlands than on the Plains of Sudan. Rainfall ranges from nearly 2,000 mm/yr in the Ethiopian Highlands to less than 200 mm/yr at the junction with the White Nile. Within Sudan, the average annual rainfall over much of the basin is less than 500 mm. In Ethiopia, it increases from about 1,000 mm near the border of Sudan to between 1,400 and 1,800 mm over parts of the upper basin, in particular, in the loop of the Blue Nile south of Lake Tana. Rainfall exceeds 2,000 mm in parts of the Didessa and Beles catchments.

The spatial distribution of temperature values is strongly related to altitude. The highest mean annual temperatures occur in the northeastern clay plains of Sudan. In Sudan, daily minimum and maximum temperatures in January are 14°C and 33°C, and those in May are 24°C and 44°C, respectively. The area located in the highlands of Ethiopia is characterized by lower minimum mean monthly temperatures that range between 3oC and 21oC, and occur between December and February.

Similar to rainfall and temperature, potential evapotranspiration also varies considerably across the basin and is highly correlated with altitude. Throughout Sudan, values generally exceed 2,200 mm per year and even in the rainy season (July to October) rainfall rarely exceed 50% of potential evapotranspiration. Consequently, irrigation is essential for the growth of crops. In the highlands of Ethiopia, potential evapotranspiration ranges from approximately 1,300 to 1,700 mm per year and in many places is less than rainfall in the rainy season. Consequently, rain fed cultivation, producing a single crop in the rainy season, is possible, though at a risk in low rainfall years. (Awlachew et al, 2008)

1.1.2 Geology

The geology of the Blue Nile Basin can be briefly summarized as:

- The highlands of the basin are composed of basic rocks, mainly basalts;
- The Ethiopian lowlands are mainly composed of Basement Complex rocks as well as metamorphic rocks, such as gneisses and marble. Where the Abay has cut through the basalts there are restricted areas of lime stones and then sandstones before the Basement Complex is reached; and
- The main part of the lowlands of Sudan is underlain by deep unconsolidated colluvial sediments of tertiary and quaternary age. To the north are older Basement Complex rocks and the Nubian Sandstones. The Nubian Sandstones are located in the northwest corner, overlying the Basement Complex rocks and comprise mainly sandstones, siltstones and conglomerates.

1.1.3 Flow

Throughout the Blue Nile Basin, river flow data are generally limited because of the remoteness of many of the catchments and the lack of economic resources and infrastructure to build and maintain monitoring sites. In Ethiopia, although there are over 100 flow gauging stations in the basin, most of these are located on relatively small tributaries and/or near the headwaters of the main rivers. Very few gauged catchments are over 1,000 km^2 and very few gauging stations are located on the main stem of the river or on the major tributaries close to their confluence with the Blue Nile. (Awlachew et al, 2008)

The mean annual outflow from Lake Tana is 3,776 Mm3 with a range from 1,075 Mm3 in 1984 to 6,182 Mm3 in 1998. The average annual outflow equates to 257 mm over the total catchment area of 15,321 km2. The mean annual rainfall over the basin is estimated to be 1,342 mm (Melkamu 2005). So, this gives a coefficient of runoff of approximately 18%. The natural seasonal distribution is slightly attenuated by the lake storage, with peak flows delayed from August to September/October and proportionally higher dry season flows than along the rest of the river. Since 2001, the outflow from Lake Tana has been controlled by the Chara Chara Weir which was built to regulate flow for hydropower production. This has resulted in a change in the natural pattern of flow from the lake, with higher dry season flows and lower wet season flows. However, because the flow from Lake Tana is a relatively small proportion of the flow at Kessie (22%) and an even smaller proportion of the flow at the border (i.e., Rosieres) (8%), the regulation is not thought to have had a significant impact on the distribution of flows downstream.

The average annual flow of the Blue Nile at the border of Sudan is 48,660 Mm^3 (excluding Dinder-Rahad). This represents approximately 40% of Ethiopia’s total surface water resources of 122,000 Mm^3 (World Bank 2006). The catchment at this location is about 200,000 km^2. Despite inflows from the Dinder and Rahad the average annual flow of the Blue Nile at Khartoum (i.e., 48,2816 million cubic meters) is slightly less than at the border. The catchment at this location is 311,548 km^2. The reduction in flows between the border and Khartoum, despite the increased catchment area, is a consequence of both water abstractions (for irrigation and water supply, primarily to Khartoum) and high transmission losses. It is estimated that annual transmission losses (i.e., both evaporation and percolation) between Roseires and Khartoum are about 2,000 Mm^3, with an additional 500 Mm^3 from the Sennar and Roseires reservoirs (Sutcliff and Parks 1999). (Awlachew et al, 2008)

1.2 Statement of the problem

The ever increasing population which virtually imposes stress on the water resource, improper land use, deforestation …etc altogether are in tremendous generation of sever effect in Abay basin. These phenomenons are slipping Ethiopia along steeply route of poverty. Food insecurity which can be said the tag of a poorest people, characterizes the worst type of poverty. This phenomenon is however the episode of life in Ethiopian community sheltering along the very beginning of Nile i.e. Abay; a well known river which protruded other countries to another arena of development. Poor water distribution system in Abay basin currently threatened millions of poverty –stricken Populations in Ethiopia and further downstream. Inefficiency in utilizing this precious resource has drawn Ethiopia long behind its planned destination.

So a better and urgent notice towards improving water and land management not only conserves Ethiopians fertile soil and precious water but also protects downstream countries from a huge expense due to siltation. Increasing the efficiency of water use for different purposes has a significant contribution to poverty alleviation. Therefore a well established, modeled water allocation mechanism in the basin is required to mitigate the effects of poor water distribution. This paper aims at being potential reference along with other researches done on this issue.

The detail study questions are as follows;

i. Is there adequate water which can fulfill the inquiries of different production activities both existing and planned in Blue Nile sub-basin, Abay?

ii. What are the successful water allocating mechanisms among these development activities which would have the greatest local benefits with no negative effect downstream?

iii. What are the impacts on hydrology and local communities?

1.3 Objectives of the study

The study implies in a further knowledge of water management technique in Abay basin. It has a direct contribution in creating coordination among different water resource projects which are being going on in the basin. It can be used as an accessory tool along with other researches, for different decision makers who appraise the planned projects and the ongoing projects as well.

The objectives of this study are three fold:

1. Developing water allocation model (HEC-*RES*SIM – 3; reservoir system simulation) and using as a tool for allocating water for major water resource development activities (both existing and planned) in Abay sub basin.
2. Assessing the availability of water to match the requirements of these developments.
3. Identifying impacts on hydrology of the system and local communities.

Chapter 2. Literature Review and Theoretical Development

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 Abay, both in thesis and numerous institutional research levels. Many hydrologic models have been developed to assess hydropower and irrigation potential with in the upper Blue Nile 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 including this paper. A model is only as good as the data it is supplied. Very few stream gauges exist along the Blue Nile River with in Ethiopia, and those that do tend to have spotty or limited records, and are often not publicly available (Block et al, 2007). Among numerous studies tried to be referred in search of the best understanding of the basin, the following documents were found most comprehensive and data sources for this study.

- A number of IWMI working papers; among those:
    - Evaluation of water availability and allocation in the blue Nile basin *(Awlachew et al , 2008)*
    - A review of hydrology, sediment and water resource use in the Blue Nile basin (*Awlachew et al, 2008). This paper gives the best review of researches and hydrologic models developed for Blue Nile, including students' theses done in different study problems of the area.*
    - Small scale irrigation in Blue Nile basin Ethiopia *(Awlachew S.B., 2008) ,and others relevant ; which are publicly available on IWMI website (www.iwmi.com)*

- BCEOM (1998) phase II & III; Abay master plan project, other project feasibility studies; including LAHMEYER (1962), USBR (1964), JICA (1977), EVDSA (1980), HALCROW-UGL (1982), WAPCOS (1990), detail design report of projects already studied (Rib, Megech, Gummera, Gilgel Abay, Koga, Jemma, Tana-Beles, Tis-Abay, Fincha, Guder, Arjo, Lower Dedessa, Karadobi, Border, Mandaya). A good review of the available hydrologic data and particular insight to particular project areas are available in these documents. All of those can be obtained in MOWR library.

In recent years, the number of models simulating the discharge from watersheds in the Blue Nile has increased exponentially. An overview of the models developed for the basin show that the lack of data both for input and calibration hinders 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 Blue Nile. (*Awlachew et al, 2008).*

2.2 Principles of Simulation software (Hec-ResSim)

A variety of analysis techniques including simulation and optimization algorithms have been developed over the last four decades to study water resources systems (Labadie
1997; Loucks et al. 1981; Simonov 1992; Wurbs 1993). Simulations track the movement of water through a system while optimization programs search for an optimal operating policy to achieve a specific objective. Labadie (1997) notes that the difference between simulation and optimization modeling is often obscured because optimization models almost always embed simulation models to verify and test proposed operating policies.

Simulation modeling provides a useful framework for explicitly testing specific
Possibilities for cooperatively operating reservoirs and is the focus of further discussion. Simulation analysis, potential alternatives including operating rules, and other possible management are reviewed.

2.2.1 Simulation analysis

Simulation models use inflows (hydrology), operations (decision rules), and mass-
Balance basin accounting (connectivity) to represent the hydrologic behavior of a reservoir system. System performance is quantified by selecting indicators of benefit based on system flow and/or storage that the modeler feels best characterizes the important aspects and objectives of the system. Indicators can include reservoir storage levels; in - stream flows; hydropower generation; irrigation; water supply deliveries or shortages;

To perform simulation analysis, the modeler first computes performance using selected indicators for a base case representing the system’s existing hydrologic behavior. Next, the modeler develops a series of alternative system behaviors by changing reservoir net works and storage allocations, operating rules, demand levels, and/or hydrology, etc. and computes performance for these hypothesized alternatives. Lastly, the modeler compares base case performance to performance under tested alternatives. The bulk of simulation work consists of formulating alternatives to test and explicitly modeling them.

2.2.2 Operating rules

Operating rules describe the logic used to make decisions on storing or releasing water.
"Guide Curve" rule is discussed.

The "Guide Curve" (see Figure 2-2) specifies the reservoir level at which the model itself tries to keep the water surface when there is no defined rule by the modeler. A guide curve operation oversees releases to maintain that storage level.

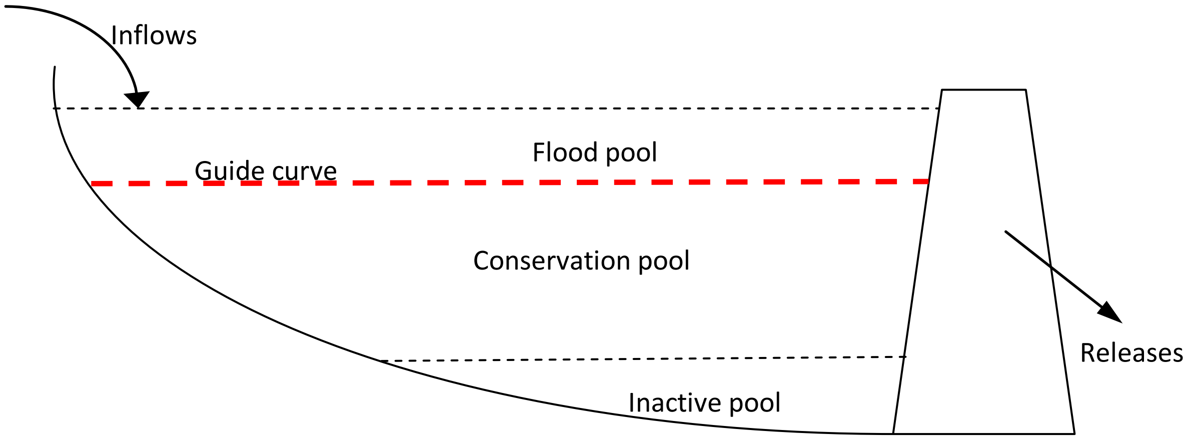
The general release operation is to:

(i) release water as quickly as possible when high inflows encroach into the flood pool and raise storage above the guide curve, or

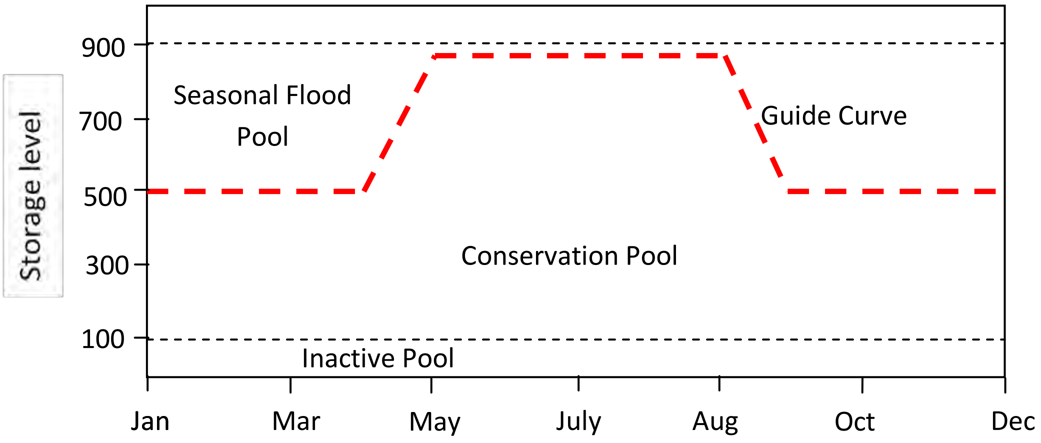
(ii) Curtail releases to the minimum required amounts necessary to satisfy conservation requirements when inflows are low and storage level is drawn-down below the guide curve. As inflows decrease (after flood pool encroachment) or inflows rise (after draw- down into conservation pools), guide curve operations tends to guide storage level back towards the "Guide Curve."

Fig 2.1, reservoir storages partitioned into zones

A. Constant Zones



B. Seasonal Zones



2.3 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 Evaluation System (HEC- ResSim), a next generation reservoir systems analysis software that is object, graphically, and database oriented for real- time or planning analysis studies. For the present study, HEC- ResSim was chosen to model water allocation trends of Abay basin for different Scenarios on monthly basis.

Chapter 3. Data collection and preparation

3.1 Hydrologic data

Generally the flow gauges available in Ethiopian portion of Blue Nile are very limited and are spotty in occurrence. This is due to the remoteness of most of the catchments which inquire a big economic input to install and manage gauged stations. Even though in Abay basin there are over 100 flow gauges, most of them are located on relatively small tributaries, and there are very small gauges on the main river route and near the confluence of main tributaries. Most of those gauge stations are again either of very short record or incomplete due to some intermediate failures of recording. This implies a big deal of challenge, and cumbersome calculation to extract the proper input out of these gauges. Accordingly a technique of regionalization to the point of interest, after a data quality check and infilling missing data, will be inevitably used to finally come up with full time series of 32 years (1960 up to 1992).

3.1.1 Data quality check

It is generally known that a model is as good as the data it is supplied. In most cases no data leads us to a lesser catastrophic conclusion than wrong data. Consequently filtering potential outliers that may exist in our hydrologic time series should be the first step forward.

Outliers are observations that have extreme values relative to other observations recorded under the same conditions. Observations may be outliers because of a single extreme large or small value of one variable or because of an unusual combination of values of two or more variables. It's an unfortunate fact of research that data are not always well-behaved. Outliers or unusual data values occur in almost all research projects involving data collection. This is especially true in observational studies where data may naturally take on very unusual values, even if they come from reputable sources. Data entry errors or rare events (such as appliance malfunctioning, personal imperfection) all these and many more are reasons for outliers to exist in a collection of data. Here two simple methods are used for identification of potential wrong values. Once the outliers were excluded monthly mean for the rest of the time series has been calculated to infill on place of the outlier;

I. Visual technique of filtration

This procedure is simple in that it quickly reveals the most obvious outliers.

For continuous data, a dot plot of a single variable is a good method to visually detect outlying observations. This is very helpful tool; it doesn't require any prior estimate of a mean or standard deviation. Values that are extreme in relation to the rest of the data are easily identified only after looking at the plot. The gauge data which are used for extracting input data for the model have been checked for consistency of their records. The following is the sample for station no 114007, which has been used to infill sta-114002 which was in turn used to prepare inflow to Anger and Nekemte dam.

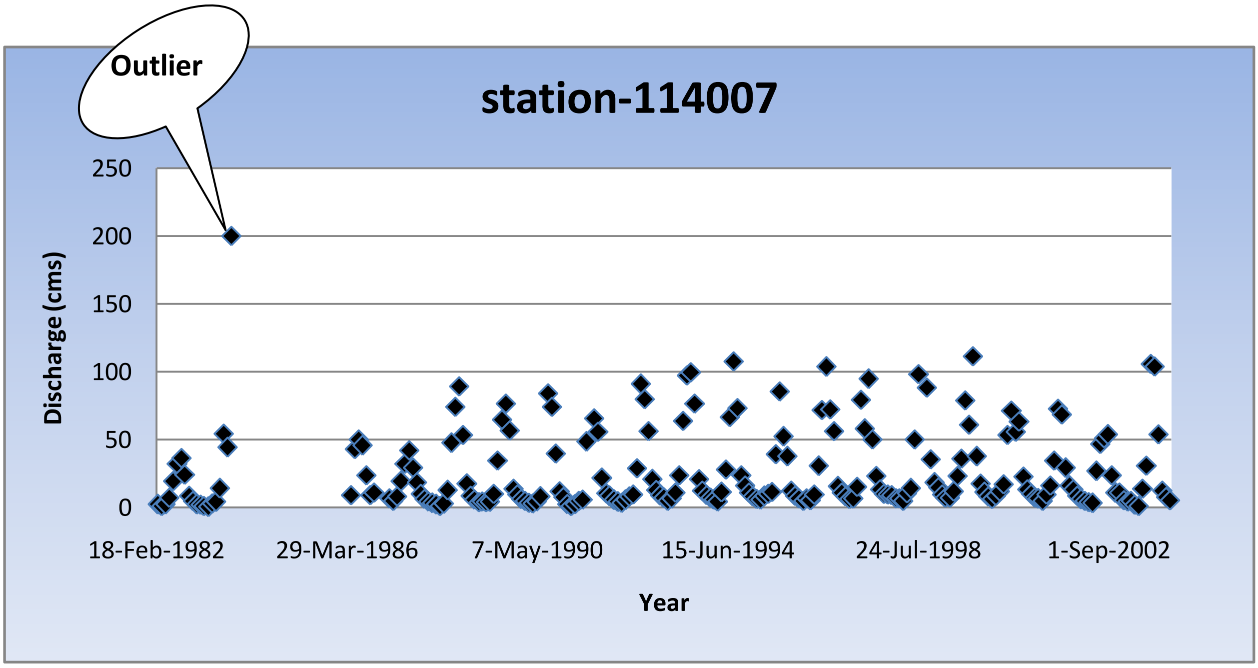


Fig 3.1 Dot plot of time series at station 114007

II. Outliers based on inter-quartile range

A simple statistical task is to compute the inter-quartile-range (IQR) for continuous data and then take a multiple of it as a cut-off value to define values which are considered outliers. It is an extremely effective approach, especially when you have 30 or more data points within each group level.

Only basic computing skills are required to find the inter-quartile-range (IQR) and then compute the number that defines what values could be considered outliers.

The first quartile (q1), third quartile (q3), and inter-quartile range (iqr) can be easily calculated using a 'quartile' function of powerful excel or simply manually; firs arrange the data in ascending order then identify the record lying at 25% of the order (q1), at 75% of the order (q3) then find the range between them and that will be inter –quartile range (iqr). You can then flag observations that lie outside of q1-(1.5*iqr) and q3+ (1.5*iqr) as potential outliers and anything outside of q1-(3*iqr) and q3+ (3*iqr) as problematic outliers.

Table 3.1 Quartile definition and calculation for sample gauge stations.

If quart equals	QUARTILE returns
0	Minimum value
1	First quartile (25th percentile)
2	Equal to Median value (50th percentile)
3	Third quartile (75th percentile)
4	Maximum value

Station	1st quartile(q1)	3rd quartile(q3)	inter quartile range(iqr)	q1-(3*iqr)	q3+(3*iqr)	outlier criteria
station 114007	6.25	42.46	36.22	-102.40	151.11	if value <-102.4 or >151.11
station 114008	8.44	104.42	95.98	-279.50	392.36	if value <-279.5 or >392.36

Here it can be seen that the value filtered visually above (200), is also out of range according to this method (i.e. 200> 151.11)

3.1.2 Infilling missing data

As indicated above one can hardly find a gauge which hasn't either short period of record or a long range of missing record in the basin. Consequently prior to going to a technique of regionalization, we first identified the nearest gauge station to our point of interest, for example to inflow point of a certain reservoir. This was done using a map which was prepared on Arc-View Gis using Avswat extension program which depends on 90x90 DEM. This helped in visualizing which gauge is the nearest to our point of interest. Then two steps are done towards filling.

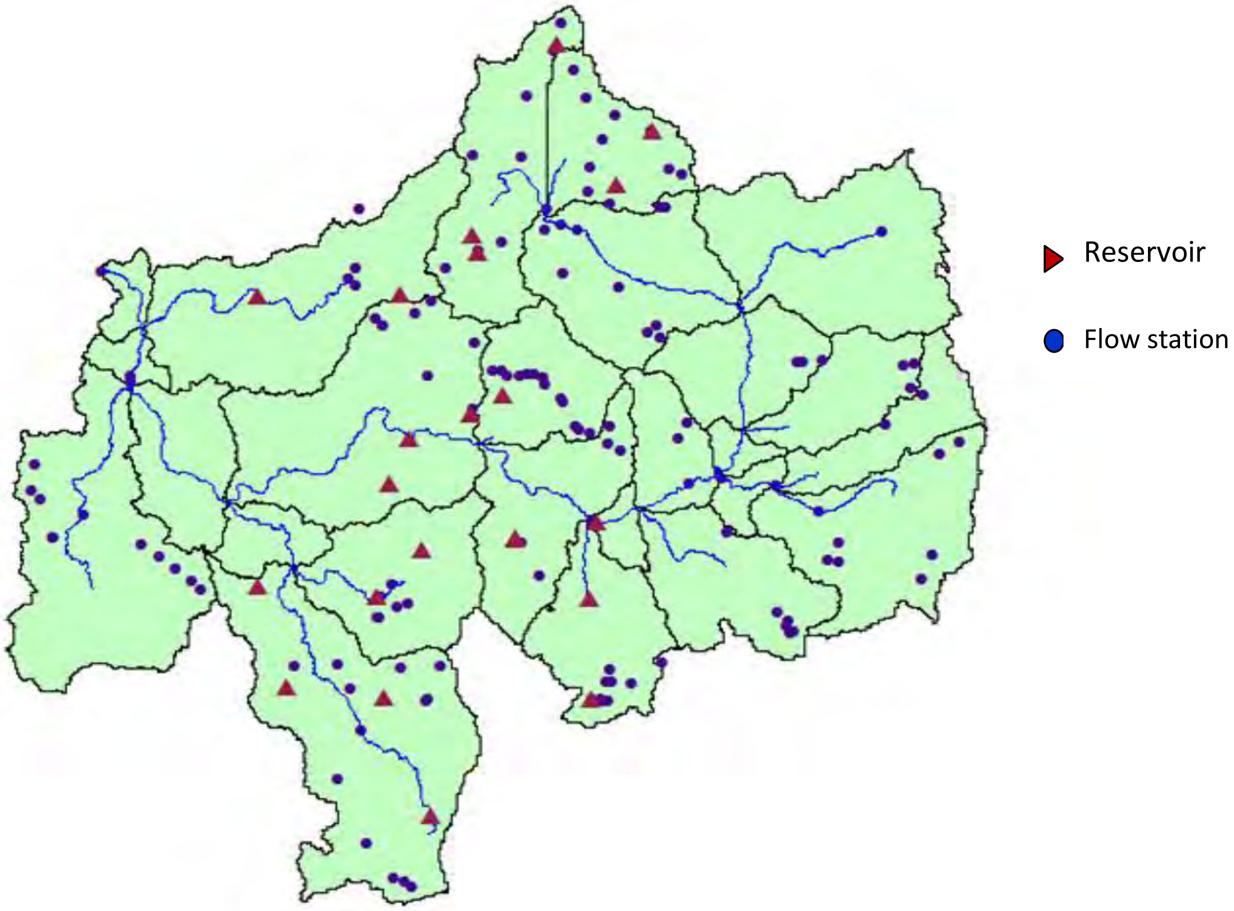


Fig 3.2 Delineated watershed with reservoire and guage locations added

I. Double mass curve

This is a method by which we can easily identify which of the neibhoring guages, if any, around the station ,which is to be filled, best corrosponds to fill the missing records.This method has not been applied for most cases due to lack of neighboring station for the station in question. However in infilling and checking records of guage stations which has been used to calibrate and validate the model (Bahirdar, kessie & border), this method helped in determining the best realistic correlation out of different guages located near by.

The method comprises of simple ploting of the cummulative time series volume of flow b/n the records of the station to be infilled and other near by.This will be reapeated as many as the available near by stations. The best neighober then will result in more or less a straight line plot. Then that station will surely be relatively the best to be used as infilling station.

II. Regression

After selecting which station best matches with the recordes of the station in query using mass curve method, performing regression between the two will give the equation into which the given should be calculatd to get the estimated records of the missing data for the coresponding time. In most cases missing data should be infilled using multiple station as the missings may not be found as a whole only in one station, insuch case either the rest unfilled will be infilled using monthly mean of already availabe (if they are of short period) or another regression will be done with another station which has a record on those months and years that the required station has no. In addition to the presented example, such a procedure has been performed many times to determine inflow to 23 reservoires and tributary contribution at the confelence point with the main river.

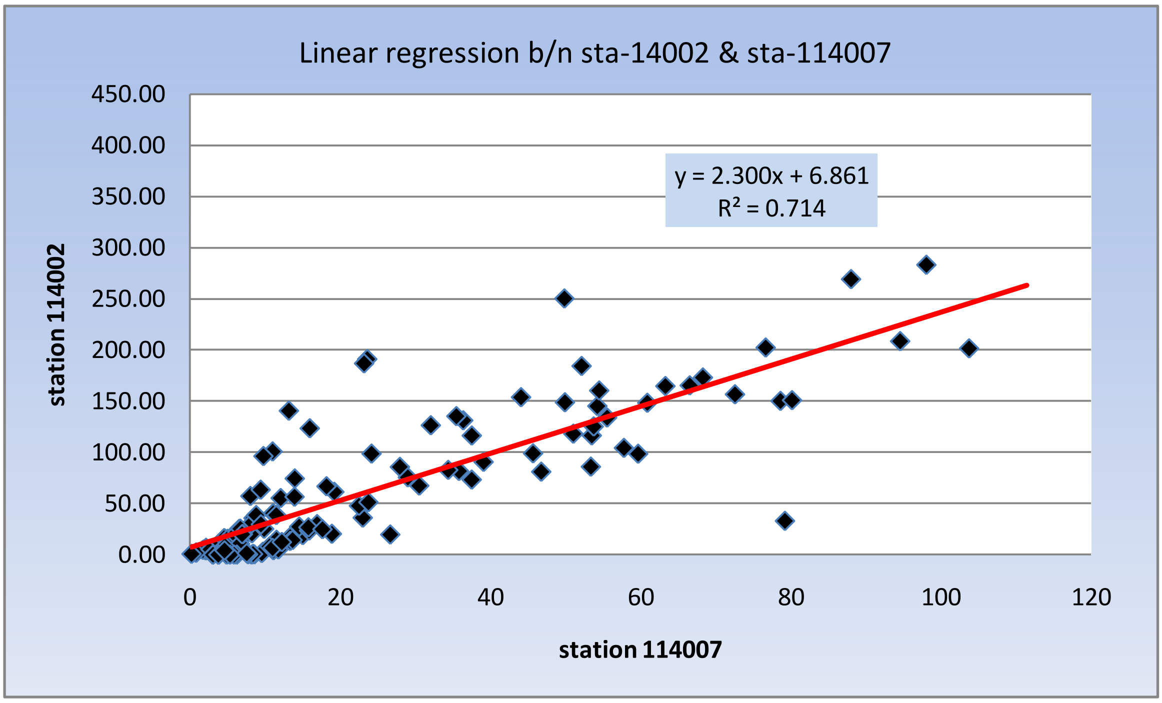


Fig 3.3 linear regression b/n sta-114002 & sta-114007 (which has been used to generate inflow to Anger and Nekemte dams)

3.1.3 Regionalization

Regionalization is a generally understood term to explain information transfer from gauged catchments to other ungauged catchments of similar characteristics.It can also be used for gauged catchments with limited record length. From the gauged catchments homogeneous regions are grouped into regions that are similar in terms of catchments hydrological responses.Ungauged catchments within the identified homogeneous regions can refer to the information (for this thesis, flow data) obtained from the gauged catchments.This approach is suitable in conditions of limited data availability.

Most extensively and sometimes only method used for regionalizing flow data from guaged to unguaged is the drainage-area ratio method (Emerson and Dressler, 2002). The method is easy to use, requires little data, does not require any development and many times, is the only method available because regional statistics or precipitation-runoff models may not be developed and would be time consuming if any . The drainage-area ratio method commonly is used to estimate streamflow for sites where no streamflow data were collected.

$$Q_{i,unguaged} = \left(Q_{i,guaged}\right) * \left(\frac{Area_{unguaged}}{Area_{guaged}} * \frac{PPT_{unguaged}}{PPT_{guaged}}\right)$$

Where; Q_i is flow record at i time,

PPT is mean precipitation of the area

To use the precipitation parameter a DPM (digital precipitation model) would be necessary to be used in Arc-view to calculate mean rainfall with in the area delinated (guaged and unguaged), and this grid was not easy to find for the basin. The other technique availabe is to use rain-guages to calculate the mean precipitation in the sub catchment in a weighing term, however the rain-guages' location in the basin is very spoty, in some cases there is only one common guage with in the unguaged and guaged areas in which case the parameter ratio becomes one. So this approach will be eminent but less effecting while inducing very time consuming and roubust duty. As guaged (stations) and ungeged areas are demanded to be near to each other, they have more or less similar rainfall characterstics. For this reason regionalization was done using area parameter only. The error may be said to none. So the following reduced equation has been used;

$$Q_{i,unguaged} = \left(Q_{i,guaged}\right) * \left(\frac{Area_{unguaged}}{Area_{guaged}}\right)$$

Where; Q_i is flow record at i time,

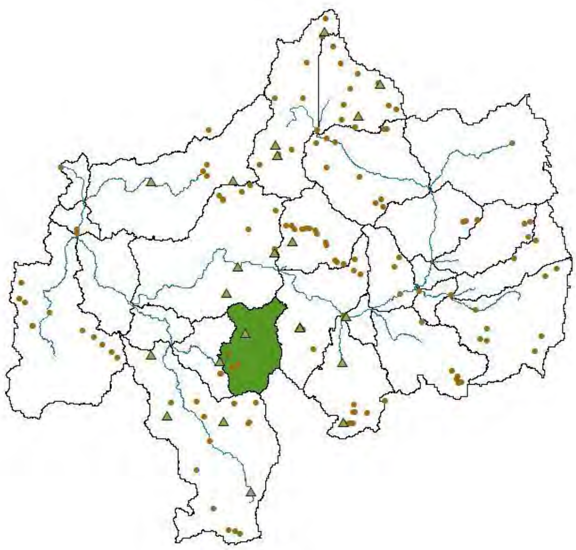


Fig 3.4(a) Delineation at gauge station-114007 to know area of gauged

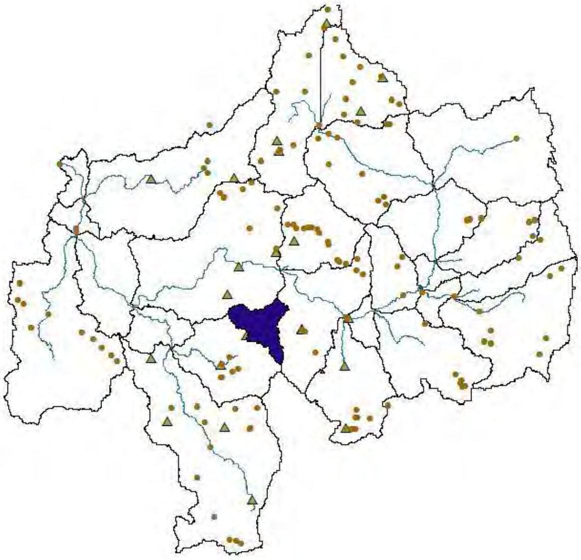


Fig 3.4(b) Delineation at Anger dam site to know area of ungauged

* Such a procedure has been followed for the rest of the reservoirs (23 in no) and tributaries.

3.2 *Water resources development data*

3.2.1 *Existing condition*

Ethiopia currently utilizes very little water of the Blue Nile, because of the inaccessibility of the river, lack of infrastructure, the major centers of population lying outside of the basin and due to its system mainly depending on the rain-fed system. To date only three relatively minor hydraulic structures have been constructed in the Ethiopian Blue Nile Catchment (Table 3.2).Of these three dams (i.e., Chara-Chara Weir and Fincha) were built primarily to provide hydropower. The combined capacity of the power stations they serve (218 MW) represents approximately 30% of the total currently installed power capacity of the country (i.e., 731 MW, of which 90% is hydropower (*World Bank 2006 as quoted by Awlachew et al, 2008*). koga reservoir, completed before one year, is built to serve small holder irrigation of about 7,200ha.

Table 3.2 Existing dams in Abay basin;

Dam	**River**	**Hydropower (mw)**	**Irrigation (ha)**	**Maximum storage (Bm^3)**
Chara-Chara (lake tana regulation weir and power generation at Tis Abay I and Tis Abay II power stations	Abay	*84*	-	*33.81*
Fincha	Fincha	*134*	*8,145*	*0.79*
Koga	Koga	-	*7200*	*0.12*
Total		***218***	***15,345***	***34.72***

3.2.2 Planned developments

There is significant potential for further water resources development in Ethiopia. Vast big and medium scale possible irrigation and hydropower projects have been investigated over a number of years by USBR 1964; WAPCOS 1990; BCEOM 1998; JICA 1977 and other many documents. However the huge amount of money needed to do the detail assessment of each identified potential sites in the master plan surely is the main reason hindering appraisal of the projects. In fact many have been assessed in detail, resulting in specific designs and financial estimation. The out put of this project specific assessment may not always be the proof of the recommendation in the master plan. Once it may be appraised, altered or omitted.

After reviewing different documents and discussing with concerned bodies of each project in the basin, the following extracted summary of projects is found to be more reliably implementable. Currently envisaged irrigation projects will cover a total of more than 300,231 ha, which represents 37% of the 815,581 ha of potential irrigation estimated in the basin (BCEOM 1998).

The major hydropower projects currently being contemplated in Ethiopia have a combined installed capacity of 6,811 MW. The exact figure depends on the final design of the dams and the consequent head that is produced at each site. The four largest schemes being considered are dams on the main stem of the Blue Nile River Abay.

Major irrigation and hydropower schemes that are currently being planned and/or being implemented are described in the following Table 3.3.

Table 3.3. Planned projects;

Dam/ Simple diversion	**River/lake**	**Hydropower (mw)**	**Irrigation (ha)**	**Maximum storage (Bm^3)**
Transfer from Lake tana to Beles	Tana/Beles	*219*	-	-
Lake tana pumping diversion	Tana	-	*6,720*	-
Megech	Megech	-	*7,150*	*0.21*
Rib	Rib	-	*20,000*	*0.27*
Gummera	Gummera	-	*14,100*	*0.07*
Jemma	Gilgel Abay	-	*11,600*	*0.14*
Gilgel Abay	Gilgel Abay	-	*12,852*	*0.41*
Upper Guder	Guder	-	*6,000*	*0.28*
Lower Guder	Guder	*100*	*4,896*	*1.70*
Neshe	Fincha	-	*7,217*	*0.30*
Fincha expansion	Fincha	-	*12,000*	*0.79*
Anger	Anger	-	*14,450*	*0.79*
Nekemte	Anger	-	*11,220*	*1.15*
Arjo Dedessa	Dedessa	-	*13,665*	*1.70*
Lower Dedessa	Dedessa	*196*	-	*3.50*
Upper Dabus	Dabus	*152*	*9,661*	*2.03*
Lower Dabus	Dabus	*174*	-	*0.82*
Dangure dam	Beles	*150*	-	*3.59*
Upper Beles diversion	Beles	-	*53,700*	-
Upper Dinder diversion	Beles	-	*10,000*	-
Lower Beles diversion	Beles	-	*85,000*	-
Karadobi	Abay	*1600*	-	*41.93*
Mabil	Abay	*1200*	-	*12.10*
Mandaya	Abay	*1620*	-	*49.20*
Border	Abay	*1400*	-	*14.47*
Total		***6,811***	***300,231***	***135.43***

3.3 Reservoir system data

A reservoir system data which includes basic physical characteristics of the dam and any intake or outlet structures along with extractions (demands) including evaporation losses, need to be determined as an input to the model. The process of determining physical parameters of the dam, spillway and intake structures may be cumbersome and a big deal of time, as sometimes the data may not be available in a tabular format at what time we were obliged to scale measure from the working drawings of the projects. Following the methods followed to determine the reservoir system data are elaborated below.

3.3.1 Physical data

This category includes the capacity curve of the dam (Elev-Vol-Area relation) and discharge rating curve for each inlet and outlet structure (spillway, irrigation intake, power intake). Also here the maximum, normal and minimum water level of the reservoir should be defined.

In most cases these data are not directly available, except for some which have a complete dam design report. The capacity curve of the dams which have not been studied in detail was mostly obtained from BCEOM phase2, vol-2 (dam project profiles) report, where all are presented graphically, tabulating by interpolation is easy task.

The capacity curves of the reservoirs have been adjusted while moving from one scenario to the other to account for Reservoir capacity curve change due to reservoir sedimentation. This has been done using a simple assumption of uniform annual sedimentation yield, which can be obtained from the master plan, then multiplying the yield by the year the reservoir is thought to have served at the point of the next scenario, after which it has been deducted from the total current capacity at each elevation, based on which the new relations are derived. The following simple formula has been used.

Current storage volume at H level - Annual sedimentation * years =
New storage volume at H level

For spillway and intake structures it was inevitable to synthesis the Elevation-capacity relationships for each after measuring the physical dimensions of the structures on the map either available on the master plan (BCEOM phase2, vol-VI) or project specific design reports.

The following formulas were used to determine the discharge capacities of the structures at varying water surface elevation;

For simple over flow spillway; $Q = CLH^{3/2}$, Broad crested weir formula

Where; Q is discharge in m^3/sec
C is coefficient of discharge, determined using spillway design discharge and max head over the spillway crest.
L is spillway length in m; to be measured from drawings.
H is head over spill way level in m

For intake structures; $Q = \mu\, na \sqrt{2gh}$, orifice flow formula

Where; Q is discharge in m^3/sec
μ is coefficient of contraction/expansion, constant based on shape of the inlet.
a area of the inlet in sqm.
n no of inlets having area of a.
g is gravity.
h is the water head above the center of the inlet in m.

3.3.2 Losses over the reservoir

Losses over the reservoir include leakage and evaporation. Due to complexity of analyzing seepage losses, only evaporation lose has been considered. For some reservoirs this loss is available in the respective hydrology report of each project. For those which have no, the FAO LocClim software has been used to find the same. This parameter could also be got from the master plan BCEOM; however its considerable variation with those calculated in some project specific reports, it couldn't be used confidentially.

FAO LocClim software is a tool for spatial interpolation of climatic data using different interpolation methods based on FAO local climate database. The software is easy and can be explored by trial and error method. Once the coordinate of the reservoir location has been given to the user interface of the software in terms of degree, minute, second or decimal format, then the program gives the average rainfall and potential evapotranspiration on different time steps; monthly time step for this case.

3.3.3 Irrigation water demand

All monthly irrigation demand estimations have been taken from the master plan except for those which are modified in specific project reports. For Fincha project the actual site water use has been used, as this is the only project currently being run in the basin.

Concerning return flow from the irrigation projects; in the model only gross irrigation requirements have been used. This is because after the completion of the projects, the factory and workmanship demands are sure to exceed the return flows (usually assumed to be 10%) as demonstrated for Fincha actual case. For this reason the return flow was assumed to be counter balanced by these unforeseen demands.

Table 3.4. Irrigation demands used in the model in Mm3;

Projects	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
TANA SUB BASIN													
Rib irrigation project	58.00	27.60	31.00	39.40	12.00	0.00	0.00	0.00	0.00	10.60	15.60	3.40	**197.60**
Megech irrigation project	10.22	11.73	12.16	4.72	0.00	0.00	0.00	0.00	0.00	0.00	6.51	11.23	**56.56**
Gummera irrigation project	7.82	10.30	7.90	0.25	0.00	0.00	37.61	6.50	15.06	22.81	1.64	4.96	**114.84**
koga irrigation project	7.85	17.06	23.69	17.06	1.73	0.00	0.00	0.00	6.26	14.90	7.63	1.58	**97.78**
Jemma irrigation project	15.03	20.33	18.60	7.19	0.00	0.00	0.00	0.00	0.00	0.00	13.34	14.59	**89.08**
Gilgel Abay irrigation project	32.54	33.96	30.81	6.90	6.90	12.88	5.81	3.88	3.88	4.01	8.38	24.19	**174.14**
Lake Tana pumping	8.86	10.83	13.16	6.27	0.00	0.00	0.00	0.00	0.00	1.61	8.25	9.17	**58.13**
BELES SUB BASIN													
Upper Beles	84.05	87.85	75.77	72.84	23.12	0.00	0.00	0.00	0.00	0.00	81.39	104.42	**529.43**
Upper Dinder	16.94	21.47	20.99	9.26	0.00	0.00	0.00	0.00	0.00	0.00	15.35	14.10	**98.11**
Lower Beles	148.30	184.99	173.24	91.70	5.17	0.00	0.00	0.00	0.00	0.00	121.61	126.17	**851.18**
DABUS SUB BASIN													
Upper Dabus multi purpose project	14.10	17.75	15.02	2.46	0.00	0.00	0.00	0.00	0.00	0.00	6.35	13.73	**69.41**
DEDESSA SUB BASIN													
Arjo Dedessa irrigation project	28.61	34.92	26.41	5.30	2.01	32.42	8.95	10.33	12.45	13.72	3.29	16.07	**194.48**
Nekemte irrigation project	15.99	18.95	10.90	2.31	0.00	0.00	0.00	0.00	0.00	0.00	9.84	13.48	**71.46**
Anger irrigation project	20.59	24.41	14.04	2.98	0.00	0.00	0.00	0.00	0.00	0.00	12.67	17.36	**92.04**
FINCHAA SUB BASIN													
Neshe irrigation project	8.16	8.08	5.82	4.41	0.31	0.00	0.00	0.00	1.28	6.13	10.02	10.16	**54.38**
Fincha multi purpose project	16.10	17.90	21.21	22.19	19.93	18.69	2.68	2.68	16.17	17.01	14.62	14.76	**183.93**
GUDER SUB BASIN													
Lower Guder multipurpose project	6.01	6.01	3.20	0.00	0.00	0.00	0.00	0.00	0.00	0.07	4.72	6.91	**26.92**
Upper Guder irrigation project	7.37	7.37	3.92	0.00	0.00	0.00	0.00	0.00	0.00	0.08	5.78	8.46	**32.99**
TOTAL													***2,992.44***

3.3.4 Environmental releases

Environmental release is the amount of water allocated from the conservation section of the reservoir for down stream users and to maintain the morphology of the river route. This is incorporated with its own independent out let structure which will be operational whenever no water spills over the spillway or when the spill is not enough. This demand particularly should be given due consideration especially for irrigation dams and hydropower dams for which the tail race is far from the dam. However fixing the numeric value of the discharge required, needs detail Environmental impact analysis for the project, which is not available for most of the projects. For some of the projects this demand has been given as percentage of monthly average inflow to the reservoir. While for Lake Tana regulation weir a constant (20m^3/sec) environmental release for Tis-Issat fall and d/s channel has been taken after Tana Beles project becomes operational.

3.3.5 Power water demand

In most cases except for Karadobi, Tis Abay and Fincha the monthly power flow requirements are not available. Most of the reports give the average annual power generated by the plant. So it was unavoidable to estimate the power flows for each month from the annual power generation estimate given in Gwh/annum. For this purpose a due consideration of the power plants as a base power plant has been taken. So the plant has been assumed to generate uniformly throughout the year. The following formula has been used; actually net power head (H_{net}) varies with the water surface level in the reservoir at a time; it is calculated taking the average level between maximum and minimum water surface level as reference effecting in insignificant error.

$$Power\ (w) = \frac{Enegy\ (Gwh) * 10^9}{Hours\ in\ the\ year}$$ … To change annual energy to power.

$$monthly\ power\ Discharge\ (m^3/sec) = \frac{Power\ (w)}{\mu\ (eff.) * \gamma * H(net\ head)}$$

Chapter 4. Simulation methods

4.1 Set up of Hec-ResSim model

The “Hydraulic Engineering Center - Reservoir System Simulation (HEC-ResSim-3)” software developed by American Army Corps of Engineers, Hydraulic Engineering Center, has been used to simulate water allocation in Abay basin under four scenarios including the base case scenario to be used for calibration and validation of the software.

HEC-ResSim offers three separate sets of function called modules that provide access to specific types of data with in a watershed. These modules are Watershed set up, reservoir network and simulation. Each module has unique purpose and an associated set of functions accessible through menus, toolbars and schematic elements. Figure 4.1 illustrates the basic modeling features available in each module.

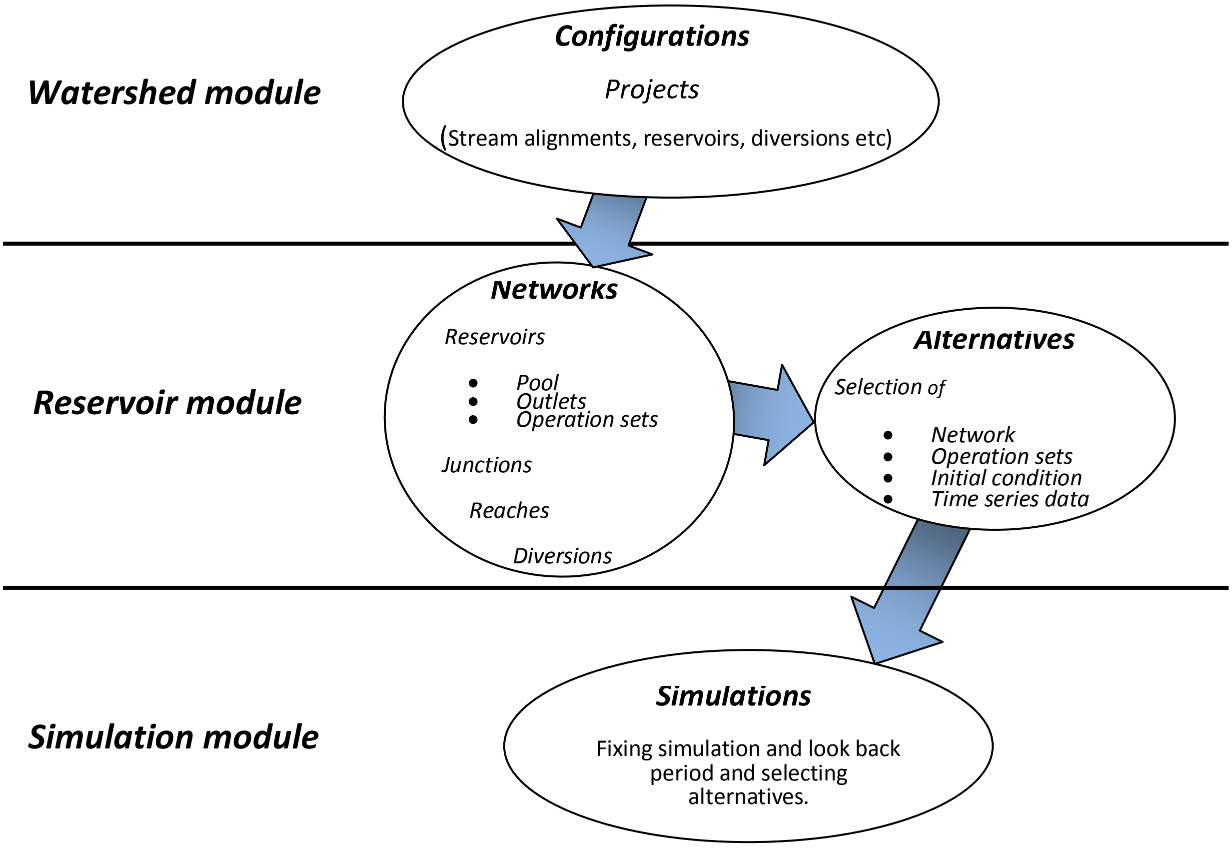


Fig 4.1 Hec-ResSim module concepts

4.1.1 Watershed set up module

In the watershed setup module, you can assemble items that describe a watershed’s physical arrangement. Once a new watershed has been created, it is possible to import maps from external sources after specifying measurement units and coordinate systems for viewing the map. Here first the shape file of Abay basin stream network which has been obtained from delineation using Arc-View Avswat extension has been imported. This map uses as a background for tracing the main stream and main tributaries of Abay when drawing using a stream alignment toolbar. Hec-ResSim also imports the map as stream alignment map by easy command which is available from the watershed menu, import wizard. The only disadvantage is that it aligns a stream tracing all smaller streams being imported which then require to be deleted. However this is a nice method in that it saves much time and energy needed to draw following the main streams. Fig 4.2 shows Abay basin configured in the watershed module of Hec-ResSim and streams drawn following the main course and main tributaries.

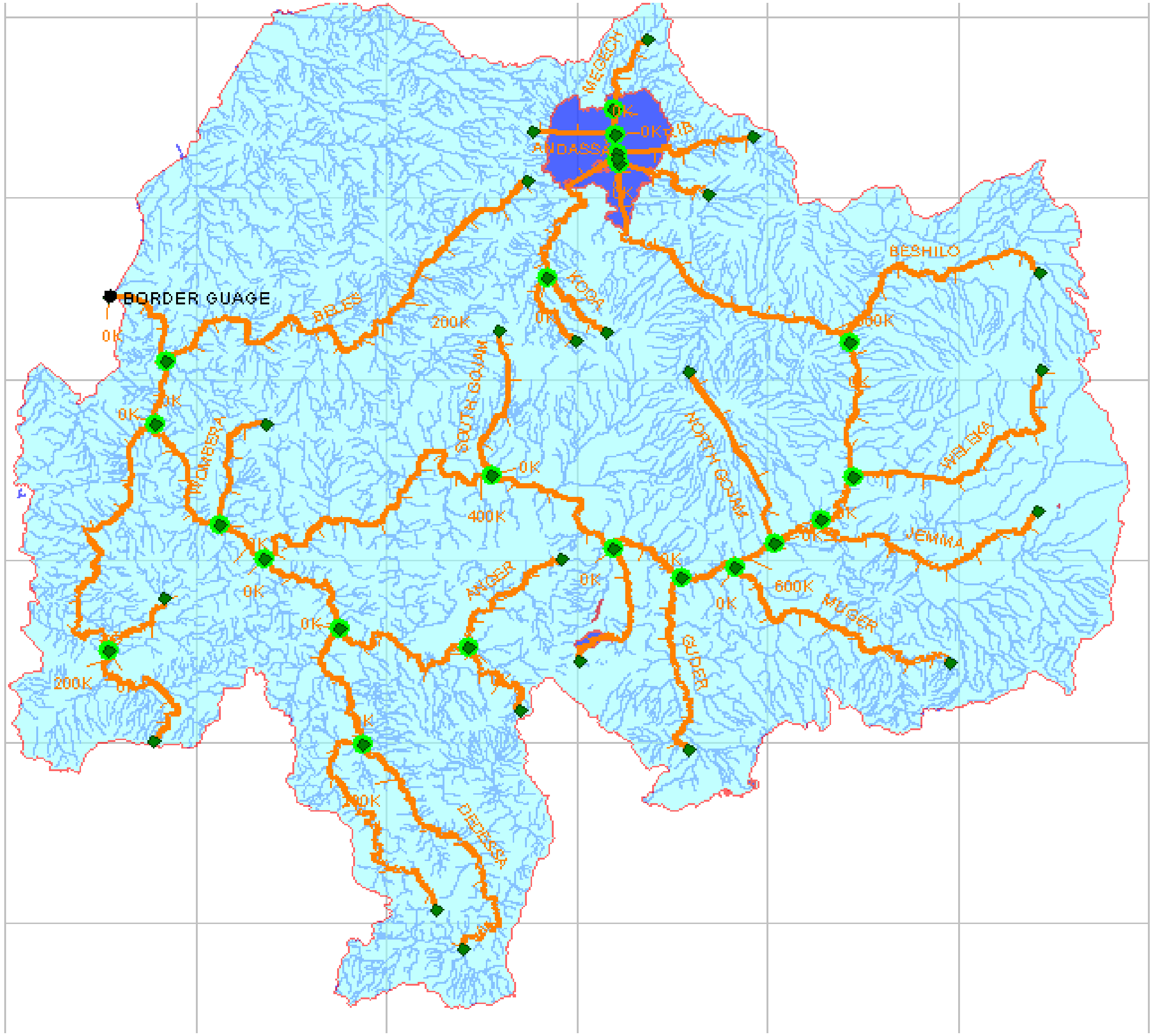


Fig 4.2: Abay basin stream system drawn on Hec-ResSim watershed module.

4.1.2 Reservoir network module

This module is the region where all available reservoir systems and simple diversions are added and joined to each other by routing reach elements, using configurations that were created in the watershed set up module as a template, for each alternative or scenario independently. Then after we built our network schematic, we described the physical and operational data of the reservoir systems using already prepared reservoir system data. Here the area-volume-elevation relationship for reservoirs has been updated to account for yield decrease due to sedimentation, during analyzing future scenarios.

The operational data of the reservoirs embrace the specification of withdrawal priority among different demands and extraction definition for each reservoir storage level i.e. whether the reservoir level is with in flood, conservation or dead storage zone. Normally higher priority has been given for environmental releases (if any) then irrigation then to power for multipurpose projects; spillway is considered the least prior in all cases.

In this module the routing reaches which connect one reservoir with the other creating reservoir systems, have routing and losses accounting property incorporated with them. However considering routing and seepage losses b/n reservoirs needs complex physical data of the river and has not been included in this thesis. The last session before quitting this module is to define alternatives that specify the reservoir network, operation sets, initial conditions, and assignment of DSS pathnames (time series data mapping).

i. Data Storage system (HEC-DSS)

This is a tool with in ResSim primarily used to store and access time series data with in the system. This tool has a vast capability of manipulating data; editing, plotting …etc. it is from this database the inflows to each reservoir and other time series data, if any has been defined during setting up alternatives or scenarios.

ii. *Scenario Setting (Defining alternatives)*

After a detail consultation with the advisor and reviewing relevant documents, for the present modeling four scenarios have been considered. These are;

1. Base case scenario or present condition scenario. **(scenario-1)**

   Under this scenario only the present condition of Abay basin has been considered. This scenario has been used to calibrate and validate the model, using Bahirdar, Kessie and Border gauges as reference.

2. Present condition plus projects appraised to be implemented with in 20 years. **(scenario-2)**

   This scenario has been set up to see the near future of the basin, probable with in 20 years, based on likely future developments currently anticipated to be implemented.

3. All identified (planned) projects in the basin excluding Tana-Beles transfer and Beles irrigation projects. **(scenario-3)**

   This setting has been basically preferred to quantify the impact of Tana-Beles transfer on the power output of the four large scale hydropower projects on the main stream and assess the overall power out put before and after Tana-Beles Project. Here the irrigation projects on Beles river, which have been included in scenario 2, have also been excluded since these projects depend on the water to be transferred from Lake Tana and in this scenario Tana-Beles project doesn't exist.

4. All identified (planned) projects. **(scenario-4)**

   This is the representation of the situation which would exist whenever Ethiopia portion of Blue Nile will be exploited by the projects which are intended to be realized with in half a century according to Ethiopian government policy.

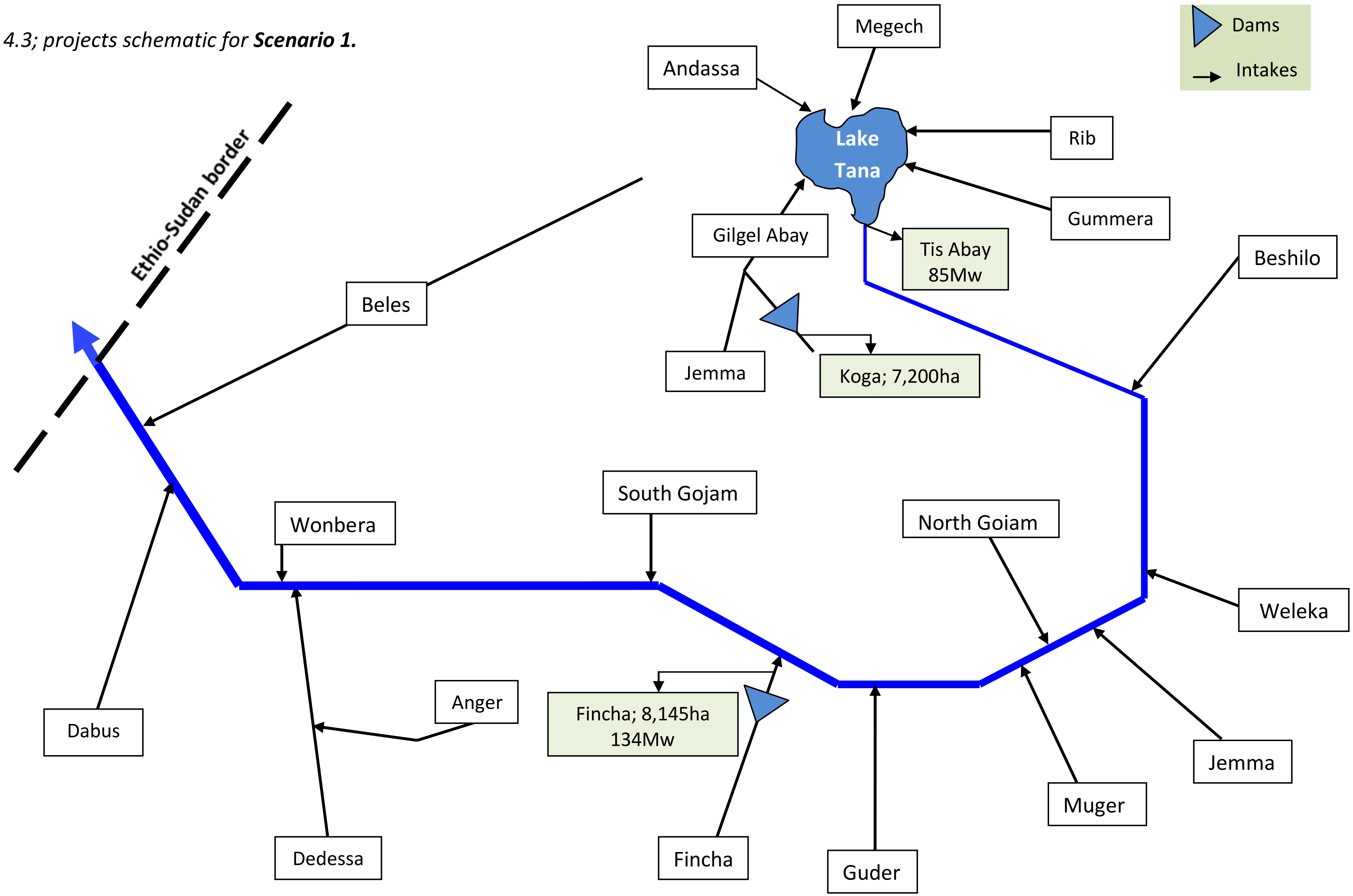
Following are tables of projects included, figures of projects' line schematic and model schematic for each scenario.

1. Base case scenario or present condition scenario (Scenario-1)

Dam	**River**	**Hydropower (mw)**	**Irrigation (ha)**
Chara-Chara (lake tana regulation weir and power generation at Tis Abay I and Tis Abay II power stations	Abay	*84*	-
Fincha	Fincha	*134*	*8,145*
Koga	Koga	-	*7,200*
Total		***218***	***15,345***

Table 4.1 Base case scenario, included projects list

Fig 4.3; projects schematic for ***Scenario 1.***



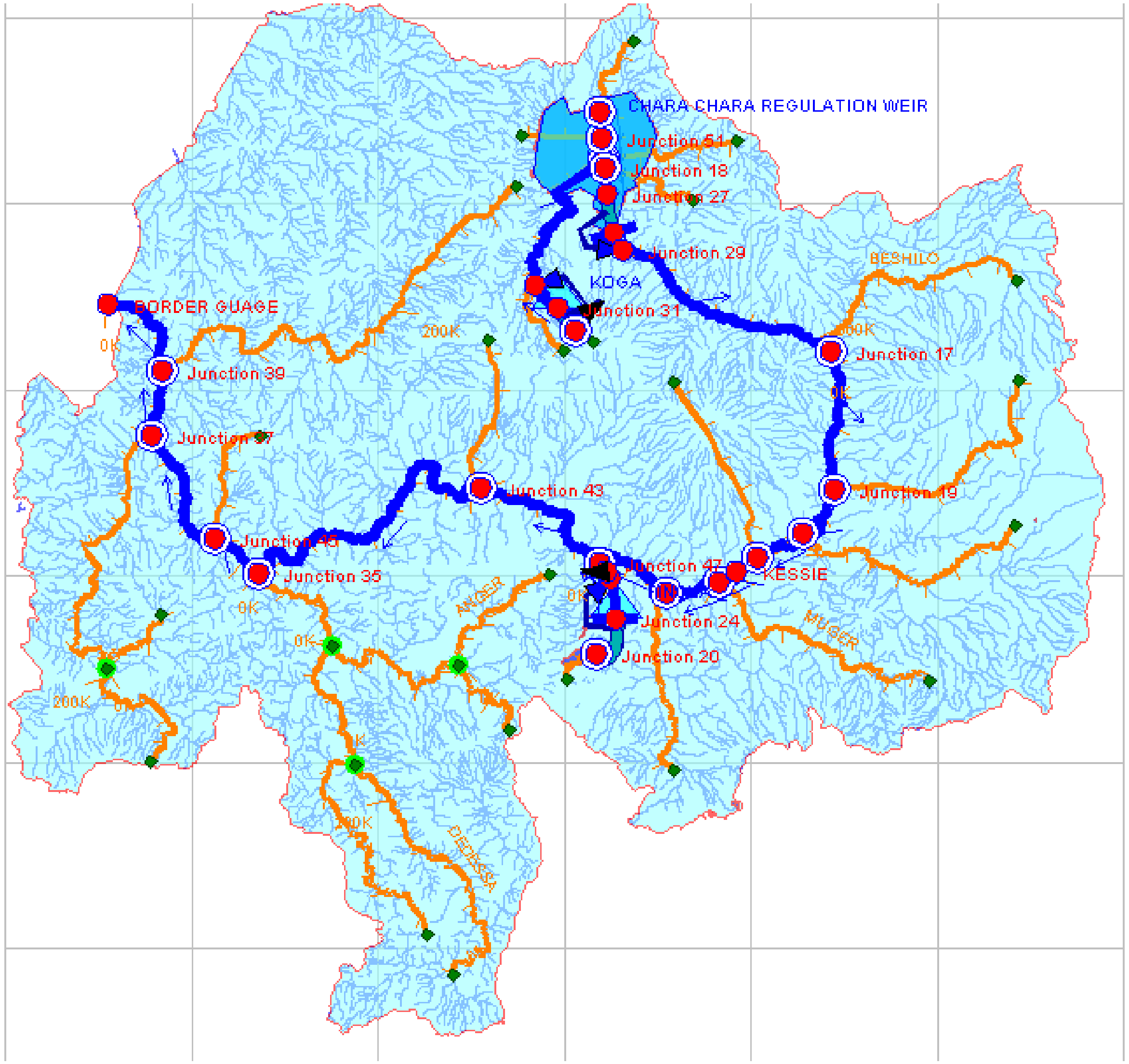


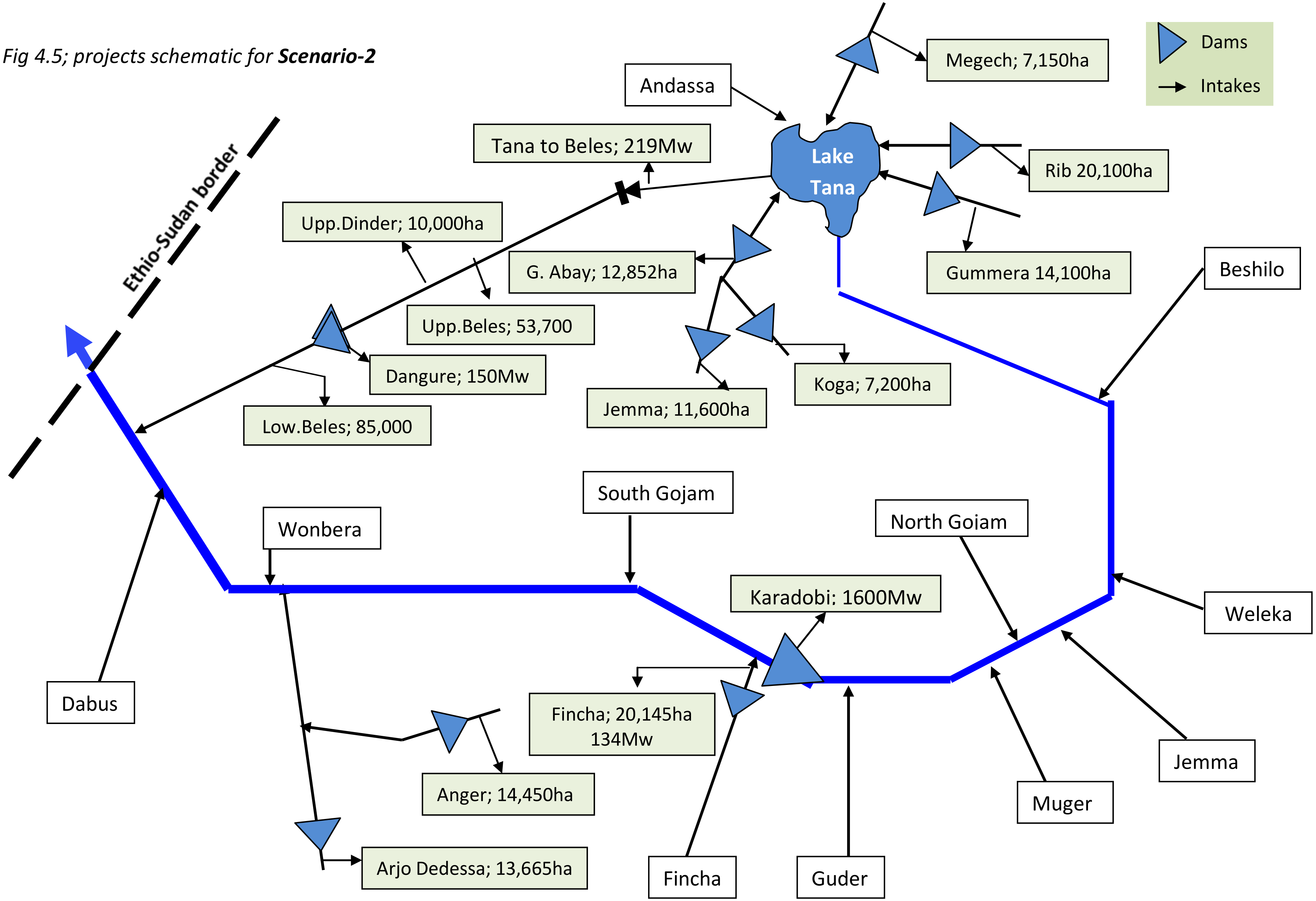
Fig 4.4; Scenario-1, HEC-ResSim model schematic

2. Present condition plus projects appraised to be implemented with in 20 yrs **(Scenario-2)**.

Dam/ Simple diversion	**River/lake**	**Hydropower (mw)**	**Irrigation (ha)**
Koga	Koga	-	*7,200*
Transfer from Lake tana to Beles	Tana/Beles	*219*	-
Megech	Megech	-	*7,150*
Rib	Rib	-	*20,000*
Gummera	Gummera	-	*14,100*
Jemma	Gilgel Abay	-	*11,600*
Gilgel Abay	Gilgel Abay	-	*12,852*
Fincha after expansion	Fincha	*134*	*20,000*
Anger	Anger	-	*14,450*
Arjo Dedessa	Dedessa	-	*13,665*
Dangure dam	Beles	*150*	-
Upper Beles	Beles	-	*53,700*
Upper Dinder	Beles	-	*10,000*
Lower Beles	Beles	-	*85,000*
Karadobi	Abay	*1600*	-
Total		***2,187***	***269,717***

Table 4.2 Scenario-2, included projects list

*Fig 4.5; projects schematic for **Scenario-2***



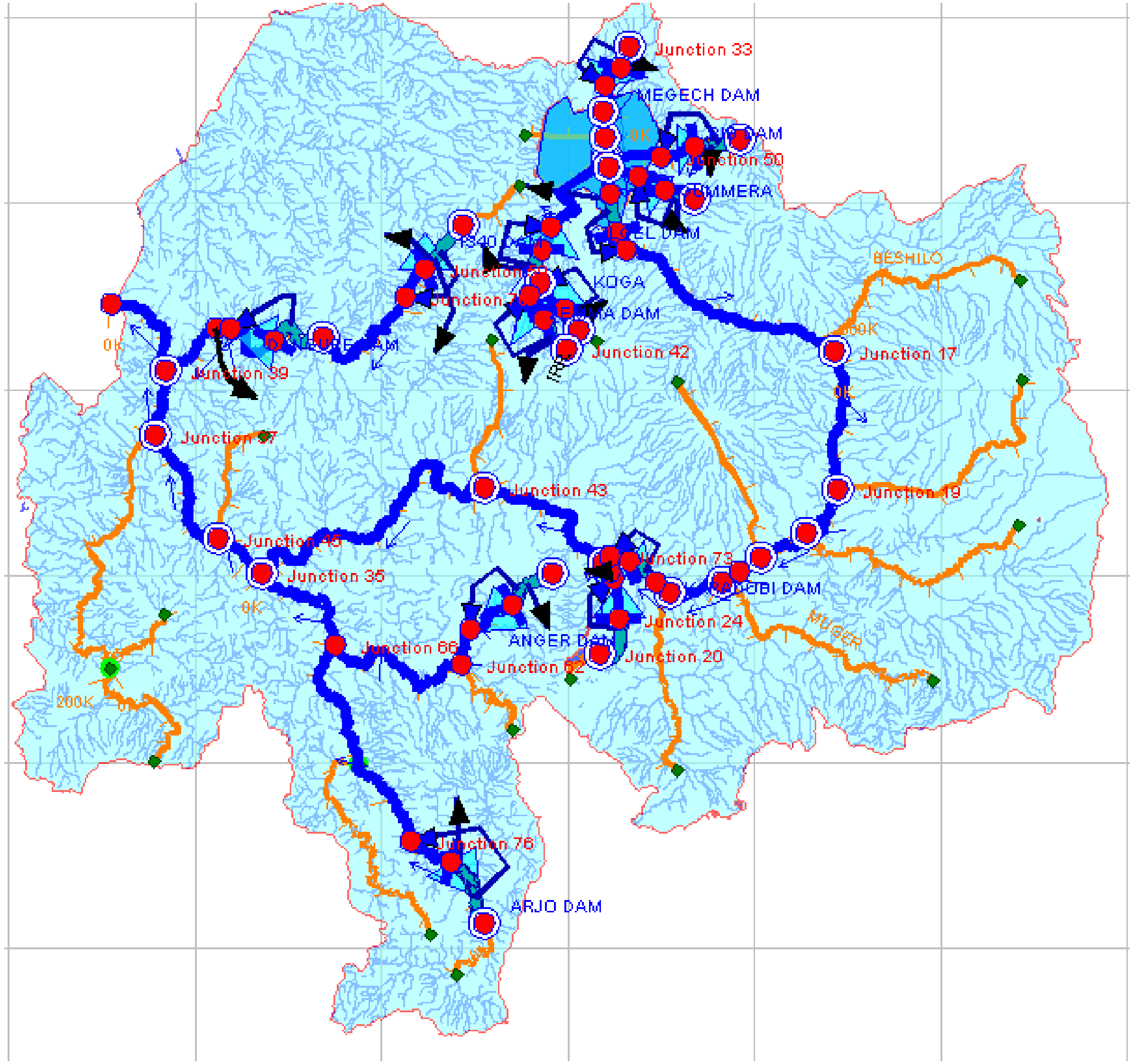


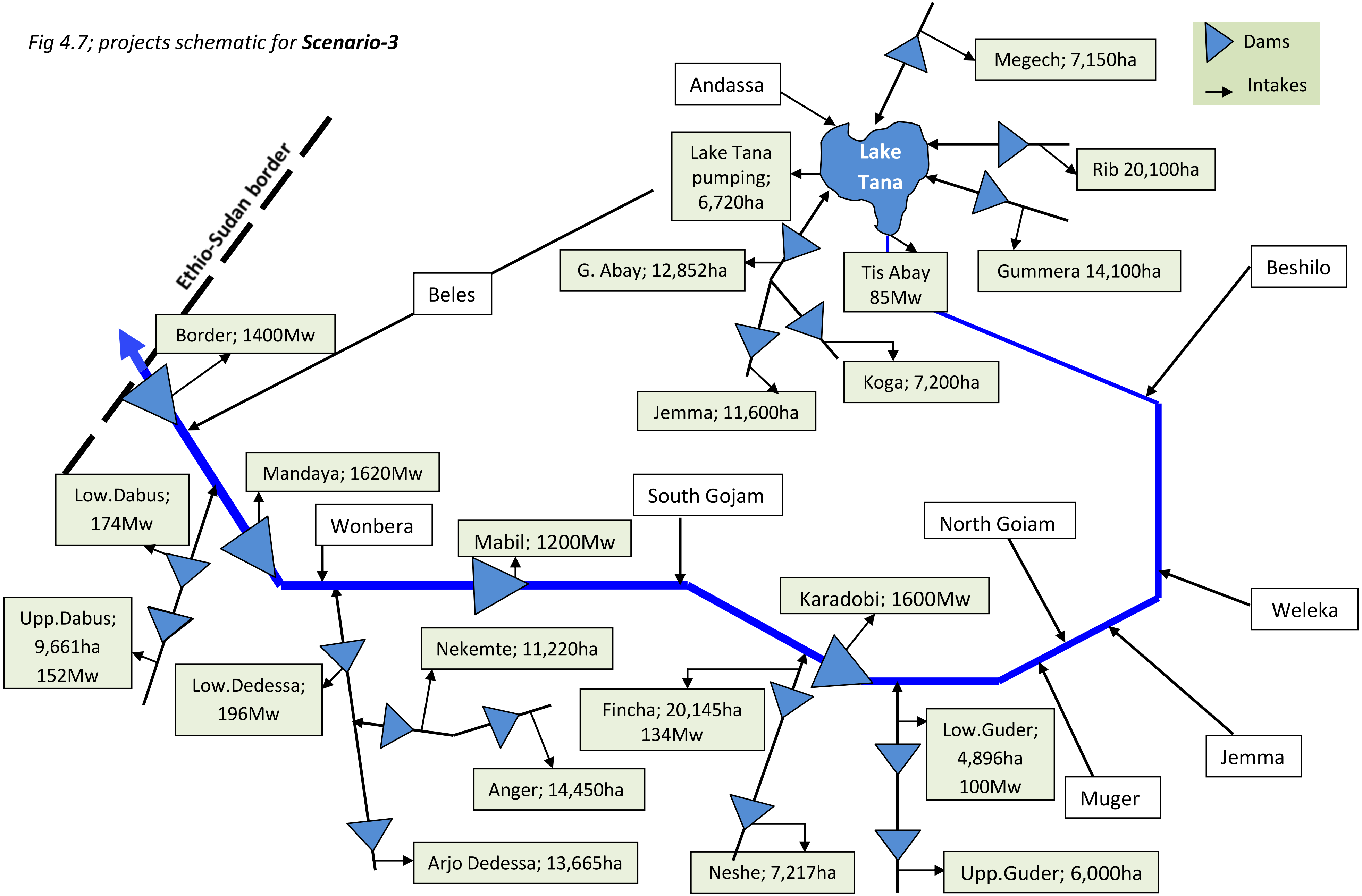
Fig 4.6; Scenario-2, HEC-ResSim model schematic

3. All identified (planned) projects excluding Tana Beles. **(scenario-3)**

Dam/ Simple diversion	**River/lake**	**Hydropower (mw)**	**Irrigation (ha)**
Chara-Chara (lake tana regulation weir and power generation at Tis Abay I and Tis Abay II power stations	Abay	*84*	-
Koga	Koga	-	*7,200*
Lake tana pumping	Tana	-	*6,720*
Megech	Megech	-	*7,150*
Rib	Rib	-	*20,000*
Gummera	Gummera	-	*14,100*
Jemma	Gilgel Abay	-	*11,600*
Gilgel Abay	Gilgel Abay	-	*12,852*
Upper Guder	Guder	-	*6,000*
Lower Guder	Guder	*100*	*4,896*
Neshe	Fincha	-	*7,217*
Fincha after expansion	Fincha	*134*	*20,000*
Anger	Anger	-	*14,450*
Nekemte	Anger	-	*11,220*
Arjo Dedessa	Dedessa	-	*13,665*
Lower Dedessa	Dedessa	*196*	-
Upper Dabus	Dabus	*152*	*9,661*
Lower Dabus	Dabus	*174*	-
Karadobi	Abay	*1600*	-
Mabil	Abay	*1200*	-
Mandaya	Abay	*1620*	-
Border	Abay	*1400*	-
Total		***6,660***	***166,731***

Table 4.3 Scenario-3, included projects list

*Fig 4.7; projects schematic for **Scenario-3***



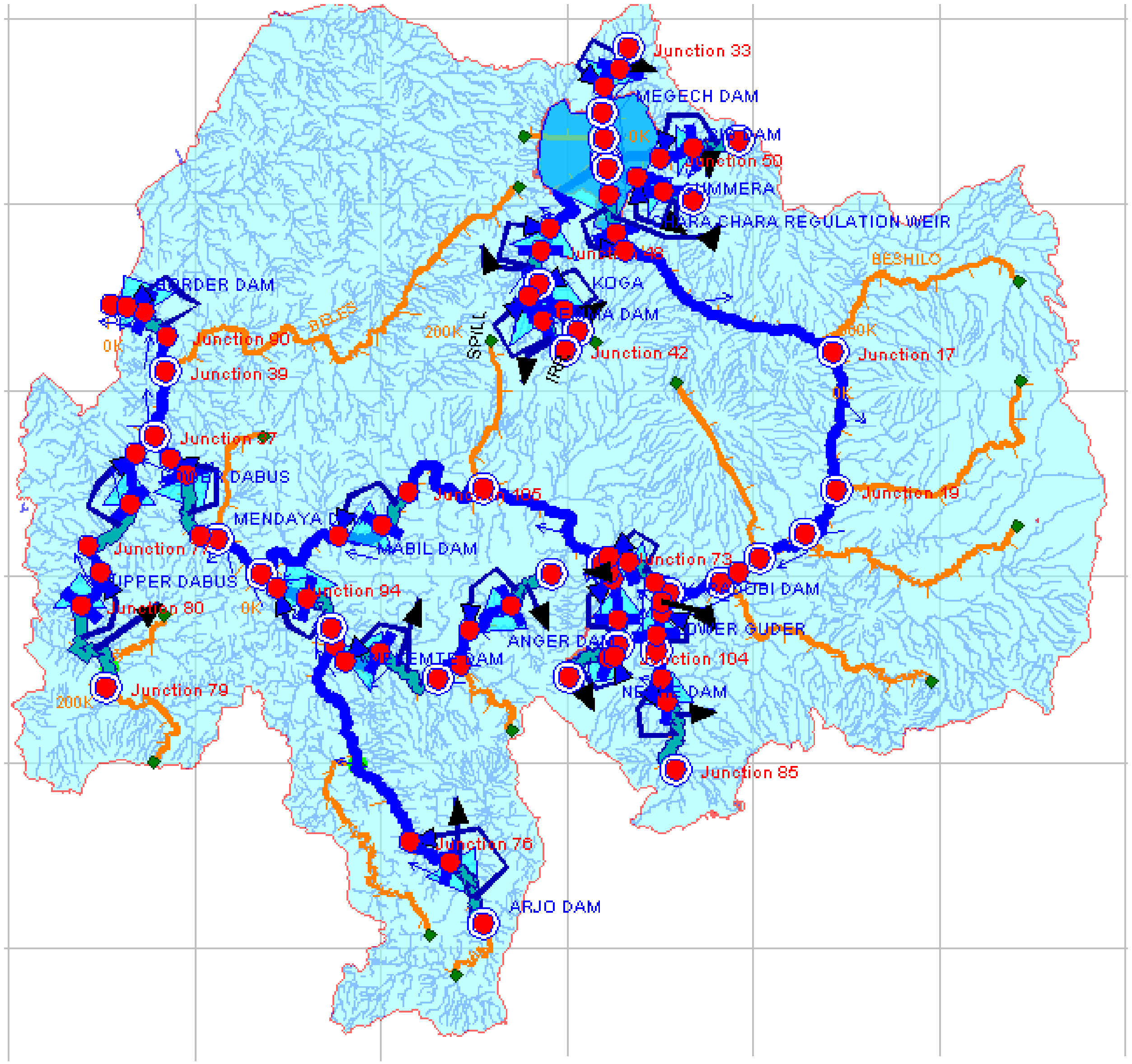


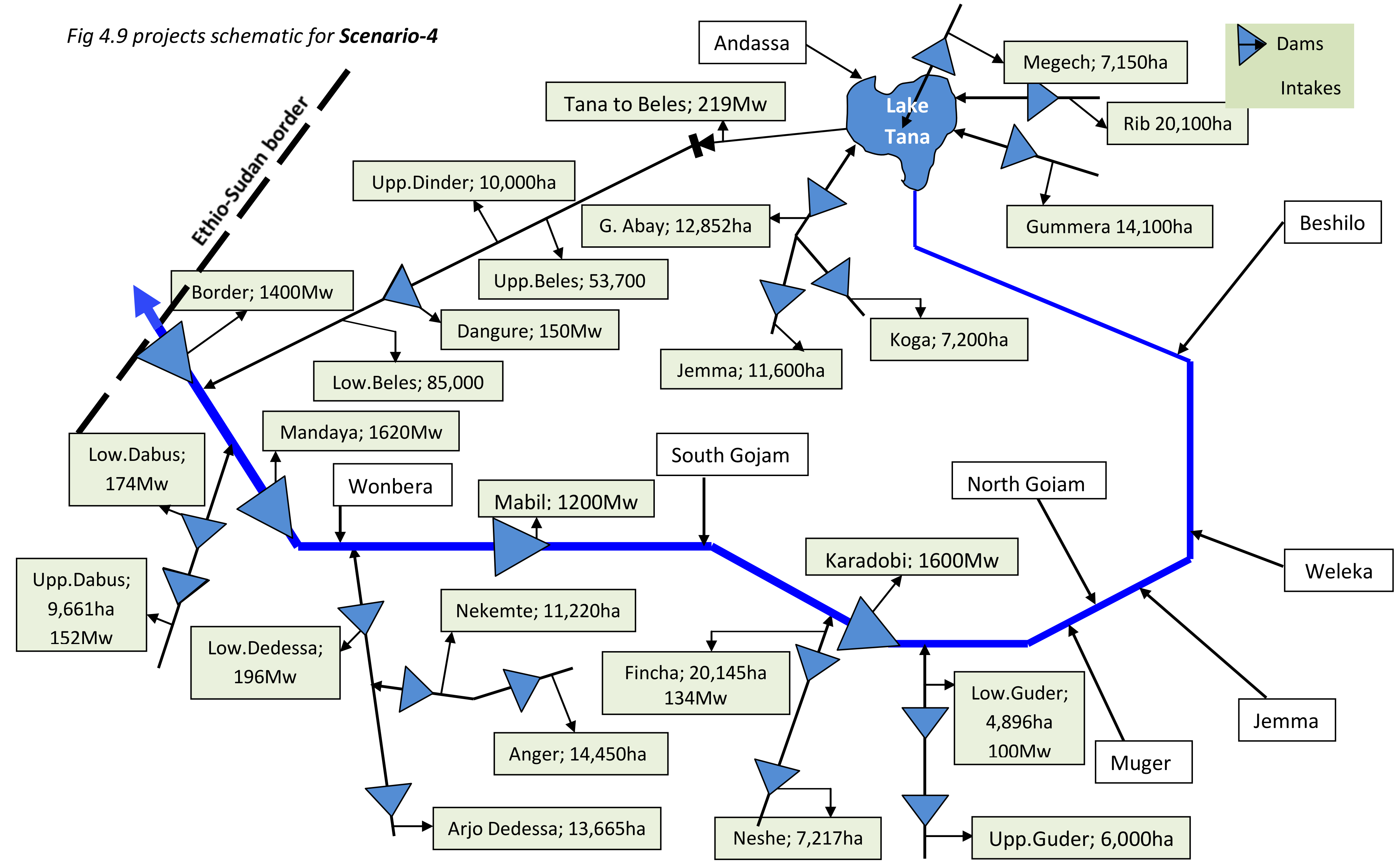
Fig 4.8; Scenario-3, HEC-ResSim model schematic

4. All identified (planned) projects. **(scenario-4)**

Dam/ Simple diversion	**River/lake**	**Hydropower (mw)**	**Irrigation (ha)**
Transfer from Lake tana to Beles	Tana/Beles	*219*	-
Koga	Koga	-	*7,200*
Lake tana pumping	Tana	-	*6,720*
Megech	Megech	-	*7,150*
Rib	Rib	-	*20,000*
Gummera	Gummera	-	*14,100*
Jemma	Gilgel Abay	-	*11,600*
Gilgel Abay	Gilgel Abay	-	*12,852*
Upper Guder	Guder	-	*6,000*
Lower Guder	Guder	*100*	*4,896*
Neshe	Fincha	-	*7,217*
Fincha after expansion	Fincha	*134*	*20,000*
Anger	Anger	-	*14,450*
Nekemte	Anger	-	*11,220*
Arjo Dedessa	Dedessa	-	*13,665*
Lower Dedessa	Dedessa	*196*	-
Upper Dabus	Dabus	*152*	*9,661*
Lower Dabus	Dabus	*174*	-
Dangure dam	Beles	*150*	-
Upper Beles	Beles	-	*53,700*
Upper Dinder	Beles	-	*10,000*
Lower Beles	Beles	-	*85,000*
Karadobi	Abay	*1600*	-
Mabil	Abay	*1200*	-
Mandaya	Abay	*1620*	-
Border	Abay	*1400*	-
Total		***7,029***	***315,431***

Table 4.4 Scenario-4, included projects list

Fig 4.9 projects schematic for ***Scenario-4***



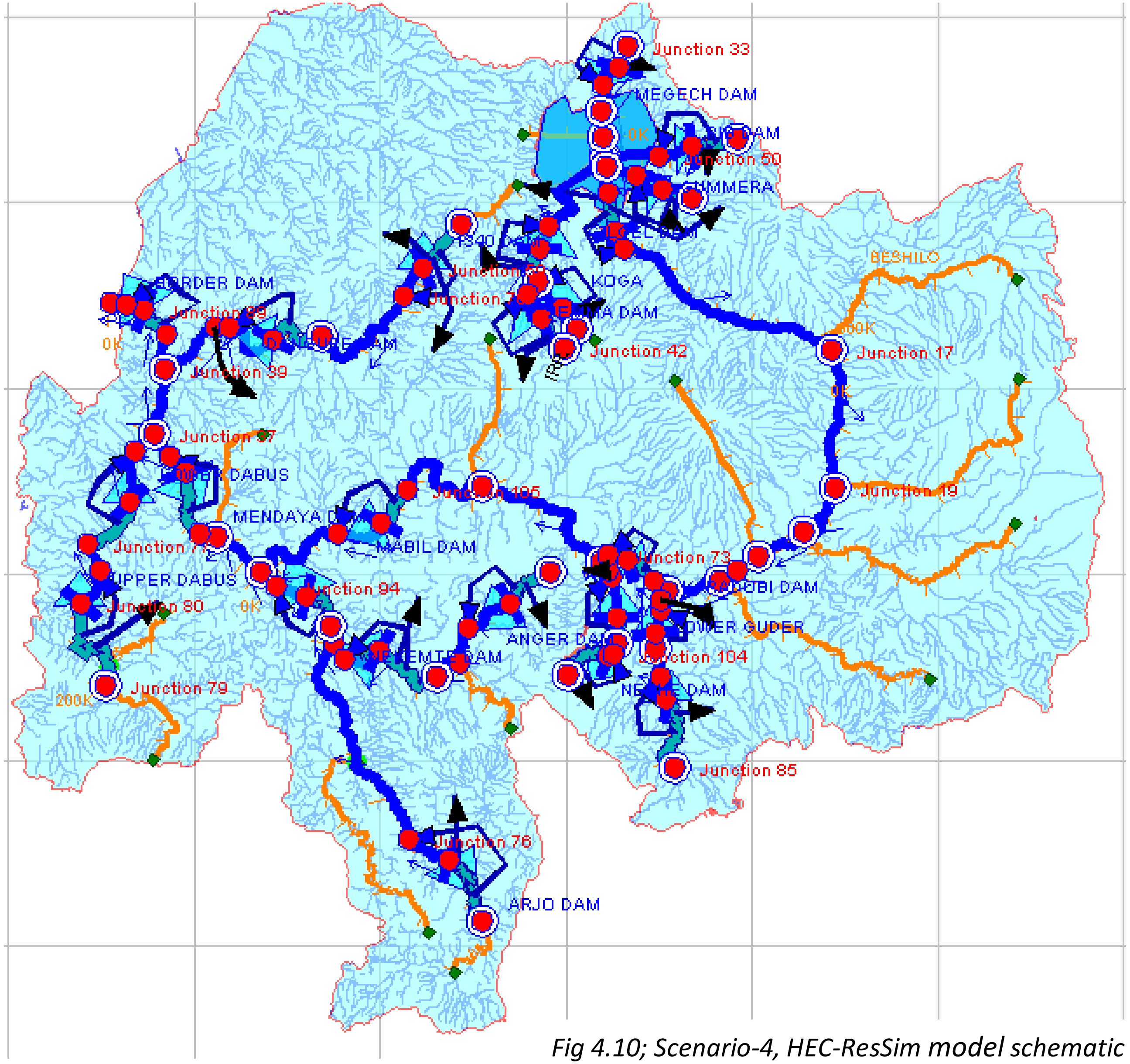


Fig 4.10; Scenario-4, HEC-ResSim model schematic

4.1.3 Simulation module

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 with in the simulation module. Here the simulation and look back or warming up time window will be specified, alternatives and computational intervals will be selected.

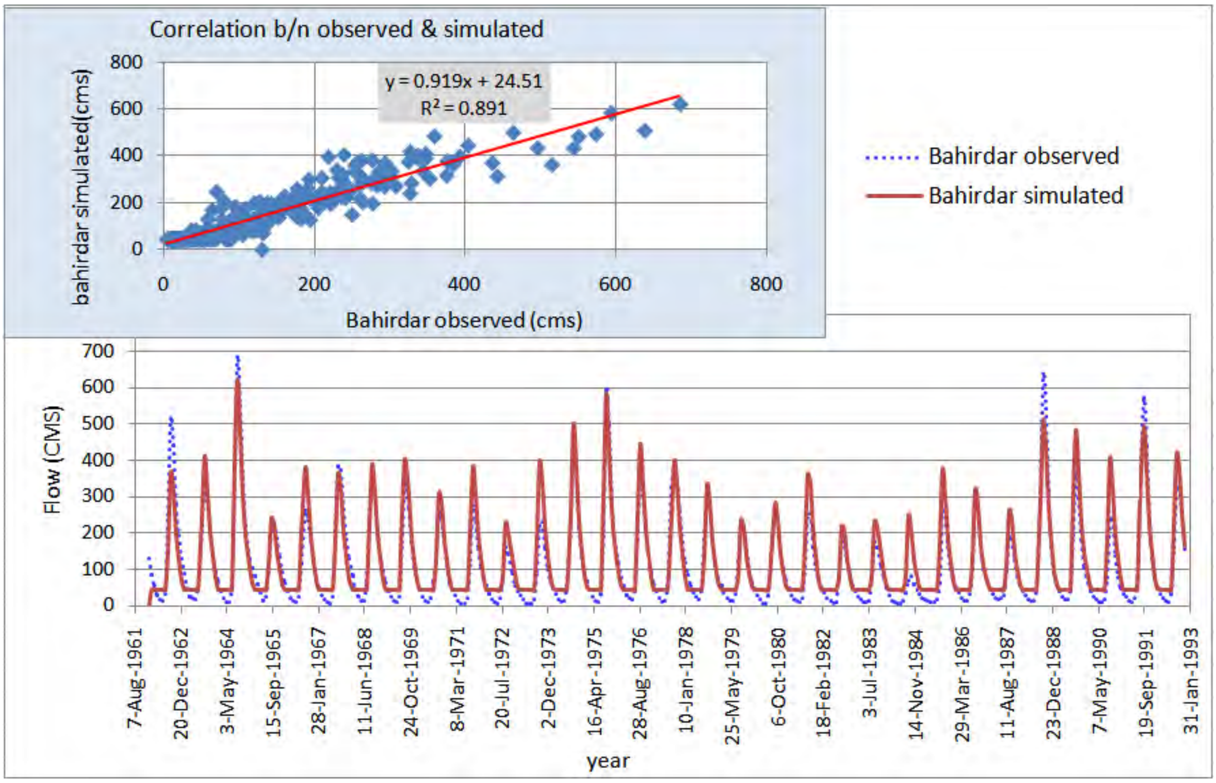
A look back or warming up time is an estimate of time needed to bring the reservoirs storage to full level. In this study the look back or initial condition for all reservoirs has been defined at spillway level, so that a shorter look back time is needed.

The simulation has been done for 30 years (1962-1992) of monthly flow time series, while using two years (1960-1961) for warming up or look back.

4.2 Calibration and validation of the model

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 unguaged, the model flows are reasonably agreeing with the observed flows at the stations. The following consecutive figures show the results.



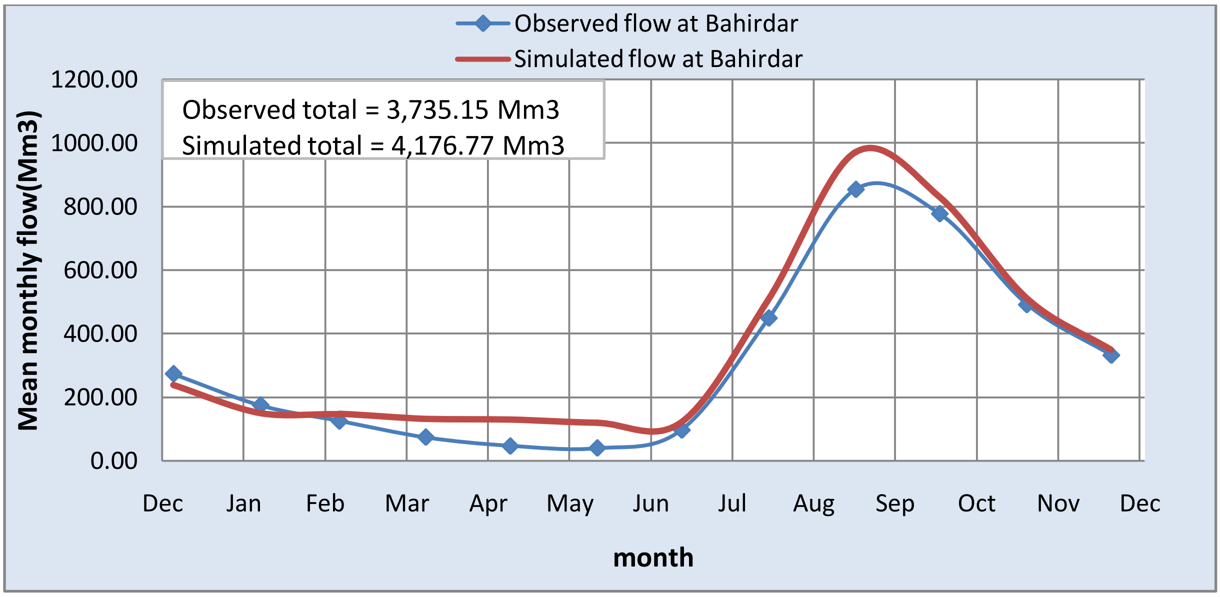
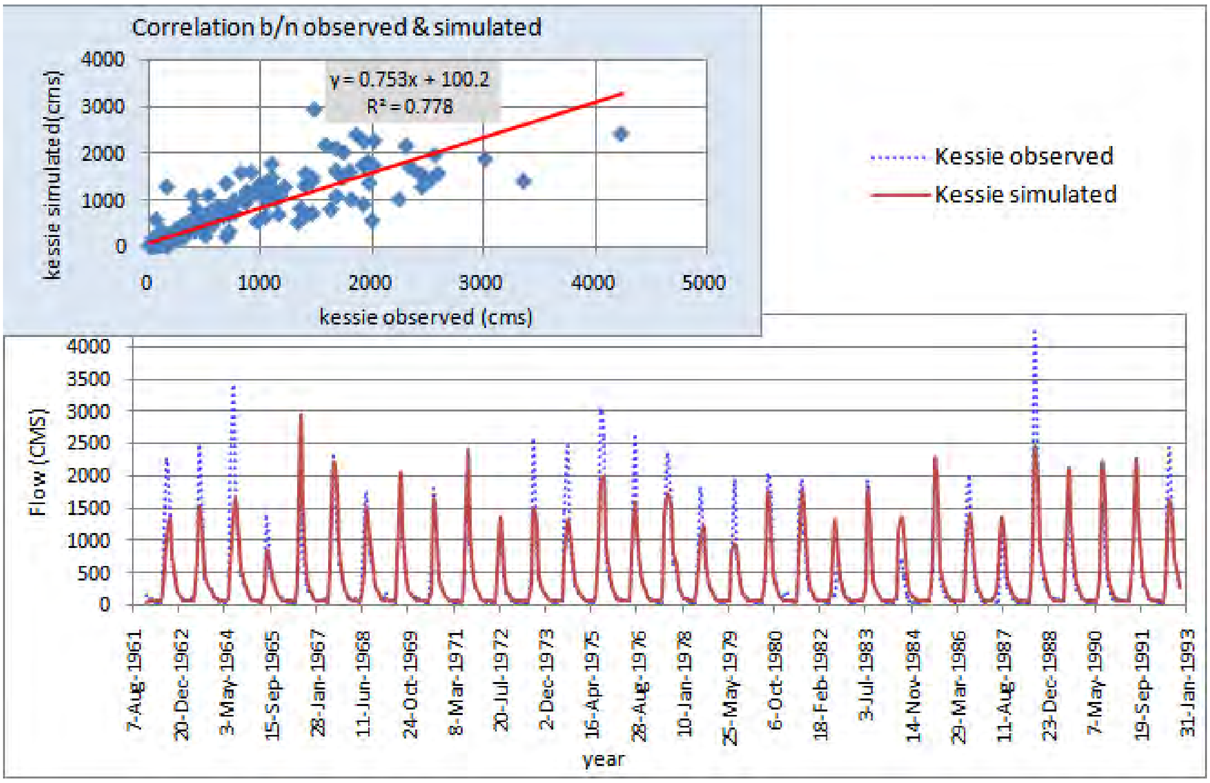


Fig 4.11; Scenario-1, Bahirdar station simulated and observed, comparison



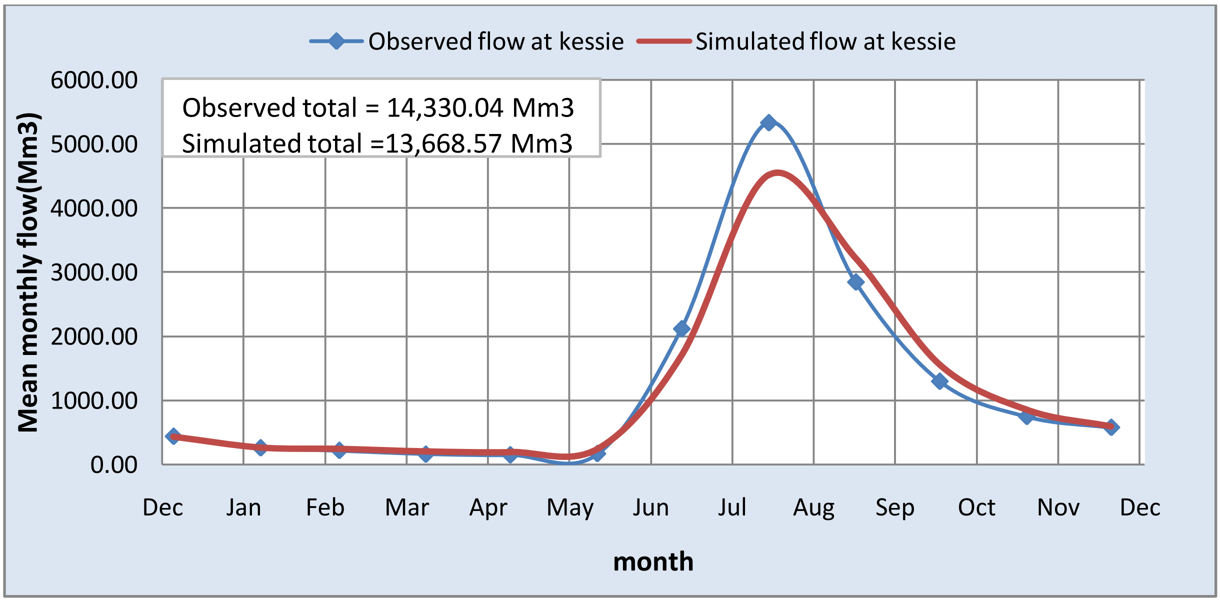
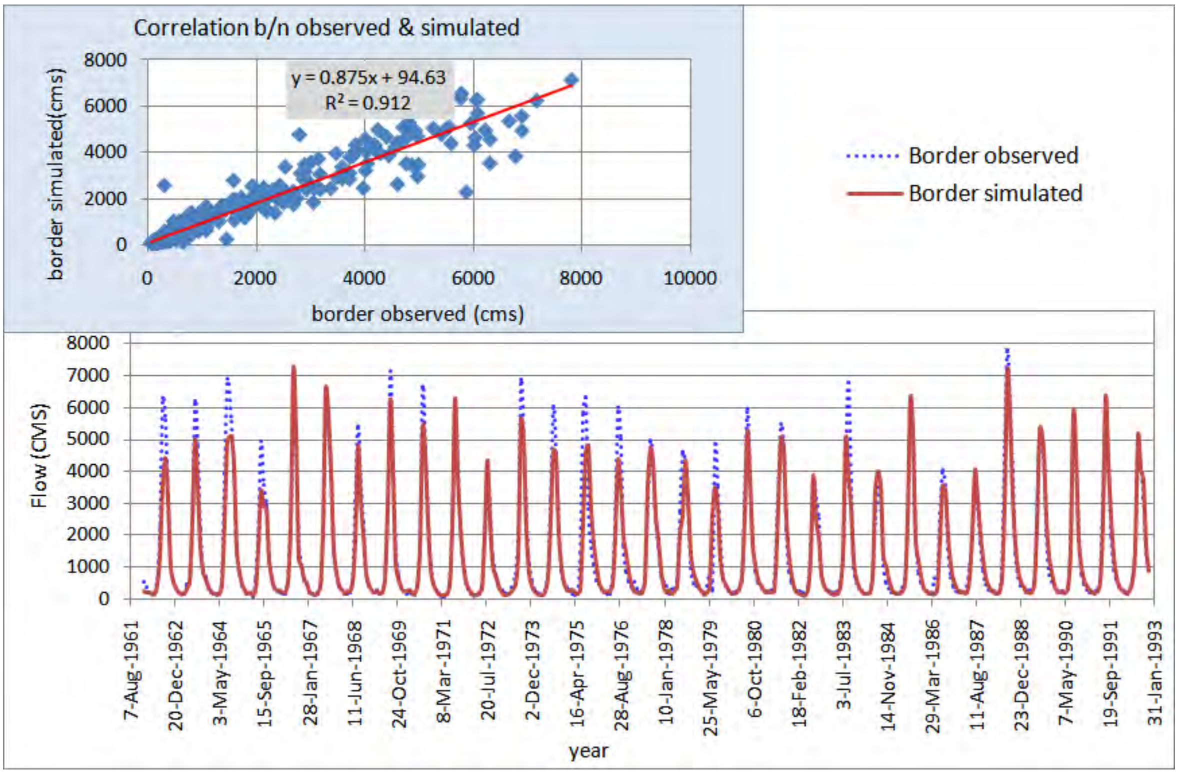


Fig 4.12; Scenario-1, Kessie station simulated and observed, comparison



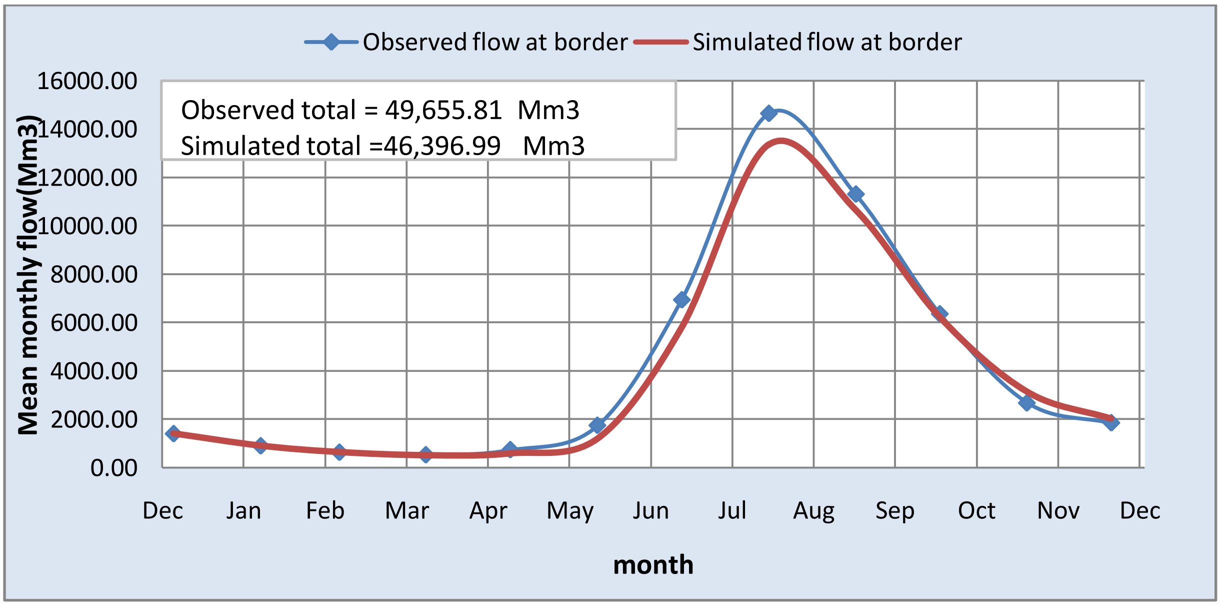


Fig 4.13; Scenario-1, Border station simulated and observed, comparison

Chapter 5. Results and Discussion

5.1 General

The Hec-ResSim model has been run for four scenarios including the base scenario for calibration and validation of the model; and using the hydrologic series over the period of 1960-1992. Varieties of reservoir characteristics have also been used to refer to more or less the fact on the ground. Some reservoir elevation-area-capacity curves have been altered while moving from one scenario to another, to account for diminishing reservoir capacity with time due to sedimentation.

The following consecutive presentations show the result of the simulation for each scenario. The alteration of contribution of each tributary river under each scenario has been assessed (table 5.1); the main stream Abay flow at key stations (Bahirdar, Kessie and border) has also been indicated for each simulation through table 5.2 to table 5.4.

The inflow to the big hydropower reservoirs on the main stream (Karadobi, Mabil, Mandaya & Border) has also been calculated for scenario-3 and scenario-4. From the numeric and graphical results shown below, one can easily visualize the effect of Tana Beles project on the inflow of the dams and also on the production yield of the plants. Lake Tana and dams on main stream, storage level variation can be seen from fig 5.8 to 5.16 before and after Tana Beles project. Here the level variation for border dam has been excluded as effect of Tana Beles project on Border dam storage variation is comparatively minimum. This is due to the fact that water taken to Beles will back join Border dam through Beles

The detail analysis for each irrigation project has also been done and discussed in section 5.2.

no	River	Scenario-1	Scenario-2	Scenario-3	Scenario-4
1	Inflow to lake tana	4700.58	4355.51	4355.51	4355.51
2	Out flow from Lake tana	4176.77	3336.66	3497.45	3336.66
3	Beshilo	2283.34	2283.34	2283.34	2283.34
4	Weleka	1277.34	1277.34	1277.34	1277.34
5	Jemma	3011.63	3011.63	3011.63	3011.63
6	Muger	1517.23	1517.23	1517.23	1517.23
7	Guder	1686.08	1686.08	730.89	1632.74
8	Fincha	989.71	746.45	730.89	730.89
9	Dedessa	9767.48	9369.75	9170.89	9170.89
10	Dabus	6928.54	6928.54	6786.77	6786.77
11	Beles	2293.65	3331.10	2293.65	3331.10
12	South Gojam	4642.63	4642.63	4642.63	4642.63
13	Norht Gojam	3304.65	3304.65	3304.65	3304.65
14	Wonbera	4517.93	4517.93	4517.93	4517.93

Table 5.1; Tributary flow for each scenario in Mm3; synthesized from model results.

Table 5.2; Abay flow at Bahirdar station for each scenario in (Mm3).

Month	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**
Jan	196.31	81.80	154.99	81.80
Feb	125.38	70.65	121.62	70.65
Mar	133.14	77.38	132.55	77.38
Apr	128.74	57.86	128.99	57.86
May	132.28	55.08	130.61	55.08
Jun	126.40	51.06	125.48	51.06
Jul	130.15	77.72	132.77	77.72
Aug	517.49	81.88	292.59	81.88
Sep	979.76	92.02	825.81	92.02
Oct	836.53	98.19	736.18	98.19
Nov	518.86	84.89	435.74	84.89
Dec	351.72	84.13	280.13	84.13
Total	***4,176.77***	**912.66**	***3,497.45***	***912.66***

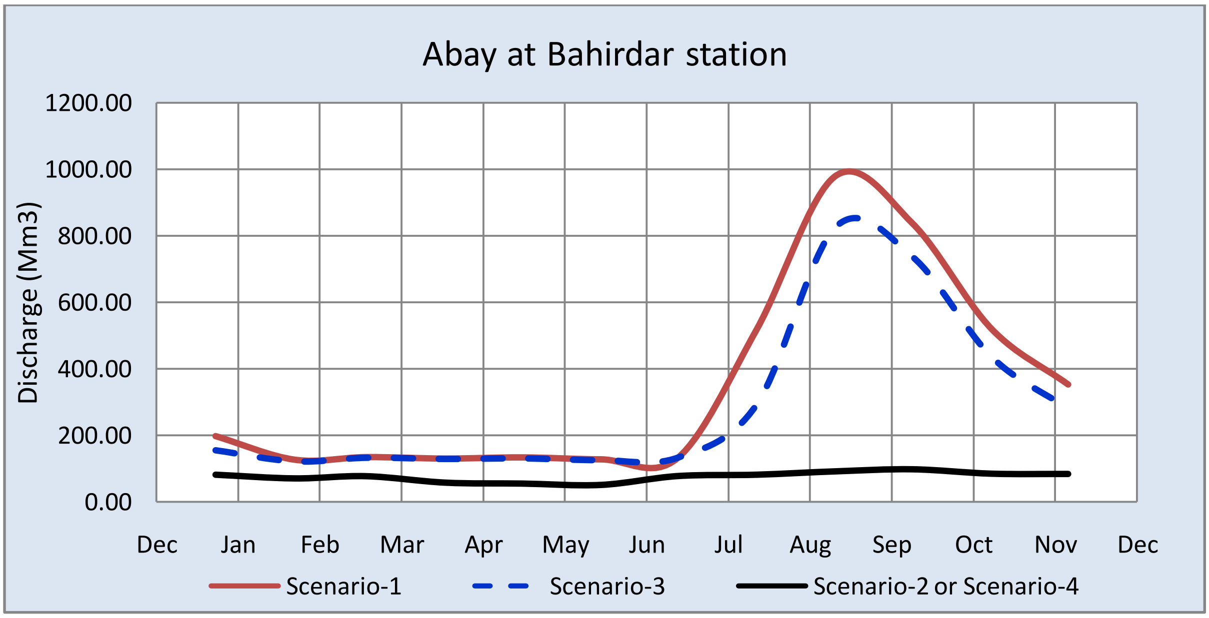


Fig 5.1 Abay at Lake-Tana outlet (Bahirdar station)

Table 5.3; Abay flow at Kessie station for each scenario in (Mm3).

Month	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**
Jan	295.05	194.98	253.42	194.98
Feb	193.32	152.88	189.23	152.88
Mar	198.33	155.74	196.98	155.74
Apr	180.78	124.04	181.13	124.04
May	185.36	121.61	183.16	121.61
Jun	241.40	183.22	242.20	183.22
Jul	1706.84	1728.73	1734.19	1728.73
Aug	4515.81	4164.32	4303.75	4164.32
Sep	3224.03	2341.69	3069.59	2341.69
Oct	1556.71	810.16	1451.28	810.16
Nov	838.86	407.41	748.22	407.41
Dec	532.08	273.00	457.01	273.00
Total	***13,668.57***	***10,657.78***	***13,010.16***	***10,657.78***

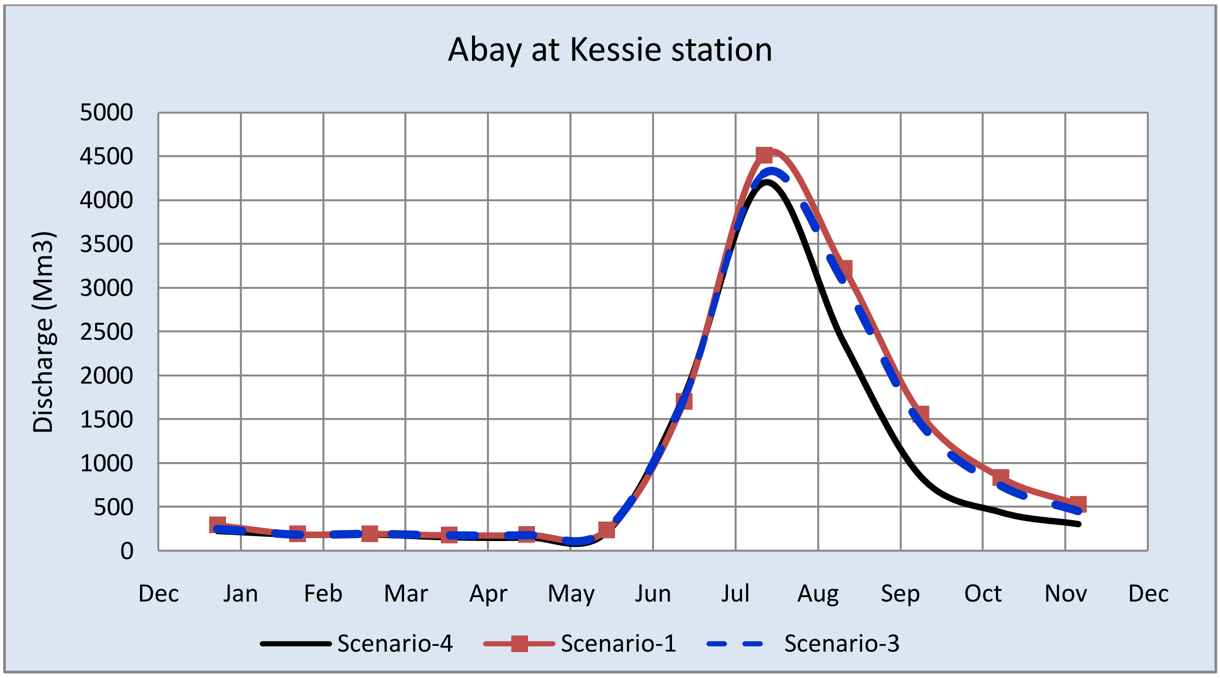


Fig 5.2 Abay at Kessie station

Table 5.4; Abay flow at Border station for each scenario in (Mm3).

Month	**Scenario-1**	**Scenario-2**	**Scenario-3**	**Scenario-4**
Jan	1068.12	2109.06	3905.75	3765.80
Feb	692.81	1491.19	3496.87	3356.91
Mar	628.38	1045.34	3673.59	3533.64
Apr	570.67	845.80	3400.99	3261.03
May	667.58	899.72	3433.46	3293.51
Jun	1308.08	1523.15	3392.62	3252.67
Jul	5915.28	4926.30	3827.31	3687.35
Aug	13456.27	8857.29	3920.77	3780.82
Sep	10851.10	8455.36	3806.65	3666.69
Oct	6306.02	6402.56	4124.75	3984.79
Nov	3105.42	3858.32	3807.30	3667.34
Dec	1827.25	2727.03	3903.46	3763.51
Total	***46,396.99***	***43,141.12***	***44,693.52***	***43,014.06***

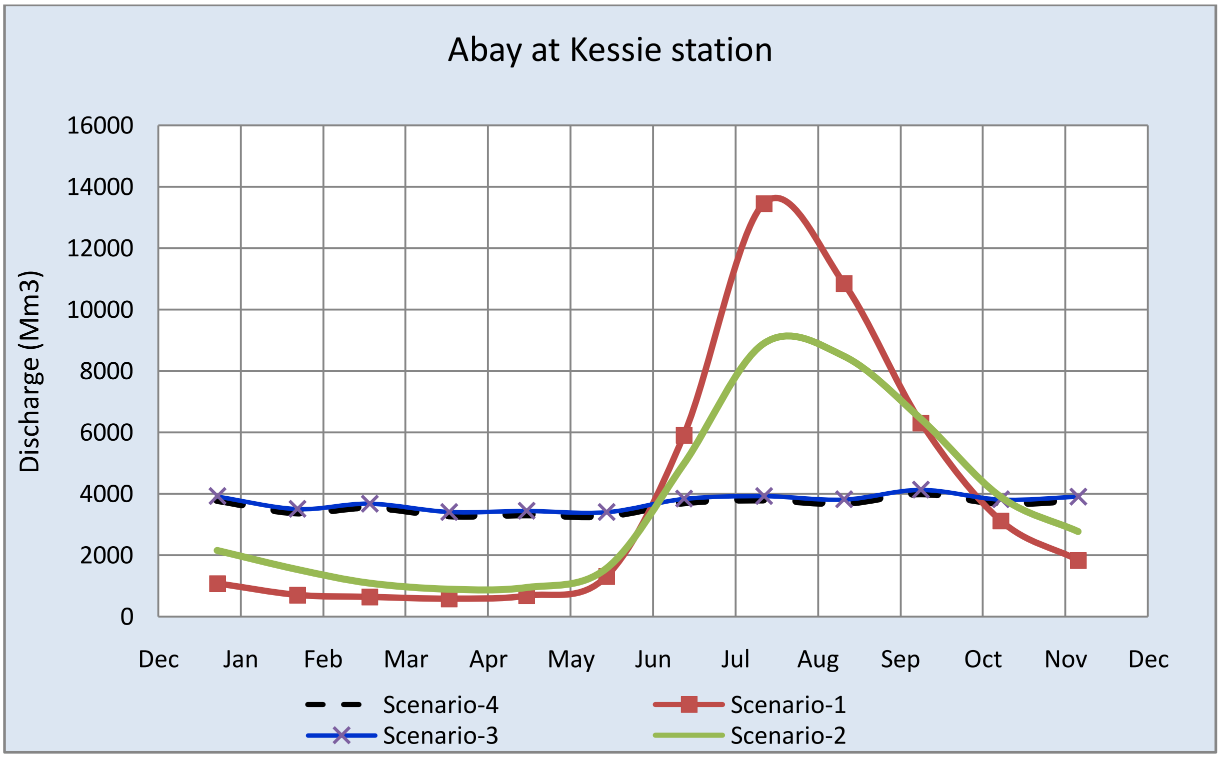


Fig 5.3; Abay at Border station

Table 5.5; Inflow to Karadobi dam for two scenarios;

Month	Inflow to Karadobi dam (m^3/sec)	
	Before Tana Beles project (scenario-3)	After Tana Beles project (scenario-4)
Jan	157.49	130.31
Feb	136.79	116.77
Mar	128.03	105.03
Apr	118.38	90.12
May	114.23	84.37
Jun	139.24	110.04
Jul	839.51	834.71
Aug	2055.70	2005.74
Sep	1436.41	1149.58
Oct	647.69	401.43
Nov	371.59	234.28
Dec	241.94	166.91
Average	***532.25***	***452.44***

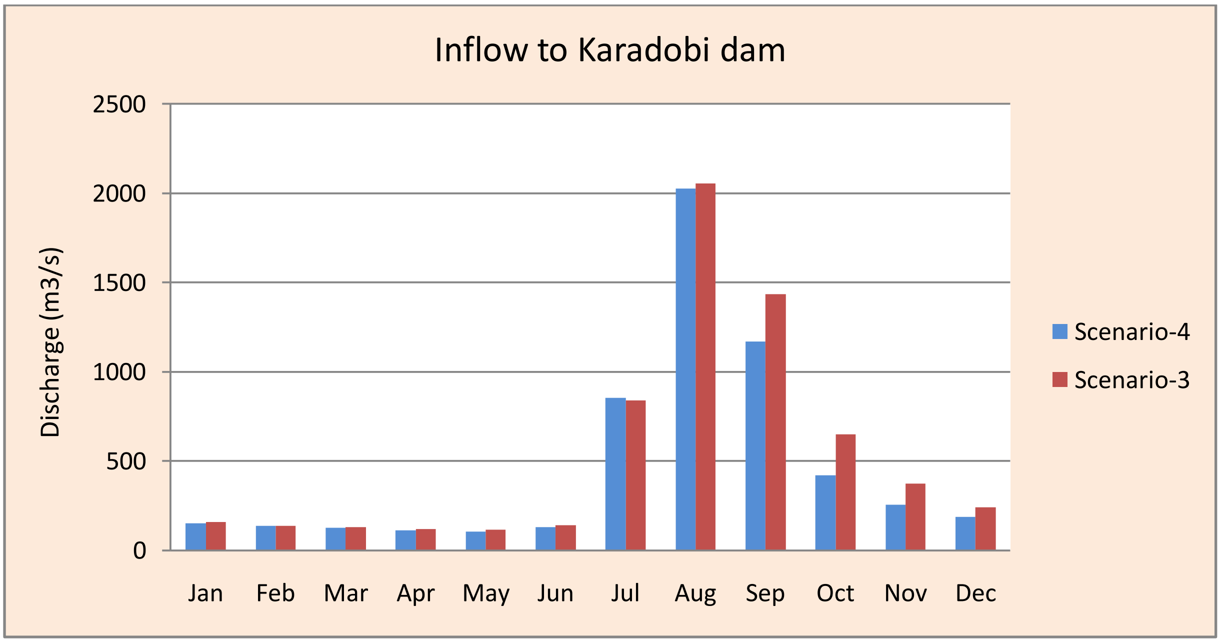


Fig 5.4; Inflow to Karadobi dam

Table 5.6; Inflow to Mabil dam for two scenarios;

Month	Inflow to Mabil dam (m^3/sec)	
	Before Tana Beles project (scenario-3)	After Tana Beles project (scenario-4)
Jan	530.28	465.13
Feb	510.02	395.96
Mar	434.14	296.38
Apr	368.68	236.19
May	349.14	183.76
Jun	333.76	204.63
Jul	840.64	825.61
Aug	1355.72	1372.03
Sep	1167.46	1163.19
Oct	930.15	880.79
Nov	725.34	668.98
Dec	602.21	548.98
Average	***678.96***	***603.47***

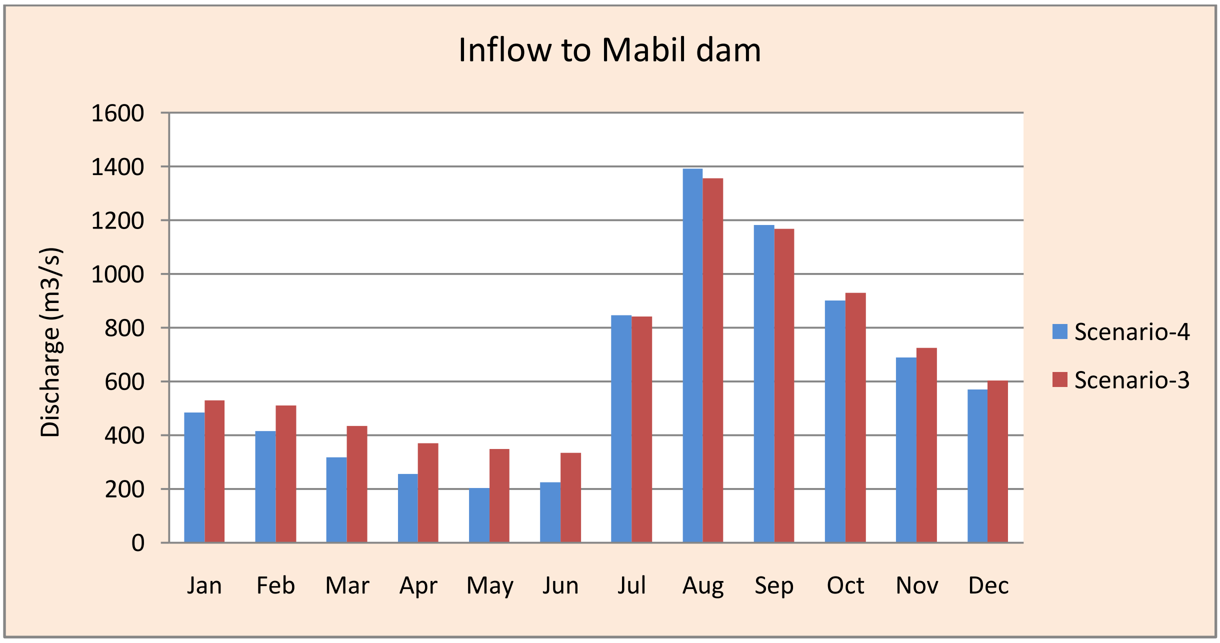


Fig 5.5; Inflow to Mabil dam

Table 5.7; Inflow to Mandaya dam for two scenarios;

Month	Inflow to Mandaya dam (m^3/sec)	
	Before Tana Beles project (scenario-3)	After Tana Beles project (scenario-4)
Jan	867.21	855.21
Feb	863.80	802.33
Mar	858.66	755.42
Apr	800.54	633.40
May	734.73	643.52
Jun	757.05	658.58
Jul	1117.06	1079.37
Aug	1944.92	1859.64
Sep	2240.17	2159.58
Oct	1625.24	1552.75
Nov	1013.02	983.57
Dec	914.98	879.03
Average	***1,144.78***	***1,071.87***

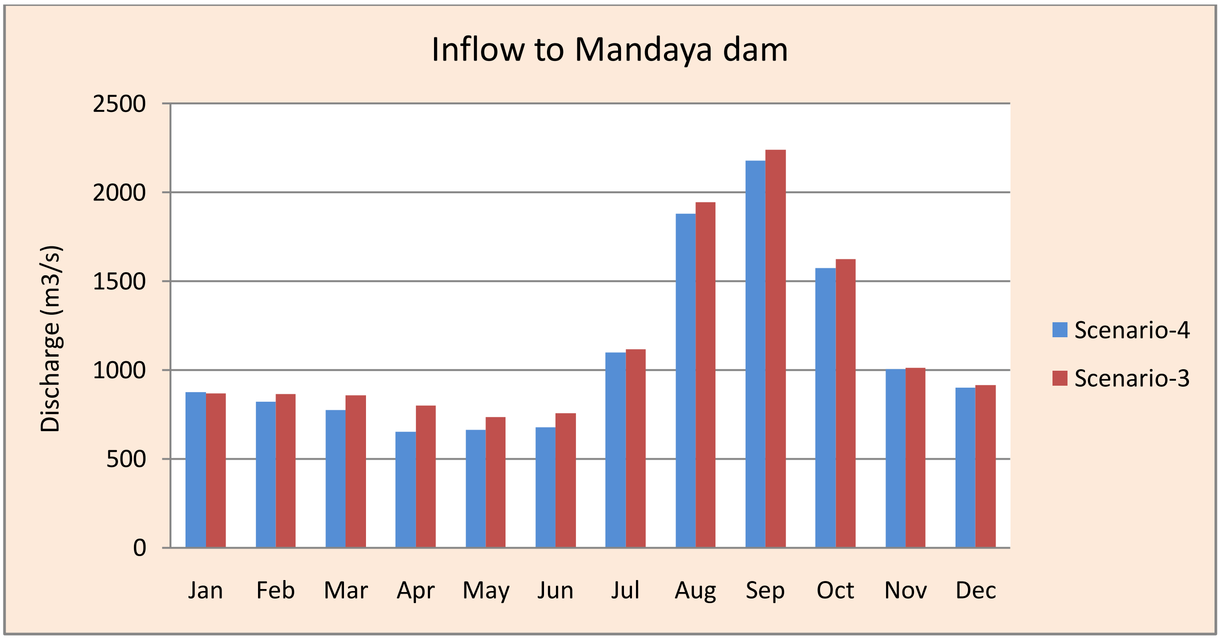


Fig 5.6; Inflow to Mandaya dam

Table 5.8; Inflow to Border dam for two scenarios;

Month	Inflow to Border dam (m^3/sec)	
	Before Tana Beles project (scenario-3)	After Tana Beles project (scenario-4)
Jan	1163.24	1233.10
Feb	1116.28	1140.29
Mar	1092.99	1096.17
Apr	1084.15	1097.81
May	1086.80	1126.37
Jun	1147.89	1190.34
Jul	1379.10	1368.35
Aug	1745.10	1546.47
Sep	2396.37	1864.37
Oct	2129.16	1907.54
Nov	1518.44	1581.18
Dec	1314.81	1348.68
Average	**1,431.19**	**1,375.05**

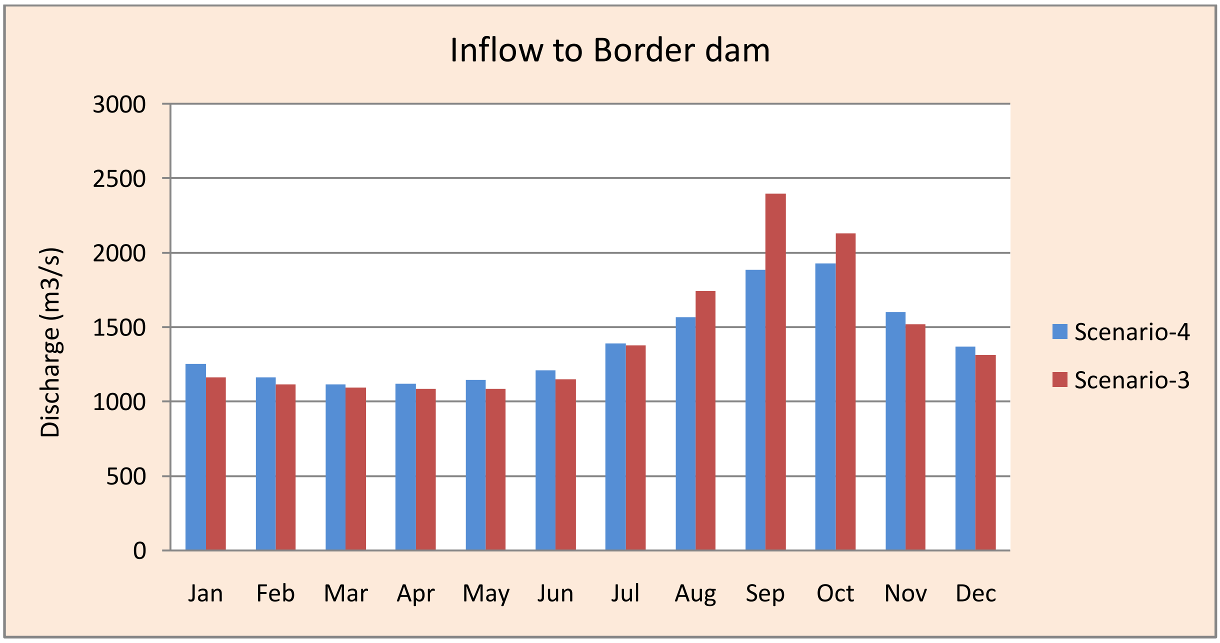


Fig 5.7; Inflow to Border dam

Table 5.9; Power generated by the power plants for scenario-4 & scenario-3

Location/Parameter	Alternative :scenario-4		
	Average	Maximum	Minimum
TANA- BELES - Power Plant			
Energy Generated per Annum (GWh)	3975.14	4204.80	0
Power Generated (MW)	453.8	480	0
Plant Factor	0.9	1	0
KARADOBI DAM-Power Plant			
Energy Generated per Annum (GWh)	7,705.30	12,711.49	0
Power Generated (MW)	859.6	1451.1	0
Plant Factor	0.5	0.9	0
MABIL DAM-Power Plant			
Energy Generated per Annum (GWh)	5,554.79	6,713.55	0
Power Generated (MW)	614.1	766.4	0
Plant Factor	0.6	0.7	0
MENDAYA DAM-Power Plant			
Energy Generated per Annum (GWh)	11,453.70	13,215.59	0
Power Generated (MW)	1280.5	1508.6	0
Plant Factor	0.8	0.9	0
BORDER DAM-Power Plant			
Energy Generated per Annum (GWh)	6,047.21	7,262.73	0
Power Generated (MW)	680.3	829.1	0
Plant Factor	0.5	0.6	0
TOTAL AVERAGE ANNUAL ENERGY (Gwh)	***34,736.14***		

Location/Parameter	Alternative :scenario-3		
	Average	Maximum	Minimum
KARADOBI DAM-Power Plant			
Energy Generated per Annum (GWh)	8,678.68	13,206.94	0
Power Generated (MW)	990.7	1507.6	0
Plant Factor	0.6	0.9	0
MABIL DAM-Power Plant			
Energy Generated per Annum (GWh)	5,931.94	6,731.66	0
Power Generated (MW)	677.2	768.5	0
Plant Factor	0.6	0.7	0
MENDAYA DAM-Power Plant			
Energy Generated per Annum (GWh)	13,081.45	13,494.23	12,563.30
Power Generated (MW)	1493.3	1540.4	1434.2
Plant Factor	0.9	1	0.9
BORDER DAM-Power Plant			
Energy Generated per Annum (GWh)	6,592.16	8,084.42	0
Power Generated (MW)	752.5	922.9	0
Plant Factor	0.5	0.7	0
TOTAL AVERAGE ANNUAL ENERGY (Gwh)	***34,284.23***		

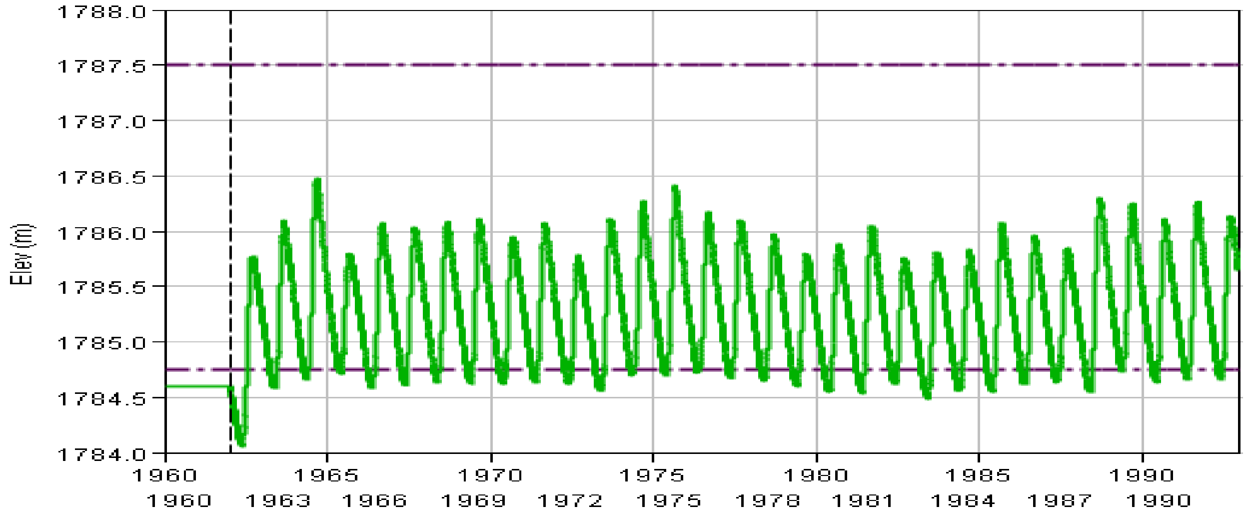


Fig 5.8; Lake Tana level variation for scenario-1 (Base scenario).

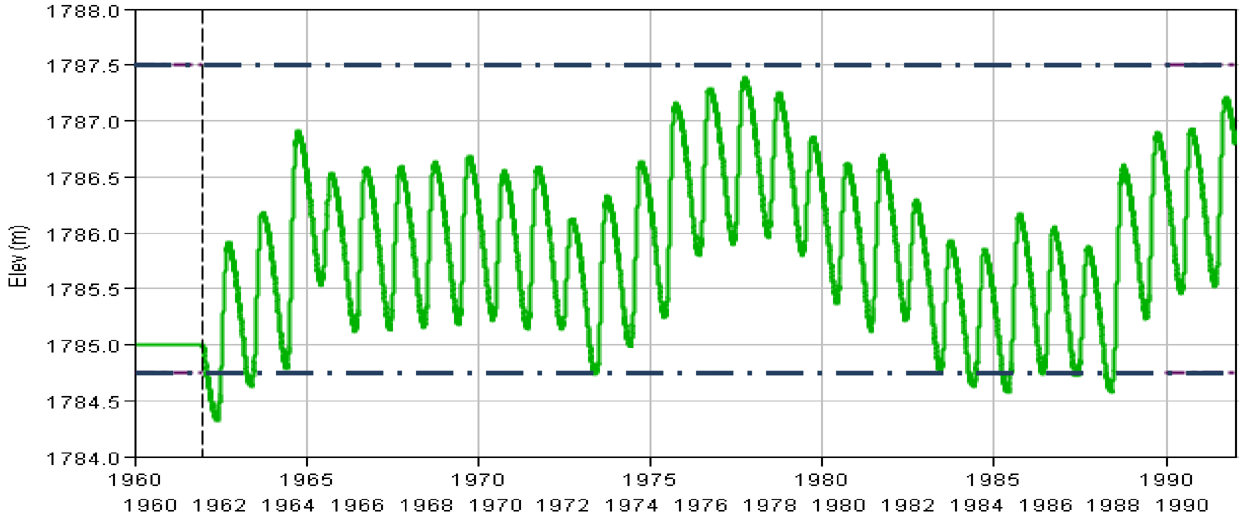


Fig 5.9; Lake Tana level variation for scenario-2 and scenario-4.

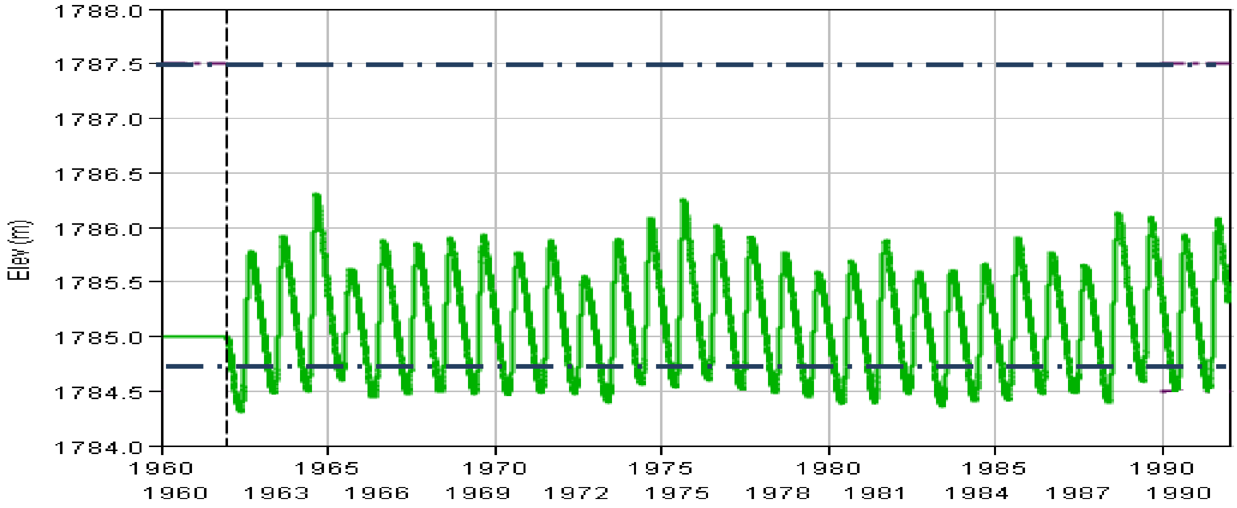


Fig 5.10; Lake Tana level variation for scenario-3

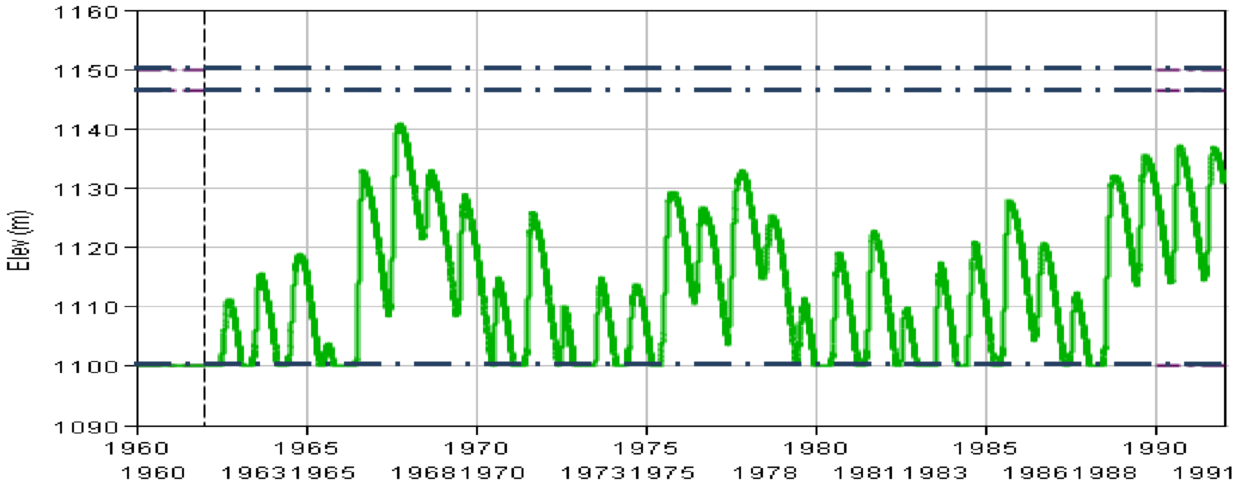


Fig 5.11; Karadobi reservoir level variation for scenario-3 (with out Beles).

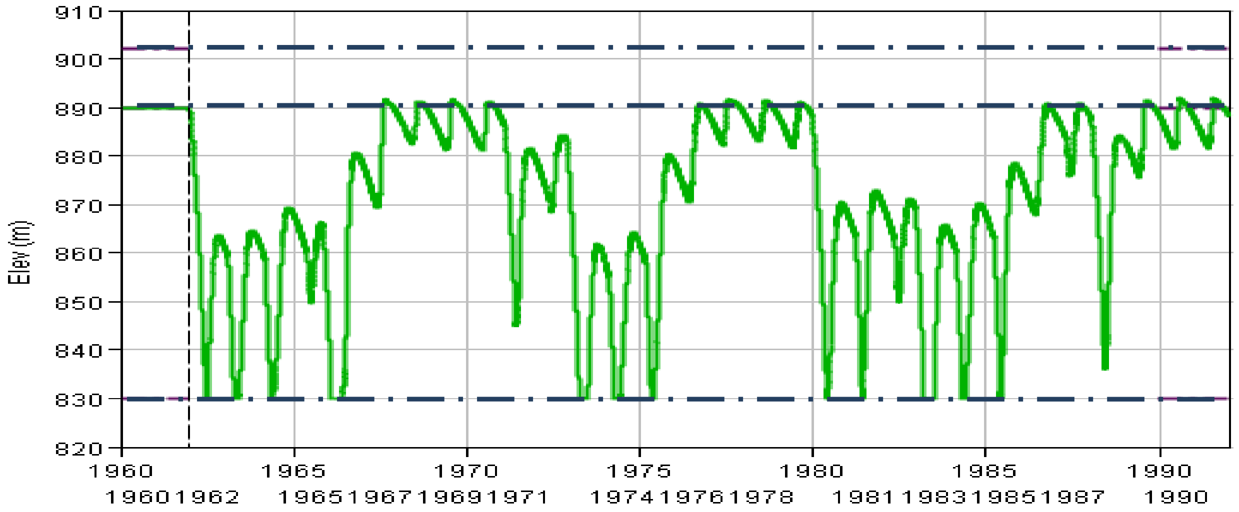


Fig 5.12; Mabil reservoir level variation for scenario-3 (with out Beles).

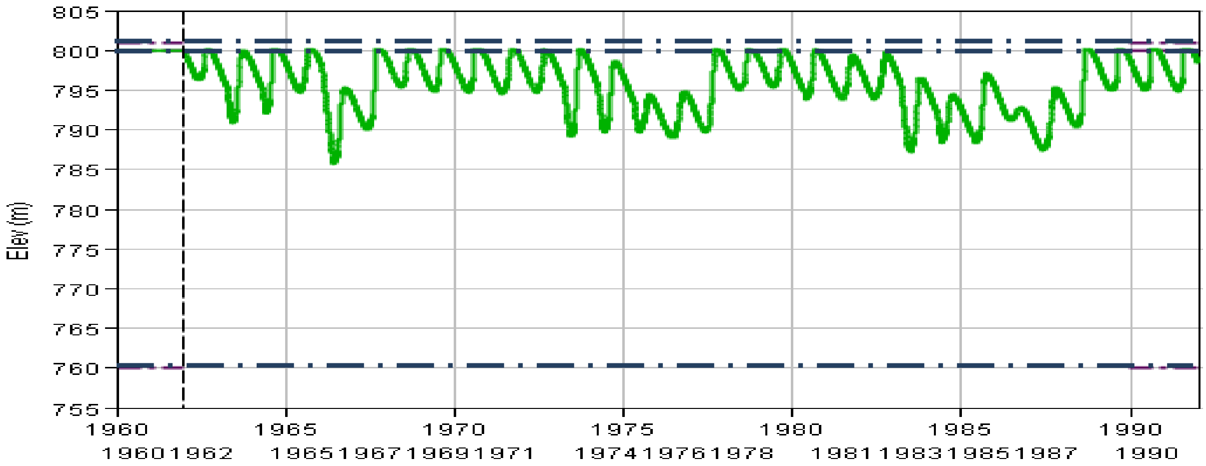


Fig 5.13; Mandaya reservoir level variation for scenario-3 (with out Beles).

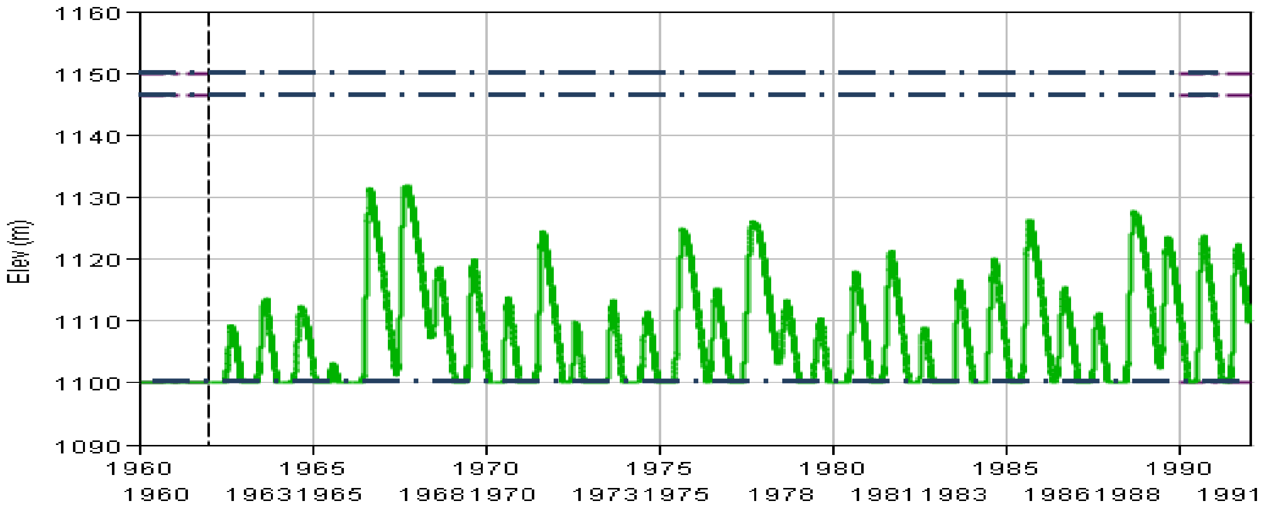


Fig 5.14; Karadobi reservoir level variation for scenario-4.

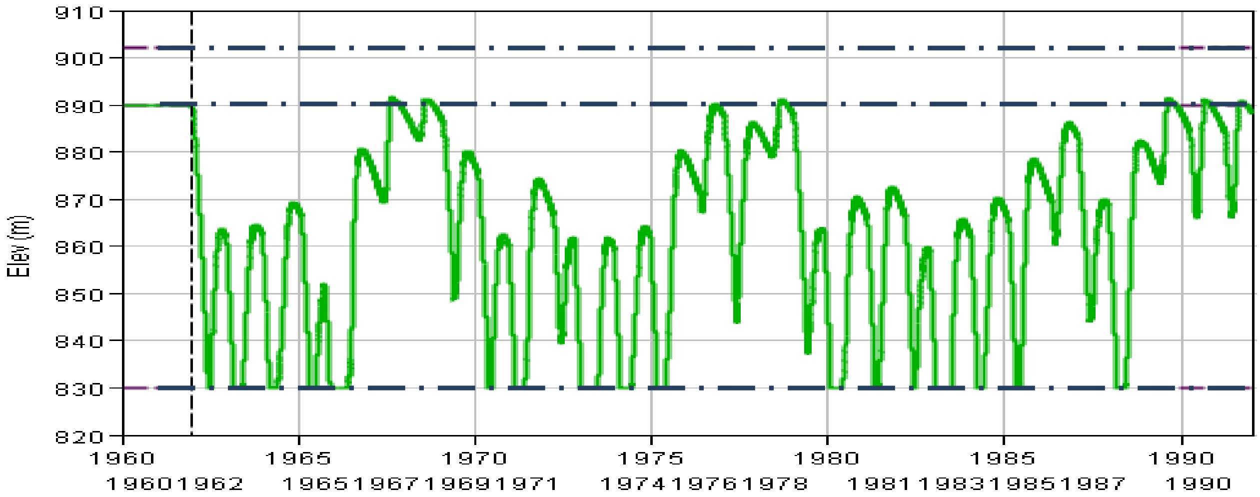


Fig 5.15; Mabil reservoir level variation for scenario-4.

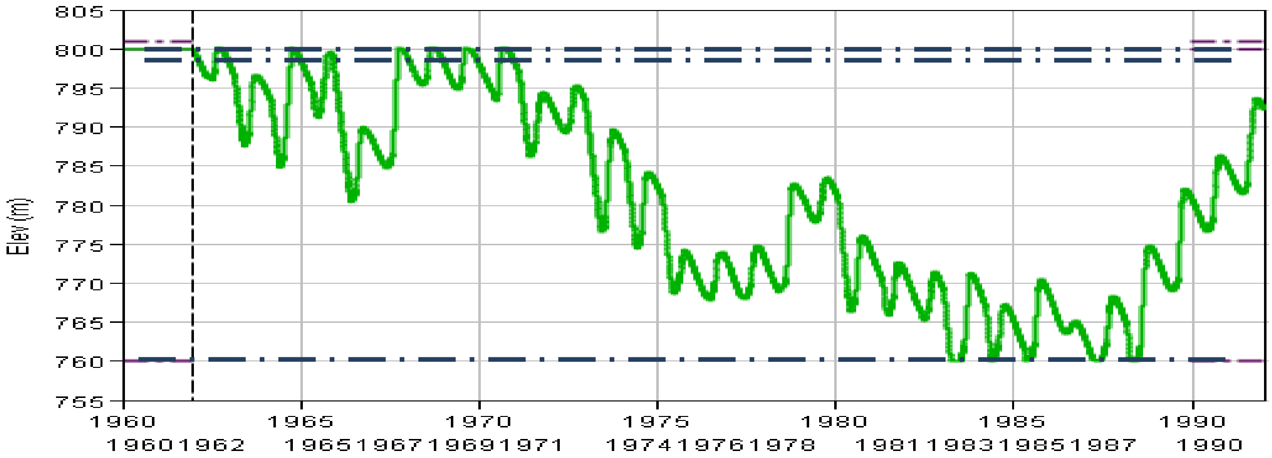


Fig 5.16; Mandaya reservoir level variation for scenario-4.

5.2 Irrigation projects analysis result

Totally 18 irrigation projects (315,431ha) have been analyzed, most of which directly abstract from reservoir; others like Fincha downstream of power plant. As can be observed from the line schematic and Hec-ResSim model schematic for each scenario, reservoirs are added down stream of already existing ones (except for Fincha) while moving from one scenario to the other , so that no influence will be reflected in the upstream reservoir already analyzed in the previous scenario. For this reason irrigation success frequencies and dependability calculation which is done for scenario-4 (all projects scenario) is true for the same project analyzed in the previous.

Frequency of monthly irrigation success for all the irrigation projects in the basin is determined based on the river basin modeling over the period 1960-1992.This analysis has been done based on the assumption that a severe deficit happens when one or more monthly deficit occurring in one growing season at least in excess of 50% of the monthly irrigation demand. The percentage actually depends on the stress tolerance of the crop to be produced. Here it is assumed to be 50%; determining the constant for each project will be out of the scope otherwise. The threshold value for acceptability this severe deficit frequency is taken at 1 in 5 growing years (i.e. 80% dependability).if it is 2 in 5 years dependability declines to 60%.

The following tables show the results of the rough analysis based on the above assumption. As indicated below most of the projects are confirmed to 100% reliability. Fincha irrigation project will be in sever deficit due to decrease in storage capacity of the reservoir due to sedimentation and expansion of the command area; together has drawn the project reliability to 80%. Minor deficits have also been observed at koga, Gummera, lower Guder, lower Beles and Lake Tana pumping totally mounting to 74Mm^3 per annum.

Table 5.10; Unmet demand of the irrigation projects in yearly basis (Mm3)

Year	Lake tana pumping	Koga	Megech	Rib	Gummera	Jemma	Gilgel Abay	Anger	Upper Beles	Upper Dinder	Arjo Dedessa	Upper Dabus	Upper Guder	Neshe	Nekemte	Fincha	Lower Beles	Lower Guder
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	13.6	0.0	0.0	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.8	0.0	0.0
1964	0.0	6.3	0.0	0.0	25.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.4	0.0	0.0
1965	0.0	13.7	0.0	0.0	10.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	0.0
1966	0.0	13.7	0.0	0.0	40.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8	0.0	9.2
1967	0.0	13.6	0.0	0.0	24.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.1	0.0	0.0
1968	0.0	6.3	0.0	0.0	18.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8	0.0	0.0
1969	0.0	13.6	0.0	0.0	40.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.2	0.0	3.2
1970	0.0	13.1	0.0	0.0	29.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6	0.0	3.2
1971	0.0	13.6	0.0	0.0	29.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.1	229.3	15.2
1972	0.0	6.3	0.0	0.0	29.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	0.0	6.9
1973	0.0	13.6	0.0	0.0	47.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.7	70.1	15.2
1974	0.0	16.2	0.0	0.0	48.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	15.2
1975	0.0	13.6	0.0	0.0	24.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	9.2
1976	0.0	6.0	0.0	0.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
1977	0.0	13.6	0.0	0.0	17.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0
1978	0.0	13.6	0.0	0.0	17.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0
1979	0.0	13.6	0.0	0.0	40.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7	0.0	3.2
1980	0.0	6.3	0.0	0.0	25.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.4	0.0	15.2
1981	0.0	13.6	0.0	0.0	16.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	3.2
1982	0.0	13.6	0.0	0.0	17.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0
1983	33.4	13.6	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	0.0	15.2
1984	10.8	6.3	0.0	0.0	27.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	9.2
1985	38.8	13.6	0.0	0.0	23.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	0.0	9.2
1986	11.3	13.6	0.0	0.0	17.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0	0.0
1987	33.9	13.4	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.3	0.0	0.5
1988	10.8	6.3	0.0	0.0	17.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.7	0.0	9.2
1989	0.5	13.6	0.0	0.0	10.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0
1990	0.5	13.6	0.0	0.0	17.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	0.0
1991	0.5	13.6	0.0	0.0	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.5	0.0	0.0
1992	0.5	13.6	0.0	0.0	20.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.5	0.0	0.0
average	***4.5***	***11.6***	***0.0***	***0.0***	***23.6***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***0.0***	***20.0***	***9.7***	***4.6***

Table 5.11; Percentage of unmet demand of the irrigation projects in yearly basis (%)

Year	Lake tana pumping	Koga	Megech	Rib	Gummera	Jemma	Gilgel Abay	Anger	Upper Beles	Upper Dinder	Arjo Dedessa	Upper Dabus	Upper Guder	Neshe	Nekemte	Fincha	Lower Beles	Lower Guder
1962	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
1963	0.0	13.9	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	23.8	0.0	0.0
1964	0.0	6.4	0.0	0.0	22.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	35.4	0.0	0.0
1965	0.0	14.1	0.0	0.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	0.0
1966	0.0	14.1	0.0	0.0	34.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	26.8	0.0	34.3
1967	0.0	13.9	0.0	0.0	21.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	45.1	0.0	0.0
1968	0.0	6.4	0.0	0.0	16.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.8	0.0	0.0
1969	0.0	13.9	0.0	0.0	35.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	50.2	0.0	11.9
1970	0.0	13.4	0.0	0.0	25.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.6	0.0	11.9
1971	0.0	13.9	0.0	0.0	25.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.1	26.9	56.5
1972	0.0	6.4	0.0	0.0	25.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	0.0	25.6
1973	0.0	13.9	0.0	0.0	41.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	43.7	8.2	56.5
1974	0.0	16.6	0.0	0.0	42.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	56.5
1975	0.0	13.9	0.0	0.0	21.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	34.3
1976	0.0	6.1	0.0	0.0	9.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.0
1977	0.0	13.9	0.0	0.0	14.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0
1978	0.0	13.9	0.0	0.0	15.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.1	0.0	0.0
1979	0.0	13.9	0.0	0.0	35.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	11.7	0.0	11.9
1980	0.0	6.4	0.0	0.0	22.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.4	0.0	56.5
1981	0.0	13.9	0.0	0.0	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.5	0.0	11.9
1982	0.0	13.9	0.0	0.0	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0
1983	33.4	13.9	0.0	0.0	19.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.9	0.0	56.5
1984	10.8	6.4	0.0	0.0	24.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	22.3	0.0	34.3
1985	38.8	13.9	0.0	0.0	20.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12.5	0.0	34.3
1986	11.3	13.9	0.0	0.0	15.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.2	0.0	0.0
1987	33.9	13.7	0.0	0.0	15.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.3	0.0	1.8
1988	10.8	6.4	0.0	0.0	14.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	21.7	0.0	34.3
1989	0.5	13.9	0.0	0.0	9.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	10.8	0.0	0.0
1990	0.5	13.9	0.0	0.0	15.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	13.5	0.0	0.0
1991	0.5	13.9	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.5	0.0	0.0
1992	0.5	13.9	0.0	0.0	18.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.5	0.0	0.0

Table 5.12; Dependability of the irrigation projects after implementation (%)

No	**Project**	**Dependability (%)**
1	*Megech*	*100*
2	*Rib*	*100*
3	*Gummera*	*81*
4	*Koga*	*90*
5	*Jemma*	*100*
6	*Gilgel Abay*	*100*
7	*Lake tana pumping*	*96 after 1983*
8	*Upper Guder*	*100*
9	*Lower Guder*	*83*
10	*Neshe*	*100*
11	*Fincha*	*80*
12	*Arjo Dedessa*	*100*
13	*Anger*	*100*
14	*Nekemte*	*100*
15	*Upper Dabus*	*100*
16	*Upper Beles*	*100*
17	*Upper Dinder*	*100*
18	*Lower Beles*	*98*

Chapter 6. Conclusions and Recommendation

6.1 Conclusions

Vast major researches have been and are being done in Abay basin by different intellectually competent researchers and by students as dissertation. As can be concluded from some of the documents available, Ethiopian portion of Nile is the basic source of existence for the rest of its stretch contributing more than 52Bm^3 and also the least utilized resource. Despite the fact that Ethiopia possesses plenty of potential water resources development sites in the basin, political and economic position of the country have hindered it back ward of other major riparian countries. 83% of Ethiopians lack access to electricity; only 5 percent of irrigable land and less than 3% of hydropower potential in the Blue Nile basin has been developed. (Arsano and Tamerat, 2005).

As dealt in this study the simulations had been done using Hec-ResSim software and hydrologic flow series of 1960 to 1992 to evaluate the effects of implementing currently envisaged hydropower and irrigation projects in the basin. Prior to setting up the future developments, the model has been tested and calibrated based on 1960 to 1992 flow data. Taking care of the basin's complexity and lack of data, the model can be said responded adequately for the current situation referring Bahirdar, Kessie and Border stations as a control points.

This study has indicated that If Ethiopia is to develop 315,431ha i.e. 38.7% of 815,581ha potential irrigation as contemplated by BCEOM (1998) and 7,029Mw, i.e. 89.6% of 7845Mw again shown in the master plan BCEOM (1998), the resulting decline in the cross border flow will be only 3,382.93Mm^3 which is 7.29% of the currently estimated Abay discharge to Sudan which is 46,396.99 Mm^3. Further more regulation of Blue Nile in Ethiopia increases the low flows to Sudan there by enabling downstream dams more effective in terms of yield.

As concluded from this study regulation works upstream in Ethiopia have resulted in a uniform monthly average flow of 3,584.51Mm3 throughout the year to Sudan. Currently as the base case simulation indicated, Sudan receives monthly average low flow of 1,233.54Mm^3 through November to June which then turns to be increasing August being flood month where 13,456.27Mm^3 has been observed.

In addition if Ethiopia is to develop 7,029Mw including hydropower projects on the tributaries, then some 38,385.81Gwh/annum of electricity will be produced.

Almost all irrigation Projects in the basin are found to have 100% dependability. This is just the output of the detail investigation done for each projects as indicated in their specific report. Each project has been appraised after in detail assessment of the basin with in which it exists. So it is unlikely that this study finds draw backs. The model has been fed the appropriate data extracted from this reports and responded just what had been done. The Expansion of Fincha project to 20,000 ha which is an upgrade by 12,000ha of land from the current and the decease in reservoir yield due to sedimentation have resulted in decrease of the project's reliability to 80% from 100%.

Scenario 3 (all projects with out Beles) was established basically to evaluate the effects of the diversion of Lake Tana flow to Beles. As shown in the results section this project has considerable effect to the inflow of hydropower dams on the main stream so that decreasing the power output. The summary of the out puts has been shown in table 5.7. This indicated that even though inflow to the main stream hydropower projects has been decreased, the power output decline has been counter balanced by Tana-Beles power plant resulting in more power overall.

6.2 Recommendations

As repeatedly spotted out the lack of hydrologic data basically influenced the reliability of not only this paper but also others many. The area ratio method used to regionalize flow from unguaged to gauged sites is the only option and also potential error introducing method. That is the reason why this paper should be used in conjunction with others related with great caution. So that implementation of more modern gauging equipments and a proper management of already available stations will surely result not less development than constructing different dams in the basin.

Even though the Hec-ResSim software has different phases to account for reservoir and river route seepage, routing and other details, these has not been taken into account due to complexity of finding river physical properties. So allowing these parameters into the model and a further filtering of the hydrologic series data may result in a more realistic representation of facts on the ground.

Chapter 7. Limitations

1. The intermediate time between completion of the dam and filling it to spillway level has undeniable effect in the downstream users. This study has initiated all the reservoirs at spillway level and a short hind cast period of 2 years has been used. However seeing and quantifying the effect of reservoir filling should also be addressed.

2. HEC-ResSim does not yet have the capability to perform simulations on monthly time-step. It only has 1day time step as maximum simulation step. This creates some cumbersome job in compiling reports.

3. In almost all projects environmental impact assessment is a key issue. Environmental releases during and after construction of a dam is a determining factor and inevitable. For this study this parameter has been introduced for some projects which incorporate this quantity in their specific detail project report; for those which have none this has been neglected. This is due to the hard to find problem of such data while assuming may induce a wrong system balance on the high priority projects, either irrigation or hydropower.

4. Reservoir sedimentation is mostly the only factor which deteriorates and throws a dam out of service. In fact it is the determining factor while deciding the life span of reservoirs. So taking into account the alteration of reservoir capacity curve due to sedimentation is taking a long step towards the fact on the ground. In this study the capacity curves have been adjusted while moving from one scenario to the other, but not as quite as it would happen. Only the yearly average rate of siltation have been used to be multiplied by the year the reservoir is thought to have served at the point of the next scenario, after ich it has been deducted from the total capacity, based on which the new relations are derived.

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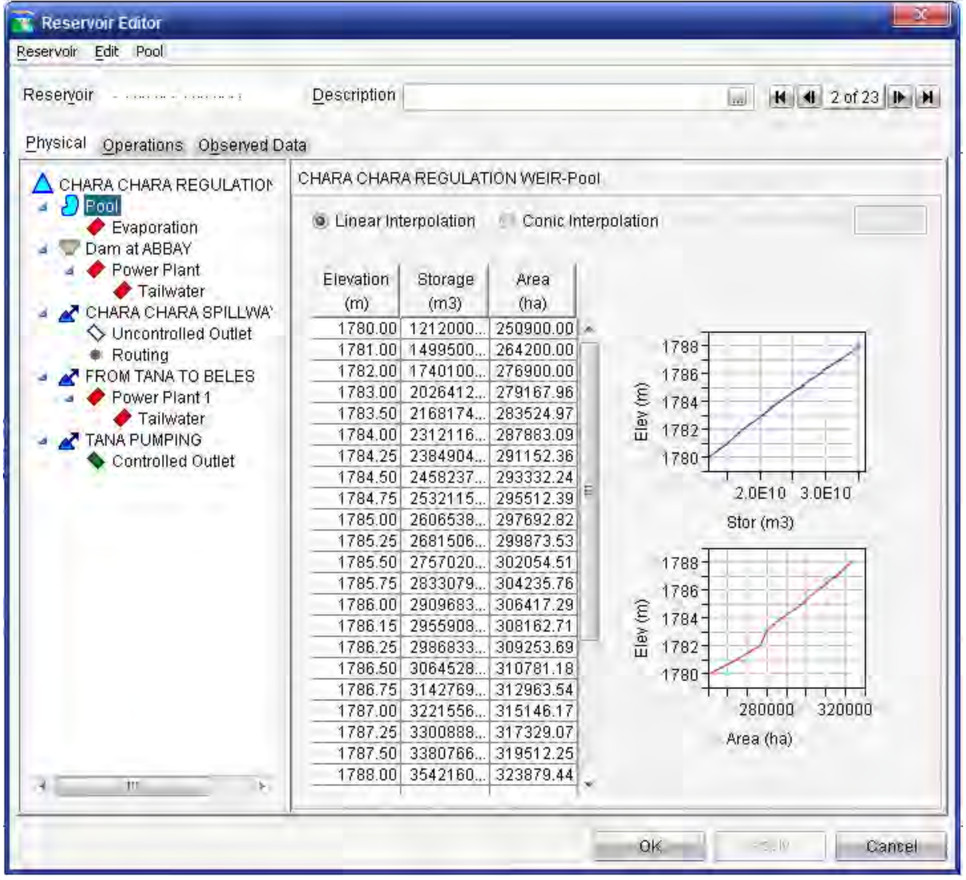
APPENDICES

Appendix A. Description of Hec-ResSim reservoir module for Lake Tana case:

This appendix presents how Lake Tana has been represented in the model as demonstration. The same has been done for the other reservoirs. Below the reservoir physical data (Figures A-1), reservoir operational data (Figures A-2), and how operational data is linked to flow hydrology and look back Starting conditions (Figure A-3) has been shown. The screen captures show data as it was entered into the graphical user interface of HEC-ResSim in the reservoir module.

Parameter values for diversion specifications, physical reservoir data (storage-elevation-area and elevation-physical capacity relationships), and reservoir storage zones are entered in this module. In ResSim, reservoir zone definitions and the prioritized stack of operating rules within each zone define an operations set. Flow hydrology is linked to the operation sets for each scenario (see Figure A-4, example for scenario-4).

Scenarios were simulated on a 1-day time step over 33years of monthly flow. HEC-ResSim uses end-of-period storage, current inflow, and current period release to update reservoir level, storage, and allowable release in each time interval. The model calculates the allowable release according to a “guide-curve operation” but subject to physical capacity limits and the maximum allowable release imposed by the prioritized set of rules defined for the flood pool. Please refer to the literature review section above for a more detailed discussion of guide-curve operation.



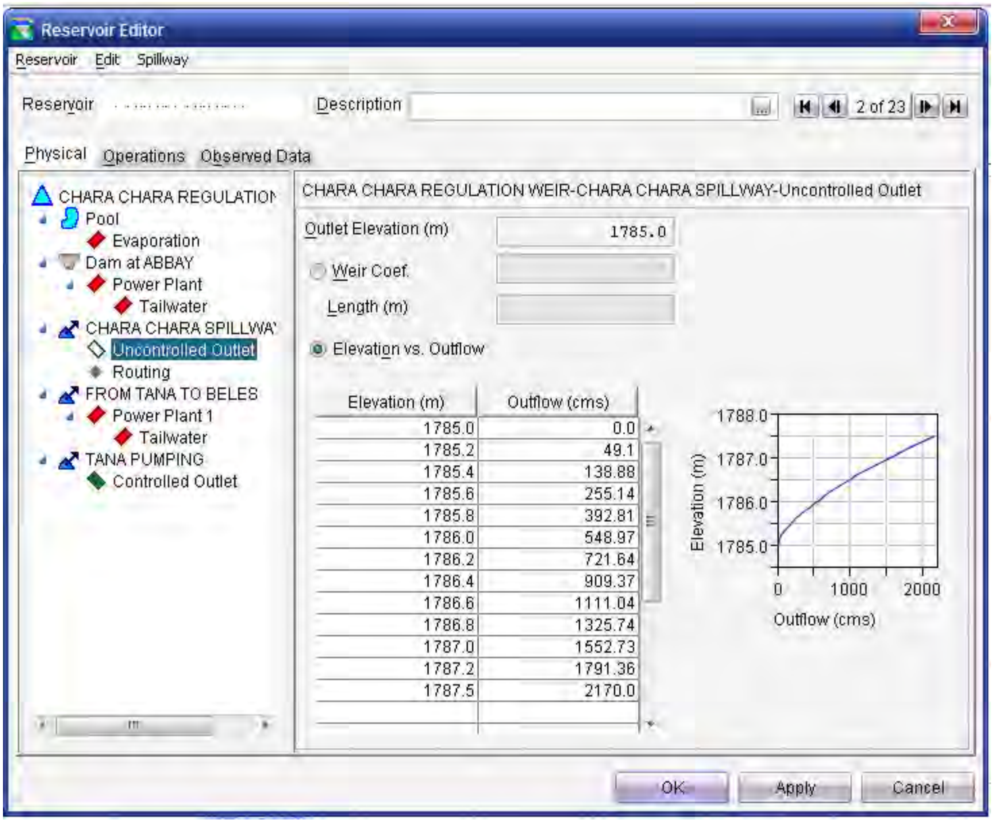
CHARA CHARA REGULATION WEIR-Pool

● Linear Interpolation ○ Conic Interpolation

Elevation (m)	Storage (m3)	Area (ha)
1780.00	1212000...	250900.00
1781.00	1499500...	264200.00
1782.00	1740100...	276900.00
1783.00	2026412...	279167.96
1783.50	2168174...	283524.97
1784.00	2312116...	287883.09
1784.25	2384904...	291152.36
1784.50	2458237...	293332.24
1784.75	2532115...	295512.39
1785.00	2606538...	297692.82
1785.25	2681506...	299873.53
1785.50	2757020...	302054.51
1785.75	2833079...	304235.76
1786.00	2909683...	306417.29
1786.15	2955908...	308162.71
1786.25	2986833...	309253.69
1786.50	3064528...	310781.18
1786.75	3142769...	312963.54
1787.00	3221556...	315146.17
1787.25	3300888...	317329.07
1787.50	3380766...	319512.25
1788.00	3542160...	323879.44

Elevation-Area and capacity relations

Elevation and maximum release capacity of Chara-Chara weir.



CHARA CHARA REGULATION WEIR-CHARA CHARA SPILLWAY-Uncontrolled Outlet

Outlet Elevation (m) 1785.0

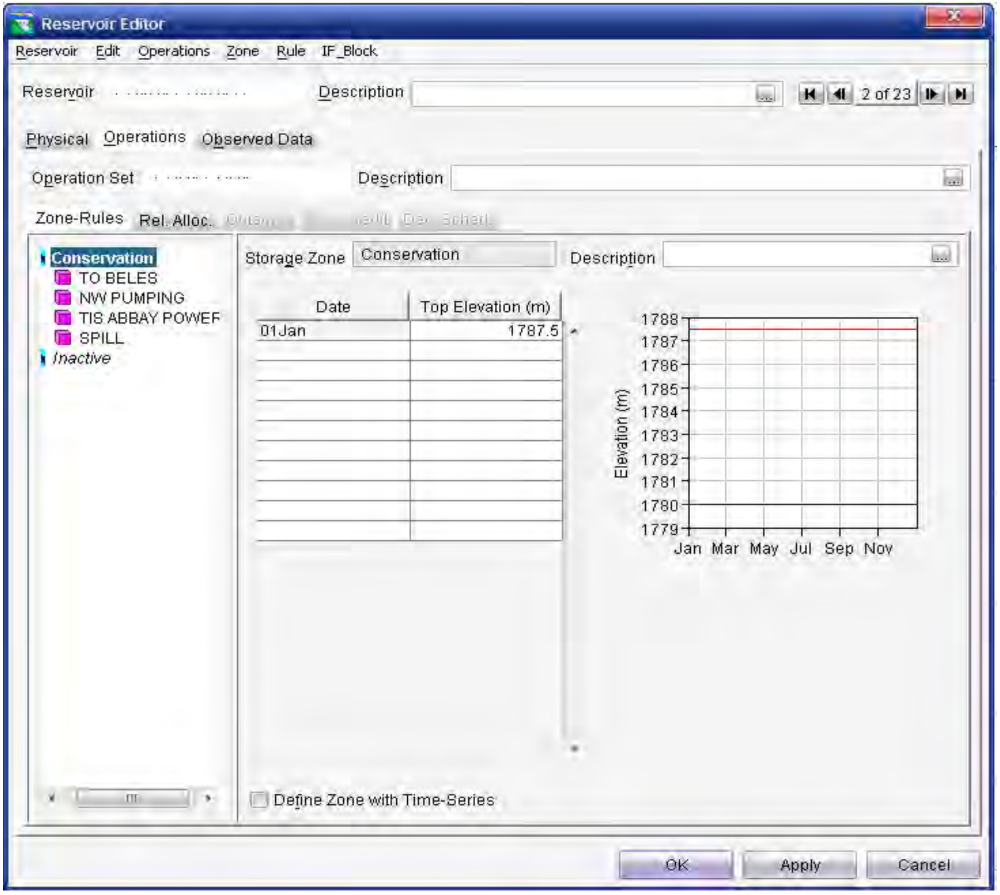
○ Weir Coef.

Length (m)

● Elevation vs. Outflow

Elevation (m)	Outflow (cms)
1785.0	0.0
1785.2	49.1
1785.4	138.88
1785.6	255.14
1785.8	392.81
1786.0	548.97
1786.2	721.64
1786.4	909.37
1786.6	1111.04
1786.8	1325.74
1787.0	1552.73
1787.2	1791.36
1787.5	2170.0

Fig A-1; Physical data entry for lake - Tana



Storage Zone: Conservation

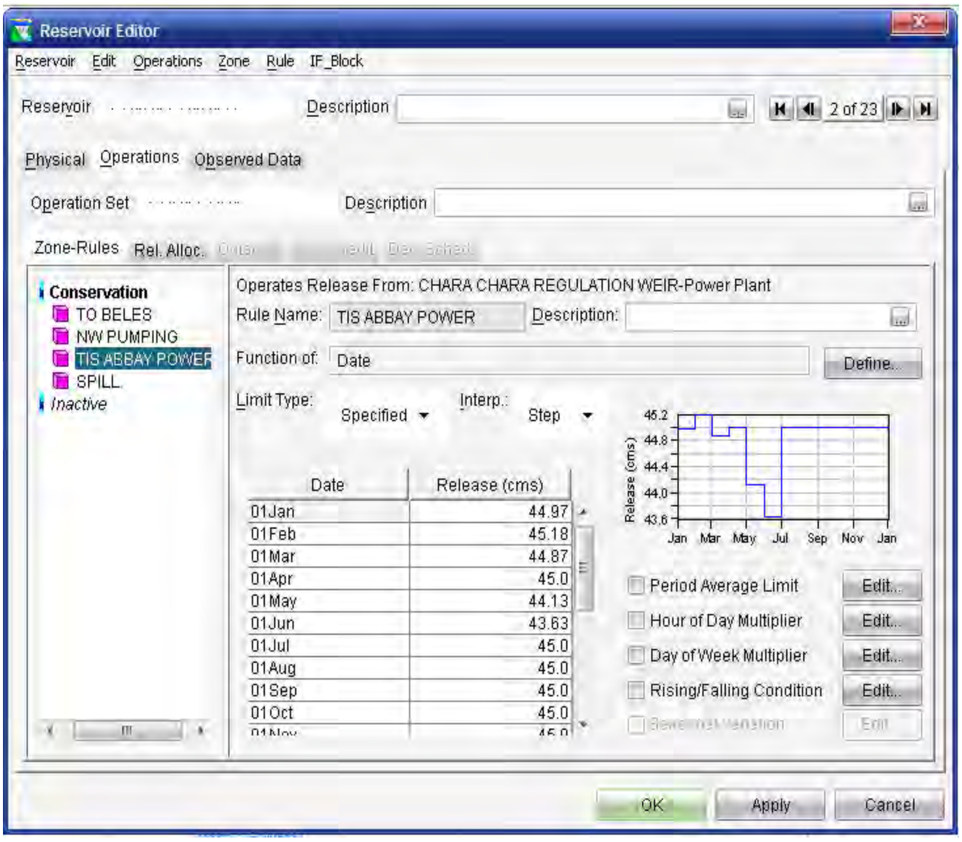
Description:

Date	Top Elevation (m)
01Jan	1787.5

☐ Define Zone with Time-Series

Lake Tana with conservation Zone defined

Tis Abay power plant requirement defined



Operates Release From: CHARA CHARA REGULATION WEIR-Power Plant

Rule Name: TIS ABBAY POWER

Description:

Function of: Date

Limit Type: Specified

Interp.: Step

Date	Release (cms)
01Jan	44.97
01Feb	45.18
01Mar	44.87
01Apr	45.0
01May	44.13
01Jun	43.63
01Jul	45.0
01Aug	45.0
01Sep	45.0
01Oct	45.0
01Nov	45.0

☐ Period Average Limit

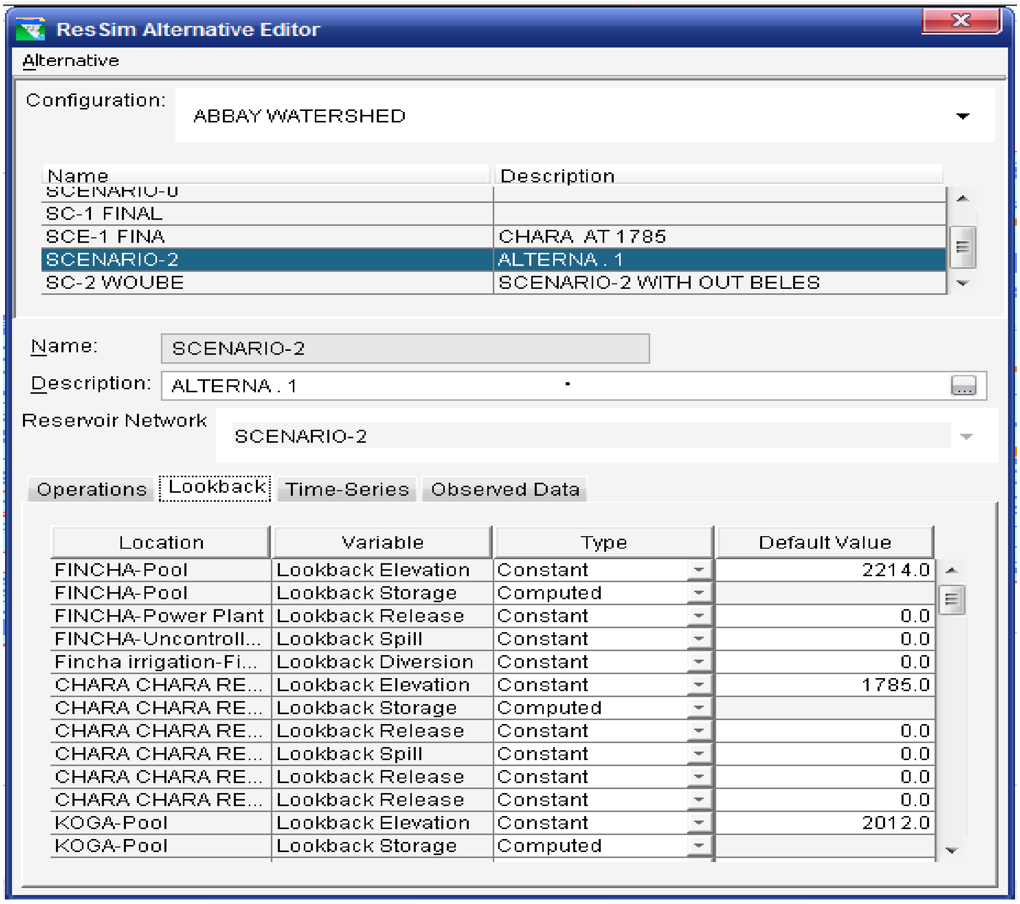
☐ Hour of Day Multiplier

☐ Day of Week Multiplier

☐ Rising/Falling Condition

☐ Seasonal Variation

Fig A-2; Operational data of Lake Tana as entered in the user interface.



Configuration: ABBAY WATERSHED

Name	Description
SCENARIO-0	
SC-1 FINAL	
SCE-1 FINA	CHARA AT 1785
SCENARIO-2	ALTERNA . 1
SC-2 WOUBE	SCENARIO-2 WITH OUT BELES

Name: SCENARIO-2

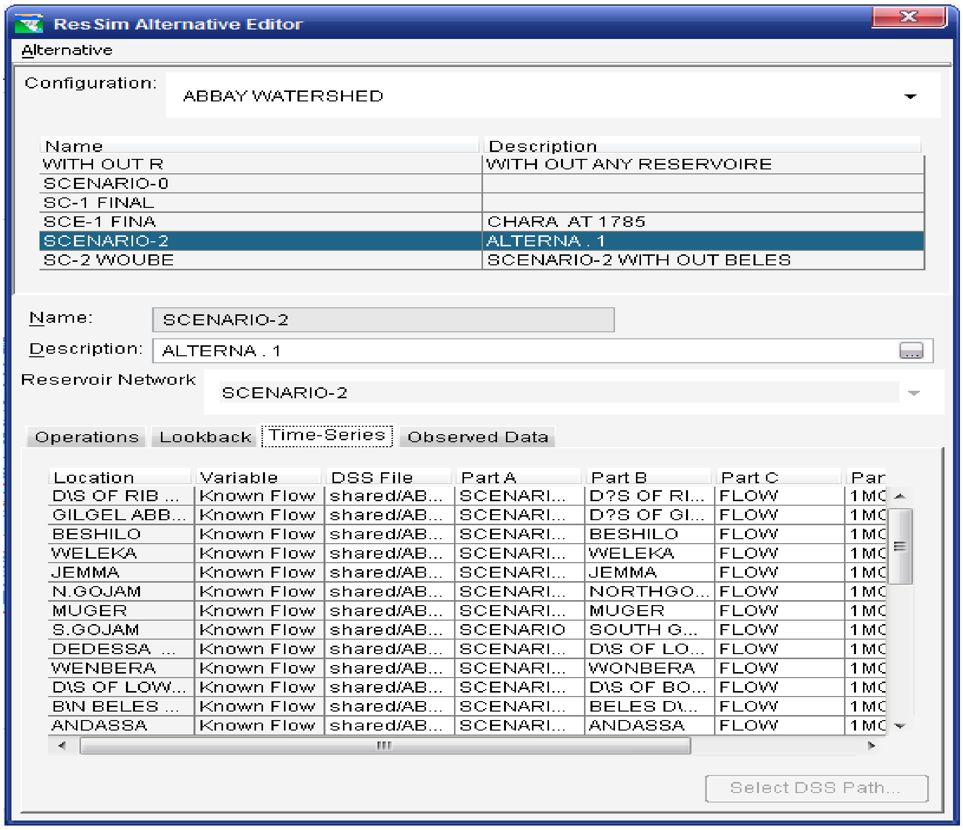
Description: ALTERNA . 1

Reservoir Network SCENARIO-2

Location	Variable	Type	Default Value
FINCHA-Pool	Lookback Elevation	Constant	2214.0
FINCHA-Pool	Lookback Storage	Computed	
FINCHA-Power Plant	Lookback Release	Constant	0.0
FINCHA-Uncontroll...	Lookback Spill	Constant	0.0
Fincha irrigation-Fi...	Lookback Diversion	Constant	0.0
CHARA CHARA RE...	Lookback Elevation	Constant	1785.0
CHARA CHARA RE...	Lookback Storage	Computed	
CHARA CHARA RE...	Lookback Release	Constant	0.0
CHARA CHARA RE...	Lookback Spill	Constant	0.0
CHARA CHARA RE...	Lookback Release	Constant	0.0
CHARA CHARA RE...	Lookback Release	Constant	0.0
KOGA-Pool	Lookback Elevation	Constant	2012.0
KOGA-Pool	Lookback Storage	Computed	

Look back info. To define the initial condition of reservoirs

Selection of DSS file where the flow series have been saved, for each local flow receiving node



Configuration: ABBAY WATERSHED

Name	Description
WITH OUT R	WITH OUT ANY RESERVOIRE
SCENARIO-0	
SC-1 FINAL	
SCE-1 FINA	CHARA AT 1785
SCENARIO-2	ALTERNA . 1
SC-2 WOUBE	SCENARIO-2 WITH OUT BELES

Name: SCENARIO-2

Description: ALTERNA . 1

Reservoir Network SCENARIO-2

Location	Variable	DSS File	Part A	Part B	Part C	Par
D\S OF RIB ...	Known Flow	shared/AB...	SCENARI...	D?S OF RI...	FLOW	1MC
GILGEL ABB...	Known Flow	shared/AB...	SCENARI...	D?S OF GI...	FLOW	1MC
BESHILO	Known Flow	shared/AB...	SCENARI...	BESHILO	FLOW	1MC
WELEKA	Known Flow	shared/AB...	SCENARI...	WELEKA	FLOW	1MC
JEMMA	Known Flow	shared/AB...	SCENARI...	JEMMA	FLOW	1MC
N.GOJAM	Known Flow	shared/AB...	SCENARI...	NORTHGO...	FLOW	1MC
MUGER	Known Flow	shared/AB...	SCENARI...	MUGER	FLOW	1MC
S.GOJAM	Known Flow	shared/AB...	SCENARIO	SOUTH G...	FLOW	1MC
DEDESSA ...	Known Flow	shared/AB...	SCENARI...	D\S OF LO...	FLOW	1MC
WENBERA	Known Flow	shared/AB...	SCENARI...	WONBERA	FLOW	1MC
D\S OF LOW...	Known Flow	shared/AB...	SCENARI...	D\S OF BO...	FLOW	1MC
B\N BELES ...	Known Flow	shared/AB...	SCENARI...	BELES D\...	FLOW	1MC
ANDASSA	Known Flow	shared/AB...	SCENARI...	ANDASSA	FLOW	1MC

Fig A-3; Defining look back and selection of DSS file for each node

Appendix B. Power summary and Reservoir level variation of all other dams for scenario-4:

Location/Parameter	Alternative :scenario-4		
	Average	Maximum	Minimum
DANGURE DAM-Power Plant			
Generation Efficiency	0.85	0.85	0.85
Power Head (m)	81.8	93.3	63.8
Energy Generated per Annum (GWh)	604.11	688.57	470.67
Power Generated (MW)	69	78.6	53.7
Plant Factor	0.5	0.5	0.4
Flow Power (cms)	101.2	101.2	101.2
FINCHA-Power Plant			
Generation Efficiency	0.85	0.85	0.85
Power Head (m)	597.1	599.2	595
Energy Generated per Annum (GWh)	806.39	990.83	0.00
Power Generated (MW)	92.1	113.1	0
Plant Factor	0.7	0.8	0
Flow Power (cms)	18.5	22.7	0
LOWER DABUS-Power Plant			
Generation Efficiency	0.85	0.85	0.85
Power Head (m)	33.3	39.5	30
Energy Generated per Annum (GWh)	228.67	368.50	0.00
Power Generated (MW)	26.1	42.1	0
Plant Factor	0.3	0.5	0
Flow Power (cms)	90.3	127.9	0
LOWER DEDESSA-Power Plant			
Generation Efficiency	0.85	0.85	0.85
Power Head (m)	128.7	147.8	96.4
Energy Generated per Annum (GWh)	1519.42	1745.03	1137.85
Power Generated (MW)	173.4	199.2	129.9
Plant Factor	0.6	0.7	0.4
Flow Power (cms)	161.8	161.8	161.8
LOWER GUDER-Power Plant			
Generation Efficiency	0.85	0.85	0.85
Power Head (m)	135.2	143.1	126.9
Energy Generated per Annum (GWh)	292.84	341.53	0.00
Power Generated (MW)	33.4	39	0
Plant Factor	0.3	0.4	0
Flow Power (cms)	29.5	32.7	0
UPPER DABUS-Power Plant			
Generation Efficiency	0.85	0.85	0.85
Power Head (m)	25.5	33.3	20.5
Energy Generated per Annum (GWh)	198.23	347.01	0.00
Power Generated (MW)	22.6	39.6	0
Plant Factor	0.4	0.6	0
Flow Power (cms)	97.4	142.7	0
TOTAL AVERAGE ANNUAL ENERGY (GWh)	***3,649.67***		

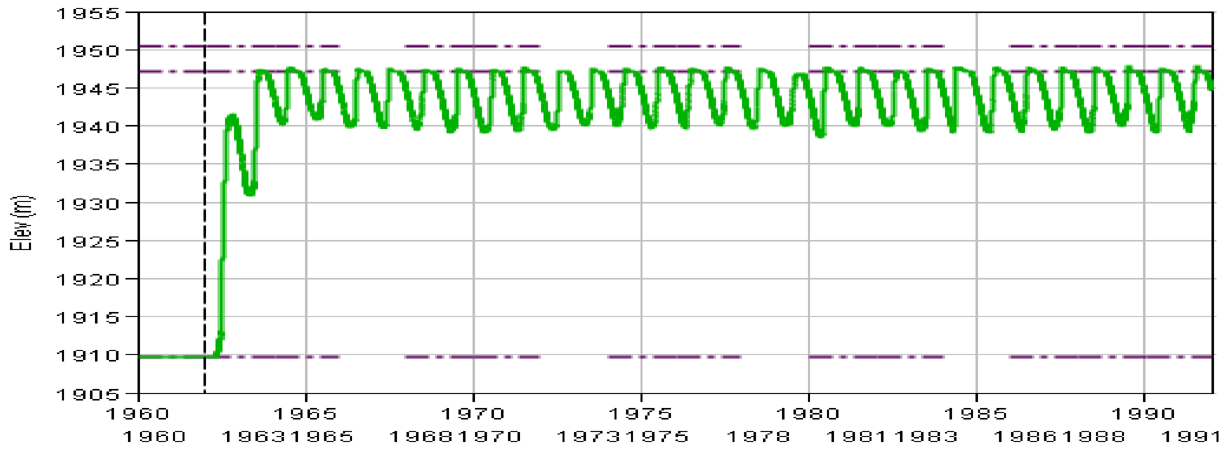


Fig B-1; Megech dam reservoir level variation for scenario-4

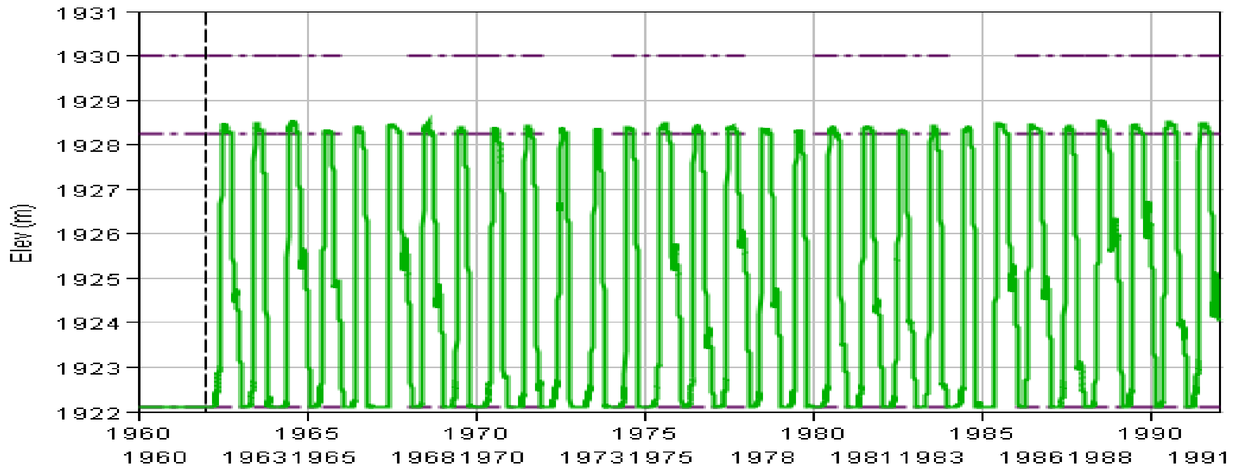


Fig B-2; Gummera dam reservoir level variation for scenario-4

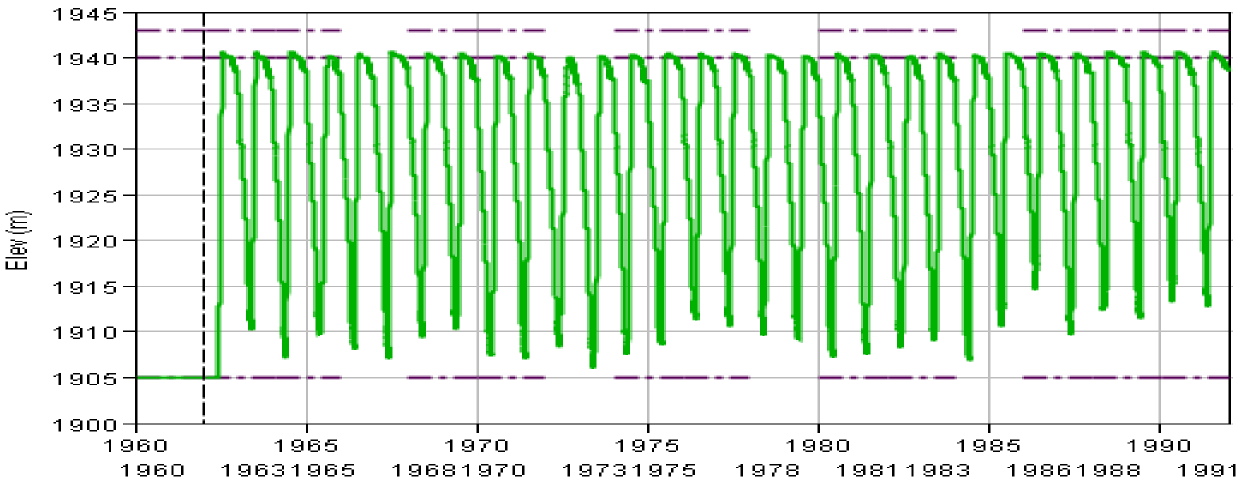


Fig B-3; Rib dam reservoir level variation for scenario-4

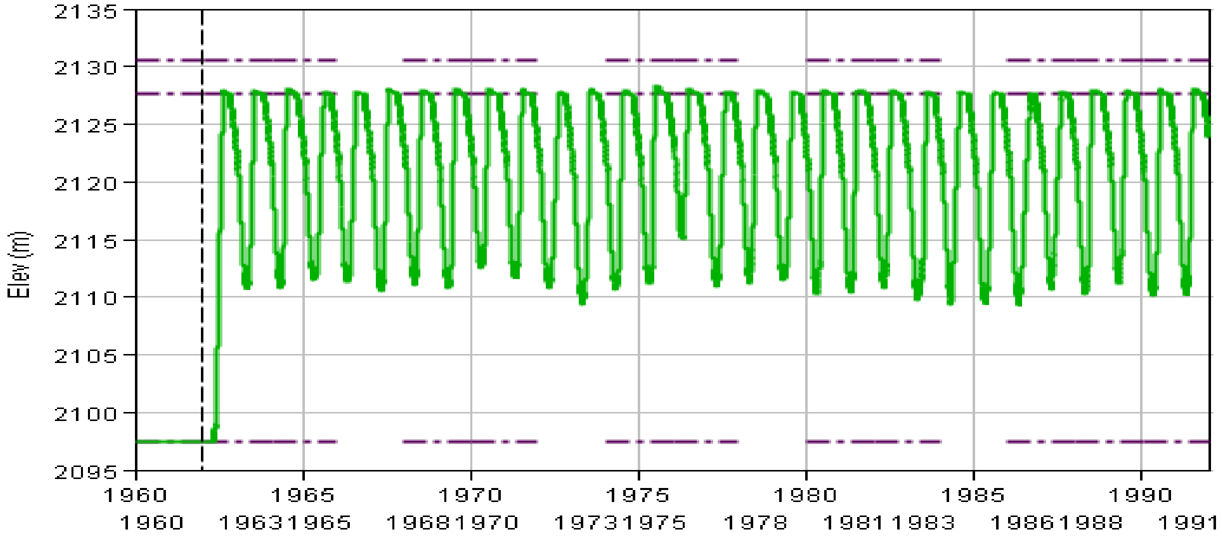


Fig B-4; Jemma dam reservoir level variation for scenario-4

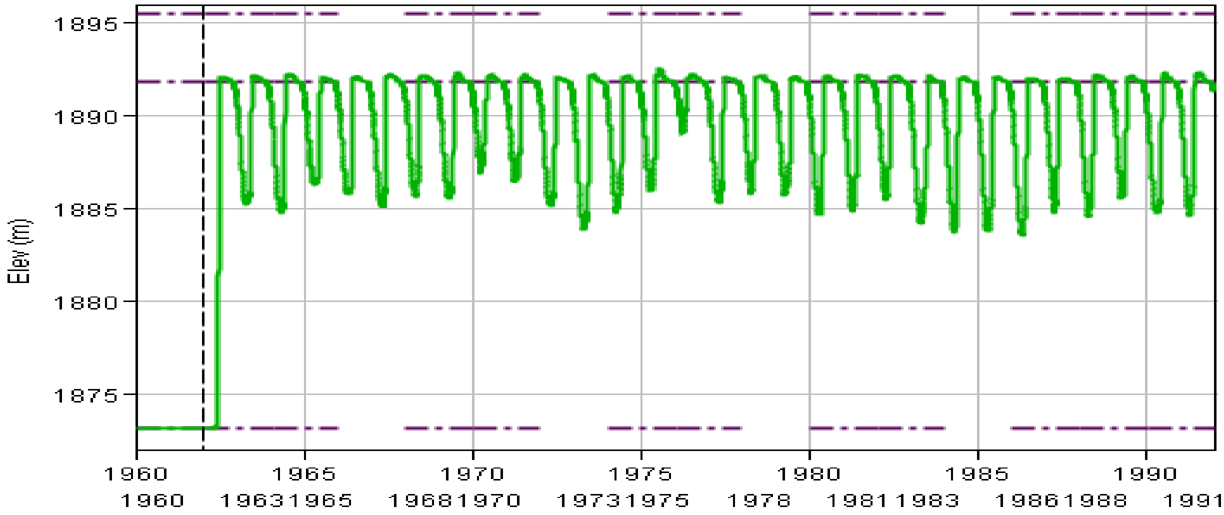


Fig B-5; Gilgel dam reservoir level variation for scenario-4

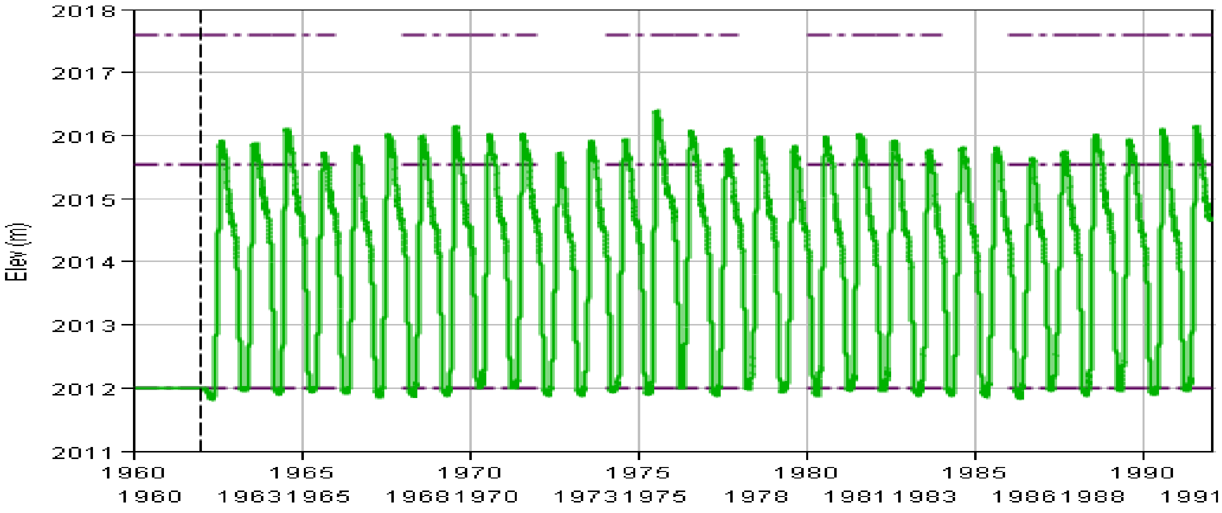


Fig B-6; Koga dam reservoir level variation for scenario-4

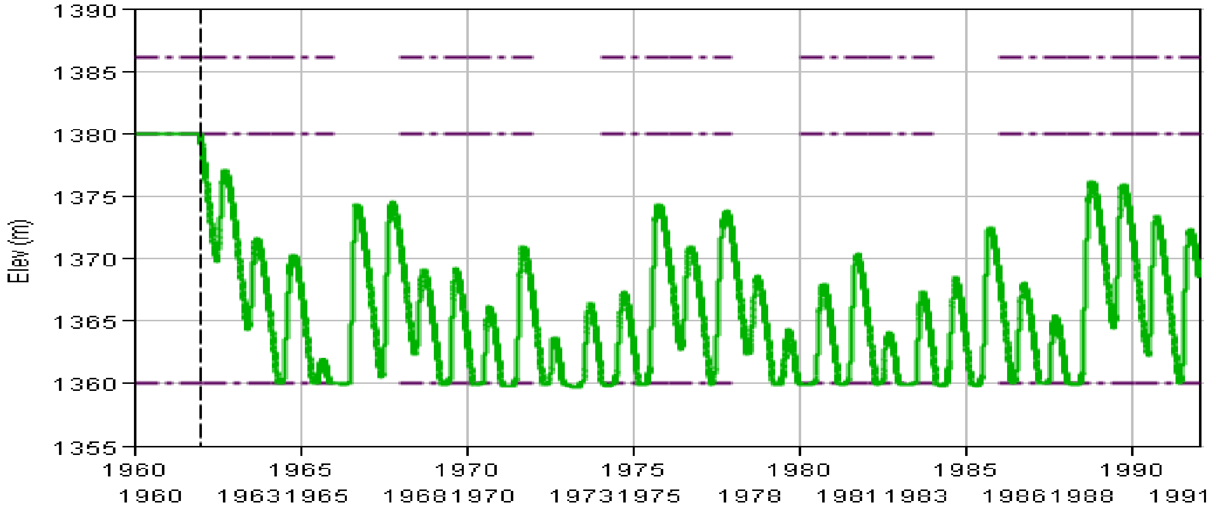


Fig B-7; Lower Guder dam reservoir level variation for scenario-4

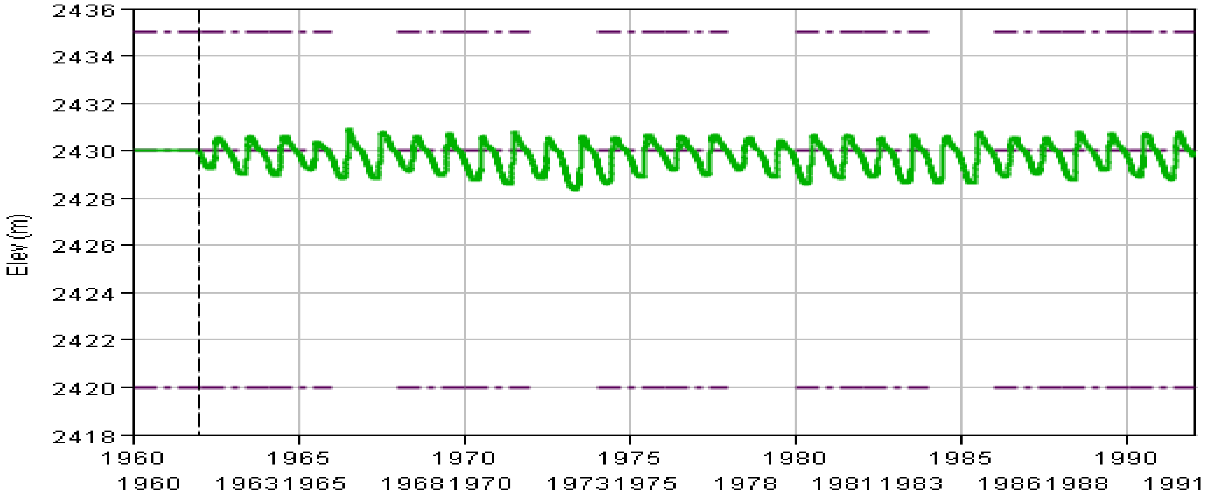


Fig B-8; Upper Guder dam reservoir level variation for scenario-4

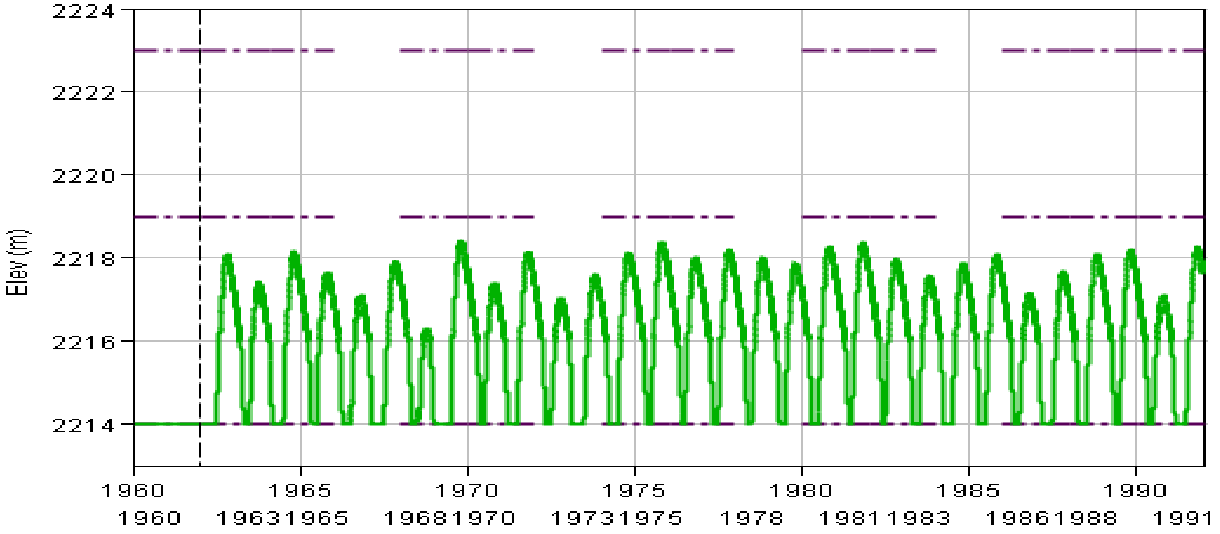


Fig B-9; Fincha dam reservoir level variation for scenario-4

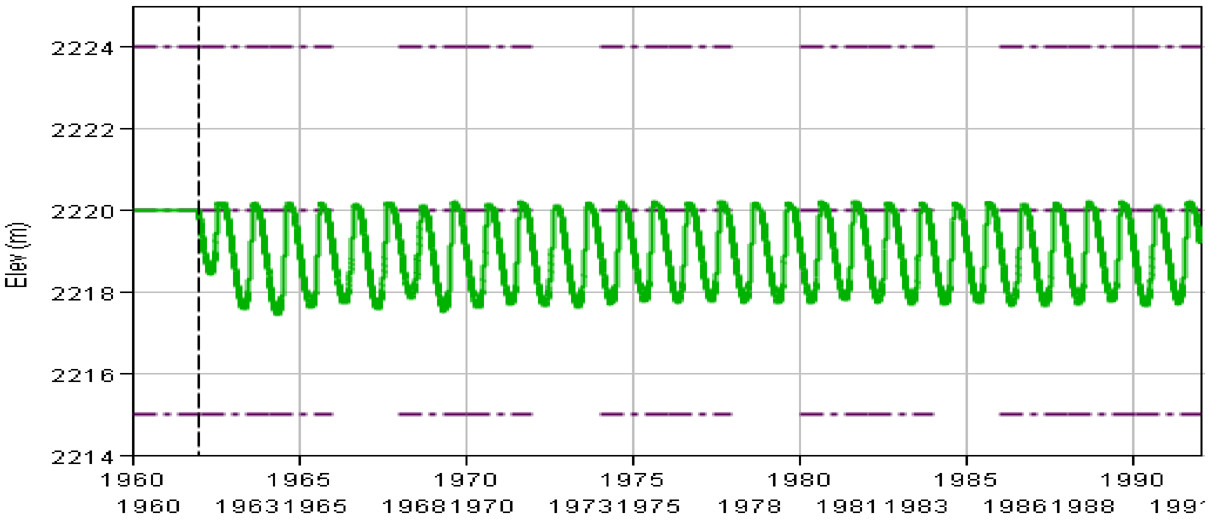


Fig B-10; Neshe dam reservoir level variation for scenario-4

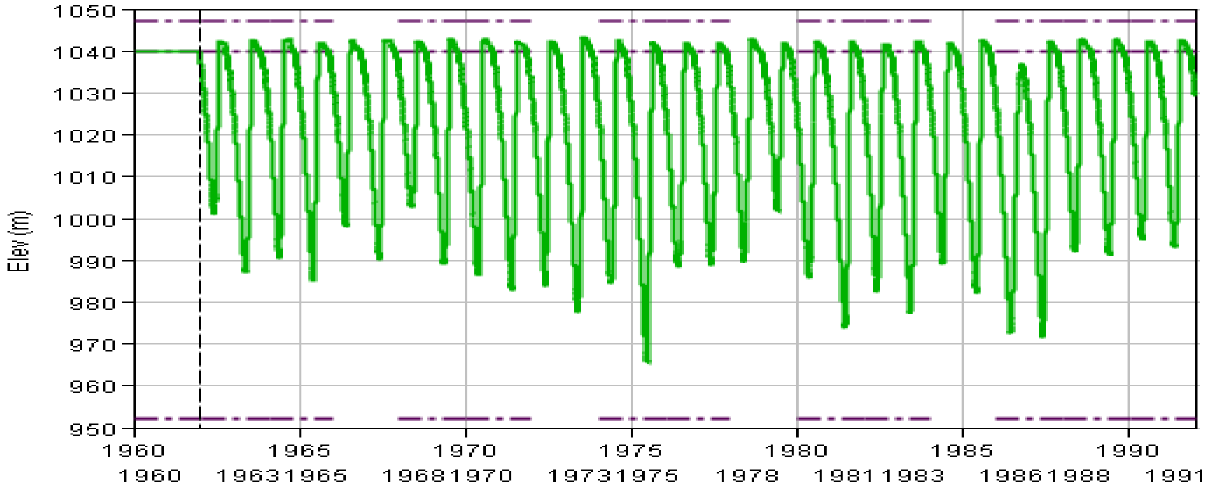


Fig B-11; Lower Dedessa dam reservoir level variation for scenario-4

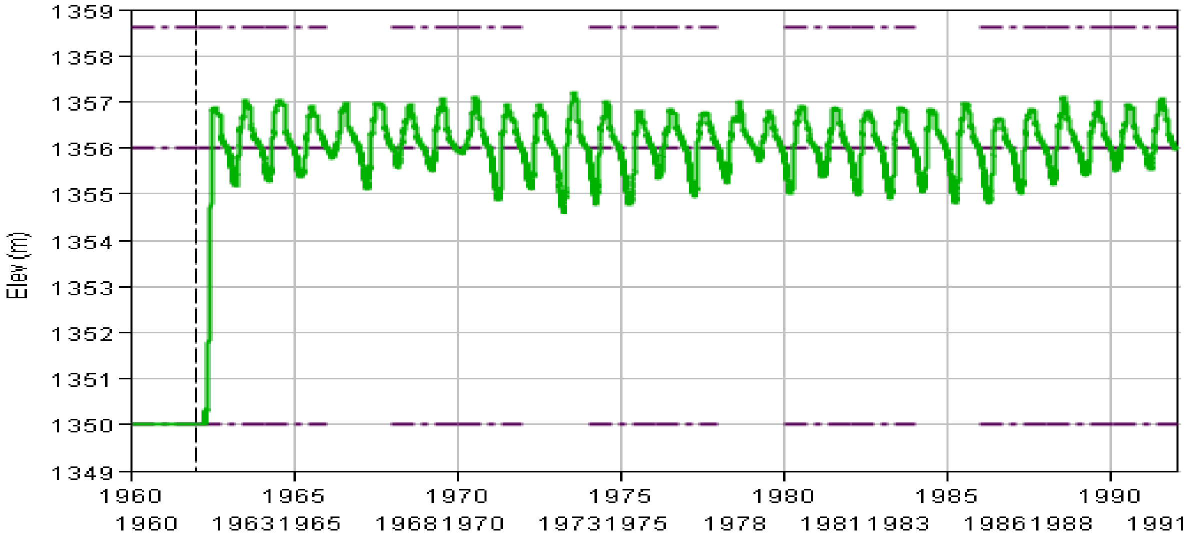


Fig B-12; Arjo dam reservoir level variation for scenario-4

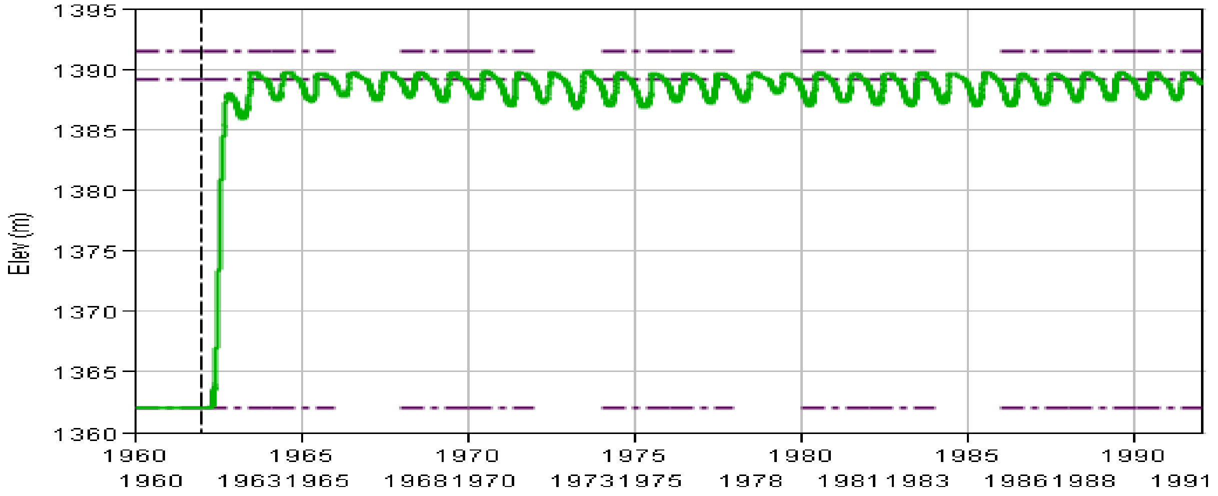


Fig B-13; Anger dam reservoir level variation for scenario-4

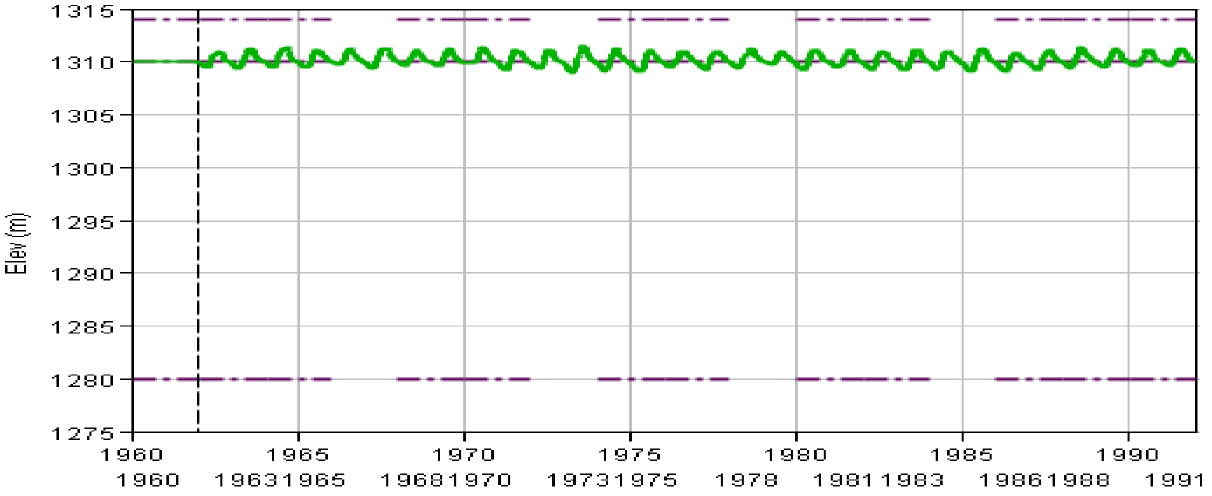


Fig B-14; Nekemte dam reservoir level variation for scenario-4

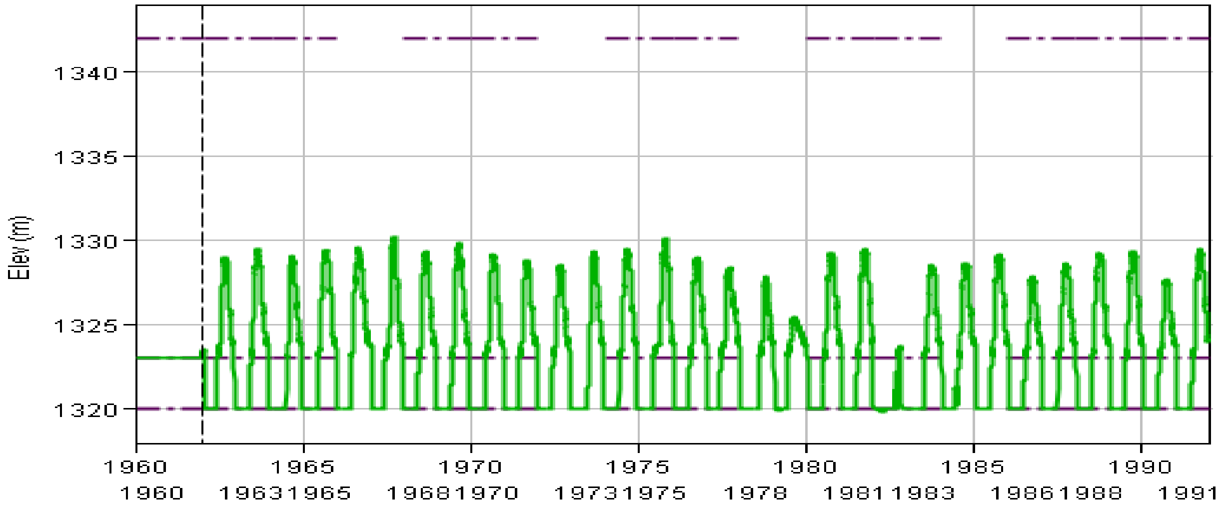


Fig B-15; Lower Dabus dam reservoir level variation for scenario-4

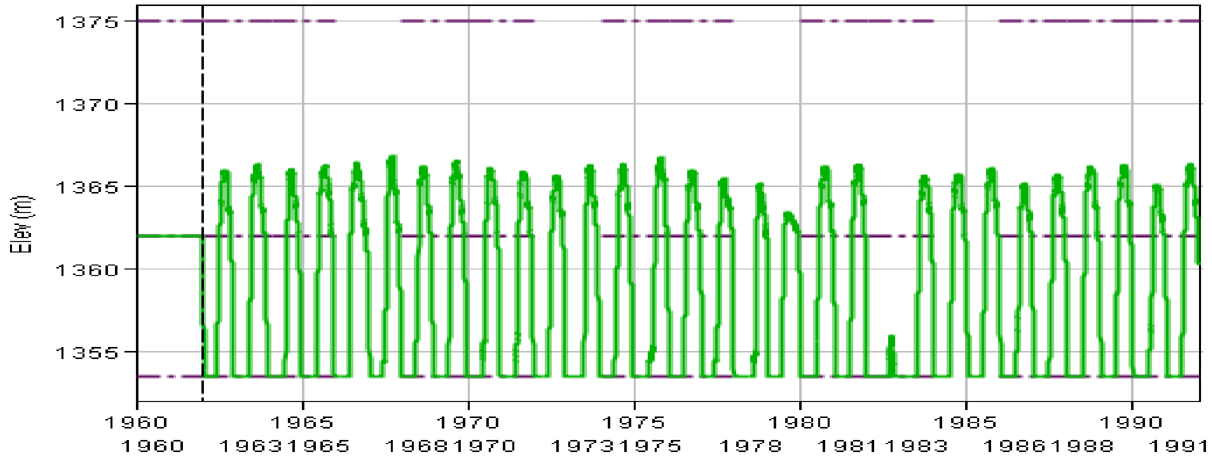


Fig B-16; Upper Dabus dam reservoir level variation for scenario-4

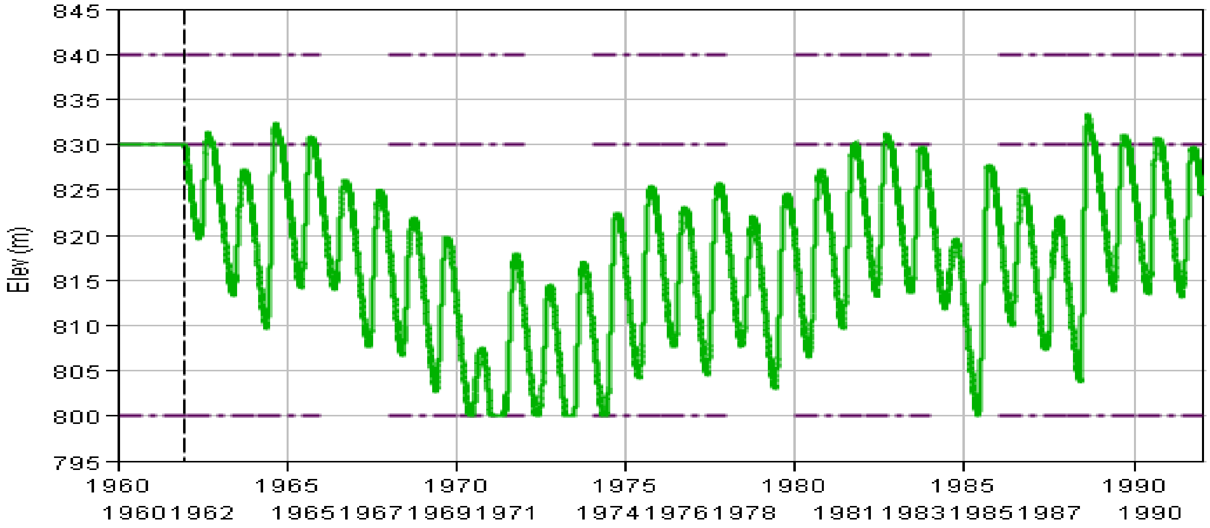


Fig B-17; Dangure dam reservoir level variation for scenario-4

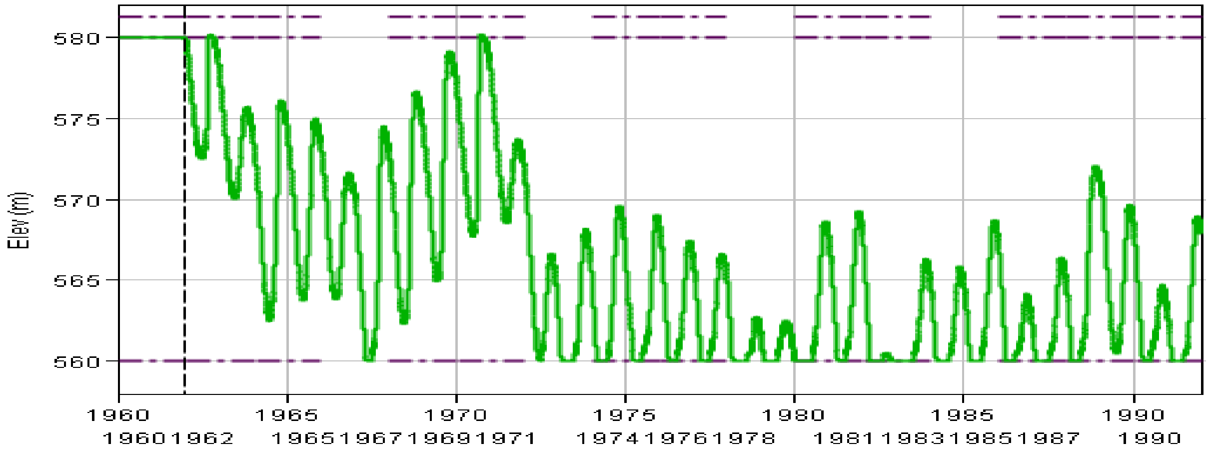


Fig B-18; Border dam reservoir level variation for scenario-4