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The Optimize Operation and Future Development of Multipurpose Tana-Beles Hydropower Project, Ethiopia

Hydropower Development

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Abstract

Different projects in Tana-Beles basins were identified as water resource development project and implemented to attain the country's development goals. One of these projects is Tana-Beles multipurpose hydropower project which has been under operation since May 2010. Water is diverted from Lake Tana through tunnel to power plants and then joins Beles Basin River towards irrigation area. Seasonally varied flow influence both products. That means at dry season water demand in the irrigation area is very high with low natural flows whereas during wet season the demand is low with high natural flow. Both upper and lower Beles irrigation areas are not fully covered. But, power production is high at wet than dry season in the project. Therefore, optimization of the project is necessary to obtain good combination and coverages of both purposes. In addition, the study has also assessed the feasibility of damming water at Dangura site.

The study found nMAG model feasible and applicable to run the given data specification. This study has analyzed hydrological data of the basin which is used for model setting. Optimization is undertaken through the development of two phase scenarios. The first phase involved regulation of Lake Tana within four scenario while the second phase involved optimization of Tana-Beles MPP with six scenarios. The second phase of optimization is followed by the identification of the best scenario in first phase. Scenario D which is release of seasonal varied flow to downstream, is selected on the basis of environmental flow, the amount of water released, power production, and energy equivalent in first phase. This scenario proceeded to the second phase and developed other six scenarios. In the second phase, scenario D2R is selected on the basis of environmental flow, the amount of water released, power production, irrigation coverages and water requirement, water consumption and energy equivalent basis which show better result.

This study found that the mean annual water release to downstream is 978 Mm3 higher than 862 Mm3 value suggested by Bellier et al. (1997) and lower than 995 Mm^3 value recommended by McCartney et al. (2009). The mean annual energy production is 2,356 and 1,278 GWh in Tana-Beles and Dangura power plant respectively. Damming of water improve irrigation product by 1% and add 1,278.1 GWh annual power to the national grid. Mean annual water of 2,043 Mm^3 is lost due to artificial storage in lower Beles. However, this artificial reservoir can be the site for tourism, fishing, and navigation. The available water in the basin is about 5,226 Mm^3 annual. To cover all irrigation area, minimum of 2,806 Mm^3 mean annual water is needed. But, this study indicated about 36.1 % of upper Beles and 100 % lower Beles irrigation area can be covered with the available water. Overall 71.2 % of the total irrigation area (11,312 ha) in Beles basin can get enough water.

Thus, the study concluded to prioritize lower Beles irrigation area with damming of water on Dangura site in order to get optimum productions of both combination, and release seasonal variable water to downstream. Upgrading Chara-Chara weir max regulation level by 0.2 m is essential for extra storage and production. The study suggest the use of night storage, highly efficient irrigation system, weir in the river, the use of special boat design, change water rout, and dredging shallow lake to maximize productions and overcome navigation problem. The study recommends a dam to be constructed at Dangura site.

Acknowledgement

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Acronym and Abbreviations

ADSEW	Amhara Design and Supervision Enterprise Work
BDU	Bahir Dare University
DMC	Double Mass Curve
DRM	Desktop Reserve Method
EEK	Energy Equivalent
EEPCo	Ethiopian Electric Power Corporation
EIA	Environmental Impact Assessment
FDC	Flow Duration Curve
GERD	Grand Ethiopian Renaissance Dam
GIRD	Generation Integrated Rural Development
GWh	Giga Watt hour
ha	hectare
HPP	Hydro Power Plant
HRWL	Highest Regulated Water Level
ITCZ	Inter Tropical Convergence Zone
KWh	Kilo Watt hour
LRWL	Lowest Regulated Water Level
LB	Lower Beles
masl	mean above sea level
MCM	Million Cubic Meter
MoWE	Ministry of Water and Energy
MPP	Multi-Purpose Project
MW	Mega Watt
SMEC	Small and Medium sized Enterprise Consultant
TaSBo	Tana Sub Basin Organization
TWL	Tail Water Level
UB	Upper Beles
WMO	World Meteorological Organization

1. Introduction

1.1. Background of the study

One of the key elements of the development of a country is Electric energy. Recognizing the role that the power sectors play in the development of the country, the Government of Ethiopia has given utmost importance to developing the level of the energy generating capacity of the country by harnessing the huge water resources potential which the country is endowed. With a view of supporting the efforts being exerted by the government, EEPCo has been engaged in implementing hydropower projects in different river basins of the country, of which Tana-Beles hydropower plant is one of them.

Ethiopia start to construct the Grand Ethiopian Renaissance Dam on Blue Nile River near the border of Sudan, which generates a 6,000 megawatt hydropower since November 2012. The dam is expected to be a boost for the Ethiopian economy. Sudan and Egypt, voiced their concern over a potential reduction in water available to them.

On the way Tana-Beles hydropower plant project start operation in 2010 which use water from Lake Tana which is the main sources and the starting point of the Blue Nile. The flow of the Blue Nile reaches maximum volume in the rainy season (from June to September), when it supplies about 67 % of the water of the Nile proper. The flow of some amount of water will change the natural flow direction to the Beles basins and finally meet at the border of Sudan (GERD). Here the natural average flow amount will decrease due to the developments of Tana-Beles Multipurpose hydropower project.

1.2. Significance of the study

To ensure the Millennium Development Goals in the country, Ethiopian like Lake Tana and the adjacent Beles river basins have been identified to achieve one of the country goals. Transform the local economy from a subsistence, predominantly agricultural one which makes limited use of the abundant water resources to an economy based on the development of water resources that contribute to growth in multiple sectors is one of the long-term vision of the Ethiopian Government. The result will be a dramatic reduction in the poverty and acceleration in regional growth as well as within the country, Ethiopia. Improved control and management of finite water resource in the Lake Tana basin is critical if continuous growth in different sectors like agricultural productivity, energy production, livelihoods, health and a reduction in poverty is to be realized. Effective water resource development will maximize social and economic benefits whilst minimizing environmental damage to Lake Tana and the Abbay River and avoiding detriment to local communities (McCartney et al. 2010).

To prevent an extra degradation of Lake Tana, its surrounding shoreline wetlands, and downstream of lake along the Abbay river sustainable, well controlled, well managed, and regulated water resource development is important. In future water resources dwindle and water stress more likely. Hence, effective management and planning of water resources is become more essential, otherwise in future climate change is likely to have a negative impact on regional growth, people's livelihoods and the environs of Lake Tana (Halcrow – GIRD 2010).

There are many, often competing, water demand and water user sectors in the Tana-Beles basins, these include: irrigated agriculture, energy production, fisheries, navigation, environment, water supply and tourism all with different demands and requirements (SMEC 2008, McCartney et al. 2009).

> *"If accelerated economic growth in the Tana-Beles basin is to be realized then effective planning, management and regulation of water resource developments is essential to prevent conflict between competing water users and sectors. Careful management of natural resources can also optimize the benefits to all competing sectors. Conflict can be reduced and benefits maximized if decision makers involve stakeholders in their decision for allocation of water resources between competing needs" (McCartney et al. 2010).*

To ensure sustainability of projects in and around the project area, to minimize negative impact and to attend optimum product from both hydropower and irrigation an optimal operation and future development of Tana-Beles Multipurpose HP project study is very crucial and important in the basin as well as the whole country, Ethiopia.

1.3. Objectives of study

Reservoirs are very important for stabilizing the power generations, regulating highly variable flows and to increase irrigation potentials in order to meet the demand timely. Such reservoirs also often will help to make a more stable, improved environmental flow and maintain good environmental quality in rivers downstream of the hydropower outlet.

On the other hand, changes in the natural flow condition can also give negative environmental impacts and lead to changes in the natural ecosystems. The analysis of how a planned or existing reservoir will impact the downstream flow regime is therefore a major part of any EIA analysis of a hydropower plant development. The change in river flow due to the developments of the project could lead to both a change in flow volume and the timing of the flow. It can also have an impact on sediment supply, storage and transport in the reservoir, downstream and to the basin which receives water.

The first part of this study consists of an analysis of Hydro-Meteorological data in the Tana-Beles basins and the volume of flow to the downstream/outlet of Lake Tana including both the volume of flow and the timing of flow in the river system as well as a seasonal release of water to hydropower plant from the lake. This will be done setting out reservoir operation scenarios related to environmental flow under a different perspective.

On the other way, this project is a multipurpose project mainly used for irrigation and power production. Here it focuses to find the optimum way of operations in order to get the optimum benefit from both power and irrigation. How much of irrigation area will be covered and in what way irrigation potentials will increase in the region will be answered in this study. In the study the optimization is neither "actual" optimization nor directly related with cost, but focused to find the best combination of irrigation area coverage for crop production and power generation through the development of different scenario.

With data availability and objective of this study, stating data specification and importing of the data that will be checked to nMAG2004 model and run it. Here, it will check the flow of water to the whole system and ultimately important to decide which way and scenarios is the best way to get optimum benefit in general in terms of area coverage and power production. How and in what way, nMAG2004 model will work on this project using the data available will be checked and answered.

In the downstream of Beles basin, there is a data and detail information limitation for detail study, however, within the available data in the basin it will assess and checking damming of water at the Dangura site which was recommended by Halcrow-GIRD 2010 study within nMAG model as future water development project in the region.

Setting of environmental flow specifications to the downstream from Lake Outlet, detail study and testing of it with model and comparing its values with different recommended values also the study areas of this thesis. It will also assess environmental impact and their mitigations, water consumption in the lake, manmade reservoir and irrigation area.

1.4. Research Questions

The project will consist of descriptions of the catchments and their rivers, power and irrigation system within maps of geographical location in the region, collection and quality control of necessary data of hydrology and meteorology, hydropower and irrigation, including seasonal water supply and production and coverage of the irrigation command area by crops as and setting up simulation model and test for different scenarios, with given constraint and input data. Type of model would have been decided depending on data availability and study objectives.

Use the model to optimize the combination of power and irrigation system, today and in the future, compared to existing operation of the systems and use the model to investigate other possible alternatives ways for irrigation and power production along Beles River to get the maximum benefits in the region. Identifications of scenario that show good combination and results of production in the both purpose is main research question in this study.

Type of hydrological model uses on the basis of the objectives is another thing that can be cover answer in this study. On the other hands, assessing of possible water development in the region need to be discussed.

Assess impacts from water losses (water consumption) from reservoirs and irrigated fields, possible impacts on environmental and socio-economical aspects and discuss adaptation and mitigation measures for the impacts.

1.5. Thesis outline

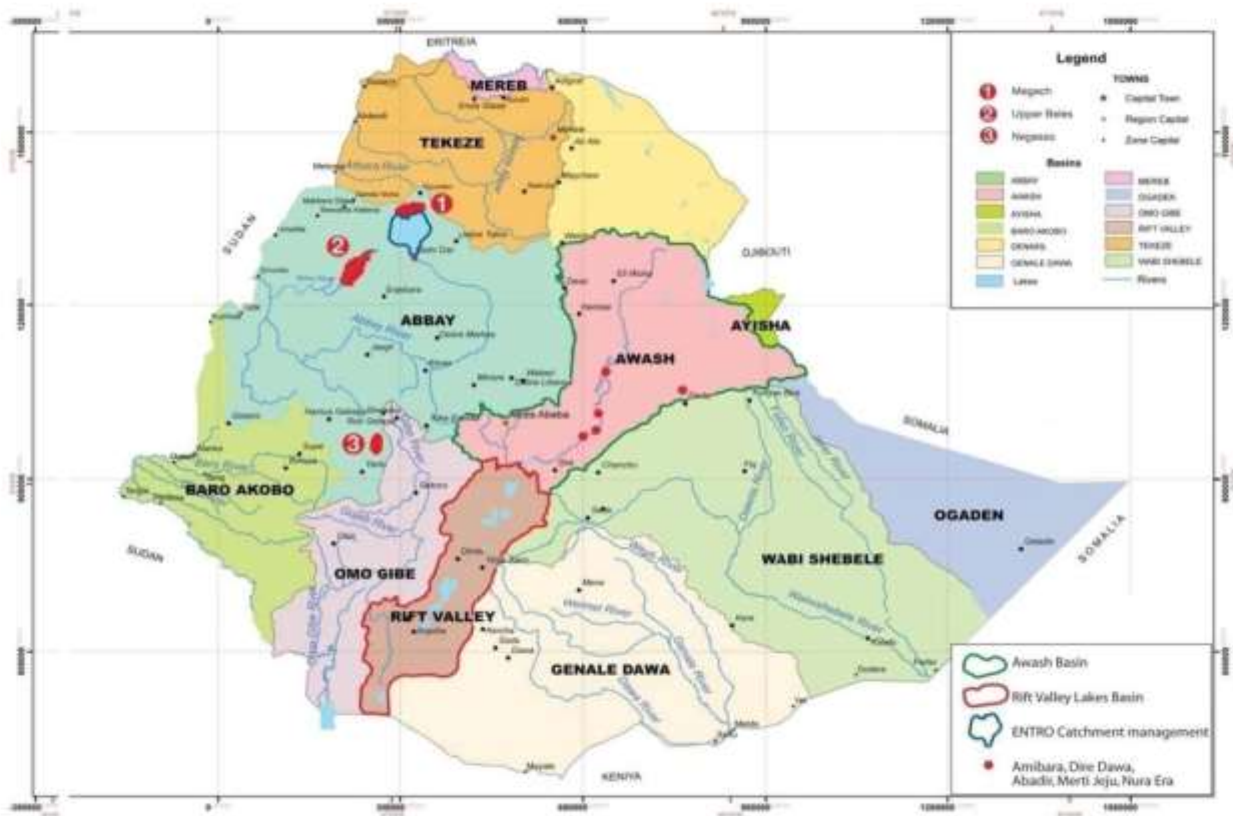
This thesis contains seven chapters organized as follows:

Chapter one gives a general introduction to this study with emphasis on multipurpose hydropower project, relevant and objective of the study. Chapter two gives a brief description of the study area. Chapter three more discuss about literature reviews of different studies, which are related to this study and the project. Chapter four deals about Hydro-Meteorological data availability, data analysis and quality checking of those data's in and around the project. Chapter five deals about the methodology of analysis, proposing and comparison and analysis of different scenarios on a different basis, water consumption computation, environmental impact and their mitigation, power production, water level analysis and future development of the project in the downstream. Chapter six deals about discussion and summary of the result of this study. Chapter seven ends with the conclusion and recommendations of this study.

2.Descriptions of Study Area

2.1.Introduction

Ethiopia has 12 basins, from those 8 are River Basins, 1 Lake Basin and 3 Dry basins, with a total annual runoff volume of 122 billion cubic meters of water and an estimated 2.6 - 6.5 billion m^3 of groundwater potential, which makes an average of 1,575 m^3 of physically available water per person per year, a relatively large volume[1]. One of the biggest basins in Ethiopia is Blue Nile/Abbay basin, which covers a larger area of the country and it has projects from small to large scale ongoing, under operation and under feasibility study. One of them is Tana-Beles Multipurpose hydropower project.



**Source Halcrow-GIRD, 2010*

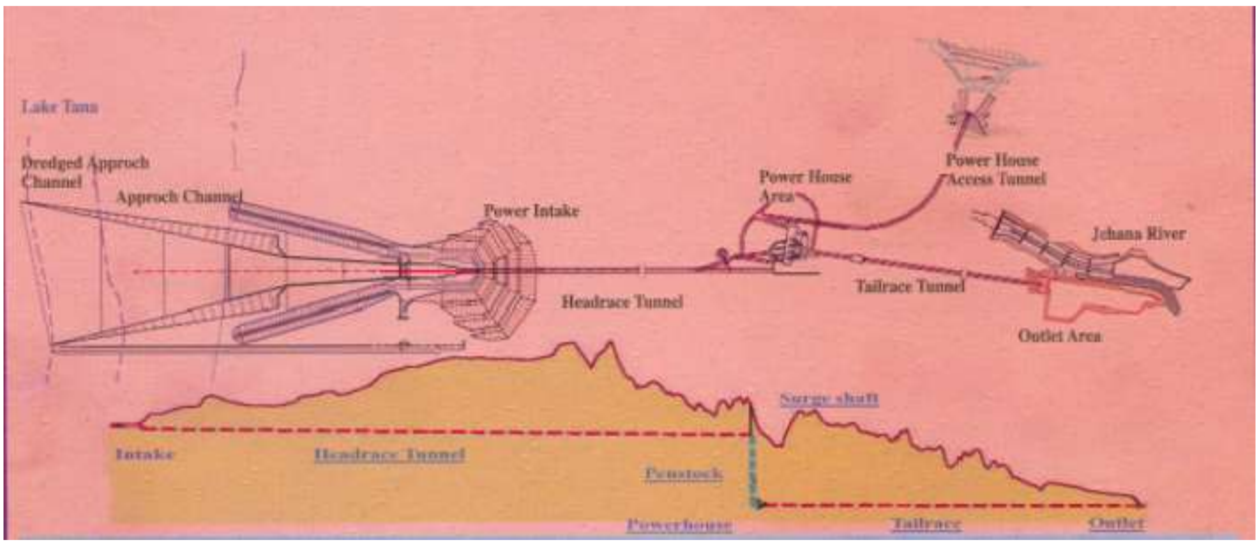
Figure 2. 1. Different Basins in Ethiopia

Among the different parts of Blue Nile basins, Tana and Beles basins are some of them. Lake Tana has a valuable water resource and ecologically fragile, which is the source of the Abbay (Blue Nile) river. There are considerable ongoing and planned water resource developments in the Tana and Beles basins involving irrigation and hydropower schemes. The planned irrigation development of about 123,000 ha in the Lake Tana basin and about 136,000 ha in the Beles catchment results in increased agricultural production improving the region's food security and providing more employment in the Agri-industry sectors (Halcro-GIRD 2010). However, a

[1] http://www.mowr.gov.et/

recent study by McCartney et al. (2010) shows that future irrigation is given a higher priority even though it reduces hydropower which guarantee supplies of electricity. The inauguration of the Tana-Beles hydropower scheme on 14th May 2010 has increased the country's energy production, generating about 217 MW of energy (installed capacity of 460 MW). Here, water is supplied to the Tana-Beles hydropower plant from Lake Tana through a tunnel. The released water to the Tana-Beles hydropower plant is expected to supply enough water to support a significant potential areas of irrigation in the Beles river catchment after generating power.

The power scheme comprises about 11.8 km headrace tunnel with a diameter of 7.2m, and 271.8m deep pressure shaft, an underground powerhouse accommodating 4*115 MW Francis Turbine and about 7.5km tailrace tunnel. Total gross head of 325.5m to generate 2051 GWh of average annual energy with an intake structure located at 1769.8masl (EEPCo 2010).



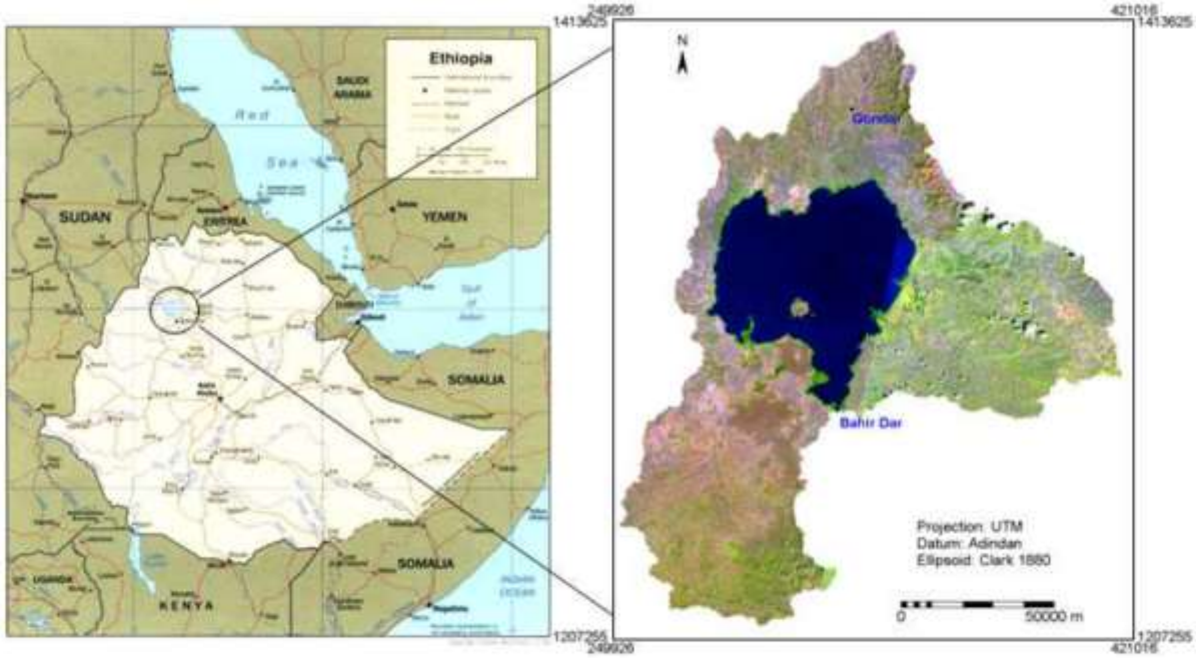
**Source: EEPCo (2010)*

Figure 2. 2.Layout of Tana Beles Hydropower

2.1.1.Location

Tana-Beles Multipurpose Hydropower project is located in the Amhara Regional State near Kunzila town about 65km (air distance) and 130km (road) to the northwest of Bahir Dar town, about 370km (air distance) northwest of Addis Ababa (capital city of Ethiopia). From the shores of Lake Tana the project extends in a South Westerly corridor some 29km into the Upper Beles valley. An approximate centroid of the area lies at latitude $11^0$52'N and longitude of $36^0$56'E (EEPCo 2010).

Lake Tana is the largest lake of Ethiopia and the third largest in the Blue Nile Basin. The lake is located in the north-west highlands at $12^0$00'N, $37^0$15'E which is 564km from the capital Addis Ababa (see Figure 2.3 below). Bathymetry, deepest point of Lake Tana is at an elevation of 1,772masl, which is about 14m below the average water level (1,786masl) with area coverage of 3,156km^2 and the average depth of the lake is about 9.5m (SMEC 2008).



**Source: Abeyou.W, Hydrological Balance of Lake Tana Thesis, 2008*

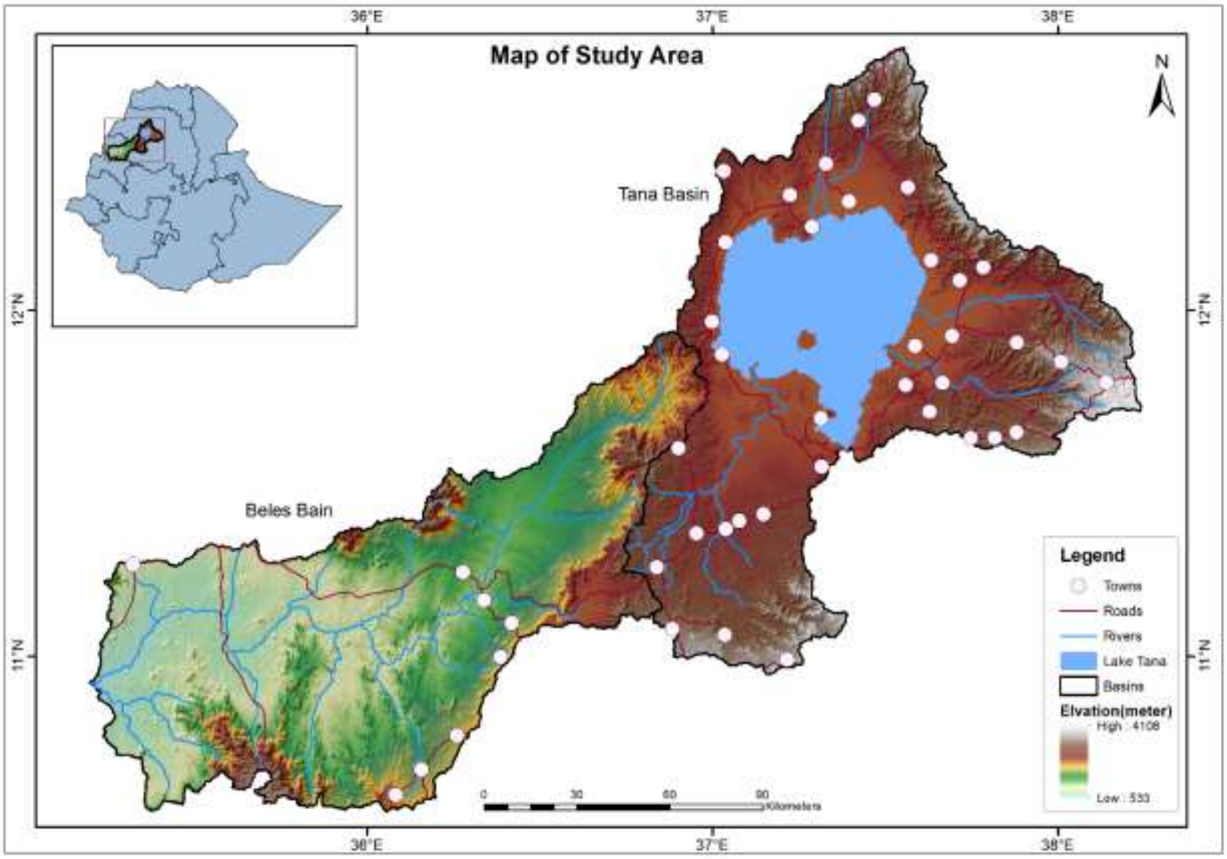
Figure 2. 3. Location of Lake Tana, 12^{0}00’N, 37^{0}15’E and Tana-Beles Basins

2.1.2.Description of Catchment Area

The Tana and Beles Basins are sub-basins of the Abbay (Blue Nile) river and both water systems of the sub-basins drain separately to the Blue Nile. However, now the water resources of the basins are interconnected through a tunnel from Lake Tana to the Tana-Beles power plant, which discharges into an upper tributary of the Beles River (Johana/Enat River) and then after it is used for irrigation in the Beles basins.

Lake Tana is fed by over 40 rivers, but inflows are dominated by four rivers Gilgel Abbay (4,517km^2), Ribb (2,156km^2), Gumara (1,604km^2), and Megech basins (Halcrow-GIRD 2010). The total catchment area which is contributing to the lake outlet of Abbay River is about 15,321km^2. The highest elevations of the basin is located in the Simien Mountains, in the north-eastern part of the Tana basin at some 4,100masl. The mean elevation of the Tana Basin is 2,025masl and at the point of outflow of the basin (Lake Tana outlet) into the Abbay at Bahr Dar, the elevation is about 1,784masl.

The total catchment area of Beles basin is 13,573km^2. This area also includes the catchments of a number of small rivers (totaling about 650km^2) that drain directly into the Blue Nile and that are not part of the Beles river basin (SMEC 2008). One of the major tributaries of the Beles basin is Gilgel Beles located at the downstream of the basin which covers 675km^2 catchment area. The mean and the highest elevation of Beles basin is 1,190 and 2,725masl respectively. The Beles drain to Abbay River and joins it near the border of Sudan. Tana-Beles basins are shown in figure 2.4 below.



**Source*[2]
Figure 2. 4. Tana-Beles Basin

2.1.3.Climate of the Study Area

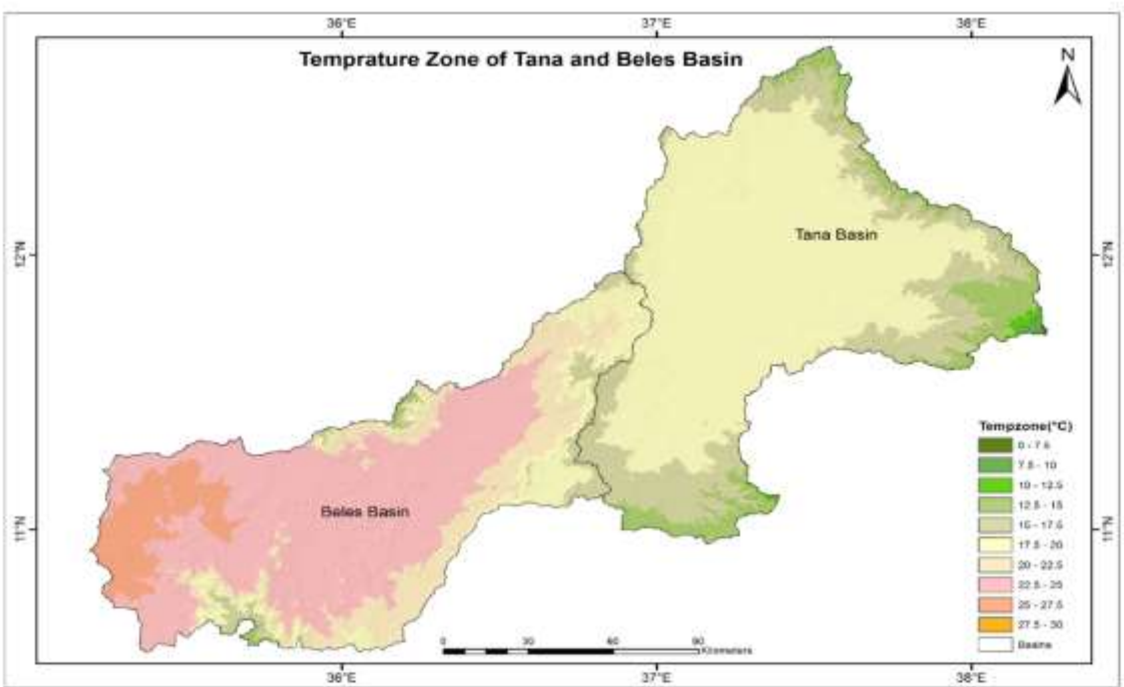
The climate of the study area, Tana-Beles near-equatorial location and an altitude ranging from 600masl and above is characterized by a hot and humid climate in the lower Beles basin. Besides, more than 4,000masl is characterized by a cool climate and transitional temperate climate in the mountain areas in Tana basin (SMEC 2008). Details of climatic data of three stations in Tana-Beles basins are shown in *(Appendix A. 1-2).*

2.1.3.1.Temperature

The Tana basin has a mean annual temperature that reaches up to 23°C in the low-lying areas (below 2,000masl) like Bahir Dar, and in the range of 15 to 20°C in the middle and high altitudes (above 2,000masl). Its annual average areal maximum and minimum temperature varies from 22 to 29.5^{0}C and 8.5 to 16^{0}C respectively (see *appendix A. 1-2*). The temperature normally increases from eastern and southern part to the central part around Bahir Dar and North western part of the sub basin.

[2] Based on data from Ministry of Agricultural, Ethiopia; and http://earthexplorer.usgs.gov/

The nearest station to the project area of Beles basin is Pawe station. Here Beles basins is characterized as humid and warm climate based on the data recorded at Pawe station which shows monthly highest temperature fluctuating between 37^0C in April and 27^0C in July. The long term mean monthly temperature varies between 28^0C in April and 22^0C in July (ADSWE 2013) while the minimum temperature varies between 12^0C in December and 19^0C in April (*see appendix A 1-2*). The spatial distribution of temperature in the project area is shown in figure 2.5 below:



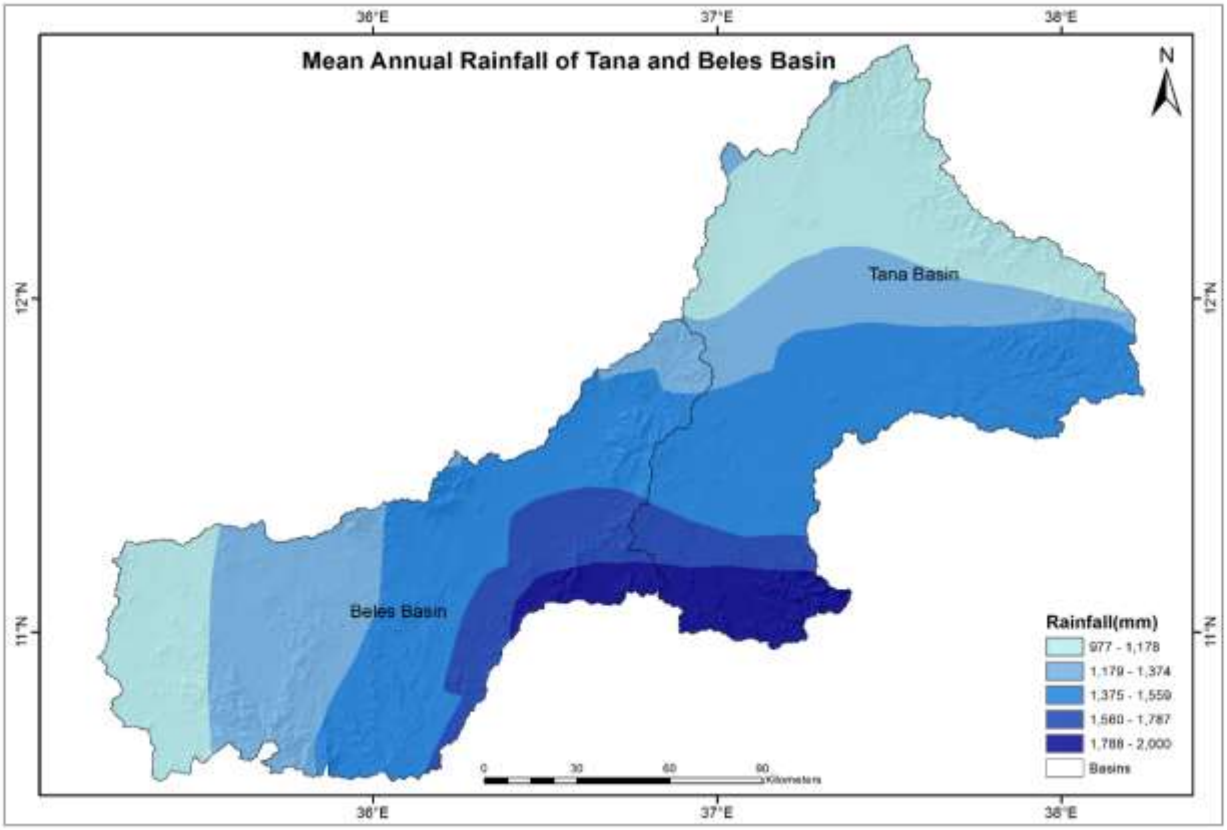
**Source*[3]
Figure 2.5. Temperature Zone in Tana-Beles Basin

2.1.3.2.Rainfall

The rainfall of Lake Tana drainage basin is mono modal. The dry season is between November and April and the wet season ranges between May and October. The mean annual rainfall in the catchment ranges from 718.3mm at Delgi to 2,124.1mm at Enjibara (TaSBo 2015). The central part of Tana basin has a rainfall ranging from 1,200mm to 1,600mm. Southwest of this basin experiences moderate and highest rainfall in the basin relatively while the north and central part of the basin experiences lower rainfall. According to the study of Halcrow-GIRD (2010) the mean annual evapotranspiration in the Tana basin is estimated to be in the range of 1,400mm at Bahir Dar and above 1,600mm at Gondar Airport. This estimated values indicate that evapotranspiration exceeds the annual rainfall amount in the basin as shown in figure 2.6 below. The rainfall distribution of Tana sub basin shows that rainfall in the region ranges from a minimum of 1,000mm to a maximum of 2,000mm.

[3]Based on data from Ministry of Agricultural, Ethiopia; and http://earthexplorer.usgs.gov/

In the Beles river sub-basin, the highest rainfall occurs in the central part of the basin. In this area the average annual rainfall ranges between 1,400mm to 1,800 mm. The Upper Beles irrigation project lies in the upper part of the Beles river sub-basin and experiences moderate rainfall. When it comes to lower Beles the rainfall distribution decreases and reaches the minimum value of 1,000mm. During wet season the amount of water needed for irrigation is enough due to the rain falling in the region.



**Source[4]*

Figure 2.6. Rainfall distributions in Tana-Beles sub basin

2.1.4.Hydrology of the Study Area

The mean annual inflow to Lake Tana and mean annual outflow to the Abbay River is about 4,986 Mm3/yr and of 3,753 Mm3/yr respectively. Lake Tana contributes about 8 % of the total flow of Abbay (Blue Nile) river (Halcrow – GIRD 2010). Because of the restriction at its outlet in Bahir Dar, the lakes large area, and storage capacity, Lake Tana rise slowly to reach the maximum stage around the end of the wet season in August and September. At dry season it recedes slowly and reaches the minimum lake level during the beginning of the main rainy season in June. Water leave from the lake, the river reaches the celebrated Tis Abbay falls, thereafter flowing in a deep and rugged gorge to the Sudan border. The computation of discharge data series (*see Section 4*) in Abbay river/Lake outlet shows the mean annual outflow to the

[4] Based on data from Ministry of Agricultural, Ethiopia; and http://www.maxhydro.com/

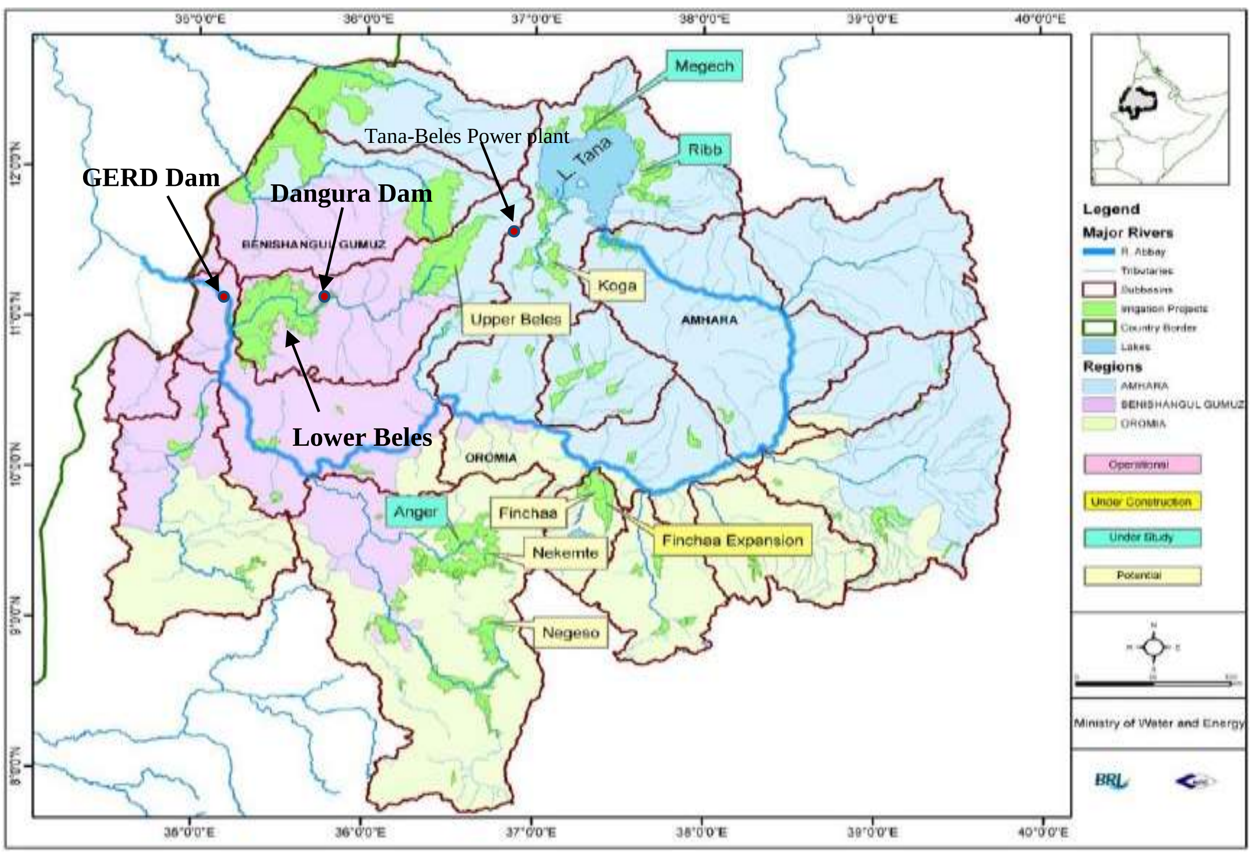
Abbay River is 3,947Mm^3/yr. However, due to the operationalization of the Tana-Beles hydropower plant, about 70.33 % of the lake's natural outflow to the Abbay is diverted through a tunnel to the Beles River for power generation as well as irrigation productions.

In Beles basins, there are two main tributaries Main/*Enat* River and Gilgel Beles/Mandura River with the mean annual flow of about 534Mm^3/yr and 1,718Mm^3/yr respectively. Enat Beles River is the main river located in the upstream of Beles catchment and Gilgel Beles River is a tributary river to the main Beles on the downstream of the basin.

2.1.5.Topography

The mean elevation of the Tana Basin is 2,025masl, with the highest elevations at some 4,100masl located in the Simien Mountains, in the northeastern part of the basin. At the point of outflow of the Lake Tana basin to Abbay River in Bahr Dar, the elevation is about 1,784masl.

The mean elevation in the Beles basin is 1,190masl and the highest point is 2,725masl. The Beles joins Abbay River near the border with Sudan at an elevation of 540masl. The study area has low to medium relief differences with an altitude that ranges from 763 to 1,246masl. The Upper Beles irrigation area has an altitude ranging from 976 to 1,246masl, which is characterized by flat topography (ADSWE 2013). The topography and the location of project area is shown in figure 2.7 below.



Source: Ministry of Water and Energy, Ethiopia and Where GERD is Grand Ethiopian Renaissance Dam

Figure 2. 7. Topography of the whole scheme

2.2.Existing Project in Tana-Beles Basin

Potential water resources developments mainly include public water supply, irrigation and hydropower which are the main project types that were developed, under study and under constructions in and within the project area. Some of main project which is related directly and indirectly to this study are Tana-Beles Multipurpose hydropower, Tis-Abbay hydropower and Beles irrigation.

2.2.1.Tana-Beles Multipurpose Project

The Tana-Beles HPP is a natural storage hydroelectric power plant in the country located near Lake Tana. This power plant receives water from the lake to produce electricity, and then the water is discharged into the Beles River (Johana River). The plant has an installed capacity of 460MW. It is also expected to provide water for the irrigation of 140,000ha in the upper and the lower Beles basin. Its construction was perceived negatively by the downstream Egypt due to the release of water diverted to Beles basin to irrigate the area.

2.2.2.Irrigation Project

Now a days, there is considerable ongoing and planned water resource development for a number of irrigation schemes on rivers that feed into Lake Tana. This totals about 77,000ha of irrigable land. Other proposed irrigation schemes will use water pumped from Lake Tana. Most of these irrigation schemes are at Megech on the Dembia Plain on the northern shoreline of Lake Tana. Pumping will support approximately 46,000ha of irrigation development (Halcrow-GIRD 2010).

Irrigation schemes are also planned and under development in the Upper Beles and Lower Beles, the former relying on releases from the Tana-Beles hydropower scheme as water is diverted to the Beles catchment from Lake Tana through a tunnel. Estimates of sum of irrigable area about 140,000ha as sum of both parts of Beles region. However, nowadays about 74 and 85 thousands of hectares in upper and lower Beles respectively, are possible to irrigate depending on the availability of water seasonally.

2.2.3.Water Supply Project

Ethiopia’s Water Resources Management Policy of 1999 gives highest priority to drinking water supply over other uses. Countrywide, about 42% of the population currently have access to potable water services and 18% to improved sanitation based on MoWR (2004) and PASDEP (2006) reports. The preferred source of raw water supply is groundwater than surface water when surface water is used, the amount of sediment in the raw water supply has an impact on both the treatment and maintenance cost.

The main water supply of Bahr Dar (estimated population 2007: 175,000) is from the Areke and Lomi springs, located in the Gilgel Abbay watershed (part of Tana basin). These springs have discharge rates of 140 l/s and 50 l/s, respectively (MoWR/World Bank 2007).

Gondar with an estimated population of 204,000 in 2007 is supplied from a reservoir on the Angareb river (a tributary of the Megech), and supplemented by wells. Heavy sediment deposition in the reservoir is a major concern. In the future, Gondar is planned to be supplied from the Megech reservoir (part of Tana basin).

Based on 2007 population estimates, the total gross water requirements for domestic, municipal and industrial use are estimated as follows: Tana Basin: 147,000 m^3/day or 53.7 MCM/year and Beles Basin: 21,000 m^3/day or 7.7 MCM/year. An estimated 80% of these gross demands returns to the surface water or groundwater system. The total evaporative "losses" of the DMI demands is comparable with the evaporative "losses" of about 2,500ha in the Tana-Beles Basins (SMEC 2008). Those water supply projects which are under construction and under operation may or may not have an impact on the optimal operation of Tana-Beles hydropower project, however, this is not included in this study.

2.2.4.Tis Abbay Hydropower Project

The flow both to Tis Abbay I and Tis Abbay II power plants are operated and regulated using a small weir constructed across Abbay River since 1996, and this weir is called Chara-Chara weir. Between the weir and the diversion at the Tis Abbay hydropower plants, there is an additional flow to the Abbay River from catchments. Water is diverted from the Abbay River just upstream of the Tis Issat Falls into a header channel and the natural head at the falls is used to generate electricity. An installed capacity of 11MW and 72MW to the hydropower plant at Tis Abbay and Tis Abbay II respectively.

**Source:*[5]

Figure 2. 8.Intake to Tis Abbay power plant I and II *Figure 2. 9.Tis Abbay power plant*

2.2.5. The Grand Ethiopian Renaissance Dam, GERD Hydropower Project

Grand Ethiopian Renaissance Dam site was identified and investigated by the United States Bureau of Reclamation at the time of Blue Nile basin survey conducted between 1956 and 1964.

[5]http://www.mediaethiopia.com/

Government of Ethiopia has also surveyed the site in October 2009 and August 2010. The design for the GERD dam was submitted on November 2010 and a day after the project was made public on 31 March 2011.

Initially the project was designed to generate 5,250MW then after in March 2012, the government announced the upgrading of the design's from 5,250MW to 6,000MW. Ethiopia has a potential for a total of about 45,000 MW of hydropower generation.

**Source*[6]

Figure 2. 10. Grand Ethiopian Renaissance Dam-GERD and their location.

The gravity of the dam will be 175m high, 1,800m long and composed of roller-compacted concrete materials. The structural volume of the GERD dam is estimated at about 10 million cubic meters (MoWR). Its reservoir will have a storage capacity of 79GCM and surface area of 1,561km^2 at a normal elevation of 640m. Supporting the dam and reservoir will be a 5000m long and 50m high rock-fill saddle dam. This project is under construction and located near the border of Ethiopia and Sudan. Tana-Beles MPP is in the upstream of this biggest project in the country and due to the uses of water for irrigation in the Beles basin they may have an impact on GERD. However, this study do not included the impact on the GERD hydropower project.

[6] https://mowr.gov.et and World Bank 2000

3.Literature Review

3.1. Hydro-Meteorological Data

In any type of project, the method of collecting, completeness and the quality of data are crucial and very important. Before using any type of data it must be checked it must be checked through different methods. In this project the main data which are basically used is hydro-meteorological data. Hydrological data include data of streamflow, sediment flow and flow gauge heights and current meter readings. Meteorological data refer to the average state of the atmosphere during a period of time (days, weeks, decades, years or millennia), and among the meteorological data, solar radiation is the major external energy source for the climate system (Rasmusson, et al. 1993). Here, for hydrological application of this work it is used the data series of streamflow, rainfall, temperature and evapotranspiration. Hence, proper data quality assessment and mode of transmission needs to be practiced to establish the best estimate of the climate during some future period of interest.

The steps followed to conduct preliminary checking of hydrological data collected manually include the following according to WMO standard:

a) Log in data at the time of the receipt of the report form;
b) Ensure completeness and correctness of the information, i.e., dates, station name, and station identification if required in subsequent machine processing;
c) Ensure completeness of the data;
d) Check the observer's arithmetic; and
e) Compare the observer's report with the recorded data.

Hydro-meteorological data can be collected and is available in hard copy and soft copy formats. Hard copy data formats need to be converted into softcopy formats for easy dissemination and analysis. The most common and widely applied soft copy format of data storage is an excel sheet and in this project data are available and collected in softcopy in different formats. However to avoid too many complications data needs to be stored in standard formats that presents the detail of the data.

3.1.1. Rainfall

Precipitation is an important hydrological variable that is notoriously variable spatially. In the tropical regions like in Ethiopia precipitation is equal to rainfall since there is no snowfall. Information required in estimating the influence of precipitation ranges from general regional and seasonal variability in the frequency and magnitude of individual storm events. Rainfall volumes and intensities can vary rapidly in space and time. Techniques that are quite common for spatial interpolation of rainfall include Kriging, Thiessen polygons, Inverse distance weighting and the arithmetic mean.

3.1.2. Runoff

Streamflow are expressed as volume per unit time, is the rate at which water flows through a cross-section. Continuous streamflow records are necessary in the design of hydraulic structures, in operation of water management systems, for forecasting, in the operation and optimization rules of hydropower projects and others. The identifications of suitable sites for stream gauging which represent the area has great contribution for the recoding of discharges in the site and for the better consistency and quality of data. The data must be representative for the given area unless it will give wrong result of the analysis.

3.1.3. Missing Data Estimation

Data may be missing from a particular gauge site which is necessary as a point of interest. For the missing data to be estimated or a representative runoff series has to be determined, the location of the site must be known in relation to nearby sites and the correlations must be computed. Some of the methods of filling of missing data are:

The first method is that, when the missed data's are fewer like one or two months with in a given year or the entire period of record, they are filled from the mean monthly runoff hydrograph by establishing a monthly distribution factor assuming that the trend of hydrograph is constant.

$$Q_{mi} = Q_{mi+1} * f_i / f_{i+1} \qquad (1)$$

Where Q_{mi} is missed monthly runoff
Q_{mi+1} available runoff
f_i distribution factor

If the length of gap is less than one month, it can be computed using

$$Q_{mi} = 0.5* (Q_{mi-1} * f_i/f_{i-1} + Q_{mi+1} * f_i/f_{i+1}) \qquad (2)$$

After filling of the gaps, the reliability of the compute will be reduced as we move away from the closest observation. Computation in this method is based on the assumption that the shape of the flow hydrograph remains same with no shifts, scale up and down. Therefore, estimation of peaks using this method is quite misleading because it has a potential for underestimation.

Another way of filling data is, when the gaps are many consecutive months or full year, a regression equation that gives an acceptable value of coefficient of determination.

On the other hands, missed value of runoff can be filled under the use of the ration of long term average annual flow multiplied by the observed flow at the gauging stations with complete data.

$$\text{Qungauged} = \frac{Q"ungauged}{Q"gauged} * Qgauged \qquad (3)$$

Where $Q_{ungauged}$ is the flow computed at the ungauging stations with gaps
$Q"_{ungauged}$ is the long term mean annual flow of the ungauging stations with gaps
Q_{gauged} is the flow at the gauging stations with complete data

Q''_{gauged} is the long term mean annual flow of the gauging stations with complete data.

3.1.4.Consistency of Data

The consistency of the data series may not be good and there are a numerous of factors which affect the consistency of data record at a given station. Among the factors are: damage and replacement of gage, change in the gage location or elevation, the growth of high vegetation or construction of a building, change in measurement procedure and/or human, mechanical, or electrical error in taking readings. The Methods used to check and adjust inconsistent of data are:

a) Double Mass Curve Analysis (DMC)
b) Accumulative Mass Curve Analysis (AMC)

Double Mass Curve Analysis (DMC) used to compare the accumulated annual (or seasonal, monthly, weekly, daily, or hourly) rainfall or runoff data at the station in question with the accumulated annual or the same time series of rainfall or runoff data for a group of surrounding stations. Whereas Accumulative Mass Curve Analysis (AMC) used to observe the trends of the accumulated annual rainfall or runoff data at the station with time series.

3.1.5.Flow Duration Curve

Flow Duration Curves (FDCs), which are cumulative frequency curves compiled by ranking all daily stream flows in order of magnitude is plotted by computing the percentage of time each flow is equaled or exceeded. The method is a useful way of treating the time variability of water discharge data in hydropower studies or other water resources practices. A flow duration curve is plotted as flow in ordinate and the percent of time a particular flow can be expected to be exceeded in abscissa. The basic advantage of the flow duration curve is it allows the characterizing of the flow over long periods of time to be presented in one compact curve.

3.1.6.Climate Variable

Meteorological data that include temperature, wind speed, sunshine hours, relative humidity, solar radiation and pan evaporation are some of climate variability data. In most parts of catchments, climate in the highlands is strongly influenced by the effects of elevation. This complicates the mechanism of data measurement and reliability of the available data. Only a few areas are properly gauged in the temperate regions at higher elevations and tropical regions of the lower elevations. Climate data measurement involves the measurement of rainfall, sunshine hours, relative humidity, wind speed, solar radiation pan evaporation and maximum and minimum temperatures.

3.1.7.Water Balance

In principles, water balance mean that any mass is conserved within a specific control volume and specified time period or a principle of describing the flow of water in and out of a system. Dingman (1994) refers to a water balance as “the amount of a conservative quantity entering a control volume during a defined period minus the amount of quantity leaving the control volume during the same time period equals the change in the amount of the quantity stored in the control volume during the same time period". Generally, water balance often leads to us an understanding of hydrological systems and in project area, Tana-Beles there are a number of water resource development studies, ongoing projects and project under operation. The water balance in the region is another main issue which will be studied in detail and the development of the project may influence water balances of the system and may have an impacts positively and/or negatively on the operations of Tana-Beles project, but not included in this study.

The water balance equation in its simplest form leads:

$$\frac{\Delta S}{\Delta T} = Inflow - Outflow \tag{4}$$

Where $\Delta S/\Delta T$ is change in storage within specified period of time

3.1.8. Water Consumption

Water consumption is a part of freshwater which is not released back to the original catchment due to evaporation and an integration products.

In most of hydropower generation, it requires the creation of an artificial storage and this associated to evaporation to the atmosphere that consumes water resources that might otherwise have been used downstream of river. The reservoirs due to the construction of dams possess a large exposed water surface area that introduce an artificial evaporative flux to the atmosphere thereby consuming water that would otherwise flow downstream. A study by Lampert, D. J. et.al. on the analysis of water consumption associated with hydroelectric power generation in the United States assets:

> *hydropower facilities were divided into three categories—facilities generating power using the run-of-the-river, facilities generating power from artificial multipurpose reservoirs, and facilities generating power from artificial dedicated reservoirs. Water consumption in run-of-the-river facilities is negligible as they require no increased exposed water surface area, whereas in the creation of the artificial reservoir there is a consideration of creating and increasing surface area of the reservoir that was exposed to evaporation (*Lampert, D. J. et.al. n.d, 1).

Here, water consumption in the 2nd and 3rd alternative has significant value. On the other hands, Land surfaces also consume water through both evaporation of water directly and transpiration from vegetation leaves.

Bakken et al. (2013) recently reviewed estimates of water consumption in hydropower and criticized the previous approaches for estimating water consumption in hydropower on the basis of introducing the relation of gross evaporation with an annual power generation which is directly dividing gross evaporation by annual power generation to estimate water consumption. The issues that were identified are lack of allocation of the water consumption burden amongst multiple purposes in multipurpose reservoirs, attribution of water consumption in natural water bodies, and inconsistent system boundaries. For the anthropogenic influence of the hydropower facility on the hydrologic cycle, Bakken et al. (2013) recommended that subtracting the background evapotranspiration rate from the gross reservoir evaporation rate is the way to appropriately account of it. According to Bakken et al. (2013), the computation of water consumption formulas in hydropower development are:

$$\text{Gross water consumption} = \frac{\text{Evaporation reservoir}}{\text{Annual power production}}$$
(5)

$$\text{Net water consumption} = \frac{\text{Evaporation reservoir} - \text{Evaporation before inundation}}{\text{Annual power production}}$$
(6)

$$\text{Water balance} = \frac{\text{Evaporation reservoir} - \text{Direct rainfall reservior}}{\text{Annual power production}}$$
(7)

In this Tana-Beles project, water is used to both power production and irrigation production. To irrigate lower Beles there is damming of water at Dangura site which will create artificial storages this introduce additional water consumption in addition to water consuming in irrigation field both upper and lower Beles. However, in Lake Tana there is small or no an additional expose of water surface to the atmosphere due to the regulations of lake and water consumption assumed to be small or zero.

3.2. Operation of Lake Tana

If water is diverted from the reservoir and used for different purposes like for irrigation, water supply, hydropower, navigation, flood control and other, the operation of reservoir is critical to meet the objectives of the project. Lake Tana used for different purposes and some of them are water supply, hydropower, irrigation, giving transportations service, navigation, and tourism. To attain this and other objectives optimum operation of Lake Tana gives priority to minimize negative impacts and if it is possible to make all project free, but not totally free from environmental and Scio-economic problems. For the different years of the time the operations of Lake Tana will change due to the development of new projects in and around Tana-Bles basins.

Lake Tana operational rules are used to control and stabilize the water levels in Lake Tana, the releases to the Abbay River, and diversion of water from the lake to the adjacent Beles catchment. The aim of the operation rules is to maximize the benefits to the different sectors and to minimise often conflicting between water user sectors without impacting adversely on the environment. The rules attempt to maximize lake storage at the end of the wet season as a buffer for the coming dry year and this is achieved by preventing spillage over the Chara-Chara weir.

The Tana-Beles hydropower scheme is complete and was commissioned on 14th May 2010 whereby releases from the tunnel are passed downstream along the Jehana River, a tributary of the Enat Beles, significantly changing its hydrological and morphological regime. Different operational ways in Tana-Beles Multipurpose project is developed within different sectors at different time and some of them are shown below:

3.2.1. Salini and Pietrangeli (2006) Operation

According to Salini and Pietrangeli (2006), at very low lake levels diversion of water to the turbines may be stopped to prevent the lake water level falling below the minimum operating level causing difficulties with lake navigation and impacting on the environment. It adopted a minimum level for Lake Tana of 1,784.0 masl and an average turbine discharge of 77 m^3/s was assumed for a wide range of lake levels (i.e. >1,784.3 but <1,787.0 masl). The discharge from the turbines are increased to 160 m^3/s at high lake level (i.e. >1,787.0 masl) but operations are stopped at low lake levels. The regulated outflow to the Abbay River is fixed at 17 m^3/s. There are 4 turbines, 3 turbines are under operation and the fourth turbine is only used as a spare, during maintenance, or is used as an additional turbine when lake levels is above 1,787 masl.

3.2.2. SMEC-2008 Operation

SMEC (2008) recommended a minimum operational level of 1,784.75 masl, and uses an average turbine discharge of 77 m^3/s. The discharge from the turbines increases to 160 m^3/s at the high lake level to prevent spillage over the Chara-Chara weir (>1,787 masl). The regulated outflow to the Abbay River could be fixed for some months to 10 m^3/s (i.e. March to June) with higher flows in other months and release an average discharge 77 m^3/s Tana-Beles HPP over a wide range of lake levels and increased to 160 m^3/s when the lake lave is above 1,787 masl. It recommended a higher minimum operation level of 1,784.75 masl to prevent serious navigation problems by shipping on Lake Tana, which most notably occurred in 2003 and discharges will be stopped whenever the lake level declines to 1,784.75 masl.

Comparison of simulation results between the operation rules of Salini and Pietrangeli (2006) and of SMEC (for a minimum operation level of 1,784.0 masl) shows electricity production increased by more than 10% and spillage over the Chara-Chara weir was reduced by almost 40% (SMEC 2008).

3.2.3. Halcrow-GIRD Operation

Halcrow - GIRD operational rule is to provide more lake storage by the end of the wet season compared to other rules, rising lake levels, and allowing greater releases from January to April when irrigation demand in the Upper Beles command area is highest and when there is greatest need for electricity as energy demands are high and typically there is a shortage in national supply. This is achieved by the continued regulation at Chara-Chara weir, and by building more lake storage and releasing less water to the Tana- Beles scheme compared to the recommended SMEC (2008) operational rule during the wet season from July to September providing a greater buffer for the coming year. Higher active lake storage allows more water to be released for longer in the following dry season from January to April when irrigation demands are the highest. When modifying the operation rules curves careful consideration has been made to optimize releases for irrigation and electricity production, but without restricting flow to the Abbay river so that environmental requirements are not met nor exacerbating flooding along the lake shoreline or, at lake minima, desiccation of shoreline wetlands.

When using a minimum operational level of 1,784 masl with the SMEC rule, about 2,375 Mm^3 of lake water is diverted per annual generating 1,860 GWh/year of electricity. When the minimum operating level is raised to 1,784.75 masl there is a reduction of electricity production by 3 % to about 1,805 GWh/year, and 1,808 GWh/year if the SMEC rule is substituted with the Halcrow- GIRD rule.

3.2.4. Chara-Chara Weir Operation

The Chara-Chara weir regulates water storage in Lake Tana by controlling its outflow to the Abbay River. It is used to regulate outflow to provide a more constant supply of water to the Tis Abbay I and II hydropower plants located about 35 km downstream of the weir (Halcrow-GIRD 2010). Initially, the weir only had 2 radial gates each with a capacity of 70 m^3/s to regulate the flow to Tis Abbay I HPP and five new gates were constructed and become operational in January 2001 increasing the ability to regulate Lake Tana outflows and improve and regulate the flow to Tis Abbay II HPP.

On the other hand, The Chara-Chara weir regulates the lake storage over a 3 m range from 1,784 masl to 1,787 masl where the active storage is about 9,100 Mm^3 which is about 2.4 times the average annual outflow (McCartney et al. 2009). The minimum operational level of the Chara-Chara weir is currently 1,784 masl. Lake Tana level seasonal changes and its outflow variations caused by the operation of the Chara-Chara weir.

Overall, in this thesis the lake operation regulations are tested and uses four scenarios of Lake outflow values with fixing of the minimum lake water level at 1,784 masl and finally run with the proposed model. Then, after gating the optimum regulation way, according to the objectives of this study, the whole systems are run in nMAG model with their data specified under six different scenario development to get the better, efficient and the optimum way of operation of the project as considered as one system.

3.3. Water Resource Development in Tana-Beles Basin

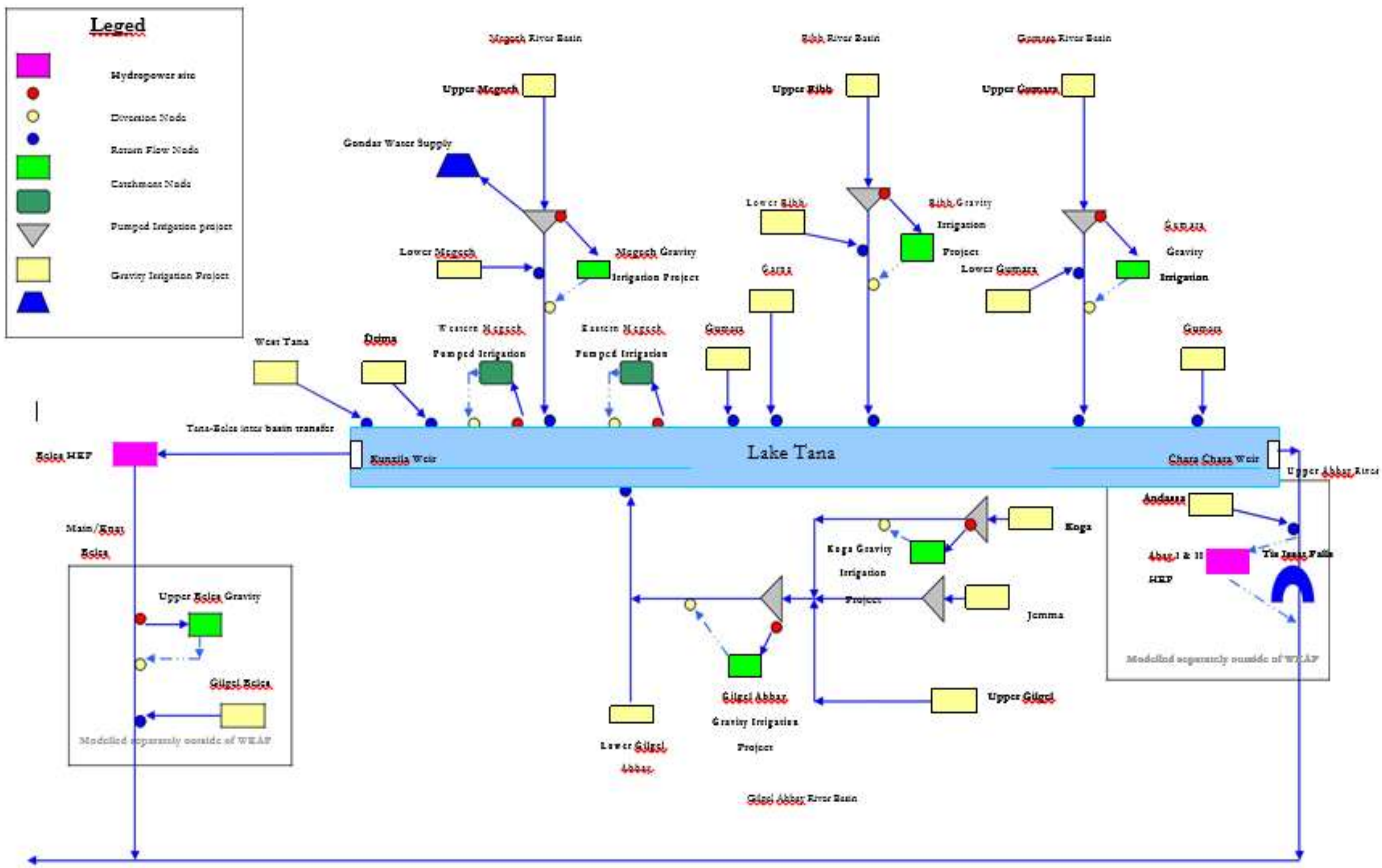
Accelerated regional development is planned in the Lake Tana basin because of the relative abundance of water resources. Recently in and around Lake Tana basin and Beles basins, there is a considerable ongoing and planned water resource development for a number of irrigation schemes on rivers. Halcrow-GIRD report shows, rivers that feeds Lake Tana used to irrigate about 77,000 ha of irrigable land and water pumped from Lake Tana for another irrigation area approximately support 46,000 ha.

Irrigation development areas in upper Beles exceeding about 65-70,000 ha (SMEC rules) and about 75,000 ha (Halcrow - GIRD rules). The BCEOM phase 3 Master plan Study estimated that about 85,000 ha could be irrigated in the Lower Beles catchment. But the total project area was estimated as 136,000 ha. There is planned dam at Dangur on the Main Beles River (Halcrow-GIRD 2010) to increase the supply of more water to irrigate more irrigation area.

Hydropower is also an important development in the Tana-Beles basins to supply electricity to the Ethiopian national grid to help meet the countries growing demand and the installed capacity is 460 MW and 2,051 GWh average annual energy production (Salini and Pietrangeli, 2006). Ethiopian Electricity and Power Corporation (EEPCo) is planned to divert approximately 2,985 Mm^3 annually through the tunnel to generate 2,310 GWh/year of electricity under existing conditions (SMEC 2008). Firm energy production is estimated at 1,866 GWh/year (SMEC 2008).

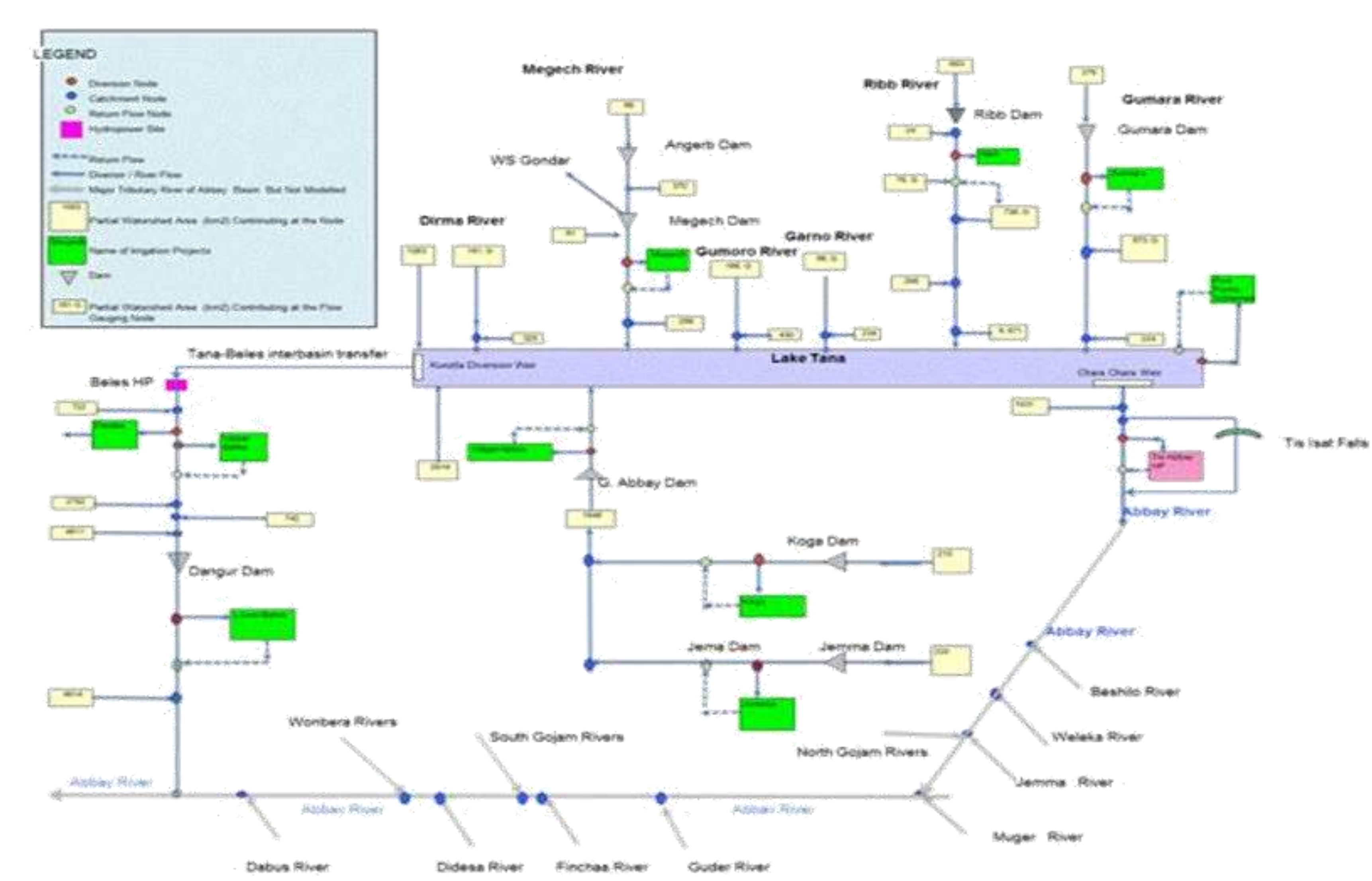
The Chara-Chara weir is used to regulate Lake Tana. This weir regulates the lake outflow to supply a more constant discharge downstream at the Tis Abbay I and II hydropower plants with an installed capacity of 11 MW and 72 MW respectively. Together the two plants produce about 434 GWh of electricity per annum. However, present Tis Abbay HPP project is categorized as emergency power plant as described by the Ministry of Water and Energy.

The water resource project development study in Tana basin done by SMEC (2008) in WEAP model and in Abbay/Blue Nile basins done by Halcrow-GIRD (2010) is shown below in the figure respectively:



**Source: SMEC (2008) report*

Figure 3. 1. Schematization of WEAP model of Lake Tana basin and Beles HPP



**Source: Halcrow-GIRD (2010) report*

Figure 3. 2. Schematisation of the river basin system

3.4. Climate

The climate in the Ethiopian highlands is strongly influenced by the effects of elevation. The "Belg", or short rainy season, occurring from mid-February to mid-May is not distinct in the Lake Tana Basin. The Lake Tana basin in general is characterized by mono-modal rainfall pattern (NMSA 1996). More than 90% of the annual rainfall falls during the main rains or "Kiremt" lasts from June to September. Normally, there is very little rainfall between October and January during the dry season.

More specifically, in Melkamu (2005) study the NMSA describes the Lake Tana as having two distinct dry and wet seasons. In terms of rainfall the rainfall regime classification of Ethiopia the Lake Tana basin is included in the rainfall regime designated as a region-B, dominated by a single maxima rainfall pattern, with the main rains decreasing northwards. Whereby, the mean annual rainfall in Bahir Dar (south portion of the basin) is 1,450 mm, 1,200 mm at Addis Zemen (eastern portion) and 1,050 mm at Gondar Airport (northern portion), indicating the spatial variation of rainfall in the basin.

In future water resources dwindle and water stress more likely. Hence, effective management and planning of water resources is become more essential, otherwise in future climate change is likely to have a negative impact on regional growth, people's livelihoods and the environs of Lake Tana (Halcrow – GIRD 2010).

3.5. nMAG2004 Model[7]

3.5.1. General

The program system nMAG is a model for simulating the reservoir operation and power production in a hydropower system. It can also be applied to the simulation of the operation of water supply works, flood control, etc., in which case the need for input data will be significantly reduced. In this version nMAG can simulate a system with up to 22 modules, consisting of the following module types:

- Reservoir(s),
- Power plant(s),
- Interbasin transfer(s),
- Control point(s)

[7] **The next 10 pages are adapted from (Killingtveit, 2005. nMAG2004 a Computer Program for Hydropower and Reservoir Operation Simulation. User's manual ver. 12/5-2004.) PP31-51. Except figures*

Module type in nMAG:

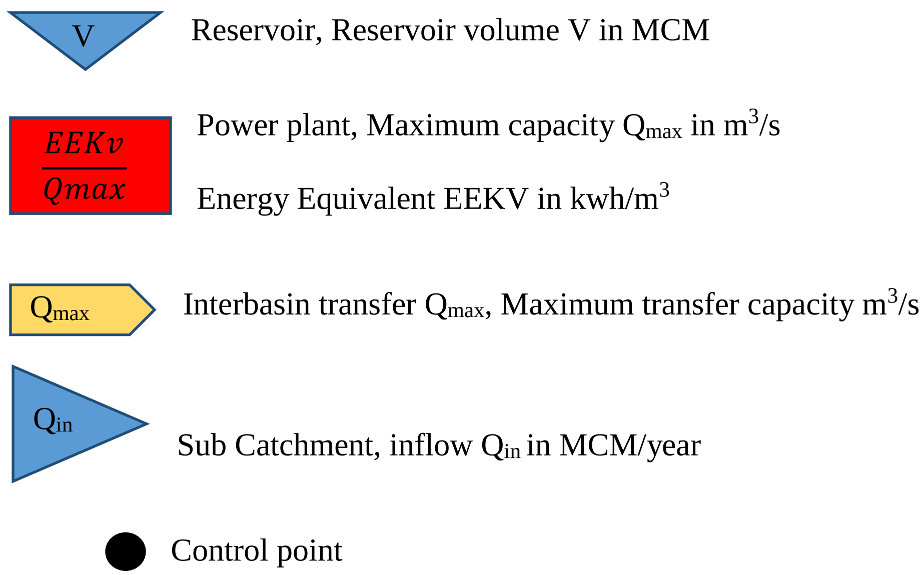


Figure 3. 3. Module type used in nMAG

nMAG describes the hydrological and hydraulic conditions in the production system in an accurate way, but the operational strategy and the consumption system slightly more simply. This means that nMAG is most suitable for calculating new projects, but is less suitable for day-to-day planning of the operation of existing plants.

3.5.2. Model Structure

3.5.2.1. Model Organization

A power production system usually contains one or all of the following components: Reservoir, Power plant and Interbasin transfer.

A simulation model should be able to deal with all of these components (sometimes called nodes) and describe the connections (also called links) between them, if the system organizes the data in an intelligent way. nMAG solves this problem by defining nodes or modules (reservoir, power plant, interbasin transfer, control point) and links between them. The links describe the way the water flows. Figure 3.4 schematically illustrates on how the modules in the system are connected into a complete system model. Theoretically the water could be addressed from one module in three different ways:

- Turbine water: Released water (equivalent to production of power) (A1).
- Bypass release: for instance mandatory minimum flow (A2).
- Spill or loss: for instance during a flood (A3).

Where capital letter A means address, and the numbers 1, 2 and 3 are released (through flow), bypass and spilled water (flood spill).

Water routing in nMAG exemplified for a power station:

A1: Production release

A2: Bypass release

A3: Flood spill

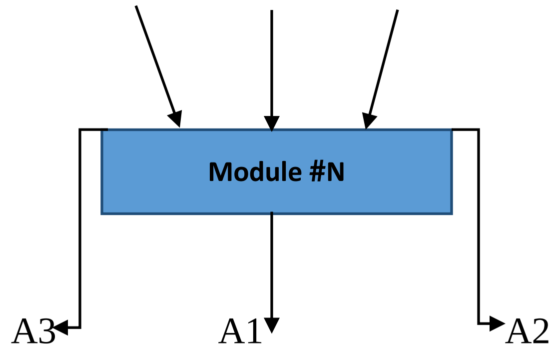


Figure 3. 4. Illustrations how the address system in nMAG works.

3.5.2.2. Reservoir

The reservoir is the key component in the most hydropower projects. It is the reservoir that makes it possible to store water in periods with a large inflow and less demand, and release it in periods with less inflow and larger demand. In other words, the reservoir works as a "buffer" to reduce the problems that show up when inflow and demand do not occur at the same time.

Many different kinds of data (called data groups) may be necessary to describe the reservoir and its operation:

- Reservoir name (compulsory in nMAG)
- Addresses for water release: turbine water, bypass and spill (compulsory in nMAG)
- Lowest and highest regulated water level (compulsory in nMAG)
- The volume of the reservoir (compulsory in nMAG)
- Water level - volume curve
- Water level - area curve
- Water level - spillway flow curve
- Water level - gate discharge curve
- Lake evaporation rate
- Routing to the next module

In some cases just some of these data groups are needed; in other cases all of the above information might be of interest. The data that are not entered will be given default values by the program.

Water level-/volume curve:

The reservoir curve is stipulated after a careful study of detailed maps. The curve should be drawn from the lower (LRWL) to the highest regulated water level (HRWL), and even sometimes all the way up to the water level of maximum flood. The maximum permitted number of points to specify is 40.

In nMAG only need to define the breakpoints where the curve changes direction. The program will interpolate linearly in between. If no reservoir curve is specified, nMAG uses the following values as default:

- 0 % volume when the water level (WL) = LRWL
- 50 % volume when WL = LRWL + 2/3 * (HRWL - LRWL)
- 100 % volume when WL = HRWL

This means that the reservoir's center of gravity is assumed to be 2/3 of the height above LRWL.

The area of the reservoir is important to know when evaporation rates and the amount of ice are being calculated, but in this project amount of ice will be negligible. nMAG estimates the area as a function of the water level from the water level -volume curve.

Water level - spillway capacity curve:

When the water level exceeds the highest regulated water level (HRWL), overflow will occur. If nothing else is specified, nMAG will assume that all water is lost in one time-step. The spillway thus has unlimited capacity above HRWL.

Many reservoirs have limited spillway capacity. In such reservoirs, the water level will exceed HRWL during a flood event. This is why nMAG has made it possible to simulate what will happen to water levels above HRWL. The maximum number of points to specify the curve is 40.

Head - gate discharge curve:

The capacity through bottom outlets or gates may also be limited. The limitation can be given in the same way as for the spillways. If the head - gate discharge curve is not specified, the capacity is assumed to be unlimited. The maximum permitted number of points is 40.

The head is calculated for each time step by nMAG, as the difference between reservoir level H(t) and outlet level, H_{out} i.e. Head = H(t) - H_{out}.

Evaporation:

In warm regions like tropical climate, evaporation is an important input parameter which creates a significant loss of water. If evaporation data are given, altogether 12 values must be entered, one for each month of the year and those values are entered as Potential evaporation. Potential evaporation values which will be entered are converted to m^3 by multiplying with reservoir area (km^2) and length of time step. Evaporation is removed from the reservoir before any water is allocated to power production or any other use. If the evaporation is negligible, nMAG will assume zero evaporation for the whole year, which is the default value in nMAG.

Routing to next module:

Due to the response time in the catchment area, reservoir and waterways the water does not necessarily flow from one module to the next in one time step. Neither is it probable that all the water will arrive the next module simultaneously. Therefore nMAG offers the user the routing-possibility. When adding the routing parameters, be aware that the sum of all % flows must be 100 and that it is free to choose any number of time steps, up to a limit of 30.

3.5.2.3. Power Plant

Production is calculated every time-step, and added to obtain annual production. From the sum we can find the sum energy production over the year, or the average of a series of years. To find the value of the energy, we need to consider what kind of power we have: firm power, occasional power, etc. and the data file must contain at least one power plant.

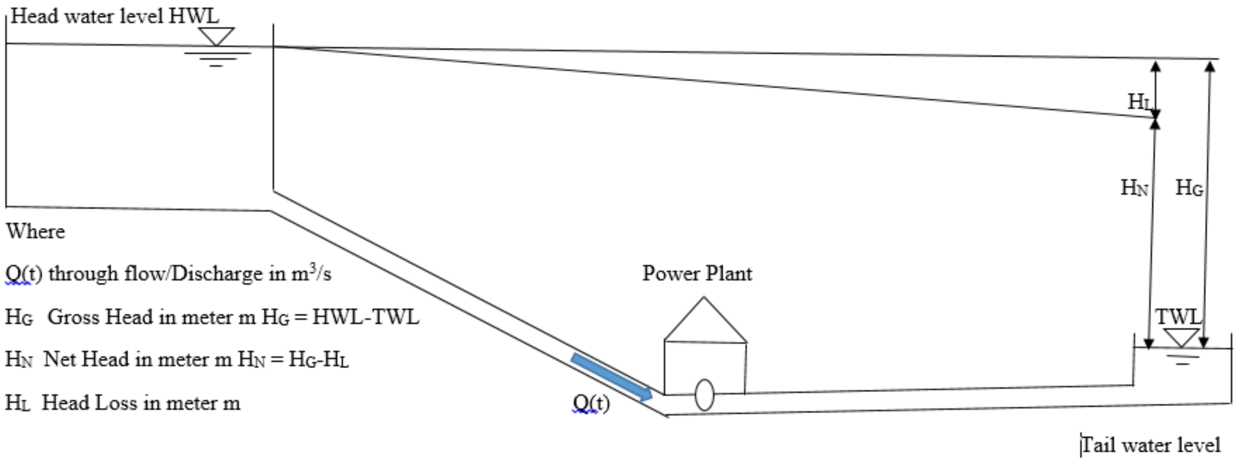


Figure 3. 5. Main components of Hydropower plant

The power and energy production from a power plant is calculated by the following equation:

Energy: $E = Q(t) * 3{,}600 * dt * EEKV$ [kWh] (8)

Where:

Q(t): discharge through the turbine during the time-step dt m^3/s

dt: length, in hours, of one time-step

$EEKV = \eta * \rho * g * H_N / (1{,}000 * 3{,}600)$ [kWh/m3] (energy equivalent) (9)

Where:

η: total efficiency
ρ: density of water (= 1000 kg/m3)
g: gravity constant (= 9.81 m/s2)
H_N: net head of water

Power: $P = E / dt$ [kW] (10)

If the power plant has an intake in the reservoir, then it must specify Optional data.

Optional Data:
This data-group should be used if the power plant runs with varying head, or when the difference between highest and lowest discharge rates is large. Under these conditions the efficiency curve will not be constant, and some or all of the following data should be included in the model:

- Nominal head [m]
- Intake level [m a.s.l.]
- Tail water level [m a.s.l.]
- Head loss coefficient of hydraulic system [s^2/m^5]
- Total efficiency of turbine, generator and transformer
- Routing to next module
- Peaking schedule

Nominal head, Intake level and Tail water level

In the simulation the P-Q curve is adjusted for deviations between the total head and the nominal head. If the power plant has an intake in the reservoir, it is necessary to adjust production to variations in the head. The program will do this automatically, based on current reservoir level and tail water outlet level.

Head loss:

The head loss in the hydraulic system is assumed to be proportional to the square of the discharge rate, and is specified by the head loss coefficient, kf in m/(m3/s)2 equivalent to s2/m5 and Manning's formula is advisable to calculating the head loss coefficient.

$$H_L = kf * [Q(t)]^2 \text{ [m]} \quad (11)$$

Where:
kf: head loss coefficient [s2/m5]
Q(t): discharge [m3/s]

Efficiency curve:

The program sets up a Power-Discharge (P-Q) curve for the power plant at nominal head, taking into account head losses and the total efficiency of the installation. The total efficiency should be the product of turbine, generator and transformer. If the power plant has more than one generating unit, the combined efficiency curve must be entered, assuming an optimal uploading. Up to 40 points may be entered on the efficiency curve.

3.5.2.4. Interbasin Transfer

An interbasin transfer is defined when water is transferred from one module (catchment) to another with a limited transfer capacity. If the transfer capacity is unlimited, then it is usually more convenient to add the two catchments together.

In addition, transfer capacity data must be specified, either as constant capacity, variable capacity (depending on reservoir level) or as a head-discharge (H-Q capacity table). Routing parameters can be included.

Constant transfer capacity:

If the outlet is above HRWL, the transfer capacity is constant. The only parameter need to specify is the maximum transfer capacity, in m^3/s.

Variable transfer capacity:

The transfer capacity may be variable if the transfer tunnel's inlet or outlet is below HRWL in the reservoir(s). In this case it will be necessary to account for variations in net head between the inlet and the outlet level. The program will automatically compute the net head for each time-step and then compute the transfer capacity given this head and the head loss parameters for the transfer system.
In nMAG the transfer capacity (variable) is estimated by the following equation:

$$Q_{max} = [(Hin - Hout) / kf]^{(1/2)} \tag{12}$$

Where:
kf: head loss coefficient [s2/m5]
Hin: inlet level [m a.s.l.]
Hout: outlet level in the reservoir [m a.s.l.]

All these data must be specified before simulating interbasin transfers with varying capacity.

H-Q Table:

This method is similar to the "Variable Transfer Capacity" method, but instead of a head-loss coefficient it is possible to specify the capacity in tabular form, as a function of net head difference between inlet and outlet. In this case the user must specify

- Inlet level [m a.s.l.]
- Outlet level [m a.s.l.]

A table must be given with the relationship between head difference (Δh, m) and corresponding capacity (q, m^3/s). The table must cover the range of possible heads.

3.5.2.5. Control Point

A control point module is used when it is necessary to compute discharge or to impose a restriction on discharge at a place in the watershed where no other module types (reservoir, power plant or transfer) can be used. The control point will usually have a local inflow, but no other "properties". The control point will always have unlimited capacity.

Restrictions on the minimum/maximum flow are entered in the data-block Restrictions. The control point is frequently used to implement instream-flow requirements along the watercourse. No data are required for the control point, except hydrological data, such as the size of the catchment area and average annual runoff. These data are entered in the Hydrological data module.

3.5.2.6. Energy Market

To calculate the value of the power which produce a power plant, it needs information about the energy market. Energy market data must be entered before it is possible to run nMAG.

Firm power distribution:

The demand for power is usually not constant throughout the year like in Norway and most European country. The most significant parameter is air temperature. The demand for power is largest during the winter-period and least in summer in cold regions. However, in Ethiopia the demand for power is most likely constant thought the whole year. Three different categories of consumers can be found:

- Public consumption (private consumption, schools, shops, etc.)
- Industry
- Special power-intensive industry (e.g. aluminium production)

The variation in demand for firm power is of great importance during optimization of the power plant system, such as the reservoir, waterways and turbines.

Occasional power / surplus power:

In periods when the inflow is large and the power demand is low, it may still be sensible to produce more than firm power demand. This could be to avoid spill later in the season, or just because there is a market for more power than just firm power. To find out how to manage the reservoir in the best way, we need to compare the economic value of the water in the reservoir with the entire energy system to which our power plant is connected. Such models, comparing water value, already exist, and can be used for special analyses.

Power deficit/curtailment:

If it is not possible to meet the firm power demand by production from the reservoir or by buying external power, it will be necessary to curtail the power supply. The consequences and economic losses due to rationing may be significant, and must be analyzed carefully during the planning process. Now in Ethiopia such type of system of buying power is not the main cases.

3.5.2.7. Restriction

An encroachment in a river system may involve many different users, and many considerations must be taken. To take care of all these interests, restrictions are introduced. In nMAG all restrictions take preference over all other operational considerations. This means that all restrictions must be fulfilled before the program can start to produce firm power. There are also priorities between the restrictions. In nMAG minimum flow restrictions take preference over reservoir level restrictions. Four types of restrictions on the operation can be defined. These are:

- Mandatory bypass releases [m^3/s]
- Mandatory minimum flow [m^3/s]

- Minimum permitted reservoir contents [%]
- Maximum permitted reservoir contents [%]

All restrictions can be varied freely over the year, and are defined by linear interpolation is used between the breakpoints entered.

3.5.2.8. Operation Strategy

Identifying the optimum operating strategy is one of the major tasks of water resource planning. The approach is always based on how to manage or run the reservoir during each time-step. When this decision is made, the rest of the simulation is quite easy.

Reservoir simulation:

The basic equations used in the simulation are actually quite simple. They are deduced from water balance considerations. The program runs through an iterative procedure to determine the reservoir volume in each time-step. To start the iteration, it will choose an initial reservoir content, as a % of full. This is specified under JobControl | New Simulation.

The water budget equation is:

$$x_{t+1} = x_t + r_t - p_t - e_t \qquad (13)$$

With the restrictions: $x_{min} < x < x_{max}$ and $p_{min} < p < p_{max}$

Where:

x_t and x_{t+1}: Reservoir volume at point of time t and (t+1)
r_t: Regulated inflow to the reservoir during time-step
p_t: Outflow from the reservoir during time-step
e_t Evaporation from the reservoir
x_{min} and x_{max}: Lowest and highest permitted reservoir volume
p_{min} and p_{max}: Minimum and maximum permitted release

The reservoir must be operated in accordance with a predefined strategy. The strategy alternatives are:

- Automatic reservoir balancing
- Reservoir release specification
- Reservoir guide curve and one of these strategies must be used for each reservoir defined.

Reservoir release specification:

One operational strategy is to specify average planned release from each reservoir in m^3/s and annual distribution in percent. When entering the annual distribution, only the breakpoints have to be entered, linear interpolation is used between the breakpoints.

Reservoir guide curve:

Empirical data show that inflow usually has a seasonal distribution that follows the same pattern, with some modification, every year. It is possible from the data to estimate how much water the reservoir should contain during every time-step throughout the year, in order to use the water as

economically as possible. The curve that is constructed from these data is called a guide curve. In other words, the reservoir guide curve tells us how the reservoir should be operated more economically.
Using the guide curve strategy, unconditional firm power demand is first assumed. At the end of the time-step the actual reservoir volume and the guide curve is compared. The deviation (reservoir volume - guide curve) is calculated, and this decides how much more water should be released. If the deviation is negative, the reservoir is below the guide curve, and a curtailment situation will occur. If the deviation is positive, the reservoir is above the guide curve, and dump power will be produced.

The guide curve is defined by any number of breakpoints during the year. Between the points the control curve is calculated by linear interpolation of the reservoir volume.

Reservoir rule curves:

This strategy can only be selected when nMAG is running in the ENMAG compatibility mode

Rule curves are an expansion and improvement on the reservoir guide curve. Two curves are established for running the reservoir. The first (“upper”) curve, the occasional power rule curve, defines when additional release for occasional power is to be implemented. The second (“lower”) curve, the rationing rule curve, defines when any rationing is to be implemented. The region between the two curves defines a region where the reservoir filling is “normal”, and firm power is produced as normal.

As long as the reservoir is between the two curves only firm power is produced. If the reservoir is above the upper curve, occasional power is produced in addition to firm power. If the reservoir is below lower rule curve, advance rationing is implemented and firm power delivery is reduced. Every effort should be made to keep the rationing at a low percentage.

The rule curves are defined by any number of breakpoints during the year. Between the points the control curve is calculated by linear interpolation of the reservoir volume.

Automatic reservoir balancing:

For small reservoirs it may be difficult to specify guide curves or release curves. In such case it is possible to let nMAG do an automatic balancing of the reservoir, where the program selects a reservoir level that will optimise the power output. This strategy does not require any additional data input.

3.5.2.9. Hydrological Data

These data are needed to describe the hydrological part of the simulation system: Length of simulation period and length of time-step, data for each catchment, and time series with runoff data.

The first and the last year used in the simulation have to be specified. The length of period cannot exceed the length of the runoff time series. There are three time-step options: 12 monthly, 52 weekly or 365 daily time-step. What length of time-step you should choose will depend on the purpose of the simulation. In most cases, such as determining how to run the power plant, nMAG will work well with daily time-steps. Runoff data will in general have a daily time step.

For each module the catchment, mean annual inflow in mill m^3/year, and a weighting factor for each runoff series must be given.

3.5.3.Result

The output from an nMAG simulation is dependent on the purpose the model is used for. The most typical way of using the model is to calculate power production from a hydropower plant. Relevant output is then total production, firm power and dump power production, external power (bought) and rationing. If energy market data are entered, these data are also converted to a user-specified currency. nMAG also computes curtailment statistics, i.e. the amount of curtailment [GWh/year] and the security of distribution, in percent.

nMAG calculates the water balance for each module. These data are useful for investigating how the discharge at certain points on the river will be influenced by regulation, and how the reservoir level will be changed.

4.Hydro-Meteorological Data Analysis

4.1.General

Hydro-meteorological data refers to both hydrological data and meteorological data. Hydrological data include data of streamflow, sediment flow and flow gauge heights and current meter readings. Meteorological data refer to the mean state of the atmosphere during a period of time (days, weeks, months, years or decades), and among the meteorological data, solar radiation is the major external energy source for the climate system.

In Tana-Beles basin, there is limitation of stream flow gauging stations and rain gauge coverage and hence inadequate hydro-meteorological data availability. In the absence of sufficient hydrological and meteorological data from the upper stream and downstream of Beles basin, results the hydrological assessment of basins and optimization of a multipurpose project becomes complex. The size and complexity of Tana-Beles basin, together with lack of data, is therefore a severe constraint to the application of sophisticated hydro-meteorological models.

4.2.Data and Data Organization

Hydro-meteorological data can be collected and is available in hard copy and soft copy formats. Hard copy data formats need to be converted into softcopy formats for easy dissemination and analysis. The most common and widely applied soft copy format of data storage is an excel sheet and within this project the data’s are available and collected in softcopy in different formats. Most of the data are collected from main office of Tana Sub Basin organization (TaSBo) and Amhara Design and Supervision Enterprise Work (AWDSW) in Bahir Dare and data related to existing power production and Lake water level from Ethiopia Electric Power Corporation (EEPCo).

Discharge at different gauging station, rainfall and temperature for both basins, water requirement in irrigation development of Beles basin and other related data’s related to power generation and irrigation product are available but still not enough. However, in Tana-Beles basin for this work runoff data in daily basis at Main Beles, Gilgel Beles, Gumar, Gilegel Abbay, Megecha, Rib and the flow series at Lake Tana outlet are used for the detail analysis which has better consistency and completeness of data’s.

4.3.Data Quality

Data’s in this study are needed for detail analysis, but there is a limitation about data availability even those data that we have got are not that many have good quality and some data even missed. Unfortunately, for this study the main data which are used basically for main analysis and the model is discharge which are gauged at different stations in and around the Tana-Beles basins.

For better data analysis and to get good result, the quality of data is the main contributing factors. And the qualities of data are checked in three ways: one using visual inspection and then graphing it, secondly using the method of DMC and on the third using AMC.

On visual inspection and graphing method just observing the trends of data in graph and values which are relatively very high and very low and those which are missing and for those values correction have been done it. The results of this inspection for five discharge gauge station runoff series in the region are shown below:

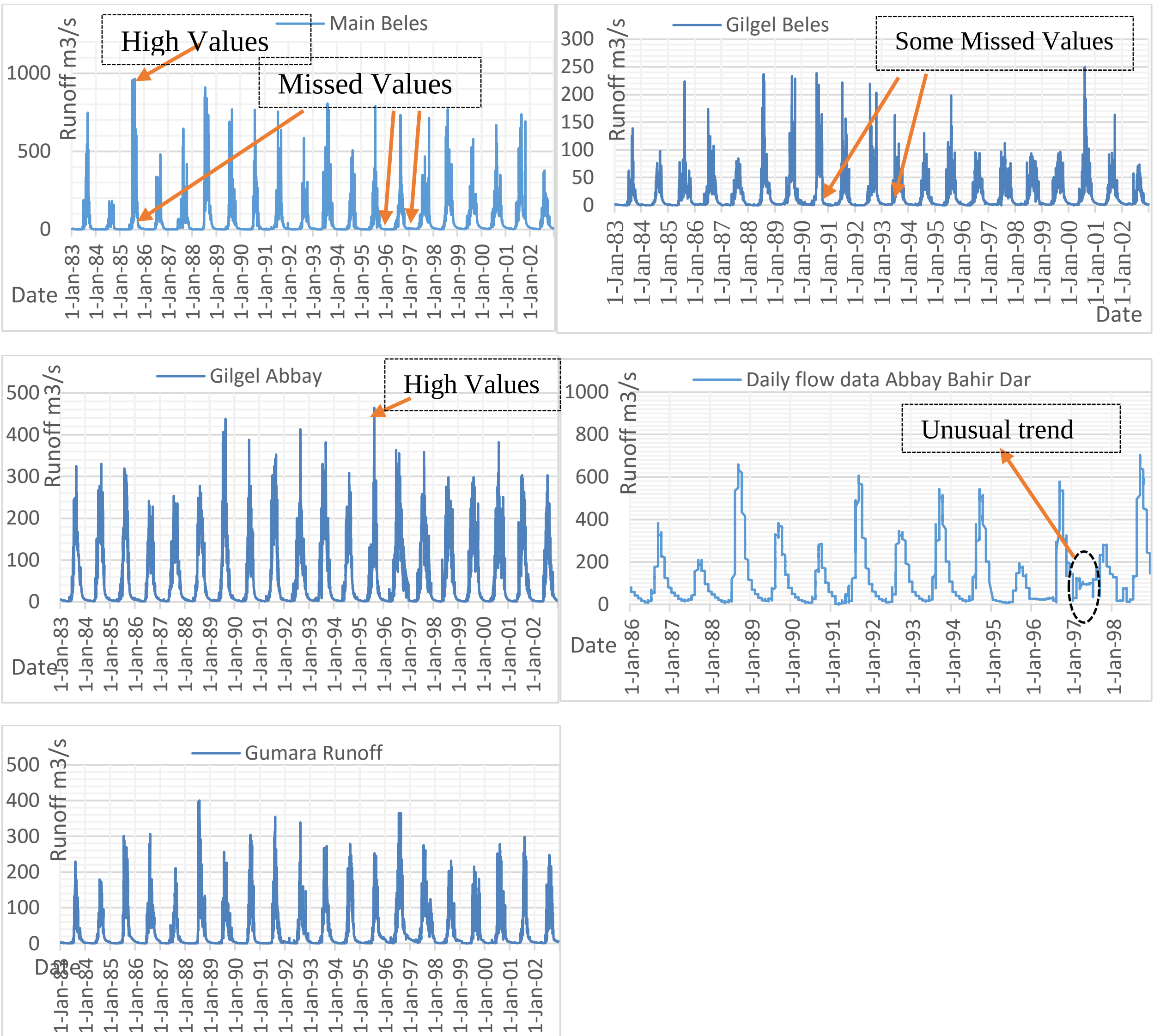


Figure 4. 1. Missed value, unusual trends and unacceptable values of five discharge gauge stations runoff series.

In this data series, the consistency has been checked using Accumulative Mass Curve and Double Mass Curve methods under section 4.5

4.4.Filling of Missing Data

Data may be missing from a particular gauge site or representative runoff is necessary as a point of interest. For the missing data to be estimated or representative runoff to be determined, the location of the site must be known in relation to nearby sites. For each gauge station, data recording start at different time, but most of them start from 1983 and used up to 2002. Total number of data records with this time interval must be 7,305 but due to different factors those data's are not completed. So 1st checking of completeness of the data from each gauge station should be handled and it will determine using the formula shown below:

$$\text{Completness} = \frac{\text{Number date data recordes}}{\text{Total number of data within the whole time}} * 100$$
(1)

Table 4. 1. Completeness of Data series

Rivers	Number of records	Total number of date	Completeness in %
Abbay River/Blue Nile	7,154	7,305	97.93
Gilgel Beles	7,059	7,305	96.63
Main Beles	7,059	7,305	96.63
Gumar	7,097	7,305	97.15
Gilgel Abbay	7,265	7,305	99.45

From the above completeness table it is possible to decide that the record of runoff series is not completely recorded. Some of the data are missed and not continually missing, but it is random and extend to some month continuously, but does not exist missing of the whole year data for each station and this may due to different factors in gauge stations of five rivers. This missed value of runoff series at different station to be filled under the use of the ration of long term average annual flow multiplied by the observed flow at the gauging stations with complete data.

$$\text{Qungauged} = \frac{Q"ungauged}{Q"gauged} * Qgauged \qquad (2)$$

Where $Q_{ungauged}$ is the flow computed at the ungauging stations with gaps
$Q''_{ungauged}$ is the long term mean annual flow of the ungauging stations with gaps
Q_{gauged} is the flow at the gauging stations with complete data
Q''_{gauged} is the long term mean annual flow of the gauging stations with complete data.

Those missed data could be computed using the above formula and the result hydrograph can be shown below after filling of missed data. And in some cases values which are extremely high or low (an unacceptable values) are observed and it could be corrected by taking the average values of data series, which are recorded one day previous and one day the next from an unacceptable value.

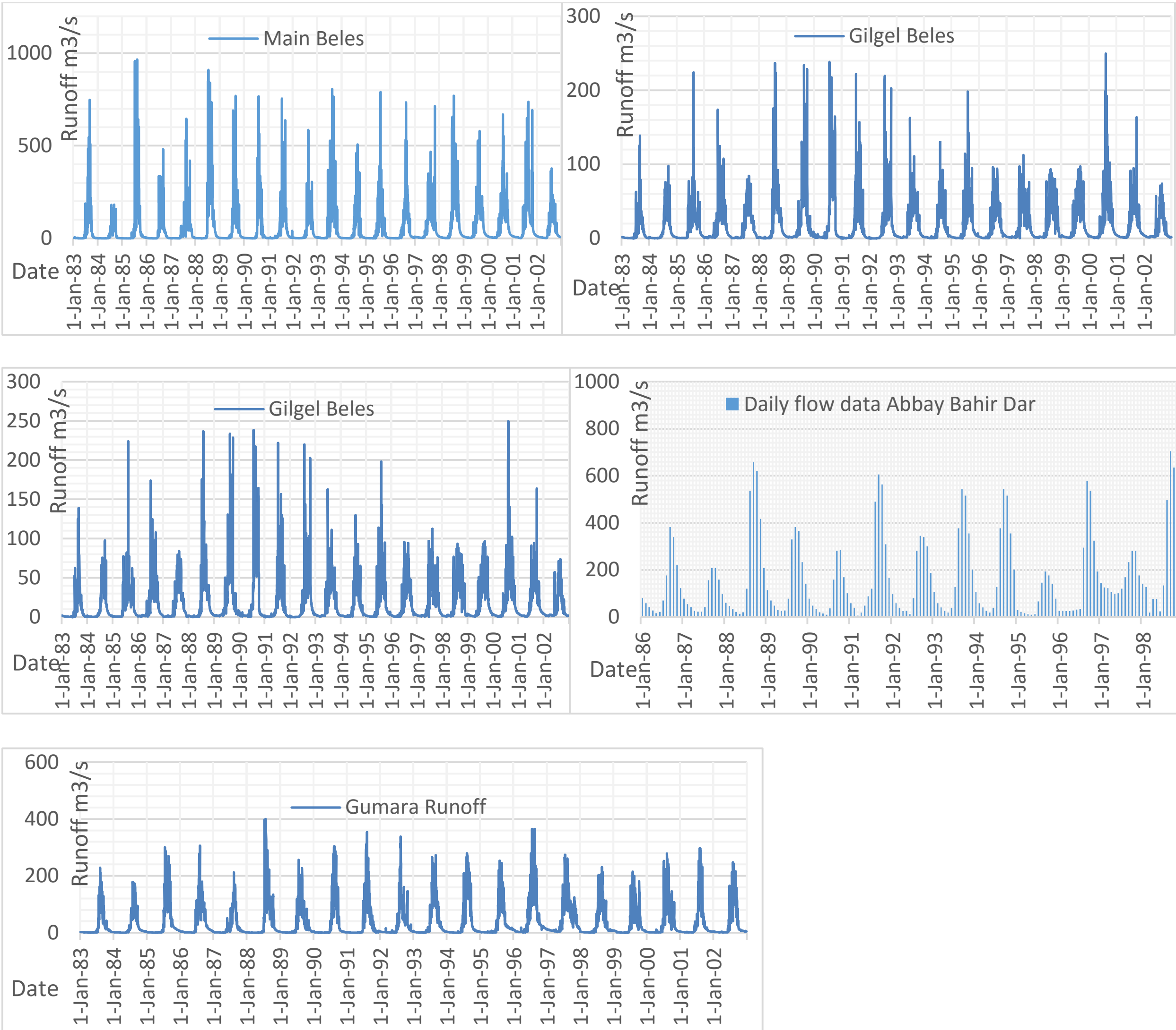


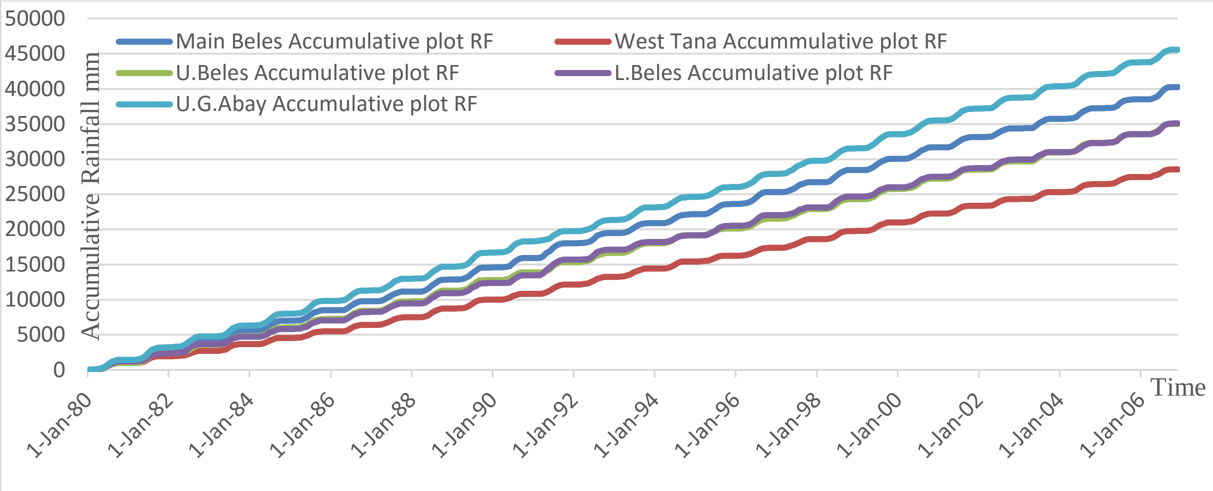
Figure 4. 2. Runoff series of five rivers after filling of missed data's and correcting unacceptable values

4.5.Consistency of Data

After all filling of missing data and correcting of unacceptable value it does not use data series directly before checking of the consistency of data. The consistency of data would be checked on both Accumulative Mass Curve analysis and Double Mass Curve Analysis. Using regression value computed from data series, Gilgel Abbay is more correlated to Gilgel Beles, Main Beles, Abbay (Blue Nile) and Gumar with R^2 value 0.75, 0.73, 0.4 and 0.81 respectively, than others and it also shows better data completeness which is about 99 % than another. It decided to use Gilgel Abbay River to check the consistency of other gauge runoff series.

Accumulative mass curve analysis AMC:

Accumulative Mass curve analysis is used to check the consistency of data and shown the cumulative value of data records in one axis with respect to the time series in another axis. So, AMC of each station as shown below in figure 4.3 indicate that the rainfall data records seem more consistence due to uniform trends of graphs. From AMC result, it is possible to use this data for further hydrological analysis and models. However, before using it further checking of data consistency using other methods is important and decrease further the uncertainty of the analysis. This would be done using double mass curve DMC analysis.



**Where U: Upper, G: Gilgel, RF: Rainfall, L: Lower*

Figure 4. 3. Accumulative Mass Curve Rainfall values of Tana-Beles Basin

However, AMC graph below figure 4.4, the runoff values between the year of 1988 and 1989 shows rise in graph trends than others and this may be expect in the wet season of the year, flooding, recording error or other factor runoff values.

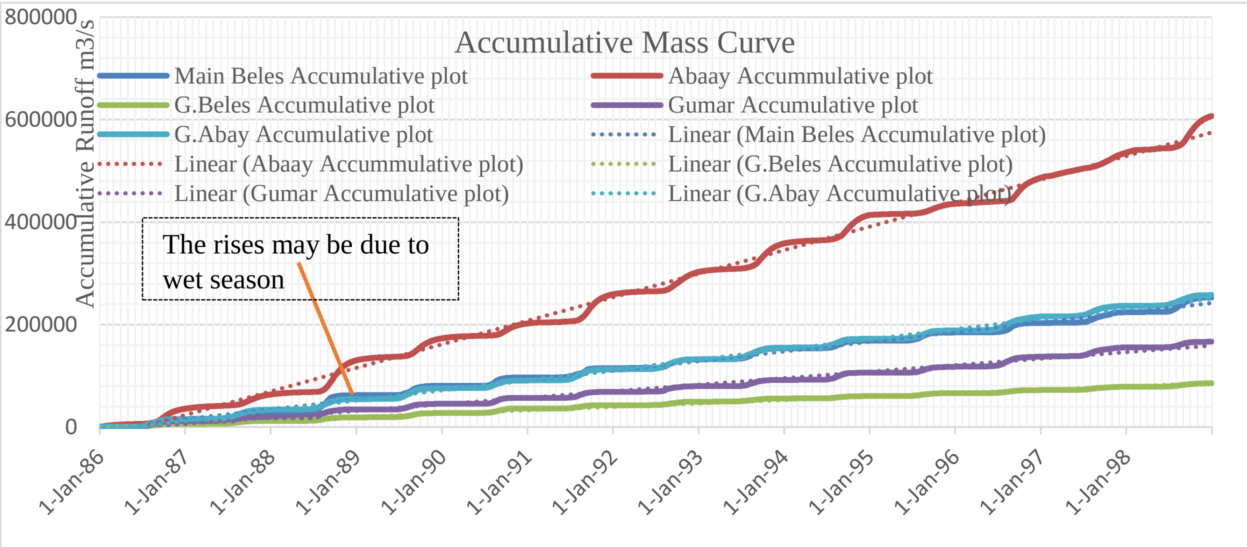
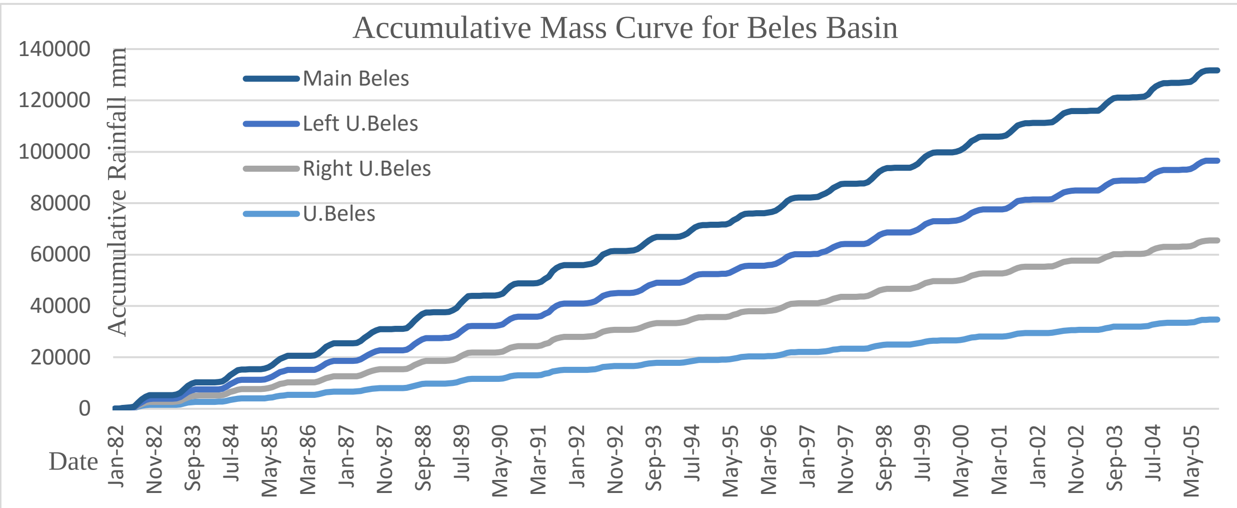


Figure 4. 4. Accumulative Mass Curve on five discharge gauge station of Runoff values

The results of Accumulative Mass Curve analysis of Beles basin shows that the runoff series of Beles basin has good quality since the trend of the graph shows very uniform and constant gradient with time series as shown below in figure 4.5. Hence it can use the data series for different purposes but for more degree of quality control checking of data with DMC is so important.

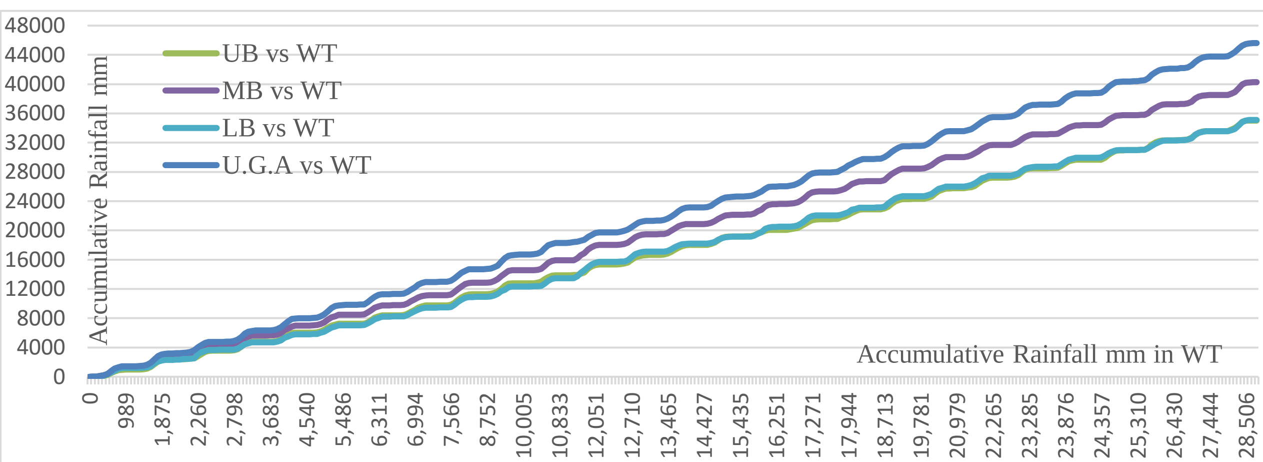


**Where U: Upper*

Figure 4. 5. Accumulative Mass Curve of Main Beles Runoff series

For more detail and further consistency checking it will compare the data of one station with others which have high correlation using Double Mass Curve Analysis. In this comparison, it would use accumulative values of each record of the station. For this analysis, for all runoff series comparison it would have been usable Gilgel Abbay runoff series as common due to better correlations and regression R^2 value.

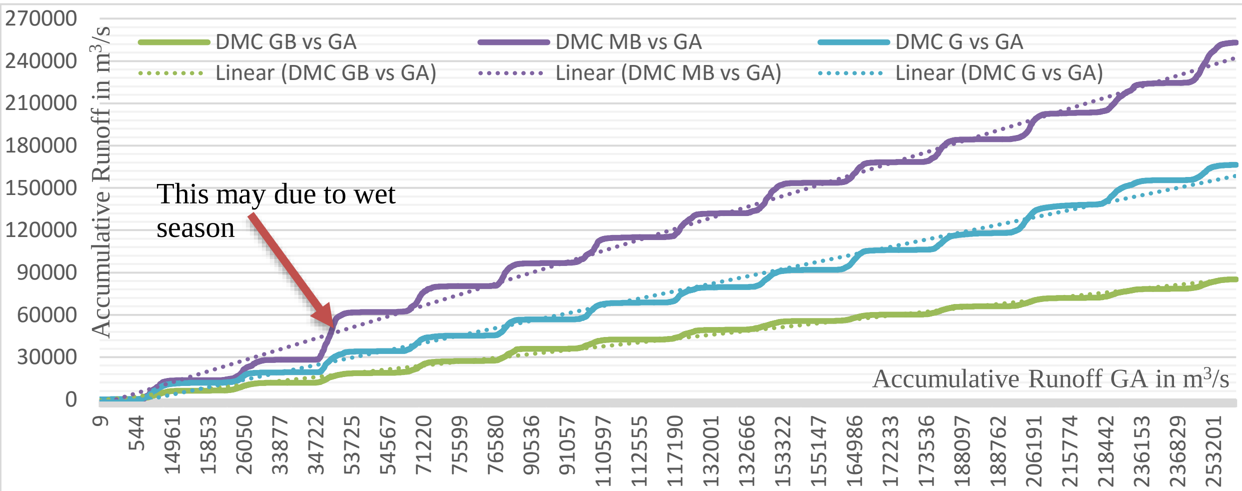
Here below in the figure 4.6, the DMC analysis of rainfall in Tana-Beles basin shows good consistency of rainfall data, uniform trends and constant gradients of rainfall series graphs.



**Where UB: Upper Beles, MB: Main Beles. WT: West Tana, LB: Lower Beles and UGA: Upper Gilgel Beles*

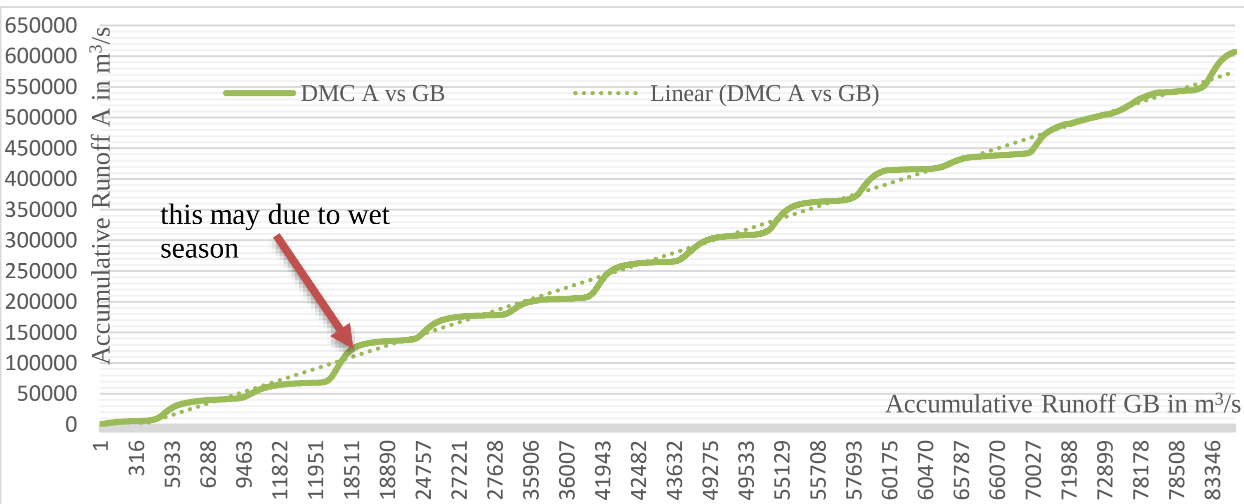
Figure 4. 6. Double Mass Curve Analysis of Tana-Beles Basin Rainfall data series

The results as shown in figure 4.7 & 4.8 indicates the consistency of data records and the filling values are good quality and it seems like to use data for this study. However, for Main Beles and Gilgel Abbay correlation at one seasons the graph somehow differs from normal trend and rise up a graph and this case also happened in Gilgel Beles and Abbay correlation graph. This may be due to wet season at that time (1988/89), flooding or recording error depending on different factors but it may not have high influence on this study as shown the value from the DMC graph.



**Where GB: Gilgel Beles, GA: Gilgel Abbay, G: Gumar*

Figure 4. 7. Double Mass Curve of Main Beles, Gumar, Gilgel Beles with respect to Gilgel Abbay runoff value



**Where GB: Gilgel Beles, A: Abbay/Blue Nile*

Figure 4. 8. Double Mass Curve Abbay/Blue Nile with respect to the Gilgel Abbay of runoff value

Finally, from hydro-meteorological data quality and consistency checking using the methods of both accumulative mass curve and double mass curve, the results of all summary graph listed above shows both rainfall and runoff series of each station has good data quality and consistency.

It decided that both rainfall and runoff series are ready and possible to use for further analysis and hydrological modeling and for this specific study those data's would use in nMAG2004 model and will run and simulate it.

4.6.Weather Data

In and around the study area, it was possible to collect meteorological data for different stations owned by Ethiopian Metrological Agency. Temporal distribution of rainfall for 11 catchment in Tana-Beles basin is shown in figure 4.9.

4.6.1.Temperature

The mean annual temperature in the basin reaches up to 23 °C into the low-lying areas (below 2,000 masl) like Bahir Dar and in the range of 15 to 20 °C in the middle and high altitudes (above 2,000 masl).

Long term average minimum and maximum temperatures for the Upper Beles command area are highest from March through to April, with lows in July when clouds persist through the wet season. A maximum monthly temperature of 37.4 °C occurs toward the end of the dry season in April with a low of 27.7°C in July and August at the height of the wet season. Monthly average minimum temperatures vary from 12.3°C in December to 19.3°C in May.

4.6.2.Rainfall

Observed point monthly rainfall is available from 27 rain gauges in and around the Tana-Beles catchment. Spatially averaged rainfall or areal rainfall is required for the estimation of available water resources and for estimation of crop water requirements for the Tana-Beles hydropower scheme. But in this study it uses runoff series mainly. The time series rainfall distributions in the Tana-Beles catchment is shown:

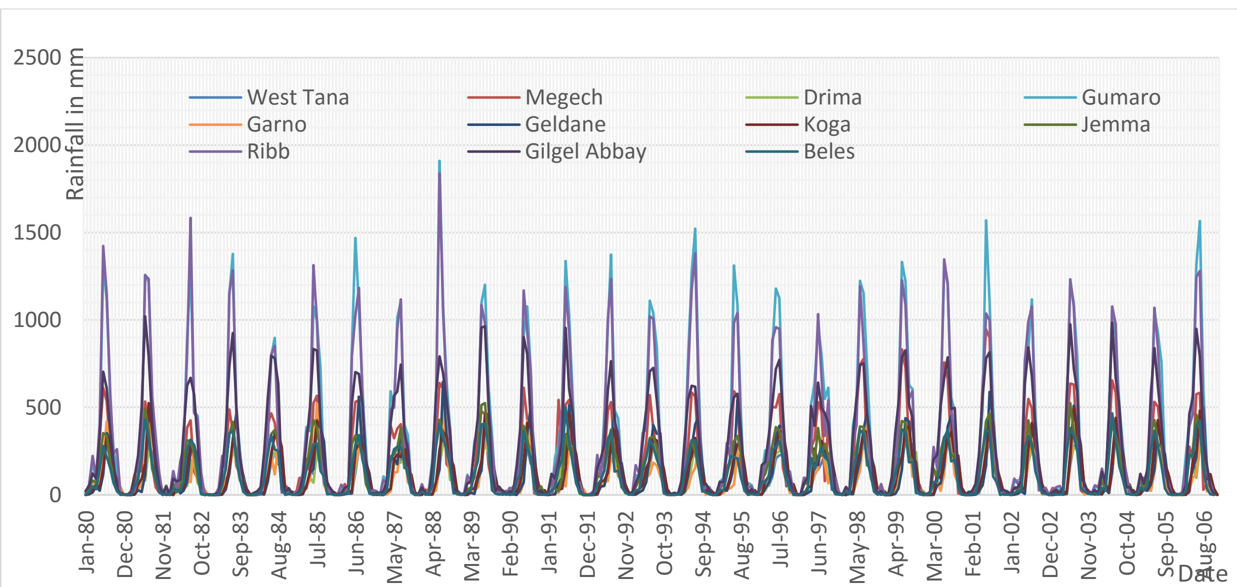


Figure 4.9. Rainfall series in Tana-Beles Basins

4.6.3.Evaporation

From SMEC 2008 report of lake's water balance an average annual evaporation rate is 1,675 mm and 1,511 mm in Lake Tana and Beles Basin respectively. During the dry season, when rainfall and river inflow are relatively small and high evaporation rate, whereas in the wet season the reverse is true in this project area. This indicates that evapotranspiration, in general, exceeds the annual rainfall amount in the basin, specifically at the time of the dry season of the year. Here figure 4.10 below is the graph which shows the meteorological data of Beles region.

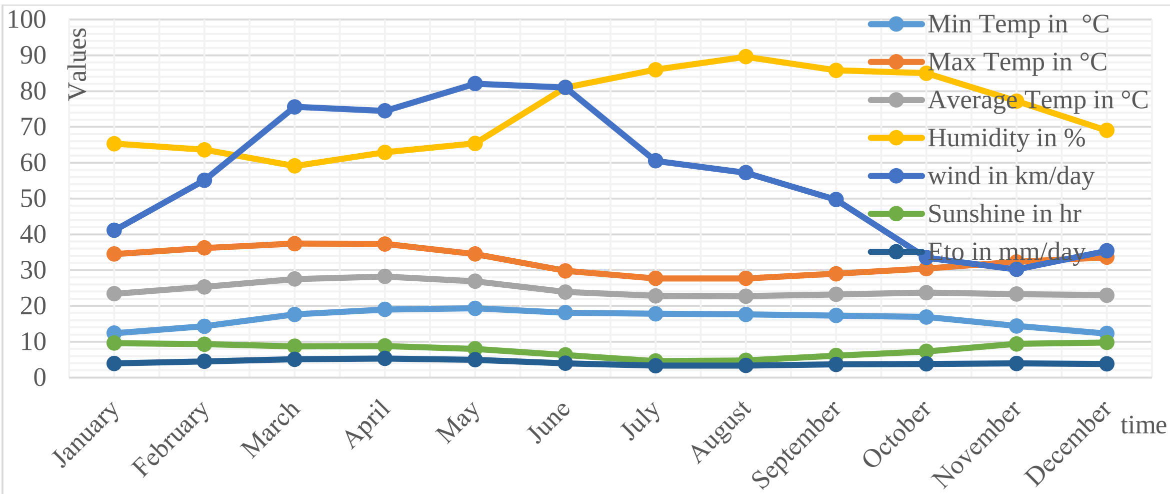
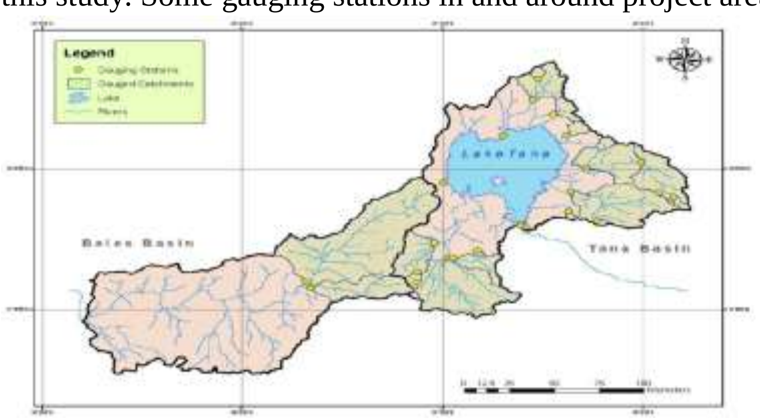


Figure 4.10. Climatic Data and ETo for Beles command area

4.7.Runoff

Hydrological data in this study are needed for detail analysis, but there is a limitation about data availability even those data that we have got are not having that much better quality specifically the data of Abbay River runoff at Lake outlet and some data even missed. Unfortunately, for this study the main data which are used basically for the main analysis and the model is a discharge gauged at different stations in and around Tana-Beles basins and this data's are checked, corrected and filled before used up in the main analysis and it is ok to use for further analysis of this study. Some gauging stations in and around project area is shown below:



**source: SMEC 2008*

Figure 4.11. Gauging stations with in Tana-Beles Basin

4.7.1.Tana Basin

Lake Tana, which covers about 20 % of the Tana Basin is fed by a large number of smaller streams and a few larger rivers with catchments in excess of 1,000 km^2: the Gilgel Abbay (4,517 km^2) in the southern part of the Tana Basin, and the Ribb (2,156 km^2) and Gumara (1,604 km^2), both in the eastern part of the Tana Basin. From runoff data series 53.9 m^3/s, 13.5 m^3/s, 33.2 m^3/s, 5.3 m^3/s and 125.2 m^3/s values are the average discharge calculated from the twenty year data series recorded at the gauge station in Gilgel Abbay, Ribb, Megecha, Gumara and Abbay at Tana Lake outlet respectively and the figures below shows the time series of runoff values and the average annual discharge of each station. The 20 year time series of flow in each station shown in *(Appendix A.2-2).*

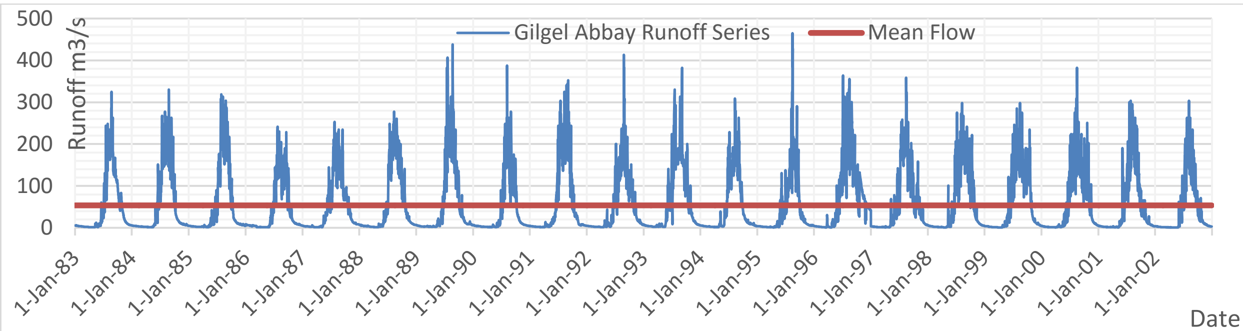


Figure 4. 12. Gilgel Abbay Runoff series 1983-2002

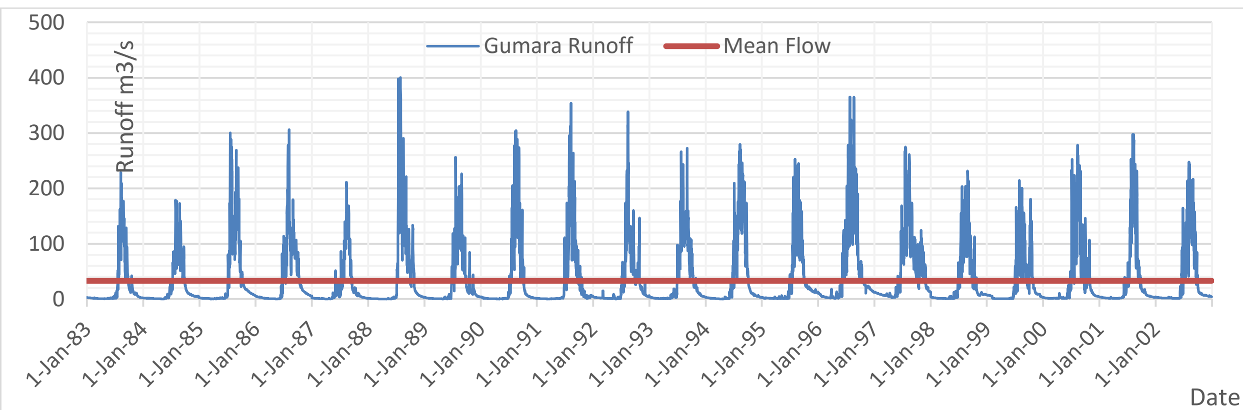


Figure 4. 13. Gumara Runoff series 1983-2002

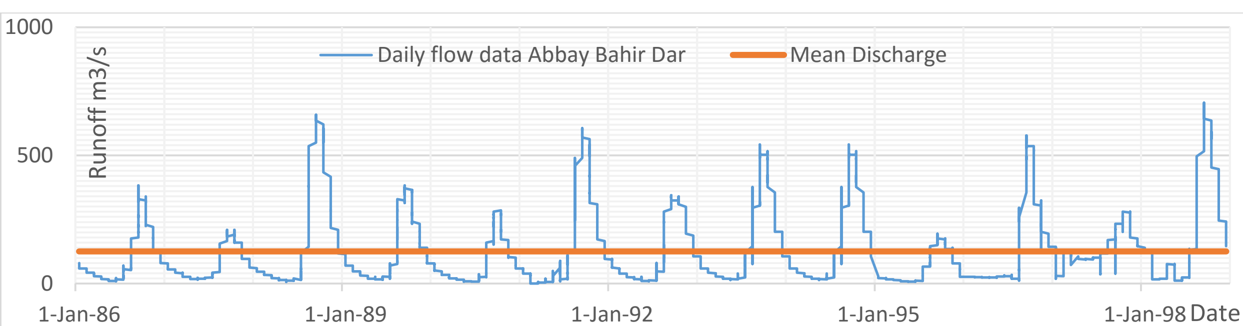


Figure 4. 14. Abbay Runoff series 1986-1998 at outlet of Lake Tana

4.7.2. Beles Basin

The main Beles River starts from high mountain range at about 2,250 masl and separating the Enat Beles basin on the west side from Lake Tana. The Enat Beles begins at the joining of the tributaries of the Kassan and Jehana rivers, and latter receives flow from the outlet tunnel of Tana-Beles hydropower scheme. The Enat Beles River lies in the central and northwestern part of the Abbay basin flowing in a southwesterly direction, and it gauged at a bridge crossing on the road some 4 km northwest of the town of Gilgel Beles, downstream of the town of Pawe (Halcrow-GIRD 2010). The catchment area of this gauge is 3,431 km^2. The discharge is measured at this gauge station of the river and the mean annual flow that is calculated from 20 year data series is 54.52 m^3/s.

Whereas Gilgel Beles River is a large primary tributary of the Enat Beles at the lower part Beles basin and is gauged at the town of Gilgel Beles which is not far from Mandura. This river has a catchment area of 675 km^2 computed from the point of gauge station with a mean annual flow of 17.06 m^3/s and for more see figure 4.15, 16, 17, and 18. The time series of runoff in Beles basin is changed after diverting of water from Lake Tana and about 2 times of the previous flow in the river.

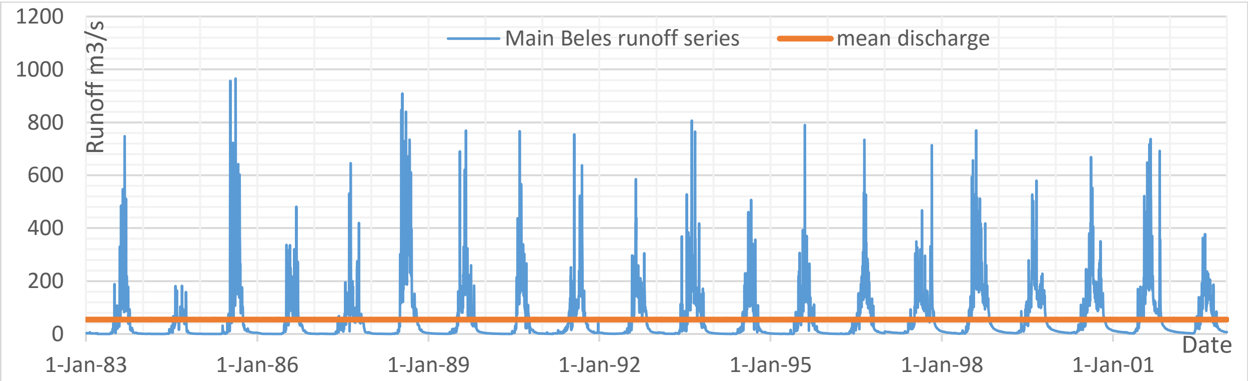


Figure 4.15. Enat Beles river Runoff series 1983-2002

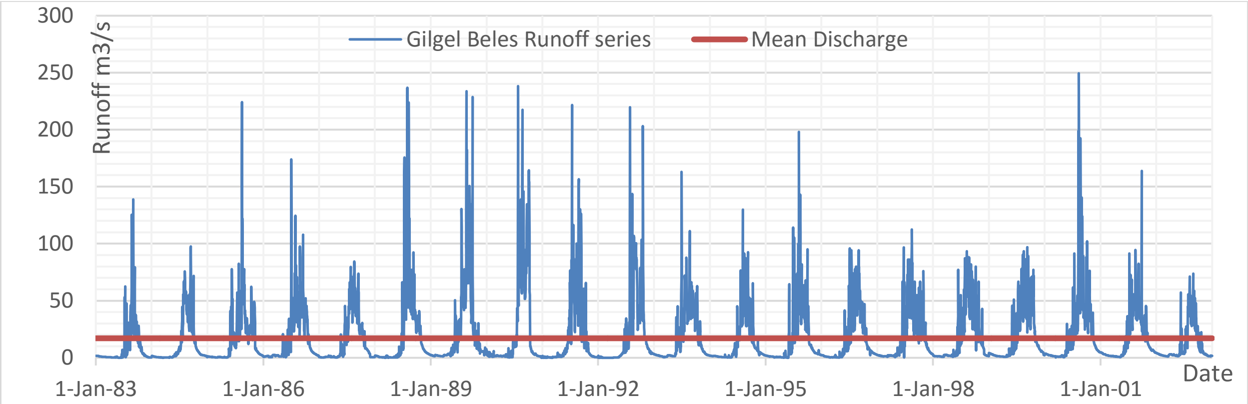


Figure 4.16. Gilgel Beles River Runoff series 1983-2002

**Source: Halcrow-GIRD 2010 Report*

Figure 4.17. Main Beles River at gauge location *Figure 4.18. Gilgel Beles River at gauge location*

The total Beles catchment before it reaches to Abbay river is about 13,573 km^2 and approximately 30.33 % of the total area is the total gauged area of the Beles river basin which is about 4,106 km^2 (Halcrow-GIRD 2010).

The outcomes of runoff series that is expected to follow the seasonal rainfall pattern which are typified by a short wet season and long dry season shown in the figure below. Typically, for the Enat Beles at the road-bridge gauging station, 120.7 m^3/s flow in July, peaking in August at 236.5 m^3/s and declining to 156.3 m^3/s in September, when it comes to in Gilgel Beles, 35.6 m^3/s flow in July, peaking in August at 58.7 m^3/s and declining to 45.4 m^3/s in September. Dry season flows from December through to May average about 3.4 m^3/s but can drop to about 2.06 m^3/s in May on the data used from 1983 to 2002.

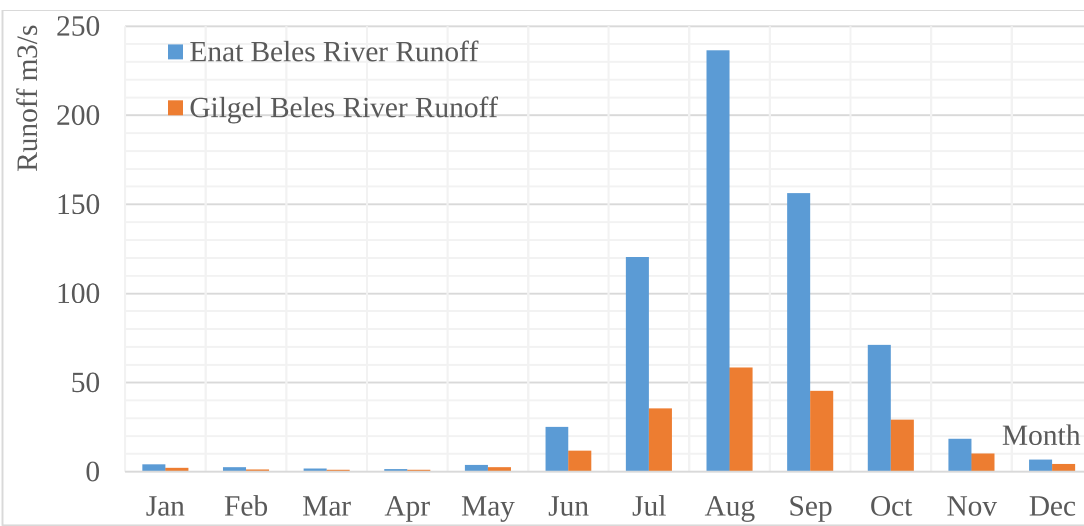


Figure 4.19. Enat Beles and Gilgel Beles tributary River average Runoff

The Tana-Beles hydropower scheme is complete and was commissioned on 14th May 2010 whereby releases from the tunnel are passed downstream along the Jehana River, a tributary of the Enat Beles, significantly changing its hydrological and morphological regime due to additional water taking it from power plants. The operation of the hydropower scheme will dictate outflows to the Enat Beles River, which will be superimposed on the natural flow regime of this river. The minimum operating level of Lake Tana will be +1,784 masl and an average of 77 m^3/s will be released through the Beles power plant over a wide range of lake levels. Discharges will be increased to 160 m^3/s at high lake levels >+1,787 masl and stopped whenever the lake level declines to +1,784 masl (Salini and Pietrangeli, 2006). Here, using the data of energy production of Tana-Beles HPP from May 2010 to July 2015 obtained from EEPCo, the result of the data show power is generating using average discharge of 86.6 m^3/s and for this study it used both 77 and 86.6 m3/s and optimize in both flow and take the one which show the better solution from different perspectives.

The natural flow regime of the Enat Beles will be changed as some 75.03 % of the natural outflow from Lake Tana will be diverted to the Beles basin resulting in an increase in natural flows in the upper part of the Upper Beles area (in the Jehana tributary) and approximately 2.21 times average discharge near Gilgel Beles town at the lower end of the scheme area.

5. Methodology
5.1.Optimization

Optimization in general, is accessing of a feasible operational way that maximizes or minimizes the value of the objective function. Hydropower is not a linear function, though the operational problems in hydropower are not a linear problems[8]. Applying of non-linear optimization techniques is the best solution to non-linear problems that can be obtained. Optimal operation of hydropower systems, reservoirs and power stations depends on a large number of variables and constraints, which interact in an unlimited number of combinations. Therefore it is complex to derive in advance, a common operating rule that would achieve optimal operation in all situations. Real-time optimization overcomes the problem by analyzing each combination of variables as it happens and provides an optimum operating rule for each particular situation. The derived operating and regulating rule can be applied immediately.

Deriving the optimal operating rules for a multipurpose reservoir which serving like for irrigation, hydropower plant, water supply and flood control are complex. A multipurpose project with one and above hydropower plant and irrigation are optimized for maximizing the hydropower production and satisfying the irrigation demands using different techniques or methods. The complexity of the optimizing is that the power releases and irrigation releases are in opposite directions and are not commensurable in one unit.

A regulation procedure is a set of rules for determining the amount of water to be stored, released, or withdrawn from a reservoir or system of more than one reservoirs under various conditions. Operating decisions involve allocation of storage capacity and water releases between reservoirs, between uses, and between time periods.

On this study, the way of optimization somehow differs from the actual meaning defined above. The actual optimization method of projects needs intensive data, information and specification which make the computation and analysis more complex. There were data limitation for high data demanding and barrier of knowledge to run optimize software. So, it decided to apply optimization here in the context differ from the above definition. Hence, optimization in this study will understand in the context of finding the best combination of power and irrigation product, assessing the area coverages by irrigation incorporate with water demand, release and evaporation lose and regulation of the lake under the application of different techniques and the development of the scenario. The main objective of this optimization is to find the best scenario that will give maximum benefit in terms of total power production and irrigation land coverage. Computing each scenario and select the one which give better production by comparing each scenario on the basis of power production, irrigation coverage, environmental flow to minimize the negative impact, the amount of water released, energy equivalent and water consumption. The development of scenarios, characterizing of it and stating of the specification was mainly done in model to optimize the whole system.

[8] http://www.maxhydro.com

Overall, to optimize this project nMAG2004 model is used and simulation has been done many times to get the best combination of power and irrigation production and minimize the impacts. In this case, each scenario has its own characteristic, objective and data specification that will be imported into the model. In general, high data demanding and barrier of knowledge is a limiting factor in this study in order to apply actual way of optimization.

5.2.Operation Scenario

The objective of this study is to find best optimal ways of operating Tana-Beles multipurpose hydropower plant is to regulate the Lake Tana and Dangura reservoir, to maximize Tana-Beles power production and irrigation coverage and to assess new water resource development in the downstream of Beles basins. To do so and to achieve the objectives of the study development of different scenarios is very crucial and then testing of it with a proposed model. Due to restriction flow and the presence of natural water fall (Tis Issat waterfall) which is one of visiting sites in Ethiopia to the downstream, setting of different scenarios on the outflow from Lake Tana is the first work of this study. Then after getting better reservoir regulation using outflow restriction recommendation, finding of optimum solution about the operation of the whole Tana-Beles Multipurpose project with and without new development of water resource project in the downstream, Dangura.

5.2.1.Scenario Development

5.2.1.1.Lake Tana Reservoir Regulation Rcenario

Due to restriction flow and presence of natural water fall (Tis Issat waterfall) to the downstream first setting different scenario on outflow flow from Lake Tana. Four scenario on Lake Tana outflow regulation are developed and optimization have been done mainly on the basis of environmental flow. Each scenario is also tested within three average flow released into the tunnel 55.65 m^3/s, 77 m^3/s from design and 86.6 m^3/s from existing power plant and it has different characteristics and objectives. Four scenarios are:

Scenario A:

Providing constant minimum outflow throughout the year from Lake Tana with a value of 10.5 m^3/s which is 95 percentiles of 1983-2002 Abbay (Blue Nile) flow series, which is recorded in Bahir Dar discharge gauge station and analyze data using nMAG model. From an environmental impact assessment (EIA) study at least the minimum flow requirement to the Tis Issat waterfall is 10 m^3/s not below and this scenario provide slightly higher value. One aim of this option is providing a constant flow to the downstream and release maximum amount of water to Tana-Beles power plant to get optimum and maximum power generation as well as irrigation production. Here release of 10.5 m^3/s throughout the year and store the remaining water in lake to use at the time of the dry season.

Scenario B:

Two seasonl constant outflow to the downstream of Lake Tana will be provide. Due to the seasonal variation flows in the given area Tana-Beles, use two different outflow to downstream and the remaining will flow for power production and some store within the lake. From the discharge flow series of river Abbay in Bahir Dar for wet seasons (3 months) July to September 90 percentile of 15.7 m^3/sec average flow and dry season October to June (9 months) 95 percentile of 10.5 m^3/sec average flow will be used. This variation increases the annual average flow of the waterfall in the downstream than scenario A. Here more water will be released to downstream and the amount of water stores slightly small relative to scenario A.

Scenario C:

Providing seasonal outflow and spill out all water when the water level is above 1,787 amsl. Chara-Chara weir constructed at the downstream of Lake Tana to regulate the outflow in the lake and Tis Issat waterfall since 1996. The regulation level of this small weir is 1,787 masl and when the water level become above this limit 1,787 masl all water will spill to the downstream. The possibility of storing water in Lake Tana is up to 1,787 masl only. In this scenario, nine different average seasonal outflow is used and tested with nMAG model. Seasonally varied regulated outflow from Lake Tana is the regulation basis of this scenario.

Scenario D:

Providing seasonal outflow, but store more spills water instead of spilling all water in order to use it the time of the dry seasons (minimize spill water). Outflow from lake are regulated using a small weir (Chara-Chara weir) and possible to upgrade the regulation level from 1,787 to 1,787.2 masl. Here an extra or flood water store in case of high flow and use again when the flow is low at dry season. This is an important since the water requirement at dry season for irrigation is very high and this scenario may add some solution to the problem. More or less the outflow from the lake for scenario C and D are the same except at the time of flow when the level is above 1,787 masl and scenario D store additional spill water than scenario C when the level is above 1,787 masl.

For each scenario the lake outflow will regulate by the Chara-Chara weir and tested using nMAG model. To satisfy environmental flow requirements to the downstream of the lake outlet, to preserve the flows over the Tis Issat Falls for aesthetic and tourist attraction in Ethiopia and to maintain the ecology of the Abbay River regulated water flow release is the key and a very crucial point. An environmental impact assessment (EIA) was undertaken by Bellier et al. (1997) before the Chara-Chara weir became operational recommending flows over the falls should remain between 10 – 60 m3/s, but these were based mostly on the aesthetic impacts of different flows over the falls (McCartney et al., 2009). For each scenario the minimum outflow is 10.5 m^3/s which is above 10 m^3/s and maximum outflow as a restriction 62.2 m^3/s in scenario C and D which is slightly higher than 60 m^3/s. The EIA results indicate that to maintain the minimum ecological functioning in the reach with contains the falls requires an annual allocation of 995 Mm^3.

Each scenario is simulated within nMAG model and make comparisons of the outcome of the model on different perspectives as well as it will compare with recommended studies to answer is that the scenario is feasible or not from environmental perspectives? Finally, the recommended alternative or scenario will proceed for further model analysis and also simulated with other six scenarios of the whole project considerations.

For common basis and comparison all parameters are consider as constant and uniform for each scenario and the simulation were under this consideration. But, after simulation the results of model is different and they are compared on the basis of environmental flow with respect to two studies, power production, energy equivalent, the amount of water released to power plant, mean annual water outflow to the downstream and others.

5.2.1.2.Tana-Beles Multipurpose Optimization Scenario

After deciding best scenario of the lake regulation system, optimization of Tana-Beles Multipurpose is considered and this will be done with and without new water resource development in the downstream area (Beles basin).

Generally, in Africa climatic and weather conditions are completely differ from like Europe countries. Like this in Ethiopia, high rain falling and high flow in the river is observed in summer season and in winter the reverse is true. This situation more or less the same to project site, Tana-Bele basins which are shown in figure 4.9 above. In irrigation project within the given project area the amount of water required is high in winter season and small and/or no need of water in summer season. In the project area, water is used for irrigation after power generation and there is seasonal water flow variation released into the project area. In summer irrigation area does not need released water from power only rainfall is enough, but the possibility of generating power is maximum. However, in winter irrigation area need high amount of water as compared with the rest of the year and little or no rainfall at all and the water released from lake for power production also low relative to other seasons. Here, it shows that, there is scarcity of water in the winter and surplus amount of water in the summer season for both irrigation and power production. Irrigation production highly influenced at dry time and power production will be high at wet season without using of water for irrigation. So balancing of this situation and obtaining of optimum solution is the objective of the study.

Therefore, optimization of Tana-Beles Multipurpose project is needed to obtain optimum benefit from both types of projects. To do so six scenarios are developed and then simulated with the nMAG model in order to obtain the best of them and for all scenarios power production taken as independent variable (constant) as an input. From the pre-feasibility study two irrigation sites upper and lower Beles with area coverages of 73,871 ha and 85,000 ha respectively are investigated and approved for irrigation productions. But, due to the limitation of water diversion from the lake and the availability of water within Beles basins, the total irrigation area is not fully covered or irrigated. To know irrigation coverages incorporated with power production different scenario development so important. The six scenarios are developed in this study (the one which will be selected under the basis of the best scenario of lake regulation), simulated with nMAG model and finally make an analysis and comparison of each on a different basis. Those scenarios which are developed:

Scenario D1:

Giving priority to upper Beles irrigations productions without providing storage in lower Beles; Water diverted from lake to power house and after generating power, water joins Enat/Johana River at the upstream of Beles basin. This water incorporated with flow from Enat River at the upstream used to irrigate upper Beles irrigation area with full capacity and full irrigation area coverage (74 thousand hectares) and the remaining water together with the downstream Gilgel Beles River will irrigate lower Beles up to their water supply capacity which means may or may not cover the total feasible irrigation area (85 thousand hectares) in lower Beles. The main goal of this scenario is to irrigate upper Beles with full irrigation area coverage within full capacity as a priority. It needs to supply about 1,304.6 Mm^3 average annual water to irrigate the whole irrigation area of 73,871 ha of land in the given region. The remaining water used in the downstream only for irrigation productions. Total irrigation area in the downstream need about 1,501 Mm^3 annually, but the major factor is the availability of water after using water in upper Beles.

Scenario D1R:

Giving priority to upper Beles irrigations productions and damming water in the lower Beles basin, specifically at Dangura site (recommended site); this scenario is similar to scenario D1 but the main difference is damming of water at Dangura to maximize irrigation production in lower Beles as well as producing additional power from this storage. So, water will damp and store for the period of 5 months in each year, which shows high rainfall and runoff (June to October) and used for the rest periods of the year (November to May). Here it expected to get total irrigation production in upstream, additional power in the lower Beles and benefit from agriculture at lower Beles basin with some percentage increase in area coverages.

Scenario D2:

Giving priority to lower Beles irrigations productions without damming of water at the lower Beles; Water diverted from lake to power house and after generating power water joins Enat River. This water together with flow from Enat River at the upstream used to irrigate upper Beles irrigation area and joins to the downstream river (Gilgel Beles River) to irrigate lower Beles with full capacity and total area coverage. The main goal of this scenario is to irrigate lower Beles with full irrigation area coverage as a priority. About 1,501 Mm^3 average annual water is needed in order to cover the whole irrigation area of 85,000 ha at the lower Beles basin. Only irrigation is considered in this scenario at the downstream of the basin. Irrigation coverage in upper Beles depending on the amount of water used in lower Beles area and lose due to evaporation.

Scenario D2R:

Giving priority to lower Beles irrigations productions and damming of water at lower Beles in Dangura site; this scenario is similar to scenario D2, but the main difference is damming of water at Dangura to maximize irrigation production in upper Beles as well as it creates additional power production in the downstream of the basin. So, water will damp and store for the period of 5 months, which is wet seasons of the region (June to October) and used for the rest period

(November to May), dry season of the year. Here maximize power production and provide stable and constant agricultural product within the year are obtained.

Scenario D3:

Giving equal priority to both upper and lower Beles irrigation areas without damming of water at lower Beles; here the average available water is not enough to cover the whole Beles basin since for the whole feasible area 2,806 Mm^3 of an average amount of water needed annually and this was spatially and temporally vary and without the considerations of water consumption value. The probability of using water is equal in both sites to irrigation and the main objective of this is to answer how much of the equivalent land will be irrigated in both sites? This shows the maximum production in the region is without influencing of power production in the Tana-Beles power plant.

Scenario D3R:

Giving equal priority to both upper and lower Beles irrigation area and damming of water at lower Beles in Dangura dam site; water will damp and store for the period of 5 months, which has high rainfall and runoff season (June to October) and used again for the rest dry period (November to May). In dry period water used for both power production and to irrigate irrigation area in the downstream. The objective of scenario D3 and D3R are the same, but the main difference is in scenario D3R there is an additional power production due to damming of water in the wet season and maximizing of irrigation product at dry season due to stored water at Dangura site.

If damming of water at Dangura site is available, 98MW power (Halcrow-GIRD 2010) will generate at lower Beles and water directly released to irrigate irrigation area after power production. However, from Jun to October low or no water supply needed for irrigation and the model simulated for both low or zero flow for five months and with some constant flow release to power production at the same time and then optimize it. The average water requirement for irrigation is 0.56 l/s/ha (Halcrow-GIRD 2010) in Beles and to irrigate and cover the total command area the minimum average of 2,806 Mm^3 water needed annually.

After stating those scenarios listed above the data specification will entered and three hydrological runoff series also imported to nMAG model and run the simulation. Abbay river runoff series, Enat//Johana river runoff series and Gilgel Beles runoff series are the 3 runoff series that is imported into the model. Each scenario has its characteristic and their properties so it does not give the same result. To differentiate and comparing the result different comparison criteria's would be develop and compare it to get the optimum way of operation and regulation as a whole one system. Power production and percentage of irrigation coverage as a benefit, environmental flow to the downstream of Lake Tana, amount of water released from the lake, water consumption and energy equivalent per unit amount of water are some of the criteria's to differentiate, compare and ranking of each scenario. The one which has the best sum rank value in all criteria is decide to say it is the optimum operation of Tana-Beles Multipurpose project and will be selected. Analysis of each scenario will be handled in the next section shown below.

5.3.nMAG2004 Model Analysis and Optimization

Number of hydrological models have been developed to assess hydropower and irrigation potential in the world. One of them is nMAG model and which can support the identification of suitable hydropower and irrigation projects, with implication to the hydrology and the economics of the entire basin.

This thesis utilizes the nMAG model for multipurpose hydropower simulation address several aspects, including environmental flow to the downstream of Lake Tana (Tis Issat waterfall), release flow to hydropower plant, diversion of water to the irrigation command area, impacts on water level of Lake Tana, water consumption in the basin, prioritize of production and in the last optimum operations and regulations of the project as one system. This model not only simulate hydropower production, but it will introduce simulations of irrigation production and optimal use of water for multipurpose Tana-Beles project. Water used in irrigation area will be synchronized as bypass flow from the control point in both areas.

Systematical representation of simulation of Tana-Beles Multipurpose Hydropower project in computer model include 9 models and their links are drawn as follows below in the figure 5.1:

- Two reservoirs
  Natural lake Tana and man-made Dangura water storage
- Two power plants
  Tana-Beles and Dangura power plant
- Three control points
  A control point below the joining point of Johana river and released water from Tana-Beles hydropower plant, Below Dangura hyrdopower plant and at the end point of the project (Blue Nile).
- Two sub catchment inflow
  Johana/Enat river and Gilgel Beles/Mandura river
- Two water transfer outflow
  Upper Beles and Lower Beles Irrigation area

The model shown below in the figure indicates how each model type interlinks and functioning as one system. Three main flow type is included in the model figures and those flows which are released flow indicated as black color line, bypass flow indicated as bold dash blue line, the spill flow indicated as blue dash line and water intertransfer as blue solid line. Each flow types are interconnected with different models i.e control points, reservoirs, irrigation area and power plant. The model simulation starts from lake Tana to downstream of the blue nile, but it does not consider here the natural way of blue nile until it joins with Beles river at the end of Beles basin. The model basically focused from lake Tana, within Beles basin and environmental flow to the downstream of Lake Tana.

The whole Module system, model type, flow path and their interlinks

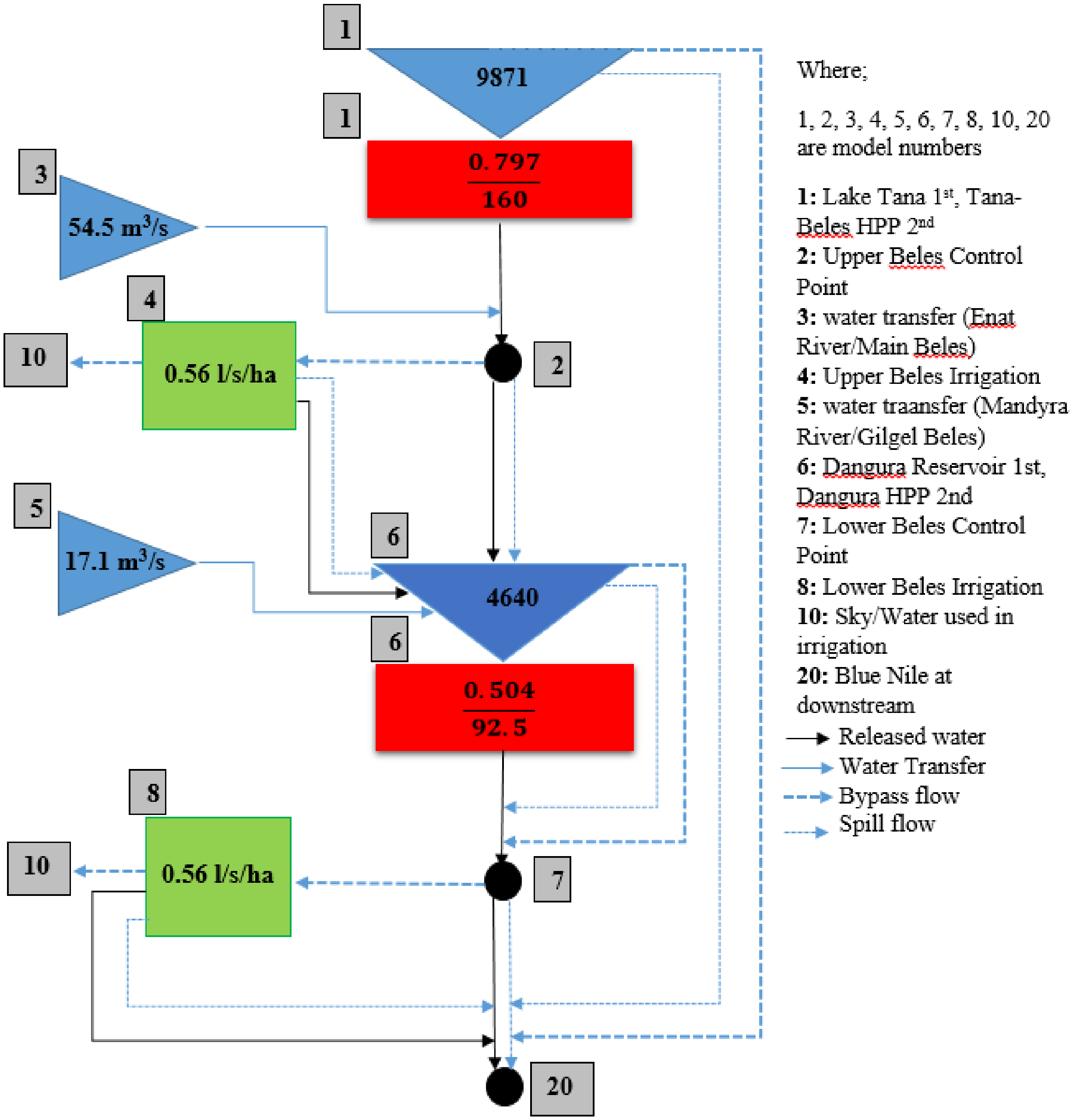


Figure 5. 1.Schematic representation of Modules and their links

5.3.1.Physical Data

In this model it considers two power plants one under feasibility study (Dangura) and one under operations (Tana-Beles power plant) and two irrigation area (Beles) under constructions. The physical data's that were specified and imported into the model are summarized as below:

Table 5. 1. Summerized physical data of Tana-Beles multipurose HPP

S.NO	Power Plant	Installed Capacity in MW	Energy Equiv. in KWh/m3	Gross head in m	Max Discharge in m3/s	Starting year
1	Tana-Beles	460	0.798	325.5	160	2010
2	Dangura	98	0.294	120	92	Under feasibility

**Source Harcrow-GIRD (2010) and Salini and Pietrangeli (2006)*

5.3.2.Reservoirs Data

In Tana-Beles multipurpose hydropower simulation system one natural lake and one man-made reservoir (under pre-feasibility study) are considered and their characteristic features are listed below:

In Lake Tana; HRWL = 1,787 masl, LRWL = 1,784 masl and Live storage = 9,871 Mill.m^3
In Dangura Reservoir; Live Storage = 4,640 Mill.m^3 and 120 m height (Data from feasible value)

5.3.3.Input Data

The data required and inserted into the model are:

Reservoirs:

HRWL, LRWL, Volume, Water level-Volume Curve, and Reservoir Evaporation.

Power plant:

Maximum discharge Q_{max}, EEKv, Nominal Head, Intake level, Tail water level, Head loss coefficient.

Gross head = elevation of the center of gravity of live storage – TWL,
Where the center of gravity is the center of gravity = LRWL + 2/3* (HRWL-LRWL)
The head loss coefficient is a function of the roughness of the waterway (tunnel) and due to limitation of real data, it is assumed to be its value zero for the two power plants.
Load-efficiency curve: 90% of constant value of efficiency is used in the simulation of both power plant.

Interbasin transfer:

Enat river/Main Beles/Johana Rivers with 236.51 m^3/s and Mandura/Gilgel Beles River with 58.56 m^3/s maximum discharge capacity are flowing at the upstream and downstream of Beles basin respectively. Both rivers are considered as inflow to the system and they are imported into the model.

Control point:

Control points have been assigned where the computation of the flow is assumed to be essential for environmental and other consideration.

Three control points that are considered in the model simulations are:

a) Upper Beles Control point: in order to ensure required amount of water to the upper irrigation area.
b) Lower Beles Control point: to ensure required amount of water to lower irrigation area.
c) The downstream end of Beles basin/Blue Nile: to know how much water will remain at the end.

Energy market:

Firm power price and it is assumed to be 0.6 Mt/kWh

Summer season: from the given region hydrology, summer season occurs about three continuous months from the day 182 to 273.

Restrictions:

Bypass release: Bypass release is applied on Lake Tana to the downstream flow (Tis Issat waterfall) with a seasonal varied flow release range from 10.5 m^3/s at dry season to 62.2 m^3/s at wet season and flow to the upper and lower irrigation command area range from 0 m^3/s to 83.5 m^3/s and 0 m^3/s to 96.1 m^3/s respectively.

Hydrology:

The mean daily flows are included in the model which are derived from different stream flow gauging stations. Three stream flows are considered in the hydropower simulation model with a runoff of series from 1983-2002. The missing value of data is filled using the nearest and the best correlated gauging station and unacceptable value also corrected. The quality and consistency of the data series are checked in both accumulative mass curve and double mass curve technique before importing to nMAG model. Imported hydrological data's to the model area:

Table 5. 2. Hydrological data used for nMAG model

SR. NO	Station Name	Catchment area (km^2)	Mean Annual flow (m^3/s)	Mean Annual flow (Mm^3)	Data used
112003	Lake Tana/Bahir Dar	15,321	125.2	3,947.67	1983-2002
116005	Main Beles	3,431	54.52	1,719.34	1983-2002
116004	Gilgel Bees	675	17.06	538	1983-2002

5.3.4.Irrigation Area Data

Here after generating 460 MW power, water release to Beles basin and then join Johana Rivers to irrigate Beles irrigation area and the physical data for irrigation are listed below in table:

Table 5. 3. Water requirment and maximum command area in Beles for irrigation

S.NO	Irrigation	Maximum Area (ha)	Water requirement (l/s/ha)	Remarks
1	Upper Beles	73,871	0.56	Under construction
2	Lower Beles	85,000	0.56	Under construction

**source Halcrow-GIRD (2010)*

5.3.5.Water Requirement Data

Tana-Beles project is a multipurpose hydropower project and therefore average water flow is used to generate power and to irrigate irrigation area. About 86.6 m^3/s, 50.4 m^3/s and 0.56 l/s/ha average annual flow are required to generate maximum 460 MW, 98 MW power and to irrigate around 159,000 ha irrigation area respectively. Minimum of about 2,731 Mm^3 and 2,806 Mm^3 annual average water must be released to Tana-Beles power plant and to Beles irrigation as well as 1,590 Mm^3 annual average water required to generate power at Dangura site.

5.3.6.Power Simulation using nMAG

The nMAG model simulation has been setup to computer for hydropower system. A detailed model layout that considers all water flows is shown in the figure 5.1 above. The setup consists of a total of 9 models including:

- Two reservoirs: - one natural (Lake Tana) and one man-made (Dangura)
- Two Power plant: - Tana-Beles HPP and Dangura HPP
- Water transfer two “in” and two “out”: - “in” from sub catchment and “out” to irrigation
- Three Control points and for each and every model, as much data as available have been entered.

Using the above all, data that is available and the objective of the study the model is run, simulate and gives different result for different scenarios in different regulation and operation system. The result of each scenario is compared on the basis of different criteria’s and priorities of benefits. The result of the analysis is discussed in the next chapter.

6.Result and Discussions of Analysis

6.1.Lake Tana Reservoir Regulation Optimization

Due to restriction flow and presence of natural water fall (Tis Issat waterfall) to the downstream first setting different scenarios on outflow from Lake Tana. Four reservoir outflow regulation scenarios are developed and optimization have been done. Each scenario is also tested within three flow released in the tunnel 55.65 m^3/s, 77 m^3/s from design and 86.6 m^3/s from existing power plant. Environmental release of water needed to the downstream of Lake Tana to stabilize water flow in Tis Issat waterfall and for the ecological functioning. Environmental flow, energy equivalent EEKv and annual stability of reservoir are the criteria to compare the scenario.

An environmental impact assessment (EIA) was undertaken by Bellier et al. (1997) before the Chara-Chara weir became operational recommending flows over the falls should remain between 10 – 60 m^3/s, but these were based mostly on the aesthetic impacts of different flows over the falls (McCartney et al. 2009). For all scenarios in this study the minimum outflow is 10.5 m^3/s in which is above 10 m^3/s and maximum outflow as a restriction 62.2 m^3/s in scenario C and D which is slightly higher than 60 m^3/s. The EIA results indicate that to maintain the minimum ecological functioning in the reach with contains the falls requires an annual allocation of 995 Mm^3. However, in this study a minimum average annual flow to the waterfall from pre-regulation are 331 Mm^3, 354 Mm^3, 708 Mm^3 and 708 Mm^3 for scenario A, B, C and D respectively. Here if scenarios A and B are used, there will be a negative impact to waterfall as well as difficult to maintain ecological function to the downstream as they indicated by EIA report. So to maintain ecological and aesthetic functioning and increasing tourist value Scenario C and D have higher priority of them on this criteria and this is before simulation have been done.

After regulation with nMAG simulation shown Appendix C.1-1, the amount of water that released to downstream as environmental flow are 629, 666, 858 and 853 Mm^3 for scenario A, B, C and D respectively, and scenario A and B values are still showing highly below the recommended amount and it does not satisfy environmental flow for both before and after regulation. Hence, environmental flow has a higher rank in any type of projects so that the probability of considering scenario A and B are almost negligible. But in scenario C and D environmental flow values have a good fit with the values of the previous study values 865 Mm^3 in DRM study and 995 Mm^3 in EIA study. Here scenario C and D are used for further checking's and it needs to re simulate the value to become equal or higher value than 995 Mm^3.

Under the considerations of energy equivalent EEKv, nMAG model analysis (after regulation) shows scenario D has higher value of EEKV 0.798 than others. EEKV values are 0.798 for scenario D and 0.7976 for the rest scenarios. About 0.798 of energy will be produced for a unit amount of water release to power plant if scenario D is used. Scenario D is best regulation options on the basis of EEKv values.

On the other hands, on the basis of annual reservoir stability change nMAG2004 result shows reservoir will increase by 11.9, 9.4, 8.7 and 0.4 Mm^3 in each year (*Appendix C.1-1)*. Scenario D is showing more stable reservoir than others due to low values of reservoir volume change within each year. Scenario D becomes more preferable than another on this criteria.

Tana-Beles multipurpose hydropower project was designed with average flow of 77 m^3/s and now the actual operation of power plant use 86.6 m^3/s of average flow from Lake Tana. nMAG model simulates for both average flows within each scenario and take the one which shows the best and better result. In the table shown below when the amount of water release to the tunnel changes, the power production of the project will also change. The difference between change of power production and through flow are compared and the highest and the best value is obtained in scenario D. This indicates if the amount of water release to the tunnel changes it is possible to get better power production with a higher factor than water release factors. For scenario D, the amount of water release change with 0.9461 factors and the amount of power production change with a factor of 0.9468 and it shows positive difference value of 0.0007 which is a better result than the rest scenarios and see the results in table 6.1. An actual average discharge of 86.6 m3/s with better scenario D is selected. From environmental point of view, actual average flow preferable than the design value. The ranking in table shows the value with high difference is rank 1 and smallest difference ranking 4, which means with some amount of water release difference it is possible to get better power production differences. For example, in scenario D, when average flow change from 77 to 86.6 m^3/s, the mean annual water released change by a factor of 0.9461 and the power production changes by a factor of 0.9468 due to change of flow. With small changes flow it could get slightly higher power production, which means positive gradient i.e. it is acceptable. The one which has a highest positive gradient is ranked first.

Table 6. 1. Comparsions of Scenarios

Scenarios	Annual through flow (A) to HPP	Annual power production (B)	Difference	Rank
	When average flow is 86.6/when it is 77	When average flow is 86.6/when it is 77	B-A	
Scenario A	0.9314	0.9320	0.0006	4
Scenario B	0.9335	0.9341	0.0006	3
Scenario C	0.9418	0.9424	0.0007	2
Scenario D	0.9461	0.9468	0.0007	1

**Detail of scenario A,B,C,D are discussed in section 5.2.1.1*

Generally, scenario D with 86.6 m^3/s average flow is selected that gave the optimum operation nd regulation of Lake Tana on the perspectives of environmental flow, stability of reservoir change, production with the released water flow and the energy equivalent of the systems. For detail analysis result *(see Appendix C.1-2).*

McCartney et al. (2009, 2010) have used a more ecological based approach to determine environmental flow requirements in the Abbay river reach containing the Tis Issat falls using a Desktop Reserve Model (DRM). DRM estimated that to maintain the basic ecological functioning of this reach an annual allocation of 862 Mm^3 is required. For all model scenarios a variable environmental flow requirement based on those recommended by Bellier et al. (1997)

are used. The environmental flow setting in this study (pre-regulation), EIA and DRM are shown in *Figure 6. 1.* (*see also Appendix C.2-1)*

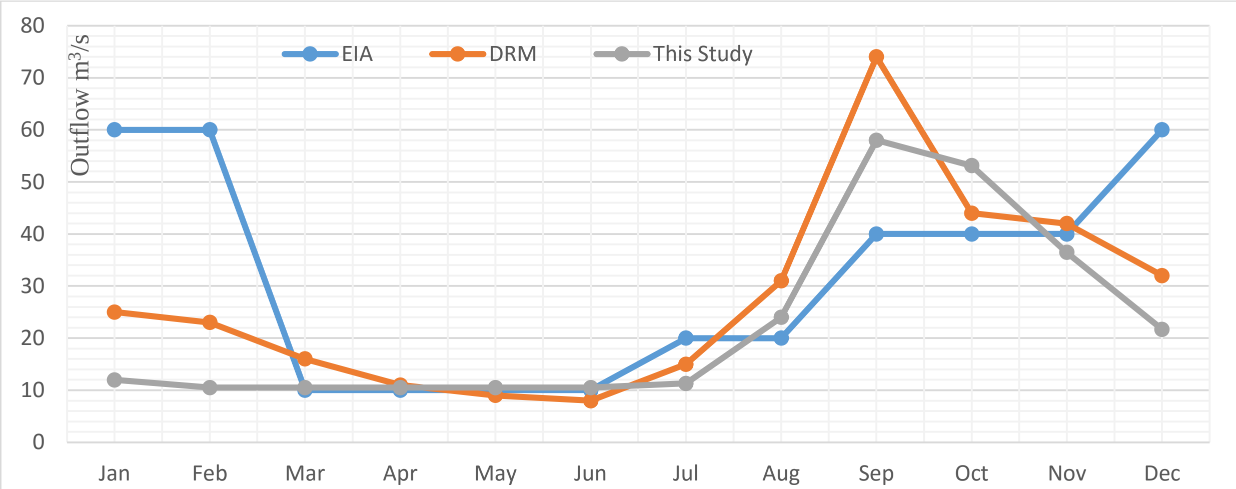


Figure 6. 2. Minimum environmental flows over the Tis Issat Falls from Lake Tana

From above graph for most months of the year value of environmental flow almost similar to the two previous recommended studies, but for three months January, February and December environmental flow are lower in this study due to higher power production and irrigation demands and it needs further analysis to optimize whole system. However, after regulations the value of EIA change from 708 Mm^3 to 853 Mm^3 annual flow, which is almost balanced with DRM recommendation value of 862 Mm^3. Still, this value needs an extra simulation at least to maintain the aesthetic functioning of waterfall and ecological functioning in the downstream. To do so, use this value as the pre regulation value and simulate it to obtain best and optimum regulated result that will be in between two study values. This has been done in the next section 6.2.

6.2.Tana-Beles Multipurpose Optimization

After identifying the best scenario of the reservoir regulation system that is scenario D, optimization of Tana-Beles Multipurpose with and without new water resource development was undertaken. Water is used for irrigation after power generation and there is seasonal water flow variation in the project area. In summer, irrigation area is not needed to release water from power, and water from the rainfall is enough, but the possibility of generating power is maximum. When it comes to winter season irrigation area needs high amount of water relative to the rest of the yearly seasons due to little or lack of rainfall at all. Besides, water from lake is also lower relative to other seasons for power production. It is possible to generate maximum power in summer and lose most part of the water as irrigation does not require water at this time. Whereas in winter, for maximum irrigation production maximum supply of water is required relative to other seasons, but do not have enough water in the lake as well as in Beles Basin Rivers (almost no flow). Synchronization of Power generation and irrigation production on both summer and winter seasons are very crucial and important to maximize production of both types. Hence, optimization of Tana-Beles Multipurpose project is needed. To do so six scenarios are developed and simulated with the nMAG model in order to obtain the best optimized solutions, and for all scenarios power production is taken as the same for pre-simulation step.

Six scenarios that are simulated with nMAG model are Scenario D1, D1R, D2, D2R, D3 and D3R (*for detailed discussion see section 5.2.1.2.)* where R indicates the damming of water at the Dangura site with maximum value of 4,640Mm^3 (with storage at lower Beles). The result of the analysis and its simulation are shown in detail in (*Appendix C.3*.). Depending on the results obtained, it is analyzed and compared to get the best combination of power and irrigation. Optimization of this whole project have been done on the basis of irrigation area coverage, power production, energy equivalent, environmental flow with respect to EIA, amount of water released to the power plant and lastly on the basis of water consumption. The one which rank first on different point of perspective is the best way of operation in this study. The analysis and comparisons to find the best way of optimization is:

On the basis of irrigation area coverage:

An objective of this criteria is to cover large irrigation areas as much as possible. Actually, due to the availability of water and large irrigable area in the given area, it is difficult to irrigate the whole area, but it is possible to get highest area coverage combined with the power production. About 73,871ha upper and 85,000ha lower Beles irrigation area are considered in the pre regulation of the project as an input. After regulating, simulating and modeling of the data specification in all scenarios, different irrigation area coverage results are obtained as shown in the summarized table 6.2 below (*for detail analysis see Appendix C.4*). Here all scenarios do not supply enough amount of water spatially and temporally to the given area but the result of one scenario is better than the others.

The summarized table 6.2 and figure 6.2 shown below indicate scenario D2R is ranked first giving priority to lower Beles irrigation areas with the damming of water at the Dangura site for power generation and irrigation production. Here it is possible to irrigate 71.23 % of the total Beles irrigation area that is around 113,260ha of land. About 111,380ha, 112,830 ha, 111,760 ha, 105,830ha and 106,440ha of the area will be covered if D1, D1R, D2, D3 and D3R scenario are used respectively. Scenario D2R are recommended when the criteria used are total irrigation area coverage. About 27 and 85 thousand hectares will be irrigated in upper and lower Beles area. The percentage of area coverage computed from the total command area of upper (73,871ha) and lower Beles (85,000) basin in each scenario are tabulated as shown in table 6.2 below.

Table 6. 2. Comparison of scenario and ranking on the basis of Irrigation area coverage

Scenarios	Irrigation area coverage (%)			
	Upper Beles	Lower Beles	Total Irrigation Area	Rank
Scenario D1	99.98	44.04	70.05	3
Scenario D1R	99.98	45.73	70.96	2
Scenario D2	36.06	100.03	70.29	4
Scenario D2R	36.06	101.79	71.23	1
Scenario D3	66.92	66.24	66.56	6
Scenario D3R	66.92	66.96	66.94	5

**For details of scenario see section 5.2.1.2. and R represent with storage at lower Beles (Dangura)*

Figure 6.2 shown below indicate computation of percentage of total irrigation area coverage, upper irrigation coverage and lower Beles irrigation coverage from about 159, 74, 85 thousand hectare of command areas respectively. For example, in D2R 36.06% means about 26,638ha of upper Beles will be irrigated out of 73,871ha.

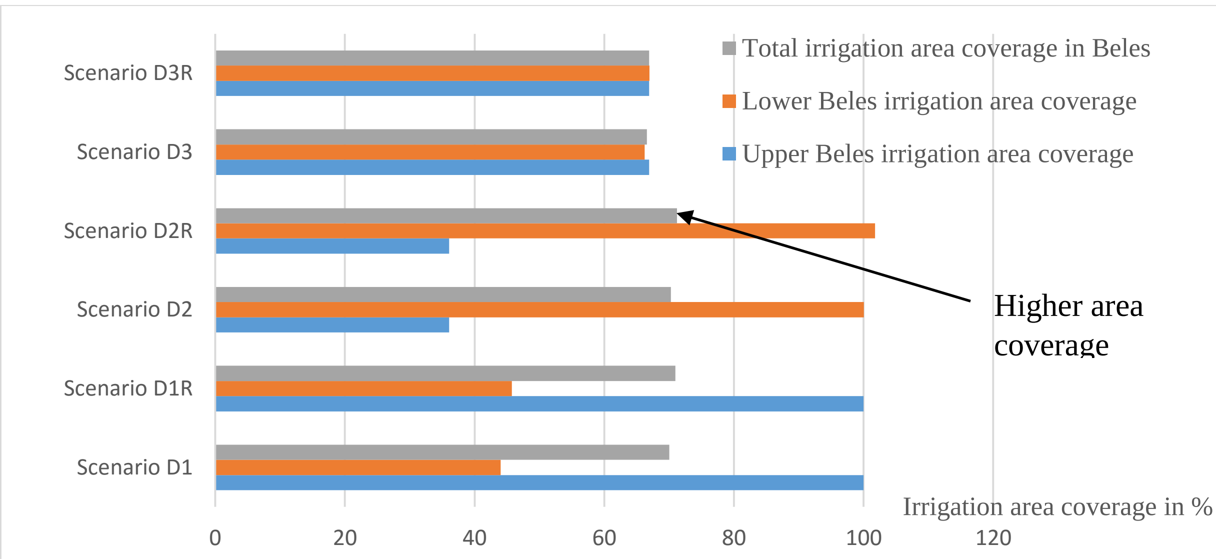


Figure 6. 3. Irrigation area coverage in each scenario

On the basis of power production:

This project area has two power plant one in operation and the other being under feasibility study (Dangura); and the new site is checked whether it is feasible or not using nMAG simulations. When water is stored at lower Beles, it increases power production and the amount of water release. Detailed simulation result is tabulated in *Appendix C.5-1*. Three scenarios are without damming of water and the remaining 3 involved damming at Dangura site and influence the water balance in the system.

Table 6. 3. Power production and ranking of each scenario

Scenarios	Production before regulation (A)	Production after regulation (B)	Change production (B-A)	Trough flow	EEKv	Rank
	GWh	GWh	GWh	Mm^3	KWh/m^3	
Scenario D1	2178	2365.5	187.5	2968.5	0.797	2
Scenario D1R	2462	2991.3	529.3	4108.3	0.728	3
Scenario D2	2178	2365.5	187.5	2968.5	0.797	2
Scenario D2R	2912	3634.3	722.3	4117.7	0.883	1
Scenario D3	2178	2365.5	187.5	2968.5	0.797	2
Scenario D3R	2646	3293.7	647.7	4671.4	0.705	4

**For details of scenario see section 5.2.1.2. and R represent with storage at lower Beles (Dangura)*

Due to storage in each scenario with R, the power production would be increased. Scenario with relatively high energy equivalent ranked as first indicate a better energy production with a unit amount of water released to power plant.

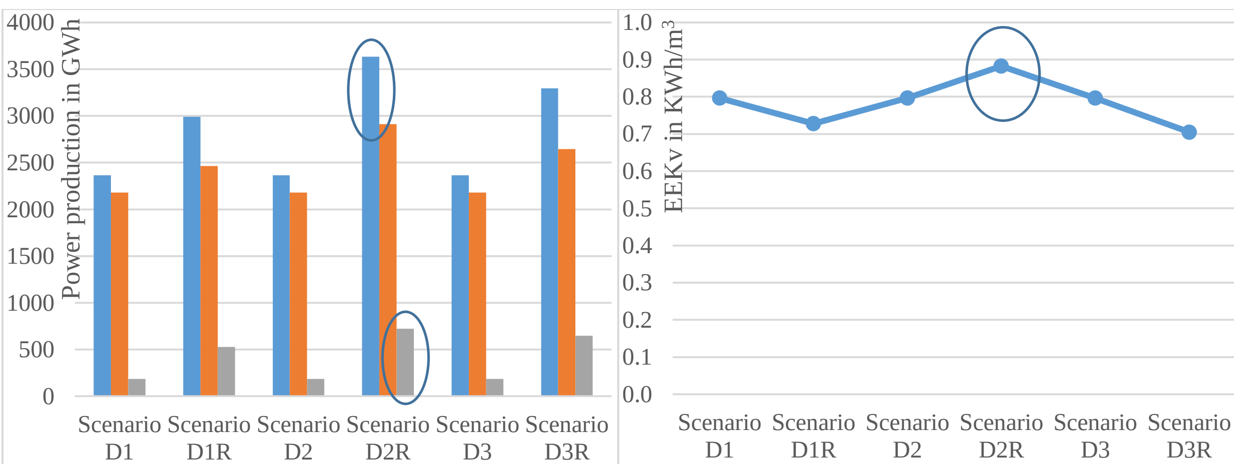


Figure 6. 4. Power production (a) and energy equivalent (b) of each scenario

Figure 6.3a above shows the power production of all scenarios before and after regulation. If we consider scenario D2R, it gives the higher power production after regulation and the difference in power production from pre regulation is 722GWh which is higher than other scenarios. Figure 6.3b above shows the value of energy equivalent with a unit amount of water releases and the one with higher EEKv is ranked first. Figure 6.3b shows the higher energy production with the unit amount of water release observed in scenario D2R with a magnitude of 0.883 EEKv. On the basis of EEKv scenario D2R, (D1, D2 and D3), D1R and D3R are ranked from 1 to 4 respectively. When it comes to power production scenario D2R, D3R, D1R and (D1, D2 and D3) ranked from 1 to 4 respectively. On the basis of both power production and energy equivalent scenario D2R show optimum and maximum power production result than others. Thus, D2R scenario is the preferable and best operational way of the project.

On the basis of environmental flow to the downstream of Lake Tana:

In the first phase of the analysis only the flow to the downstream is emphasized without considering the irrigation on Beles basin. But the second phase includes irrigation production in Beles basin within the selected Lake Tana operation scenario which is scenario D and simulated using the model. After simulation, in all scenarios the average flow of water to the downstream is 978.9Mm^3. This value maintains ecological functioning in the downstream and aesthetical functioning of waterfall. McCartney et al. (2009, 2010) have used a more ecological based approach and determine environmental flow requirements in the Abbay river reach containing the Tis Issat falls using a Desktop Reserve Model (DRM). DRM estimated that to maintain the basic ecological functioning of this reach an annual allocation of 862Mm^3 is required and this value is without aesthetical consideration of a Tis Issat waterfall. However, in this study the value obtained from simulation is 978.9 Mm^3 and increases on average by 125.9 Mm^3 annually. This minimum environmental flow increases the aesthetic value of Tis Issat waterfall in addition to maintaining an ecological functioning to the downstream. Therefore, the result shows better regulation of the lake compared with McCartney et al. (2009, 2010) value. On the other hand, this value is slightly lower than Bellier et al. (1997) value, but with different value of release with respect to time. The environmental flow that was provided in this study almost satisfy recent studies carried out by Bellier et al. (1997) and McCartney et al. (2009, 2010). Hence, all scenarios give the same environmental flow to the downstream and have the same ranking on this basis *(see monthly flow in Appendix C.2-2).*

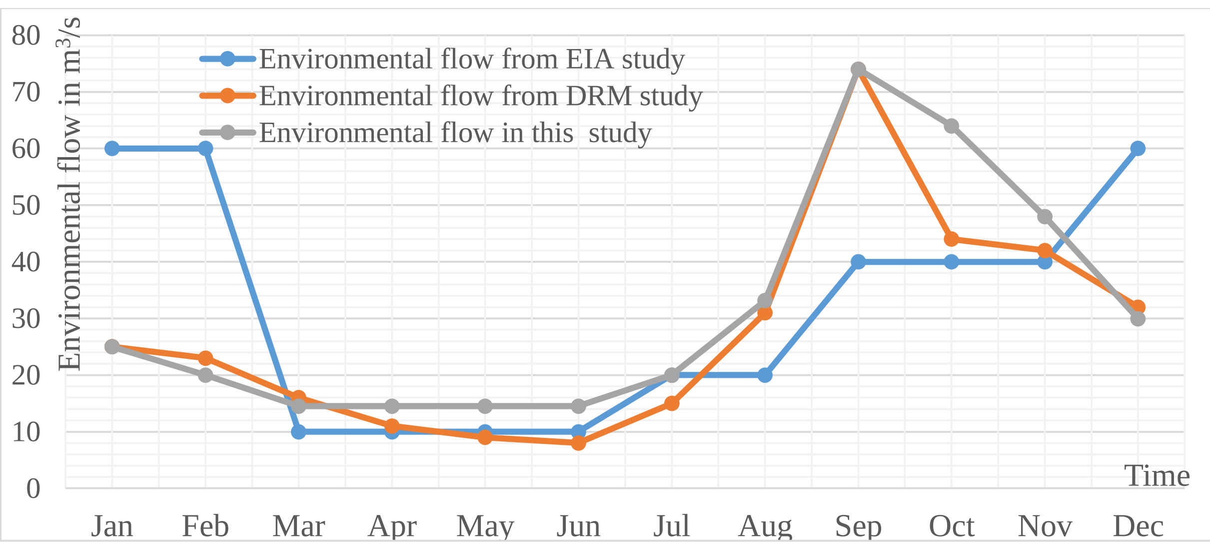


Figure 6. 5. Environmental flow after simulation in all scenario

In the figure shown above the average amount of environmental flow released to the downstream of the lake is relatively small for three months (Dec, Jan and Feb). This is due to high demand of water in irrigation area as one way of operational strategies. For the remaining months of the year it is better and higher than the two studies even at the time of dry season as the flow changes to 14.5m^3/s. Overall, the environmental flow regulation to optimize the project is feasible and hence decided to apply it in this study.

On the basis of the amount of water release from Lake Tana to power plant:

Water released from lake to Tana-Beles power plant is very crucial to get optimum benefit of power and irrigation productions. Minimum amount of water that is supplied from Lake Tana is 2,731Mm^3 as pre-simulation; and the result of the simulation shows that the amount of water release is higher than 2,950Mm^3 which is above the minimum requirement. This is true in all scenarios and it satisfies the minimum requirement on the basis of this criterion.

Generally, the above criteria comprising irrigation area coverage, power production, energy equivalent, flow through the tunnel, and environmental flow and aesthetic functioning in Tis Issat waterfall and the downstream have lead to the selection of Scenario D2R. On the basis of the above criteria, scenario D2R is ranked as the first and the overall result of ranking is shown in figure 6.5 below. Environmental flow and aesthetic functioning are compared against previous studies.

The optimum operations of Tana-Beles Multipurpose project is obtained by using scenario D2R. Thus, the optimum way of handling this project is must involve the specifications of D2R scenario. See the overall ranking of all scenarios in figure 6.5 below and detailed simulation values presented in *Appendix C.5-2*.

Finally, it is decided to use scenario D2R operation system and the specifications as best combinations of power generation and irrigation production than other scenarios.

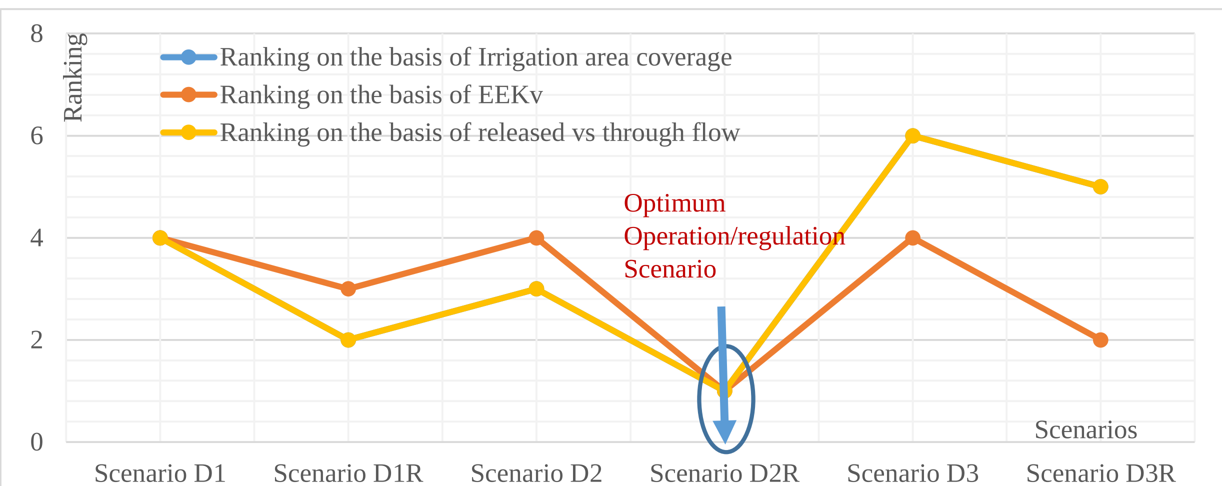


Figure 6. 6. Ranking of all scenarios on different criteria

When taking scenario D2R, seasonal variable water is released as environmental flow to the downstream of 978.9Mm^3 average annual flow and the lake stores spill water in order to use it at dry seasons. The highest water regulation level is 1,787.2masl and an amount of 2,957.3Mm^3

water is released to the tunnel for both power and irrigation production. The average flow to the tunnel is 86.8m^3/s and the flow of Juhana River is changed with 2.6 factors from natural flow value. The whole project will be operated by giving priority to the lower irrigation area and damming of water at the Dangura site for additional energy productions as well as providing of seasonal stable water to lower Beles irrigation area. About 100 % lower irrigation area and 36.1 % of the upper irrigation area will get enough water for full productions. Due to damming of water, it will get additional power of 1,278 GWh. Detail water balance of scenario D2R is shown below:

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD2R.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

Print

Close

NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2957.3	706.6	272.2	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4676.7	4206.2	470.4	0.0	0.0
4	UBI	0.0	470.4	0.0	470.4	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
6	Dangurahp	0.0	4744.2	2535.9	0.0	176.8	6.5
7	LB Control Point	0.0	2712.6	1184.6	1528.0	0.0	0.0
8	LBI	0.0	1528.0	0.0	1528.0	0.0	0.0
10	Sky	0.0	1998.5	1998.5	0.0	0.0	0.0
20	blue nile	0.0	2163.5	2163.5	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)	
AVER. INFLOW TO SYSTEM	: 6205.0
ACTUAL INFLOW TO SYSTEM	: 6205.0
RESERVOIR EVAPORATION	: 2043.1
INITIAL RESERVOIR LEVEL	: 14172.8
FINAL RESERVOIR LEVEL	: 14172.8
RES. CHANGE per YEAR	: 0.0
OUTFLOW	: 4161.9

Figure 6. 7. Model Water Budget result of the whole system after regulation (Scenario D2R)

6.3.Operation Impact

6.3.1.Impact on Irrigation Production

Generally irrigation is consumptive use of water and after using water, it does not return back to the natural flow unlike power productions. Average demand of water per hectare of land is 0.56 l/s for both upper and lower Beles sites. Time series of flow to irrigation sites after regulation and model analysis are shown in the following figure 6.8,9,10 in different cases:

Firstly, from total river flow, simulated with and without storage and actual required flow to irrigation area figure 6.8, there is an inadequate amount of water released for the first six and half months (1st Jan to 15th June and the whole December) and the remaining months of the year access enough amount of water for full irrigation productions. Here there are a limitation for full irrigation products of the whole area coverages for six and half months and for the five and half months it is possible to irrigate the whole area. This comes due to rain falling in the summer seasons is high and water requirement for irrigation at this season is very low almost negligible where as in winter high water requirement with no rainfall. The figure shows the scarcity of water for 6.5 months.

Secondly, from the actual water needed and simulated flow to lower Beles with and without power production at Dangura figure 6.9 shows, in case of scenario D1 and D1R the water demand in lower Beles and the actual delivered water will be matched for five months only for the remaining day they are a scarcity of water to irrigate full lower Beles irrigation area 85,000 ha. Here it will be the focus of the seasonal crop production, which has lifetime less or equal to six months. When it comes to scenario D2 and D2R, almost for the whole months of the year water demand on irrigation and water delivered fits and there is the possibility of producing maximum product in lower Beles and the operation has no impact to the lower Beles area. On the other hands, scenario D3 and D3R has similar trend with scenario D1 and D1R but the amount of water released to the lower Beles irrigation site is higher and as a result it will cover better command area in lower Beles. Here also it will consider seasonal crops that grows twice a year, or their lifetime less or equal of half of the year. June to end of November the amount of water released is higher than the amount of water required in irrigation area. This is to provide stable and higher power production at this season without the use of water fully in irrigation. After generating power at this season some parts of water flow to the downstream, Blue Nile River without irrigating irrigation area.

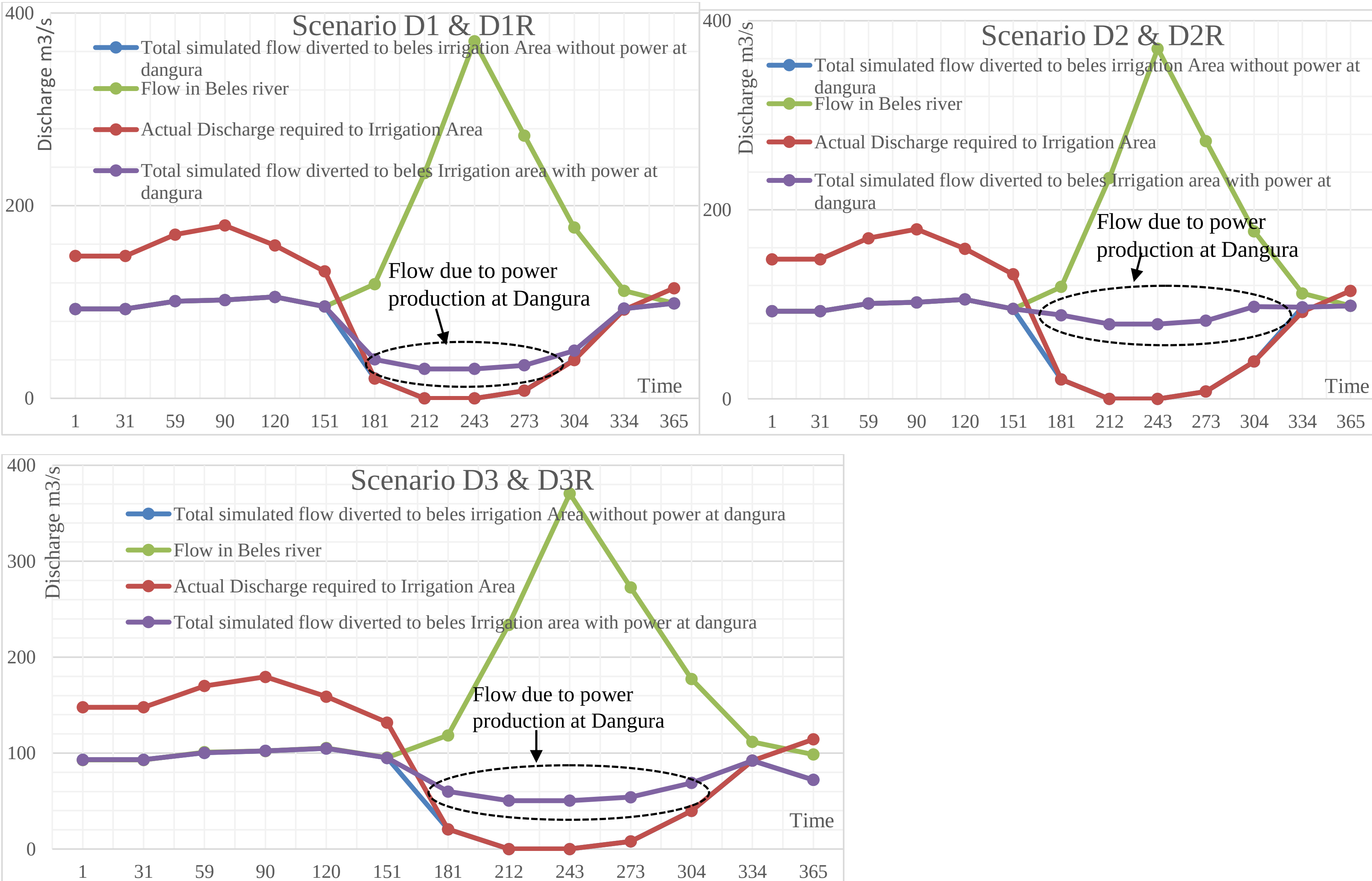
Thirdly, from the actual flow required and simulated flow to upper Beles figure 6.10 which show in scenario D1 and D1R there are a good fit with the demands and supply of water to the upper Beles irrigation area. Here full irrigation production will be possible and total irrigation area 73,871 ha will be irrigated with water. In scenario D2 and D2R, the demand and supply of water for irrigation fit only for five months of the year (August to end of November) and there are high gaps between the required amount of water for irrigation and the actual delivered water to the upper Beles irrigation area about 7 months (January to end of August and in December). Here the operation has a high effect on agricultural production in the upper Beles. For example, in scenario D2 & D2R at the end March water requirement 84 m^3/s and the actual supply is 11 m^3/s almost no product at all in upper Beles. When it comes to scenario D3 and D3R the figure seems like a better fit than in scenario D2 and D2R and the gaps would be narrow. For example, at the end March water requirement 84 m^3/s and the actual supply is 48 m^3/s which is better value than 11 m^3/s.

Finally, water does irrigate the whole Irrigation command area as we seen from the figures 6.8-10, however, from the optimum operating point of view scenario D2R are the best of those scenarios. This operation has no impact on irrigation product at the lower Beles area, but when it comes to upper Beles it has an impact on irrigation production. There is no full area coverage and the possible solution is providing two seasonal crops in the given region. Summer season crops cover the total area with full production in both sites and enough water supply. In winter season crops cover about 36.1 % of total command areas (upper Beles). As a recommendation for such problem in this study is providing seasonal crops, crops that use water efficiently and crop species with low evaporation flux, use best and efficient irrigation system instead of using furrow irrigation and overall providing of night storage at the upper Beles gives additional water to the crops. This will improve the production in upper Beles as well as lower Beles area and improve the water balance the system.

**Source: Google Image*

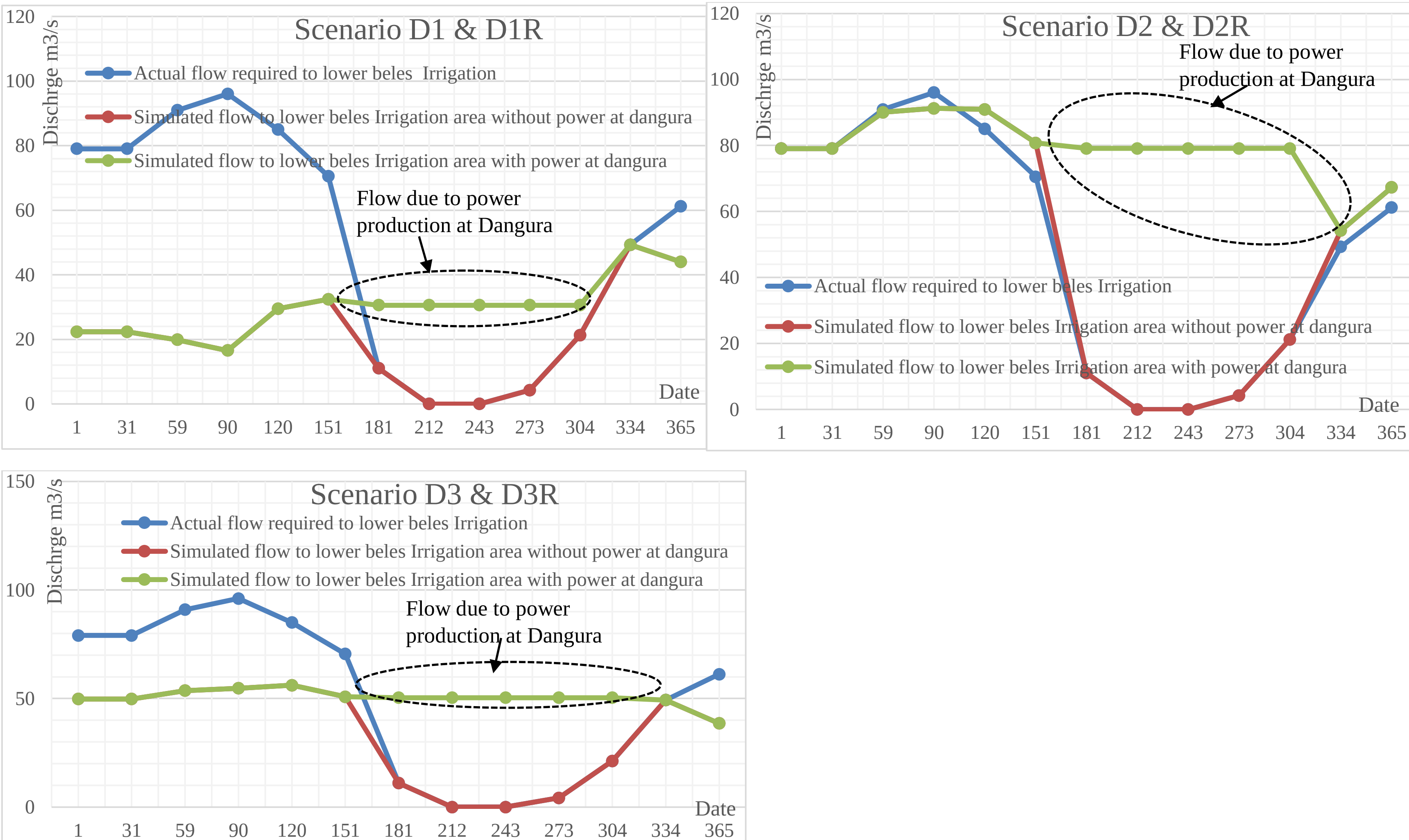
Figure 6. 8. Beles Irrigation Area

The analysis summarized as figure shown below in figure 6.8,9,10 and the simulation value and the results of all computation in the model are present in (*Appendix C.4-1 & C.4-2).*



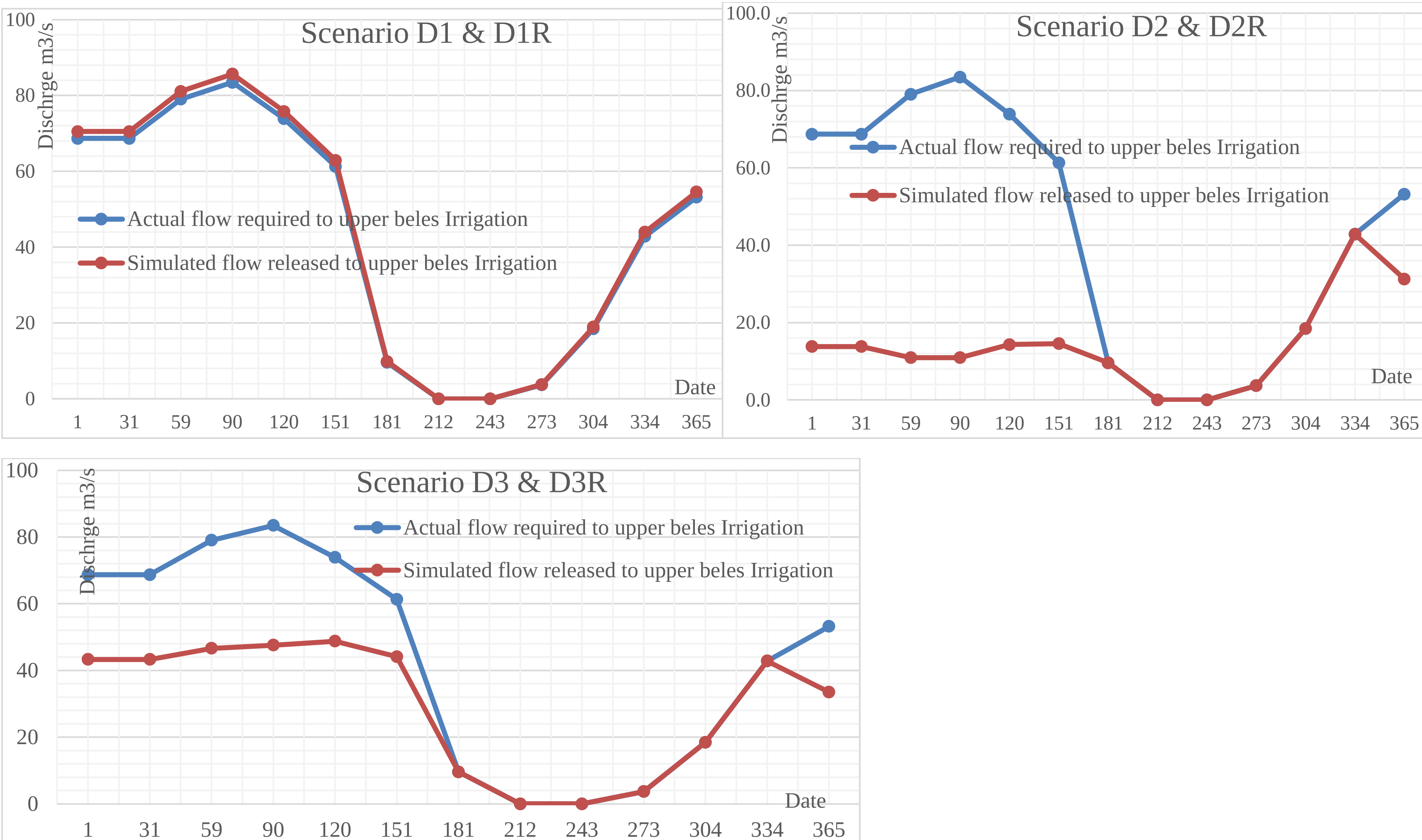
**for detail description of figures see section 6.3.1 and Appendix C.4-1 and 4-2*

Figure 6. 9. Flow in Beles river, simulated flow with and without storage and actual flow required to irrigation area in six scenario



**for detail description of figures see section 6.3.1 and (Appendix C.4-1 & 4-2)*

Figure 6. 10. The actual required and simulated flow to Lower Beles irrigation with and without power production at Dangura in six scenario

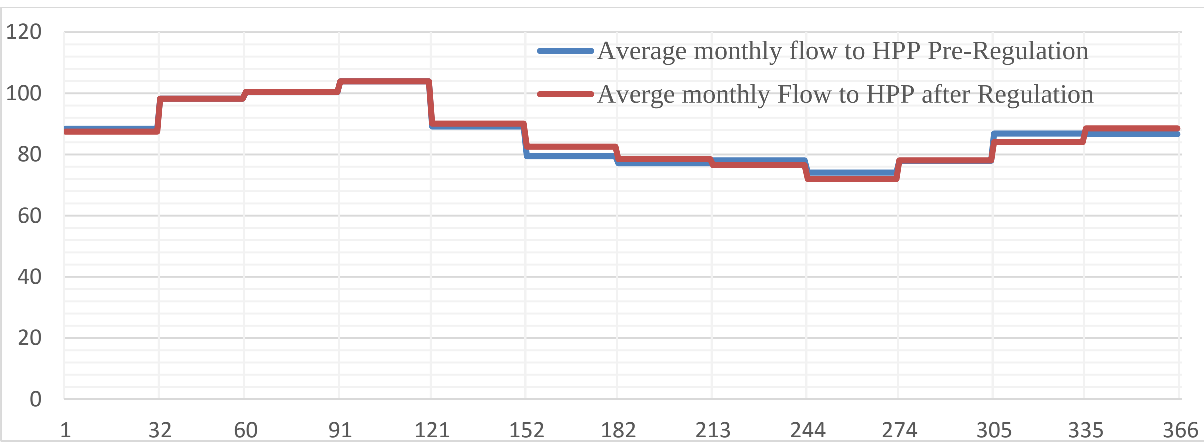


**for detail description of figures see section 6.3.1 and (Appendix C.4-1 & 4-2)*

Figure 6. 11. The actual required and simulated flow to Upper Beles irrigation in six scenario

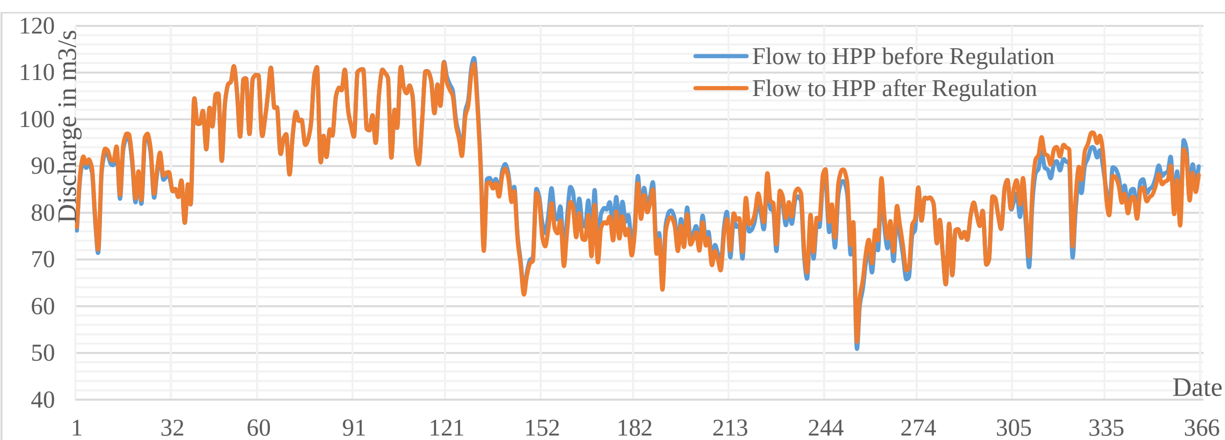
6.3.2. Impact on Power Production

Hydropower project design to generate electric power and the actual generation and the design value may not be necessarily the same, but either increase or decrease from design. This may happen due to improvement of design during construction, hydrological parameters, damage, repair and maintenance of any parts, changes of its efficiency, sedimentation, reservoir volume changes and climatic change are some of them. Like this Tana-Beles hydropower project was designed to generate 2,051 GWh annual according to Saline design and now the actual annual power generation from May 2010 to July 2015 is 2,177 GWh obtained from EEPCo which is higher with the value of 126 GWh annually. In this optimization and simulation of data with the given model, an average annual power production after regulation are 2,366, 2,357, 2,366, 2,356, 2,366, 2,360 GWh for all six scenarios D1, D1R, D2, D2R, D3 and D3R respectively and these values only considers Tana-Beles power plant productions and for details refer *(Appendix C.5)*. For the optimum solution (Scenario D2R) average monthly flow to power plant before and after simulation are graphed as shown in figure below:



**where HPP is hydropower plant*

Figure 6. 12. Average Monthly flow to power plant before and after regulation



**where HPP is hydropower plant*

Figure 6. 13. Time Flow series to HPP before and after regulation

It has possible to say the flow before and after the simulations has high degree of fits in the figure shown above and from this, selection of alternative D2R as the optimum way of operation to generate better power on the basis of this study data specification. May someone get another solution using their own data specified in a different way or on their objectives? At the end, due to Tana Beles operation, power production will increase by 189 GWh from existing and this is the positive effects of operations that was stated in this study.

In this study additional energy production would be obtained due to damming of water at Dangura site which will add additional power to the national grid. The annual average generation is 1,278 GWh at scenario D2R.

6.3.3.Impact on Lake Tana

Outflow from the Lake Tana and lake level data are available from 1959 to 2006 and 1973 to 2002 respectively, and the lake level data are measured at the Bahir Dar station. The lake level varies approximately by 1.68 m annually from average lake level of 1786.1 m between 1959 and 2006. Since the operation of the Chara-Chara weir the lake level has dropped dramatically, reaching the historical minimum water level of 1784.36 m masl at July 1, 2003 shown in figure 6.13. The outflow data of the river recorded downstream of the weir in graph below shows after weir operation starts the natural flow of the river is distributed. The average lake level will increase by 0.38 m from 1786.61 of weir annual average regulation levels.

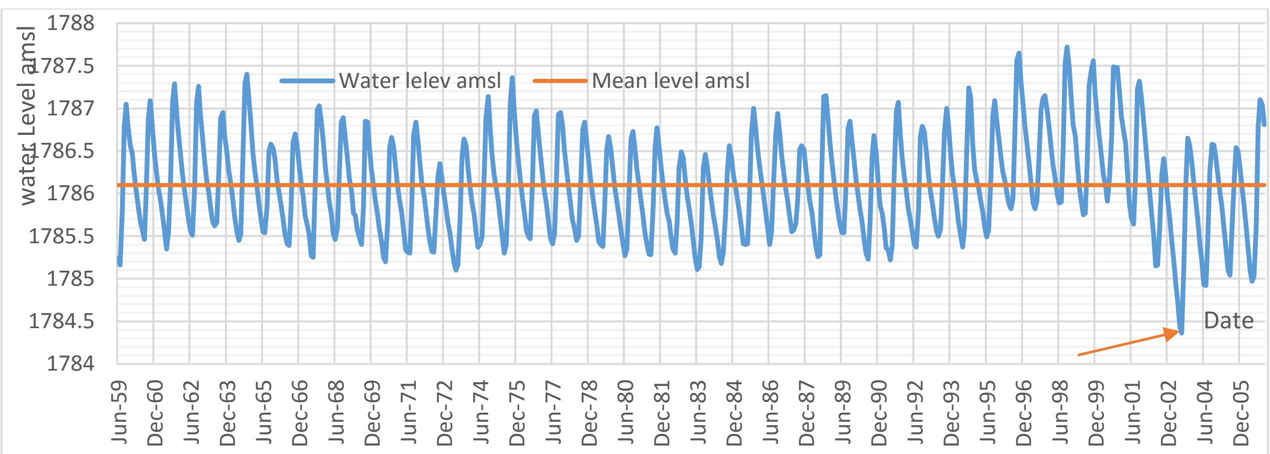


Figure 6. 14. Water Level of Lake Tana, 1959-2006

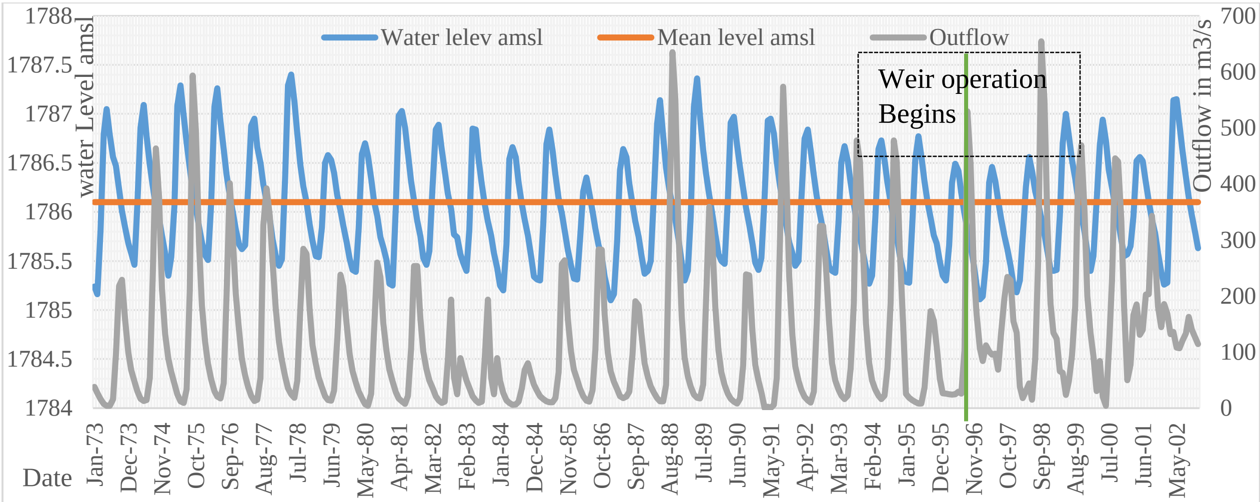


Figure 6. 15. Water Level and respective outflow of Lake Tana, 1973-2002

The lake level-outflow relationship of the Lake Tana show that for outflow discharge less than 200 m^3/s the lake level-outflow relation is scattered, also relations change from year to year. For the discharge larger than 200 m^3/s Lake level-outflow shows a better stable relationship than for low outflows. This scattered relations of water level vs out flow may due to sedimentation, water currency fluctuation and vegetation coverage in the river beds.

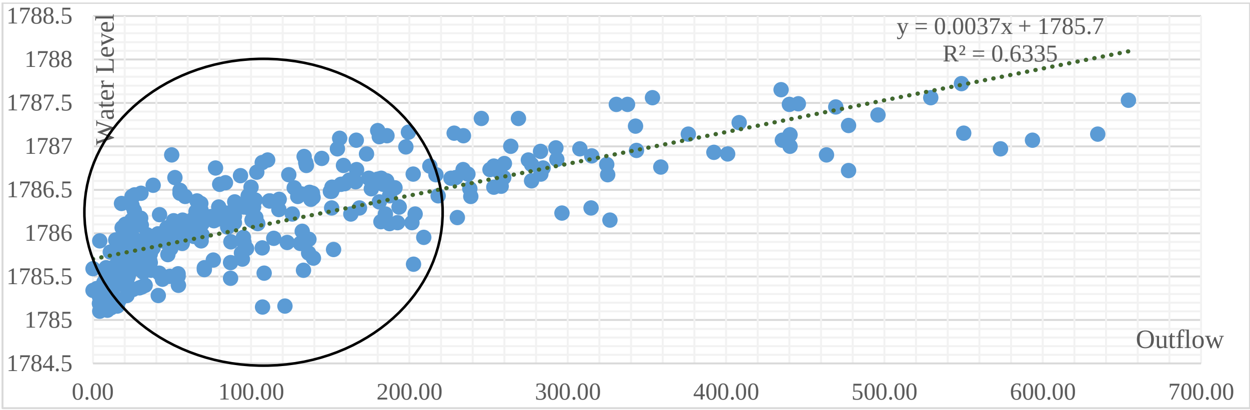


Figure 6. 16. Lake level-outflow relationship of Lake Tana

6.3.4.Impact on Water Consumption

Water consumption is the amount of water which is not released back to the natural watershed due to evaporation and product integration. The study area is a multipurpose project mainly for power and irrigation uses. The primary source of water is Lake Tana which is a natural reservoir and two tributary rivers in Beles Basin, Gilgel Beles River and Johana River.

To attain maximum outcomes it requires the damming of water at the dangur site and the dam possess a large exposed water surface area due to water reservoir that will cause loss of water by evaporation to the atmosphere. The issues that were identified recently by Bakken et al. (2013) related to water consumptions are lack of allocation of the water consumption burden amongst multiple purposes in multipurpose reservoirs, attribution of water consumption in natural water bodies, and inconsistent system boundaries. For the anthropogenic influence of the hydropower facility on the hydrologic cycle, Bakken et al. (2013) recommended that subtracting the background evapotranspiration rate from the gross reservoir evaporation rate is the way to appropriately account of it.

Assume the water consumption due to energy production in Tana-Beles HPP is negligible, since the average water level before and after operation lake area is not changed as whole shown in Lake water level section. The Lake water level is 1786.05, 1786.23 and 1786.61 masl and the respective surface area 3,090.91, 3,091.92 and 3,093.93 km^2 pre, post Chara-Chara weir operation (1996) and after Tana-Beles operation (2010) respectively shown below. Here, the surface area increased by 0.65 %. In SMEC (2008) report of lake's water balance an average annual evaporation rate is 1,675 mm in Lake Tana. The average amunt of annual water evaporated due to this change area in Lake Tana is about 3.38 Mm^3. Net water consumption will be 0.0016 m^3/Kwh.

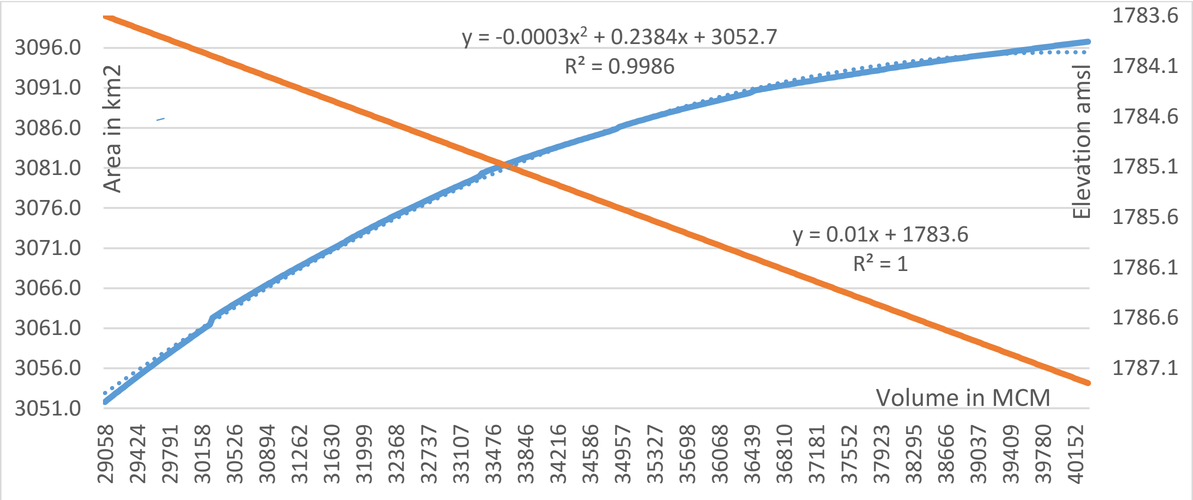


Figure 6. 17. Elevation-Volume and Area-Volume Relationship

On the other hand, in three scenario water will store in lower Beles and create an artificial reservoir for both power generations and irrigation production. Model simulation shows the amount of water lost by evaporation at this site annually is 2,370.4 Mm^3 for 634 GWh, 2,043 Mm^3 for 1,278 GWh, 2,271.9 Mm^3 for 933 GWh in scenario D1R, D2R and D3R respectively and the corresponding net water consumption will be 3.74, 1.60 and 2.44 m^3/kwh. Even in a net water consumption scenario D2R is showing better results of others. After regulation in the optimal scenario, the total annual evaporation value is 2,046.4 Mm^3 with about 1.60 m^3/kwh net water consumption value. Creation of artificial reservoirs in Beles basin has a greater and higher contribution to water consumption values in this project.

The value of irrigation product let's assume to be the same in both site and the water diverted to irrigation site does not return back to the original waterway or river. The amount of water diverted and irrigation coverages in each scenario are shown in the appendix. Bakken et al.

(2013) recently were identified some issues in water consumption includes inconsistent system boundaries, lack of allocation of the water consumption burden amongst multiple purposes in multipurpose reservoirs, and attribution of water consumption in natural water bodies. In this study water consumption in irrigation site computed using annual water release per command area coverages. The net water consumption in Beles irrigation sites is 0.0177 Mm^3 per hectare in each scenario.

6.3.5.Impact on Abbay River

Lake Tana is the main source of Blue Nile/Abbay River and the mean annual inflow to Lake Tana is about 4,986 Mm^3 (Halcrow-GIRD 2010). The mean annual outflow to the Abbay River computed from hydrological discharge series recorded at the outlet of Lake Tana is about 3,947 Mm^3 with an average discharge of 125.2 m^3/s. Because of the restriction at its outlet in Bahir Dar (Chara-Chara weir), the lakes, large area and storage capacity, water resource development in and around the basins, the outflow of the Abbay River will influenced.

In the operation of Tana-Beles Multipurpose project, 70.33 % of the total amount of annual water outflow from the lake would be diverted and flow to another basin, Beles basin and the remaining amount of regulated water will flow in the downstream, Abbay River. In the optimum operation of this study, 978.8 Mm^3 mean annual water released into Abbay Rivers and it is better value than the value 490 m^3/s recommended by Salini and Pietrangeli, 2006 for ecological functioning, environmental consideration as well for the visually of Tis Issat Waterfall and the average flow will decrease to 24.6 % from natural flow. Due to high active storage of Lake Tana about 9,251.7 Mm^3 which is about 2.34 times the average annual outflow (3,947 Mm^3) will have an impact to the downstream and its main advantages of this optimum operation are to release regulated and seasonal water. So the ecological functioning, morphology and hydraulic properties of the river, the aesthetic value of waterfall are highly influenced from the natural flow before the project implemented. On the other hands, problems related to flooding in the river are decreased as the consequences of regulated and diverted flow.

6.3.6.Impact on Beles River

Starting from May, 2010 water would divert from lake to Beles catchment with an average amount of 86.6 m^3/s and the total amount of water 2,963.8 Mm^3 released annual. Before this project Beles River was seasonal river and now due to the continuous supply of water the river flow changes from seasonal river to a perennial river flow. Without irrigation development in the catchment the average flow changed by about 2.6 times the previous flow in upper Beles and 2.2 times the previous flow in lower Beles. Due to storage in lower Beles a regulated water will flow in the lower Beles River.

The ecological and the morphology of the river could be changed, especially in upper Beles at the time of flood/high water flow the release of additional water may have negative impacts results the phenomena of erosion, sedimentation and morphology changes. Maximum release from the power plant is 160 m3/s and the maximum flow of river occur in August with an amount of 236.5 m3/s. At the time of meeting this two maximum flow, the river will influence negatively and it depends on the morphology and soil types of existing river.

Generally, it has positive and negative impact depending on the amount of water and time of flow. The morphology, hydraulic properties of the river now depend upon the amount of water diverted from power plant incorporated with the natural flow in the river. For those negative impacts mitigation measures must be handle to minimize the impact or totally to avoid it.

6.3.7.Impact on Environmental Aspects

Water demand and water user sectors in the Tana-Beles Basins that are affected by the planned water resources developments, but do not benefit from them are: Fisheries, Navigation, Tourism and Environment (SMEC 2008) and they are treated under the Environmental Impact as well as Scio-Economic.

Fish breeding generally takes place in the vegetated areas along the shore of the lake. The rivers entering Lake Tana also provide breeding areas for the lake fish. Fish travelling upstream for spawning as far as 80 km has been observed on the Ribb River. Spawning occurs towards the end of the wet season. In September Barbs aggregate at the river mouths, where up to 90 % of all Barbs may be sexually mature. After hatching, fry development takes place in the rivers and the young Barbs spend the first years in the rivers before returning to the lake (SMEC 2008). Lake level more or less stable due to the regulation of the weir and the sediment gets the chance to settling down. This may affect the spawning, breeding and migration behavior of the fish and result in a decline of the fish population and production.

Navigation on Lake Tana plays an important role in the transport of people and goods. According to the Enterprise, the minimum level of the lake should be 1,785 masl. However, according to this study there will be a problem of navigation, especially at the time of the dry season and result the access to markets, schools, and health facilities are seriously affected during the operation of the lake between the level of 1784 and 1785 masl. Since the minimum operating level of the lake is 1,784 masl which is below the recommended level. So, it needs a solution to mitigate it for suitable and comfortable navigation in the lake to attain social activities and increasing tourism value since within Lake Tana, it has a number of the monastery's that will be visited by a number of people.

Lake Tana is an important tourist destination in Ethiopia. From Bahr Dar boat trips are made on the lake to visit ancient monasteries on the various islands. Near Bahir Dar, Tis Issat waterfall is a major tourist attraction located about 35 km south-west of the town. The 70.33 % of outflow of from Lake Tana will divert to Beles basin, result the flow of Abbay River is reduced and this will have a pronounced impact on the biodiversity as well as attractively of the waterfall.

Whereas in the Beles, the biodiversity impacts are thought to be much less, but here morphological changes may be quite significant. Damming of water in dangur will also change the biodiversity in damming area. Some disease may introduce due to artificial storage in Beles and non-wetland species will replaced by wetland species.

In case of high rainfall, flooding will the main problem for irrigation area and also have an impact on both the morphology and hydraulic properties of the river together with water released from Tana-Beles power plant.

6.3.8.Impact on Socio-economic Aspects

There will be a substantial increase in employment and income in the Tana-Beles area due to the water resources developments related to agriculture and hydropower, and their multiplier effects on other sectors. And, additional energy will add to the national grid, which will boost the Scio-economic activity of the country, Ethiopia.

Water released to Tis Issat waterfall is reduced and the economic benefit obtained from tourist will reduced and the water resource development project in and around Lake Tana will influence the production of fish result reduction of economic benefits. But, it needs special study about this scenario.

Creation of an artificial storage in lower Beles will introduce fish spawning and breeding and this results the start of an economic activity in the region. In addition, the site will become a tourist attraction due to artificial water body storage and some lake bird treat like a bird treat in Lake Tana which results an increase of socioeconomic activity in the region. However, the potential of irrigation area covered would be about 71 % and this may introduce the settlement of peoples in the region, but due to the constraint of data it is not included in this study of how many people will be resettle.

6.4.Future Water Resource Development

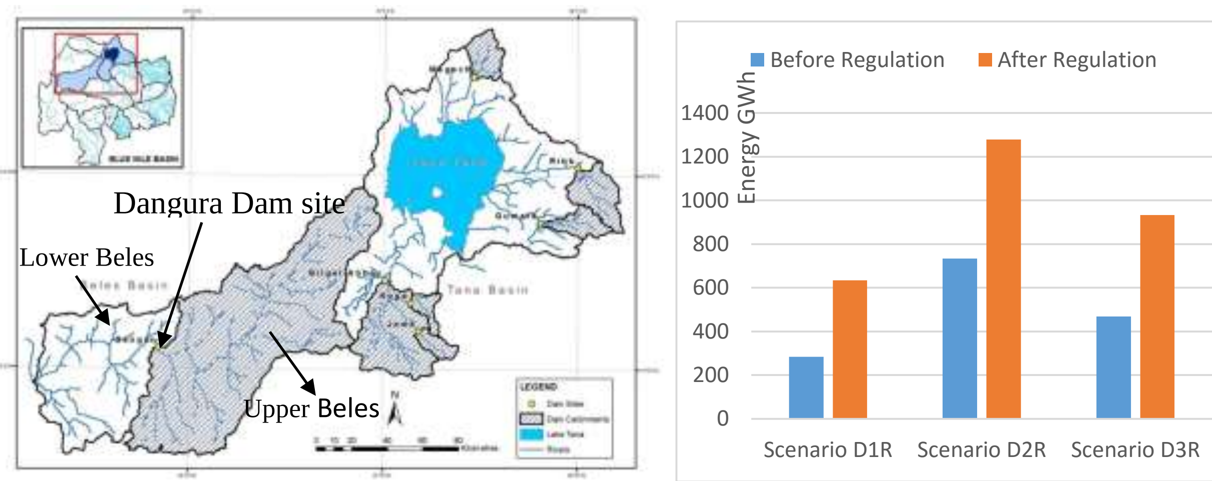
Tana-Beles Sub-Basins are rich in water resources and intensive water resource development projects are implemented around Tana-Beles basin and there are some study under pre-feasibility and feasibility stage in the basin. Integrated planning, management, and development in the Tana and Beles Sub-basins are very crucial to accelerate sustainable growth in the region as well as the whole Ethiopia.

In this study it is focused on the future development, water resource project within and along the downstream of Beles basin which are linked with Lake Tana water diversion. Here the water is diverted from Lake Tana to Tana-Beles HPP to generate power and directly joins to the Johana River in another basin, Beles basins. There are constraint of sufficient data in and around Beles basin, and in this study it only concerned with the development of project in upper and lower Beles regions under data limitations and it focused on the feasible project of power plant, Dangura.

Harcrow-GIRD (2010) report recommend to damming of water at the place of Dangura to use water in the dry season for irrigation after generating 98 MW power. In this paper, it focuses to study this site, whether feasible or not with the aid of nMAG model for further improvement and it considered as a new project in this paper. From previous study the site has the capability of storing an amount of 4,640 Mm^3 average annual water.

The location of dam site is at 11⁰06'3'' N, 35⁰05'30'' E, and is reported to have better stage-storage properties. A 120 m high dam would store about 4,640 Mm^3. The natural catchment of the Dangur dam is 8,980 km^2 larger and its reservoir would flood about 12,000 ha. Using availability of data, the Dangur dam is much cheaper than for the Enat Beles dam with the same dam height in cost per volume stored (Halcrow-GIRD 2010).

Here, using the information that investigated from Halcrow -GIRD (2010) the site is checked either feasible or not with the existing multipurpose project. In this study the site considered as to store water in the wet season and use it at the time of the dry season. The exceptional cases in this study is at the time of wet season almost irrigation area do not need any amount of water that will be diverted, but it will continuously release water to generate almost uniform power for five months without using of whole water diversion into irrigation. The actual water release from Dangura dam to irrigation after producing power within five months are not totally used since the amount of water required to power higher than irrigation (almost zero for irrigation due to high rainfall). This project simulated in nMAG model with three scenario cases (D1R, D2R and D3R). The model result shows the dam site receive 4,750.7 Mm^3 average annual water to store and used to power generation as well as to irrigation timely. From this average annual amount of water about 2,592 Mm^3 water lost annually from the reservoir as evaporation and 2162.9 Mm^3 amount used to generate power and to irrigate lower Beles irrigation area.



**Source of map: Halcrow-GIRD (2010)*

Figure 6. 18. Location of Dangura Dam and Energy Production before & after simulation

The Power generation results of the site before and after simulation with 50.4 m^3/s average annual flow in three scenarios shown above figure and from optimizing scenario the one with 1,278 GWh energy production is selected, i.e scenario D2R. The maximum discharge capacity is 92.5 m^3/s and it assume 90 % total efficiency of the system.

6.5.Mitigation

To optimize the overall benefits for the beneficiaries and to minimize at the same time the negative impacts to different sectors, operation and regulation rules have to be set up to control the water level in Lake Tana as well as the releases of water. Implementation of the operation of Tana-Beles project is not totally free from negative impact, but for optimum operation, regulation and to minimize the negative impact introducing of mitigation measures are so importation.

One mitigation measure is proper regulation of Chara-Chara weir which is very important to minimize high fluctuations of water level in the lake even upgrading and improvement of design will also solve the problem of being water level below 1,785 masl mainly for navigation. Buoying and dredging of the lake also another way, but it need the detail cost analysis. Release of regulated water to the downstream also critical to preserve the aesthetic view of Tis Issat Waterfall and the ecological functioning in the downstream of Abbay River.

Lake Tana gives navigation service and when water level is below 1,785 masl there will be a problem of transportation according to Amhara Transport Agency report. Providing special boat design and changing the size of boat and changing of routs in the lake considered as mitigation for navigation problems.

On the Beles River, small weir and energy dissipation structures will construct to dissipate energy of turbulent flows as mitigation against environmental damage in the downstream and to maintain the morphology and hydraulic characteristics of the river. Providing feasible drainage structure is quite important to maximize irrigation product and to avoid flooding of irrigation area and changing of the morphology and hydraulic properties of Beles River.

Finally, to maintain stable water balance and to minimize negative impact in the region, proper, organized and sustainable watershed management practice will be adopted in the region. Specially watershed management around Lake Tana is so important and have direct impacts. This leads to minimize yearly variations of the inflow and outflow of the basin and climatic change will be minimized.

7.Conclusion and Recommendations

7.1.Conclusion

This study analysis the power production and irrigation coverages of the operational Tana-Beles Multipurpose hydropower project and the envisioned water resource development (under feasibility study) in Beles basin employing nMAG2004 model.

The optimization operation is undertaken through the development of scenarios using nMAG model. Accordingly, scenario D2R is selected as it allows capturing environmental flow perspective, the amount of water released, power production, irrigation coverages and water requirement, water consumption and energy equivalent basis. Based on this scenario the study concluded the need to prioritize the lower Beles irrigation area than the upper Beles through damming of water on Dangura site. Moreover, in order to get extra water the study concluded to store spill water by upgrading the maximum regulation of Chara-Chara weir to 1787.2 masl, and releasing seasonal variable water to the downstream of Lake Tana. Hence, the mean annual water release will be 978 Mm^3 which is higher than 862 Mm^3 recommended value by Bellier et al. (1997) and lower by 17 Mm^3 recommended value of McCartney et al. (2009). It concluded that the environmental flow value re-examined in this study satisfy the ecological function and aesthetic value of waterfall in Abbay river.

Productions of maximum energy in this project is the primary objective of this study. The mean annual energy production will be 2,356 and 1,278 GWh for Tana-Beles and Dangura power plant respectively, and it concluded that scenario D2R gives higher production than existing system and the remaining scenarios.

The study intends to supply enough water to irrigation area. To attain optimum production, I conclude to give priority to lower Beles with 100% (85,000 ha) irrigation area coverage. At the same time, only 36.1 % of upper Beles irrigation area will irrigate and overall 71.2 % of the total irrigation area in Beles basin, 113,117 ha will irrigate with sufficient water. It will divert an amount of 2,968 Mm^3 mean annual water lake to meet the objectives of this study.

The study also covers the damming of water at lower Beles and simulated with nMAG model. Damming of water improves irrigation product by 1% and will add 1,278.1 GWh mean annual power to the national grid. However, 39.1 % of the total mean annual available water will be lost due to the construction of artificial storage. The artificial reservoir become tourism site in the region and will start fishing and water transport in the site in additions to incrasing power production and irrigation coverage. So, I suggest a dam to be constructed in this site.

The study employed nMAG model which is used to run within the given data specification and hence become quite feasible and applicable. The model is also used to check the feasibility of Dangura power plant and water flow link in the whole system. The model also address the amount of irrigation area covered that incorporate with the availability of water and the amount of water lost as a result of evaporation. Generally, the water balance of the whole system is determined and optimized using the model. An extra optimization of this model requires complementation of other software but for the purpose of this study, nMAG model is sufficient to optimize this project.

7.2.Recommendations

Within and around the project area, a number of ongoing, under study and operation water resource development projects are there and it boosts the development of the country, Ethiopia in different sectors. The development of those project influence this project, so, I suggest to apply well manage, control and regulate integrated water resource study before project implementation to maintain the sustainable benefit.

I recommend to construct night storage in irrigation area to solve and minimize the problem of evaporation, and to increase irrigation productivity and energy production. I also recommend to change boat design, the size of boat and water way routs, and may dredging of the shallow part of the lake if it is feasible and economically feasible.

Total Beles irrigation area is not fully covered due to insufficient availability of water, and most of irrigation system in this area is furrow/surface irrigation which demands high amount of water. So, I suggest to introduce high efficiency of irrigation systems like drip, sprinkler irrigation system which leads to increase irrigation area coverage and reduce the probability water loss through evaporation. I also suggest to use seasonal grow plants and plants with low water demanding.

Overall, I recommend to implement watershed practices and management activities in both basins to preserve storage from sedimentation, pollution and further reduction of water level, and to maximize both production.

Generally, the water balance of the whole system is determined and optimized using nMAG model. An extra optimization and analysis of this project requires complementation of other software but for the purpose of this study, nMAG model is sufficient to optimize it.

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Appendix

Appendix A. Hydro-Meteorological Data and Analysis

Appendix A. 1. Meteorological Data and Analysis

Appendix A. 1-1 Climatic data and ETo for Beles command area

Month	Min. Temp (°C)	Max. Temp (°C)	Average Temp (°C)	Humidity (%)	Wind (km/day)	Sunshine (hr)	ETo (mm/day)
January	12.4	34.5	23.4	65.3	41.1	9.6	3.95
February	14.3	36.2	25.3	63.6	55.1	9.3	4.51
March	17.6	37.4	27.5	59.1	75.6	8.7	5.09
April	19.0	37.3	28.2	62.9	74.5	8.8	5.32
May	19.3	34.5	26.9	65.4	82.1	8.0	4.97
June	18.1	29.8	23.9	81.0	81.0	6.3	3.97
July	17.8	27.7	22.8	86.0	60.5	4.6	3.31
August	17.6	27.7	22.7	89.6	57.2	4.8	3.33
September	17.3	29.0	23.2	85.8	49.7	6.1	3.67
October	16.9	30.4	23.7	85.0	33.5	7.3	3.79
November	14.4	32.3	23.3	77.2	30.2	9.4	3.93
December	12.3	33.6	23.0	69.0	35.4	9.8	3.81
Mean	**16.4**	**32.5**	**24.5**	**74.2**	**56.3**	**7.7**	**4.14**

**data source. Amhara Design & Supervision Works Enterprise (Feasibility and design study of TBIDP: Tana-Beles Integrated Development Project)*

Appendix A. 1-2 Climatic data for Pawe, Bahir Dar and Gonder gauge stations

Station	Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pawe	Max Temp (ºC)	34.3	36.0	37.1	37.2	33.7	29.8	27.2	27.6	28.8	29.9	32.3	33.5
	Min Temp (ºC)	12.5	14.9	18.2	19.3	19.2	18.0	18.0	17.5	17.3	16.7	13.9	12.3
	Humidity (%)	73.4	69.8	66.0	69.7	74.2	86.5	84.3	83.4	92.3	91.3	86.2	73.4
	Sunshine (hrs)	9.6	9.5	7.5	9.8	8.7	6.4	4.9	4.7	5.9	7.4	9.6	9.9
	Wind (m/s)	0.62	0.77	0.95	0.95	1.01	1.00	0.78	0.68	0.65	0.45	0.40	0.45
Bahir Dar	Max Temp (ºC)	26.6	28.0	29.5	29.8	28.8	26.5	23.9	23.8	25.2	26.1	26.2	26.1
	Min Temp (ºC)	7.0	8.6	11.5	12.6	14.0	13.7	13.4	13.3	12.5	11.9	10.0	6.7
	Humidity (%)	54.5	48.0	44.6	44.5	56.3	69.7	78.4	79.2	75.2	67.0	60.7	57.2
	Sunshine (hrs)	9.7	9.4	8.6	8.9	8.0	6.9	5.1	5.1	6.6	8.7	9.5	9.5
	Wind (m/s)	0.6	0.6	0.7	0.8	0.7	0.7	0.6	0.6	0.6	0.6	0.5	0.5
Gondar	Max Temp (ºC)	27.6	28.8	29.6	29.4	28.3	25.3	22.6	22.7	24.8	26.0	26.6	26.8
	Min Temp (ºC)	10.9	12.2	14.3	15.2	15.0	13.8	13.3	13.0	12.6	12.2	11.7	10.9
	Humidity (%)	40.2	36.3	35.2	38.4	49.3	68.0	79.5	79.4	72.4	61.5	49.3	44.4
	Sunshine (hrs)	9.3	9.0	8.2	8.0	6.6	4.6	4.3	4.9	7.0	7.7	9.0	8.9
	Wind (m/s)	1.6	1.8	1.9	1.8	1.9	1.9	1.4	1.2	1.4	1.3	1.4	1.5

**data source. Amhara Design & Supervision Works Enterprise (Feasibility and design study of TBIDP: Tana-Beles Integrated Development Project)*

Appendix A. 1-3 The mean monthly distribution of rainfall for five rainfall station

Station	Stat.	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Bahir Dar	Mean	1.7	3.1	13.9	22.3	74.8	208.7	438.8	390.3	211.9	111.3	8.8	3.7	1489.2
	St.dev	2.9	6.0	17.0	25.0	55.6	71.1	114.5	94.7	46.6	55.6	13.8	4.3	507.2
	CV	1.7	1.9	1.2	1.1	0.7	0.3	0.3	0.2	0.2	0.5	1.6	1.1	1.1
Dangila	Mean	1.2	3.6	22.5	38.5	144.7	269.5	348.7	359.7	240.4	134.9	34.1	5.9	1603.6
	St.dev	1.8	5.4	31.3	30.3	67.5	55.7	72.7	53.4	52.6	78.0	28.0	10.3	487.2
	CV	1.5	1.5	1.4	0.8	0.5	0.2	0.2	0.1	0.2	0.6	0.8	1.8	1.1
Enjibara	Mean	8.2	6.8	32.9	64.4	202.0	357.4	496.3	514.0	382.7	192.1	56.6	15.9	2329.3
	St.dev	9.3	9.1	26.5	48.4	84.6	76.7	80.4	68.3	69.4	103.1	58.2	17.0	651.0
	CV	1.1	1.3	0.8	0.8	0.4	0.2	0.2	0.1	0.2	0.5	1.0	1.1	1.1
Gondar	Mean	2.2	3.5	16.8	36.8	84.4	154.3	285.1	269.6	109.4	71.1	19.9	7.8	1060.9
	St dev	5.2	7.2	17.1	30.7	50.3	60.0	48.5	50.1	35.2	52.4	17.1	11.4	385.1
	CV	2.3	2.0	1.0	0.8	0.6	0.4	0.2	0.2	0.3	0.7	0.9	1.5	1.1
Pawe	Mean	0.1	0.5	6.7	26.3	111.9	283.6	345.3	382.8	260.2	144.4	13.0	1.1	1576.0
	St.dev	0.4	1.8	12.4	24.2	68.5	86.1	70.3	74.9	119.1	50.8	13.1	1.8	523.4
	CV	3.9	4.0	1.8	0.9	0.6	0.3	0.2	0.2	0.5	0.4	1.0	1.7	1.1

**data source. Amhara Design & Supervision Works Enterprise (Feasibility and design study of TBIDP: Tana-Beles Integrated Development Project)*

Appendix A. 2. Hydrological Data and Analysis

Appendix A. 2-1 Discharge gauging station locations in Tana Basin

SL No.	MAIN CATCHM.	SUB CATCHM.	STN. No.	RIV/LAKE	SITE	LAT.	LON.	UTM North	East
1	ABBAY (11)	LAKE TANA 1	111001	LAKE TANA	@ BAHIR DAR	**11d36'n**	**37d23'e**	**1282709**	**323731**
2	ABBAY (11)	LAKE TANA 1	111002	GELGEL A.	Nr. MARAWI	**11d22'n**	**37d02'e**	**1257136**	**285380**
3	ABBAY (11)	LAKE TANA 1	111003	KOGA	@ MERAWI	**11d22'n**	**37d03'e**	**1257124**	**287200**
4	ABBAY (11)	LAKE TANA 1	111004	LAKE TANA	@ GORGORA	**12d14'n**	**37d18'e**	**1352816**	**315072**
5	ABBAY (11)	LAKE TANA 1	111005	RIBB	Nr. ADDIS ZEMEN	**12d00'n**	**37d43'e**	**1326761**	**360284**
6	ABBAY (11)	LAKE TANA 1	111006	GUMARA	Nr. BAHIR DAR	**11d50'n**	**37d38'e**	**1308372**	**351119**
7	ABBAY (11)	LAKE TANA 1	111007	MEGECH	Nr. AZEZO	**12d29'n**	**37d27'e**	**1380370**	**331553**
8	ABBAY (11)	LAKE TANA 1	111009	UPPER RIBB	ON D.TABOR ROAD	**12d03'n**	**37d59'e**	**1332169**	**389339**
9	ABBAY (11)	LAKE TANA 1	111010	ANGAREB	Nr. GONDER	**12d38'n**	**37d29'e**	**1396941**	**335272**
10	ABBAY (11)	LAKE TANA 1	111011	LAKE TANA	@ KUNZILA	**11d54'n**	**37d00'e**	**1316163**	**282157**
11	ABBAY (11)	LAKE TANA 1	111013	ZUFIL	Nr. DEBRE TABOR	**11d50'n**	**38d05'e**	**1308171**	**400146**
12	ABBAY (11)	LAKE TANA 1	111014	GELDA	Nr. AMBESSAME	**11d42'n**	**37d38'e**	**1293625**	**351047**
13	ABBAY (11)	LAKE TANA 1	111015	RIBB	Nr. GASAI	**11d48'n**	**38d09'e**	**1304462**	**407397**
14	ABBAY (11)	LAKE TANA 1	111016	GEMERO	Nr. MAKSEGNIT	**12d23'n**	**37d33'e**	**1369249**	**342362**
15	ABBAY (11)	LAKE TANA 1	111017	FEGODA	Nr ARB GEBEYA	**11d38'n**	**37d46'e**	**1286186**	**365549**
16	ABBAY (11)	LAKE TANA 1	111018	GARNO	Nr. INFRANZ	**12d14'n**	**37d37'e**	**1352620**	**349526**
17	ABBAY (11)	LAKE TANA 1	111019	EZANA	Nr. BAHIRDAR	**11d29'n**	**37d24'e**	**1269795**	**325476**
18	ABBAY (11)	LAKE TANA 1	111020	BERED	@ MEREWI	**11d25'n**	**37d10'e**	**1262572**	**299971**
19	ABBAY (11)	LAKE TANA 1	111021	AMEN	@ DANGILA	**11d16'n**	**36d52'e**	**1246201**	**267104**

**data source. Tana Sub Basin Organization (TaSBo), Bahir dare*

Appendix A. 2-2 Average daily runoff values of five gauge stations from 1983 to 2002

Date	Abbay/ Blue Nile	Gilgel Beles@ Mandura	Main Beles @Brigde	Gumar	Gilgel Abbay	Date	Abbay/ Blue Nile	Gilgel Beles@ Mandura	Main Beles @Brigde	Gumar	Gilgel Abbay
1	100.94	2.28	4.99	5.09	7.43	184	37.34	29.68	36.27	38.56	81.73
2	99.83	2.27	4.92	4.80	7.56	185	38.91	36.80	51.90	32.09	96.07
3	102.12	2.32	4.80	4.73	7.37	186	42.59	23.56	54.25	30.16	92.41
4	97.02	2.18	4.78	4.58	7.29	187	41.29	17.40	52.92	42.52	100.60
5	94.95	2.16	4.93	4.03	5.28	188	41.57	19.33	57.39	45.72	105.92
6	89.82	2.05	4.84	3.98	5.22	189	45.50	21.83	70.24	42.88	108.85
7	85.89	2.08	4.81	3.94	5.15	190	43.42	22.52	77.57	57.79	116.11
8	84.36	2.08	4.73	3.86	5.03	191	45.09	25.43	58.14	63.86	122.38
9	83.88	1.98	4.64	3.77	4.93	192	45.13	19.48	55.91	56.00	112.34
10	82.74	2.11	4.55	3.71	4.84	193	43.11	23.29	100.11	54.59	134.68
11	85.14	1.89	4.52	3.60	4.72	194	44.17	35.75	116.16	55.21	138.70
12	87.24	1.86	4.44	3.54	4.69	195	48.53	32.77	143.93	64.07	146.21
13	87.75	1.97	4.36	3.47	4.53	196	48.80	31.16	101.30	48.28	137.65
14	87.00	1.83	4.43	3.43	4.53	197	54.31	39.46	126.30	79.51	147.27
15	86.73	1.78	4.39	3.39	4.53	198	55.11	34.07	94.96	104.80	160.78
16	85.60	1.84	4.33	3.33	4.53	199	53.97	40.49	109.58	78.45	166.29
17	85.10	1.81	4.30	3.29	4.41	200	53.75	40.89	117.75	79.03	167.09
18	83.95	1.80	4.25	3.23	4.34	201	54.28	37.72	138.11	91.62	165.07
19	82.96	1.69	4.19	3.15	4.30	202	60.09	37.53	109.70	100.98	162.86
20	82.60	1.60	4.11	3.09	4.21	203	62.53	37.41	104.55	84.49	147.17
21	78.64	1.56	4.04	2.99	4.19	204	68.81	42.30	152.69	87.71	155.24
22	74.73	1.54	4.00	2.92	4.10	205	67.21	45.81	132.74	112.36	178.88
23	73.90	1.70	3.93	2.87	4.02	206	66.17	41.36	136.81	115.38	176.42
24	73.69	1.63	3.87	2.88	3.97	207	66.67	45.51	181.45	98.21	174.19
25	73.09	1.63	3.96	2.81	3.95	208	67.42	48.51	164.80	120.68	180.25
26	72.41	1.60	3.82	2.72	3.86	209	71.09	51.82	194.41	139.36	175.99
27	71.24	1.48	3.64	2.64	3.81	210	73.70	46.58	176.95	152.70	188.05
28	65.56	1.47	3.57	2.60	3.77	211	79.08	59.31	177.78	156.32	196.89
29	65.13	1.47	3.47	2.62	3.70	212	84.06	54.06	205.80	159.16	177.12
30	64.78	1.34	3.40	2.54	3.64	213	83.47	42.80	155.15	149.93	194.87
31	63.83	1.36	3.32	2.47	3.57	214	84.20	51.05	163.51	141.02	184.64
32	63.53	1.45	3.26	2.45	3.55	215	88.70	51.76	162.52	142.67	200.29
33	63.83	1.45	3.48	2.42	3.50	216	92.00	49.01	191.18	149.03	166.33
34	62.97	1.44	3.22	2.39	3.46	217	94.97	51.90	188.75	134.58	180.51
35	62.76	1.41	3.12	2.40	3.45	218	96.67	49.21	201.21	149.14	172.28
36	62.06	1.41	3.07	2.37	3.41	219	102.82	51.47	192.19	164.37	200.53
37	61.59	1.39	3.03	2.34	3.33	220	98.88	50.26	169.85	164.58	206.00

38	61.31	1.35	3.00	2.30	3.29	221	100.40	49.34	164.68	155.01	181.67
39	60.44	1.31	2.96	2.27	3.27	222	103.31	62.99	221.34	154.29	201.64
40	57.40	1.24	2.93	2.12	3.18	223	105.26	55.93	209.76	140.93	181.98
41	54.64	1.14	2.87	2.04	3.15	224	109.41	56.80	209.85	148.05	184.07
42	53.70	1.11	2.84	2.00	3.03	225	126.25	60.54	260.30	143.17	187.10
43	53.28	1.09	2.82	1.96	2.99	226	129.72	65.20	257.70	161.40	211.23
44	52.32	1.08	2.78	1.92	2.96	227	126.42	69.63	202.51	174.23	210.66
45	51.79	1.09	2.73	1.90	3.04	228	129.32	62.52	259.62	184.58	205.07
46	51.89	1.06	2.69	1.86	3.00	229	137.62	70.32	269.74	157.30	194.31
47	57.04	1.06	2.65	1.83	2.97	230	139.15	65.08	282.57	160.58	210.16
48	60.85	1.18	2.58	1.81	2.91	231	143.97	59.81	287.21	164.73	201.89
49	60.59	1.29	2.57	1.83	2.88	232	153.12	52.04	246.49	155.12	205.01
50	59.96	1.07	2.55	1.81	2.79	233	184.36	51.48	232.92	157.81	206.62
51	59.57	1.04	2.52	1.71	2.76	234	169.33	55.31	221.65	145.59	208.34
52	59.45	1.02	2.36	1.68	2.71	235	165.86	55.23	283.38	148.79	193.56
53	59.18	1.00	2.34	1.64	2.69	236	186.33	69.86	283.53	141.41	207.22
54	58.62	0.99	2.30	1.63	2.70	237	190.61	63.57	207.58	146.37	185.57
55	58.02	0.97	2.29	1.61	2.69	238	195.62	59.88	201.85	153.75	189.41
56	57.71	0.95	2.27	1.61	2.72	239	205.51	67.27	243.06	146.51	217.34
57	51.95	0.93	2.20	1.60	2.68	240	212.48	66.22	240.71	142.64	186.97
58	50.13	0.90	2.17	1.58	2.58	241	223.37	66.73	234.75	151.29	185.29
59	49.99	0.88	2.13	1.53	2.59	242	228.42	64.91	208.12	139.73	183.07
60	49.45	0.87	2.10	1.52	2.58	243	238.80	58.79	264.45	127.76	192.80
61	49.09	0.88	2.08	1.47	2.58	244	247.20	54.37	249.01	142.65	186.69
62	48.79	0.89	2.04	1.44	2.58	245	253.71	58.97	222.70	143.82	177.41
63	48.34	0.89	2.01	1.43	2.53	246	263.15	58.81	249.55	131.10	194.03
64	48.17	0.89	1.97	1.40	2.50	247	272.16	60.62	270.21	139.55	179.57
65	47.86	0.94	1.95	1.59	2.62	248	283.80	53.67	256.85	150.05	168.31
66	47.56	0.91	1.93	1.98	2.55	249	296.99	57.10	252.38	136.27	172.35
67	47.03	0.88	1.90	1.93	2.46	250	303.16	57.83	230.54	107.82	158.01
68	46.77	0.86	1.90	1.94	2.43	251	309.65	54.24	202.15	124.45	174.69
69	46.17	0.88	1.89	1.26	2.38	252	323.96	54.97	224.74	102.22	173.96
70	45.18	0.93	1.88	1.24	2.37	253	333.26	52.10	235.25	104.20	173.19
71	43.79	0.93	1.96	1.24	2.29	254	347.19	50.81	226.84	112.56	166.42
72	42.24	0.91	1.99	1.23	2.22	255	351.68	55.07	183.15	97.56	162.05
73	41.42	0.94	1.82	1.24	2.18	256	354.53	56.32	195.26	90.34	154.24
74	41.17	0.98	1.81	1.24	2.20	257	359.38	57.30	168.17	89.57	144.92
75	40.74	1.09	1.80	1.22	2.15	258	364.95	54.29	150.96	77.02	137.56
76	41.10	1.11	1.79	1.21	2.10	259	370.37	48.21	145.88	76.40	151.20
77	39.58	1.04	1.77	1.22	2.08	260	368.77	45.28	138.82	75.78	134.27

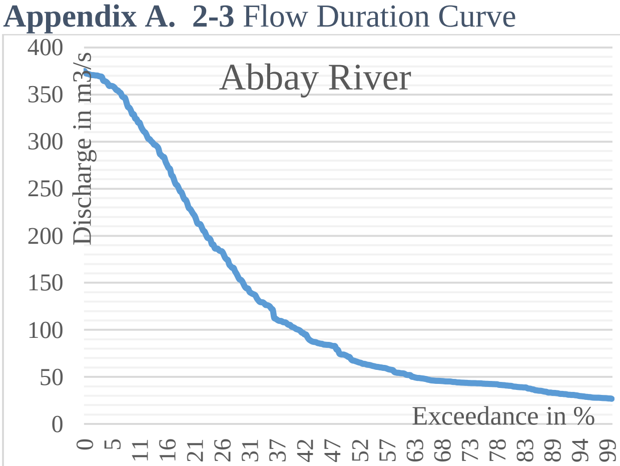
78	40.28	1.02	1.72	1.31	2.06	261	370.33	46.73	148.06	76.05	136.61
79	40.80	0.97	1.70	1.35	2.03	262	370.85	44.99	141.15	69.27	144.76
80	40.45	0.98	1.69	1.25	2.02	263	372.18	39.88	114.34	80.04	137.89
81	42.38	0.94	1.68	1.18	2.07	264	371.86	37.43	105.80	68.83	134.04
82	44.65	0.98	1.66	1.17	2.04	265	369.37	37.10	118.54	76.31	129.98
83	43.30	1.00	1.65	1.31	2.02	266	370.82	42.80	125.89	70.30	121.69
84	44.01	1.04	1.70	1.31	2.09	267	371.17	40.02	102.93	65.17	130.36
85	44.50	1.03	1.70	1.34	2.09	268	372.75	35.27	98.42	60.78	107.35
86	44.55	1.06	1.73	1.31	2.17	269	375.09	32.32	113.23	58.86	114.18
87	45.40	1.03	1.71	1.49	2.87	270	369.61	31.66	111.24	51.66	101.15
88	45.86	1.03	1.76	1.63	3.74	271	370.56	36.38	119.75	49.16	99.09
89	45.73	1.02	1.72	1.55	3.23	272	364.37	32.88	99.03	40.34	92.28
90	46.35	1.02	1.64	2.05	2.63	273	363.63	32.98	88.23	49.82	97.77
91	46.05	1.05	1.61	1.43	2.24	274	359.40	34.63	92.72	38.68	93.36
92	44.97	1.06	1.54	1.30	2.17	275	362.00	40.92	103.94	42.05	94.35
93	42.48	1.07	1.53	1.13	2.02	276	359.18	43.42	116.05	36.85	89.30
94	42.10	1.13	1.50	1.09	1.99	277	357.02	42.43	99.67	35.55	94.15
95	43.60	1.22	1.48	1.16	1.98	278	358.53	39.59	98.68	35.98	87.12
96	43.28	1.18	1.44	1.21	1.99	279	354.91	38.70	87.42	38.03	86.54
97	42.73	1.15	1.37	1.26	1.96	280	352.80	36.07	81.00	37.25	80.06
98	43.06	1.14	1.35	1.18	1.89	281	348.29	37.49	75.03	32.86	82.25
99	42.40	1.11	1.31	1.12	1.86	282	346.54	33.71	68.78	31.92	71.35
100	42.78	1.14	1.32	1.08	2.09	283	341.53	37.94	85.31	31.20	71.99
101	43.05	1.05	1.33	1.10	2.15	284	336.87	33.20	85.46	31.35	74.46
102	42.27	1.09	1.41	1.09	2.41	285	336.06	35.60	74.86	32.08	68.66
103	43.74	1.31	1.87	1.24	2.83	286	329.13	37.83	62.45	29.55	67.39
104	45.68	1.05	1.42	1.18	2.45	287	329.10	30.32	68.56	33.80	68.28
105	45.74	1.02	1.41	1.31	2.46	288	324.62	27.99	97.28	39.10	69.89
106	45.59	0.98	1.38	1.24	2.17	289	320.36	24.91	71.20	36.41	60.83
107	45.09	0.95	1.36	1.07	2.04	290	320.28	23.90	69.87	31.66	57.41
108	44.07	0.91	1.22	1.07	1.84	291	316.13	20.93	70.57	28.94	47.77
109	43.41	0.91	1.22	1.04	1.83	292	313.14	21.85	55.69	28.63	49.13
110	43.64	1.00	1.41	1.21	2.04	293	310.86	21.02	53.32	28.95	52.68
111	43.87	1.03	1.52	1.48	2.51	294	306.62	18.57	54.54	35.13	52.55
112	43.26	1.01	1.38	1.29	2.29	295	302.74	25.19	67.74	30.89	52.08
113	43.12	1.07	1.39	1.12	2.34	296	300.57	29.02	58.89	30.14	50.49
114	43.29	1.05	1.46	1.13	2.40	297	299.28	26.75	66.49	29.85	56.16
115	42.57	1.00	1.29	1.15	2.24	298	295.09	22.32	55.41	28.42	52.07
116	42.13	0.98	1.24	1.14	2.23	299	296.39	21.18	54.64	28.11	63.59
117	40.52	1.07	1.50	1.04	2.89	300	292.88	19.71	55.87	27.17	56.40

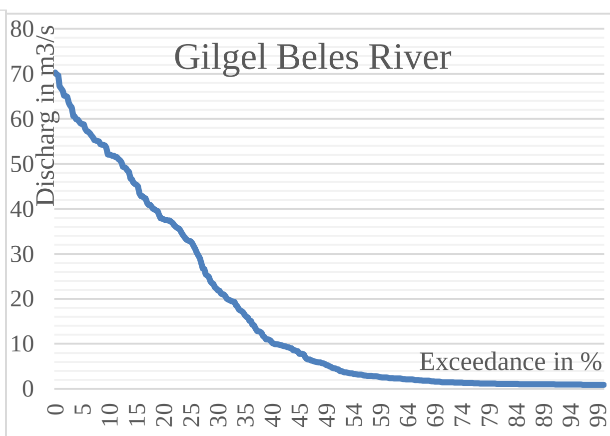
118	38.69	1.01	1.38	0.94	2.99	301	287.09	17.17	46.35	24.76	45.95
119	39.21	1.00	1.33	1.07	3.74	302	285.69	20.04	48.24	25.13	43.66
120	39.44	0.97	1.39	1.10	3.18	303	283.49	20.50	49.26	24.63	44.07
121	39.08	0.97	1.38	1.10	3.65	304	278.58	15.95	57.86	27.64	50.49
122	38.96	0.88	1.40	1.17	3.39	305	275.43	15.80	76.26	21.65	42.20
123	37.68	1.18	1.45	1.00	2.75	306	271.14	18.34	79.30	23.49	45.13
124	39.74	1.20	1.53	1.43	3.33	307	264.73	16.37	48.96	19.82	42.08
125	38.71	1.20	1.54	1.04	2.75	308	258.62	15.04	52.91	20.81	41.93
126	38.63	1.38	1.53	1.07	2.83	309	254.73	13.42	42.16	17.25	32.70
127	36.65	1.24	1.51	1.23	3.19	310	250.75	12.86	32.84	18.48	32.56
128	37.51	1.33	1.54	1.08	2.83	311	246.19	12.45	29.79	16.80	29.35
129	36.67	1.36	1.53	1.24	3.19	312	242.13	11.49	27.77	14.67	27.89
130	35.21	1.94	1.57	1.18	3.12	313	237.95	9.94	26.73	13.85	26.04
131	34.89	2.24	1.57	1.29	4.56	314	234.16	9.56	24.61	12.91	24.45
132	35.13	1.34	2.47	1.30	4.40	315	229.52	9.88	23.03	14.12	25.56
133	34.49	1.18	2.45	1.22	7.40	316	225.93	8.57	21.64	12.94	21.95
134	35.67	1.32	2.41	1.34	7.39	317	221.37	8.33	22.41	15.27	21.62
135	35.40	1.26	2.10	1.79	6.56	318	217.65	9.21	21.20	15.83	23.60
136	32.84	1.42	2.11	2.01	5.80	319	213.13	9.07	20.30	14.64	21.39
137	32.89	2.09	2.78	1.53	10.30	320	212.17	9.77	19.24	13.41	23.19
138	31.59	2.27	3.44	1.77	7.54	321	208.91	8.58	18.47	12.13	20.31
139	30.95	2.44	3.11	2.09	8.26	322	204.26	7.79	17.60	12.34	20.35
140	30.75	2.08	2.91	1.97	5.92	323	200.55	7.06	16.53	12.29	17.88
141	28.74	2.34	3.44	2.02	8.18	324	197.68	6.53	15.35	11.57	18.13
142	27.16	2.85	3.30	1.94	7.99	325	197.42	7.80	14.52	13.23	20.95
143	28.46	3.43	3.62	2.25	8.55	326	190.82	6.21	13.78	10.54	18.35
144	27.86	2.51	3.47	3.39	9.81	327	186.62	6.10	13.07	10.50	16.17
145	27.33	2.49	4.49	2.55	8.73	328	183.25	6.04	12.74	10.00	15.97
146	26.98	3.30	4.35	2.91	7.64	329	186.20	5.89	12.34	10.46	15.19
147	28.17	2.95	5.26	2.94	7.87	330	183.74	5.62	11.93	9.94	14.82
148	27.68	2.86	5.68	1.97	10.69	331	180.51	5.48	11.64	9.54	15.34
149	26.96	4.40	7.97	2.41	11.68	332	174.04	5.32	11.06	10.76	12.98
150	27.37	5.97	7.65	1.99	15.81	333	175.03	5.19	10.66	10.86	11.76
151	26.65	5.90	6.89	3.01	15.41	334	176.94	4.98	10.49	9.02	10.91
152	27.53	3.92	6.09	2.15	16.61	335	167.61	4.86	10.17	10.42	11.56
153	27.78	4.66	9.72	2.43	13.72	336	165.73	4.55	9.83	10.19	13.10
154	30.96	5.70	10.52	2.57	17.96	337	162.03	4.51	9.61	9.71	12.76
155	29.88	6.31	9.98	7.70	22.17	338	159.57	4.31	9.17	8.29	11.94
156	30.30	7.62	12.34	3.48	18.33	339	156.47	3.95	8.91	7.86	12.21
157	29.46	9.74	10.70	3.52	21.06	340	153.66	3.77	8.61	8.99	11.94

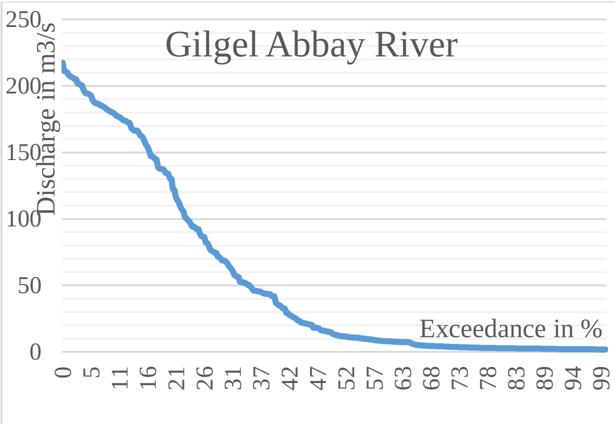
158	27.95	10.19	13.51	3.79	27.39	341	151.23	3.68	8.37	7.70	11.50
159	27.42	6.52	11.08	4.46	35.20	342	148.06	3.65	8.12	7.50	11.10
160	27.80	7.79	13.57	3.82	26.65	343	145.30	3.56	7.99	7.47	11.01
161	28.45	11.78	14.64	8.37	46.17	344	143.77	3.48	7.87	7.40	10.95
162	29.14	9.39	13.82	8.56	33.32	345	140.26	3.47	7.77	7.45	10.80
163	28.78	6.65	13.34	8.67	43.60	346	138.26	3.28	7.61	6.91	10.42
164	29.57	9.28	17.65	7.91	29.34	347	136.60	3.19	7.50	7.00	10.78
165	30.76	12.72	46.99	8.29	43.81	348	133.52	3.20	7.41	6.73	10.42
166	30.39	9.01	19.44	10.99	34.76	349	131.43	3.11	7.22	6.91	9.90
167	31.86	9.48	18.97	10.10	36.91	350	129.28	3.13	7.05	6.56	9.85
168	27.81	10.95	17.99	12.54	35.84	351	128.20	3.13	6.99	6.70	9.71
169	29.26	19.36	25.63	13.47	46.04	352	125.73	2.93	6.92	6.31	9.55
170	30.68	10.96	25.21	9.34	51.38	353	124.72	2.83	6.72	6.43	9.42
171	31.62	9.89	21.08	9.80	44.52	354	122.50	2.90	6.54	6.10	9.24
172	31.37	10.69	24.10	9.67	43.43	355	121.29	2.72	6.39	6.18	8.98
173	31.86	10.97	23.29	8.91	45.49	356	112.64	2.77	6.23	6.11	8.78
174	32.01	8.44	27.19	15.64	45.59	357	111.79	2.88	6.10	5.94	8.50
175	34.24	10.05	28.30	13.45	57.82	358	110.69	2.83	6.17	5.93	8.37
176	32.49	12.80	34.24	18.54	62.86	359	108.20	2.70	6.87	5.83	8.25
177	32.62	15.15	31.48	18.29	68.71	360	107.96	2.59	7.64	5.72	8.10
178	32.96	14.13	36.06	24.97	65.59	361	109.76	2.55	5.91	5.50	8.05
179	33.28	14.27	29.88	17.77	76.87	362	109.30	2.48	5.58	5.40	7.78
180	33.33	16.91	36.51	25.81	75.95	363	107.76	2.38	5.46	5.29	7.64
181	33.28	19.83	53.39	35.64	74.58	364	106.24	2.35	5.35	5.23	7.50
182	34.09	17.60	43.82	31.46	75.44	365	105.17	2.30	5.24	5.07	7.45
183	35.82	26.62	60.11	37.90	86.87						

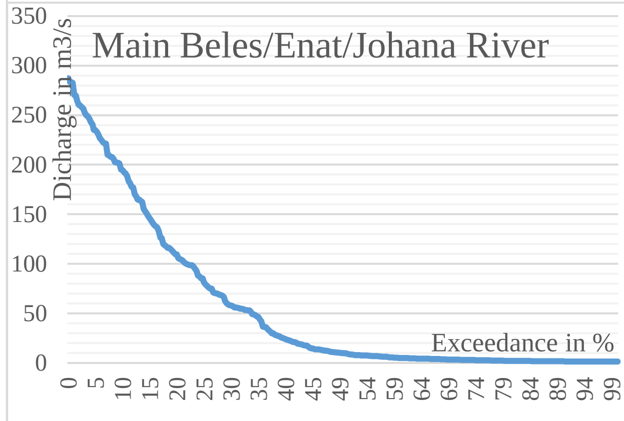
**data source. Tana Sub Basin Organization (TaSBo), Bahir dare*

Appendix A. 2-3 Flow Duration Curve









Appendix B. Water Level

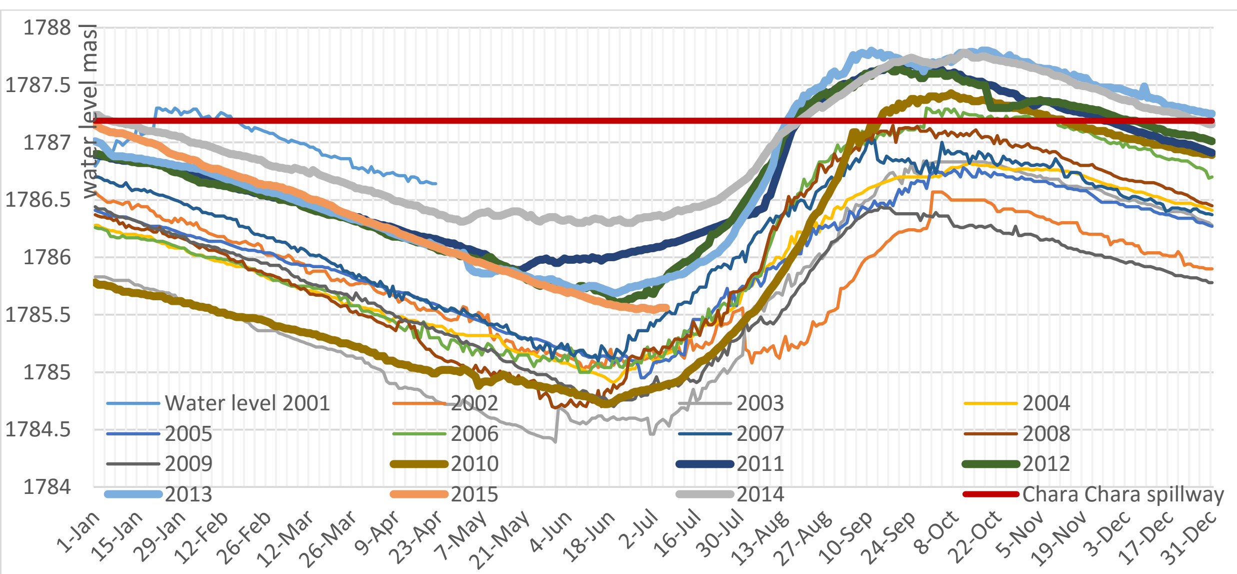
Appendix B.1. Lake Tana Water Level from June 1959 till 2006

Year	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
1959						1785.24	1785.16	1785.81	1786.79	1787.05	1786.78	1786.56
1960	1786.47	1786.23	1786.01	1785.84	1785.68	1785.58	1785.46	1786.07	1786.86	1787.09	1786.77	1786.48
1961	1786.27	1786.05	1785.93	1785.76	1785.58	1785.35	1785.54	1786.06	1787.08	1787.29	1786.98	1786.71
1962	1786.45	1786.22	1786.04	1785.85	1785.69	1785.56	1785.51	1786.1	1787.07	1787.26	1786.92	1786.64
1963	1786.38	1786.17	1786.01	1785.82	1785.67	1785.62	1785.66	1786.22	1786.88	1786.95	1786.66	1786.5
1964	1786.28	1786.11	1785.93	1785.72	1785.55	1785.45	1785.52	1786.34	1787.29	1787.4	1787.13	1786.8
1965	1786.47	1786.26	1786.1	1785.87	1785.7	1785.55	1785.54	1785.84	1786.5	1786.58	1786.53	1786.4
1966	1786.17	1786.02	1785.86	1785.7	1785.52	1785.41	1785.39	1785.83	1786.59	1786.7	1786.57	1786.34
1967	1786.11	1785.96	1785.74	1785.64	1785.51	1785.27	1785.25	1786.04	1786.98	1787.03	1786.86	1786.6
1968	1786.31	1786.12	1785.91	1785.75	1785.53	1785.46	1785.6	1786.26	1786.84	1786.89	1786.63	1786.42
1969	1786.18	1786.03	1785.77	1785.74	1785.57	1785.48	1785.4	1785.82	1786.85	1786.84	1786.53	1786.28
1970	1786.08	1785.9	1785.76	1785.58	1785.43	1785.25	1785.2	1785.67	1786.54	1786.66	1786.56	1786.3
1971	1786.08	1785.92	1785.76	1785.55	1785.34	1785.31	1785.3	1785.87	1786.69	1786.84	1786.63	1786.38
1972	1786.14	1785.99	1785.81	1785.61	1785.45	1785.32	1785.31	1785.72	1786.21	1786.35	1786.19	1786.01
1973	1785.83	1785.66	1785.54	1785.34	1785.19	1785.1	1785.16	1785.7	1786.43	1786.64	1786.56	1786.29
1974	1786.08	1785.9	1785.75	1785.54	1785.37	1785.4	1785.5	1786.18	1786.9	1787.14	1786.77	1786.45
1975	1786.23	1786.06	1785.92	1785.72	1785.48	1785.3	1785.4	1785.95	1787.07	1787.36	1786.98	1786.63
1976	1786.39	1786.17	1785.97	1785.77	1785.57	1785.5	1785.47	1786.12	1786.91	1786.97	1786.68	1786.46
1977	1786.24	1786.04	1785.87	1785.68	1785.48	1785.41	1785.53	1786.15	1786.93	1786.95	1786.8	1786.51
1978	1786.27	1786.07	1785.88	1785.69	1785.58	1785.45	1785.5	1786.13	1786.75	1786.84	1786.63	1786.37
1979	1786.16	1785.98	1785.81	1785.63	1785.44	1785.4	1785.38	1785.89	1786.51	1786.67	1786.52	1786.3
1980	1786.08	1785.9	1785.75	1785.58	1785.43	1785.27	1785.35	1785.93	1786.64	1786.73	1786.53	1786.3
1981	1786.1	1785.92	1785.75	1785.55	1785.4	1785.29	1785.28	1785.83	1786.53	1786.77	1786.57	1786.31
1982	1786.11	1785.94	1785.76	1785.68	1785.49	1785.35	1785.3	1785.66	1786.3	1786.49	1786.42	1786.19
1983	1785.98	1785.82	1785.66	1785.46	1785.25	1785.11	1785.14	1785.48	1786.3	1786.46	1786.32	1786.12
1984	1785.92	1785.75	1785.62	1785.45	1785.26	1785.18	1785.3	1785.74	1786.26	1786.56	1786.42	1786.21

1985	1786.09	1785.94	1785.77	1785.6	1785.41	1785.4	1785.41	1785.96	1786.7	1787	1786.78	1786.53
1986	1786.34	1786.14	1785.98	1785.8	1785.59	1785.4	1785.55	1786.11	1786.68	1786.94	1786.73	1786.43
1987	1786.25	1786.06	1785.92	1785.72	1785.55	1785.57	1785.65	1785.95	1786.52	1786.56	1786.52	1786.3
1988	1786.11	1785.92	1785.78	1785.58	1785.39	1785.26	1785.28	1786.29	1787.14	1787.15	1786.89	1786.61
1989	1786.36	1786.15	1785.96	1785.79	1785.63	1785.54	1785.54	1786.12	1786.76	1786.85	1786.62	1786.38
1990	1786.16	1785.99	1785.82	1785.66	1785.46	1785.3	1785.23	1785.69	1786.42	1786.68	1786.47	1786.14
1991	1785.86	1785.76	1785.59	1785.36	1785.34	1785.22	1785.4	1786.23	1786.97	1787.07	1786.7	1786.42
1992	1786.19	1786.02	1785.83	1785.68	1785.54	1785.4	1785.37	1785.81	1786.67	1786.79	1786.73	1786.48
1993	1786.22	1786.03	1785.87	1785.7	1785.57	1785.5	1785.58	1786.11	1786.72	1787	1786.79	1786.48
1994	1786.23	1786.06	1785.87	1785.66	1785.5	1785.37	1785.6	1786.43	1787.24	1787.13	1786.6	1786.29
1995	1786.15	1786.06	1785.92	1785.78	1785.6	1785.49	1785.57	1786.18	1786.91	1787.09	1786.84	1786.64
1996	1786.44	1786.26	1786.15	1786.01	1785.88	1785.82	1785.94	1786.7	1787.56	1787.65	1787.32	1787.07
1997	1786.81	1786.58	1786.37	1786.14	1785.89	1785.82	1785.91	1786.39	1786.99	1787.12	1787.15	1786.97
1998	1786.78	1786.55	1786.34	1786.17	1786	1785.89	1785.9	1786.54	1787.53	1787.72	1787.48	1787.12
1999	1786.81	1786.67	1786.37	1786.09	1785.92	1785.75	1785.77	1786.36	1787.27	1787.45	1787.56	1787.16
2000	1786.88	1786.66	1786.46	1786.23	1786.1	1785.91	1786.15	1786.63	1787.49	1787.48	1787.48	1787.18
2001	1786.9	1786.75	1786.59	1786.22	1785.88	1785.71	1785.64	1786.22	1787.23	1787.32	1787.11	1786.86
2002	1786.6	1786.29	1786.02	1785.77	1785.54	1785.15	1785.16	1785.57	1786.22	1786.41	1786.22	1785.94
2003	1785.7	1785.45	1785.23	1784.93	1784.72	1784.45	1784.36	1785.15	1786.1	1786.65	1786.57	1786.36
2004	1786.13	1785.92	1785.67	1785.4	1785.21	1784.93	1784.92	1785.5	1786.26	1786.58	1786.57	1786.41
2005	1786.22	1786	1785.84	1785.6	1785.34	1785.1	1785.04	1785.56	1786.15	1786.54	1786.5	1786.28
2006	1786.06	1785.86	1785.63	1785.34	1785.09	1784.97	1785.03	1785.61	1786.78	1787.1	1787.04	1786.81
Mean	1786.26	1786.07	1785.9	1785.7	1785.53	1785.4	1785.43	1786	1786.78	1786.94	1786.74	1786.48

**data source. Tana Sub Basin Organization (TaSBo), Bahir dare*

Appendix B.2. Average monthly Lake Tana Water Level graph



**data source. Ethiopian Electric Power Corporation (EEPCo), Addis Ababa*

Appendix C. Model Simulations

Appendix C.1. Lake Tana operation (regulation) model result

Appendix C.1-1. Lake Outflow regulation scenario of nMAG model analysis results within three different through flow

	Average flow	Qtotal	Through flow	Bypass flow	Spill flow	Bypass + Spill flow	Spill	Initial Reservoir level	Reservoir change per year
	m3/s	Mm3	Mm3	Mm3	Mm3	Mm3	%	masl	masl
Design	55.65	3947.7	2570.8	536.1	778.9	1315	20	8013.8	8.7
	77	3947.7	3401.9	536.1	19.5	555.6	0.5	8013.8	-9.8
Existing	86.6	3947.7	3175.8	536.1	227	763.1	5.8	8013.8	8.7
Scenario A	55.65	3947.7	2628.2	331.1	926.4	1258	23.8	8013.8	11.9
	77	3947.7	3550.6	331.1	62.2	393.3	1.6	8013.8	3.8
	86.6	3947.7	3307.1	331.1	297.6	628.7	7.6	8013.8	11.9
Scenario B	55.65	3947.7	2619.4	392.5	893.9	1286	23	8013.8	9.4
	77	3947.7	3505.8	392.5	48.7	441.2	1.2	8013.8	0.7
	86.6	3947.7	3272.7	392.5	273.2	665.7	6.9	8013.8	9.4
Scenario C	55.65	3947.7	2527.1	706.3	652.5	1359	16.8	8013.8	8.7
	77	3947.7	3271.7	706.3	0.4	706.7	0	8013.8	-30.6
	86.6	3947.7	3081.2	706.3	151.5	857.8	3.8	8013.8	8.7
Scenario D	55.65	3947.7	2525.5	706.3	649.9	1356	16.7	8550.2	9.3
	77	3947.7	3270.4	706.3	0	706.3	0	8550.2	-29
	86.6	3947.7	3094	706.3	147	853.3	3.7	8550.2	0.4

**For details of scenarios refer section 5.2.1.1*

Appendix C.1-2. Lake Outflow regulation scenario of nMAG model analysis results within three different through flow related with power

	Average flow	Production	Utility	Demand Coverage	Average Deficit	Firm power value	Net Benefit	EEKV
	m3/s	GWh	%	%	GWh/yr	Mill.MT/yr	Mill.MT/yr	KWh/yr
Design	55.65	2051.01	59.5	95.1	100.9	12.31	32.17	0.798
	77	2711.4	77.2	77.2	467.7	12.31	70.82	0.797
Existing	86.6	2532.9	72.5	73.6	540.9	12.31	67.01	0.798
Scenario A	55.65	2097.2	60.8	94.3	117.8	12.31	34.76	0.798
	77	2830.2	80.9	79.2	426.9	12.31	73.73	0.797
	86.6	2637.7	75.6	75.3	505.9	12.31	69.56	0.798
Scenario B	55.65	2090.1	60.6	94.2	118.2	12.31	34.21	0.798
	77	2794.4	79.8	78.6	437.9	12.31	72.79	0.797
	86.6	2610.2	74.7	75	513.3	12.31	68.84	0.798

Scenario C	55.65	2016	58.5	94	122.2	12.31	31.48	0.798
	77	2607.4	73.9	75	512.6	12.31	68.69	0.797
	86.6	2457.3	70.3	71.9	576.2	12.31	26.16	0.798
Scenario D	55.65	2015.9	58.5	94.1	121.8	12.31	31.46	0.798
	77	2607.7	73.9	74.5	522.4	12.31	69.19	0.797
	86.6	2468.9	70.5	72.3	568.3	12.31	65.66	0.798

**For details of scenario refer section 5.2.1.1*

Appendix C. 2 Environmental flows

Appendix C. 2-1. Recommended minimum environmental flows over Tis Issat waterfall by this study (pre-simulation), EIA and DRM

Parameter		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
[1]EIA	Flow (m^3/s)	60	60	10	10	10	10	20	20	40	40	40	60	
EIA	Volume (Mm^3)	161	146	27	26	27	26	54	54	104	107	104	161	995
[2]DRM	Flow (m^3/s)	25	23	16	11	9	8	15	31	74	44	42	32	
DRM	Volume (Mm^3)	68	56	42	28	23	21	39	83	192	117	109	86	862
In this study	Flow (m3/s)	12.0	10.5	10.5	10.5	10.5	10.5	11.3	24.0	58.0	53.1	36.5	21.7	
	Volume (Mm3)	32	25	28	27	28	27	30	64	150	142	95	58	708

[1]Source Bellier et al, (1997); [2] Source McCartney et al. (2009)

Appendix C. 2-2. Recommended minimum environmental flows over Tis Issat waterfalls by this study (after simulation), EIA and DRM

Parameter		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Total**
[1]EIA	Flow (m^3/s)	60	60	10	10	10	10	20	20	40	40	40	60	
EIA	Volume (Mm^3)	161	146	27	26	27	26	54	54	104	107	104	161	**995**
[2]DRM	Flow (m^3/s)	25	23	16	11	9	8	15	31	74	44	42	32	
DRM	Volume (Mm^3)	68	56	42	28	23	21	39	83	192	117	109	86	**862**
In this study	Flow (m3/s)	25	20	15	15	15	15	20	33	74	64	48	30	
	Volume (Mm3)	67	48	39	38	39	38	54	89	192	171	124	80	**978**

Appendix C.3. Water flow balance for different purpose of each scenario

Scenarios	Qtotal	Through flow	Bypass flow	Spill flow	Bypass + Spill flow	Spill Flow	Initial Reservoir level	Reservoir change per year	Initial Reservoir
	Mm^3	Mm^3	Mm^3	Mm^3	Mm^3	%	masl	masl	%
Scenario D1	3947.7	2968.5	706.3	272.6	978.9	6.9	9870.9	0	100
Scenario D1R	3947.7	2958.4	706.3	272.2	978.5	6.9/25.9	14203.2	0	97.88
Scenario D2	3947.7	2968.5	706.3	272.2	978.5	6.9	9870.9	0	100
Scenario D2R	3947.7	2957.3	706.3	272.2	978.5	6.9/6.5	14172.8	0	97.67
Scenario D3	3947.7	2968.5	706.3	272.2	978.5	6.9	9870.9	0	100
Scenario D3R	3947.7	2962.3	706.3	272.2	978.5	6.9/17.9	14317.9	0	98.67

**For details of scenario refer section 5.2.1.2*

Appendix C. 4. Simulated flow in irrigation

Appendix C. 4-1. Simulated model result of 3 scenarios without storage at Dangura mainly for irrigation

Date	Flow			A	B	C	A+B+C	Scenario D1			Scenario D2			Scenario D3		
	To UB	To LB	Total= UB+LB	To HPP	Enat River flow	Mandura River Flow	Total River Flow	(1) Flow to UB irrigation	(2) Flow to LB irrigation	Total flow (1)+(2)	(1) Flow to UB irrigation	(2) Flow to LB irrigation	Total flow (1)+(2)	(1) Flow to UB irrigation	(2) Flow to LB irrigation	Total flow (1)+(2)
1	68.7	79.1	147.8	87.5	4.1	2.2	92.8	70.5	22.4	92.8	13.8	79.1	92.8	43.3	49.8	93.1
31	68.7	79.1	147.8	87.5	4.1	2.2	92.8	70.5	22.4	92.8	13.8	79.1	92.8	43.3	49.8	93.1
59	79.0	91.0	170.0	98.2	2.6	1.2	101.0	81.1	19.9	101.0	10.9	90.0	101.0	46.6	53.7	100.3
90	83.5	96.1	179.5	100.4	1.8	1.0	102.2	85.6	16.5	102.2	10.9	91.2	102.2	47.6	54.7	102.3
120	73.9	85.0	158.9	103.9	1.4	1.0	105.3	75.8	29.5	105.3	14.3	91.0	105.3	48.8	56.1	104.9
151	61.3	70.6	131.9	90.1	3.7	2.5	95.3	62.9	32.4	95.3	14.6	80.8	95.3	44.1	50.8	94.9
181	9.6	11.1	20.7	82.5	25.2	11.9	118.6	9.9	11.1	20.9	9.6	11.1	20.7	9.6	11.1	20.7
212	0.0	0.0	0.0	78.5	120.7	35.6	233.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
243	0.0	0.0	0.0	76.5	236.5	58.6	370.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
273	3.7	4.3	7.9	72.0	156.3	45.4	272.7	3.8	4.3	8.0	3.7	4.3	7.9	3.7	4.3	7.9
304	18.5	21.3	39.7	78.0	71.2	29.2	177.4	18.9	21.3	40.2	18.5	21.3	39.7	18.5	21.3	39.7
334	42.8	49.3	92.1	84.0	18.5	10.2	111.7	44.0	49.3	93.3	42.8	54.2	97.1	42.8	49.3	92.1
365	53.2	61.2	114.4	88.5	6.8	4.3	98.6	54.6	44.0	98.6	31.3	67.3	98.6	33.5	38.6	72.1

****UB: upper Beles, LB: lower Beles and HPP: Hydropower plant and all flows are in m^3/s*

Appendix C. 4-2. Simulated model result of 3 scenarios with storage at Dangura mainly for irrigation

Date	flow			A	B	C	A+B+C	Scenario D1R			Scenario D2R			Scenario D3R		
	To UB	To LB	Total= UB+LB	To HHP	Enat River flow	Mandura River Flow	Total River Flow	(1) UB irrigation	(2) LB irrigation	Total flow (1)+(2)	(1) UB irrigation	(2) LB irrigation	Total flow (1)+(2)	(1) UB irrigation	(2) LB irrigation	Total flow (1)+(2)
1	68.7	79.1	147.8	87.5	4.1	2.2	92.8	70.5	22.4	92.8	13.8	79.1	92.8	43.3	49.8	93.1
31	68.7	79.1	147.8	87.5	4.1	2.2	92.8	70.5	22.4	92.8	13.8	79.1	92.8	43.3	49.8	93.1
59	79.0	91.0	170.0	98.2	2.6	1.2	101.0	81.1	19.9	101.0	10.9	90.0	101.0	46.6	53.7	100.3
90	83.5	96.1	179.5	100.4	1.8	1.0	102.2	85.6	16.5	102.2	10.9	91.2	102.2	47.6	54.7	102.3
120	73.9	85.0	158.9	103.9	1.4	1.0	105.3	75.8	29.5	105.3	14.3	91.0	105.3	48.8	56.1	104.9

151	61.3	70.6	131.9	90.1	3.7	2.5	95.3	62.9	32.4	95.3	14.6	80.8	95.3	44.1	50.8	94.9
181	9.6	11.1	20.7	82.5	25.2	11.9	118.6	9.9	30.6	40.5	9.6	79.1	88.7	9.6	50.4	60.0
212	0.0	0.0	0.0	78.5	120.7	35.6	233.8	0.0	30.6	30.6	0.0	79.1	79.1	0.0	50.4	50.4
243	0.0	0.0	0.0	76.5	236.5	58.6	370.6	0.0	30.6	30.6	0.0	79.1	79.1	0.0	50.4	50.4
273	3.7	4.3	7.9	72.0	156.3	45.4	272.7	3.8	30.6	34.4	3.7	79.1	82.8	3.7	50.4	54.1
304	18.5	21.3	39.7	78.0	71.2	29.2	177.4	18.9	30.6	49.5	18.5	79.1	97.6	18.5	50.4	68.9
334	42.8	49.3	92.1	84.0	18.5	10.2	111.7	44.0	49.3	93.3	42.8	54.2	97.1	42.8	49.3	92.1
365	53.2	61.2	114.4	88.5	6.8	4.3	98.6	54.6	44.0	98.6	31.3	67.3	98.6	33.5	38.6	72.1

Appendix C. 5. Comparison of results

Appendix C. 5-1. Power production and Irrigation coverage before and after simulations of each six secnario

Scenarios	Production before regulation	Production after regulation	Utility	Demand Coverage	Average Deficit	EEKV	UB Irrigation water before regulation	LB Irrigation water before regulation	Total Irrigation water before regulation	UB Irrigation water after regulation	LB Irrigation water after regulation	Total Irrigation water after regulation	Water at downstream of Blue Nile
	GWh	GWh	%	%	GWh/yr	KWh/yr	Mm3	Mm3	Mm3	Mm3	Mm3	Mm3	Mm3
Scenario D1	2178	2365.5	67.5	100	0	0.797	1304.6	1501.1	2805.7	1304.3	661.1	1965.4	4239.3
Scenario D1R	2462	2991.3	67.5	100	0	0.797/0.55	1304.6	1501.1	2805.7	1304.3	686.5	1990.8	1843.8
Scenario D2	2178	2365.5	67.5	100	0	0.797	1304.6	1501.1	2805.7	470.4	1501.6	1972	4233
Scenario D2R	2912	3634.3	67.4	100	0	0.797/0.504	1304.6	1501.1	2805.7	470.4	1528	1998.4	2163.5
Scenario D3	2178	2365.5	67.5	100	0	0.797	1304.6	1501.1	2805.7	873	994.4	1867.4	4337.6
Scenario D3R	2646	3293.7	67.5	100	0	0.797/0.546	1304.6	1501.1	2805.7	873	1005.2	1878.2	2054.9

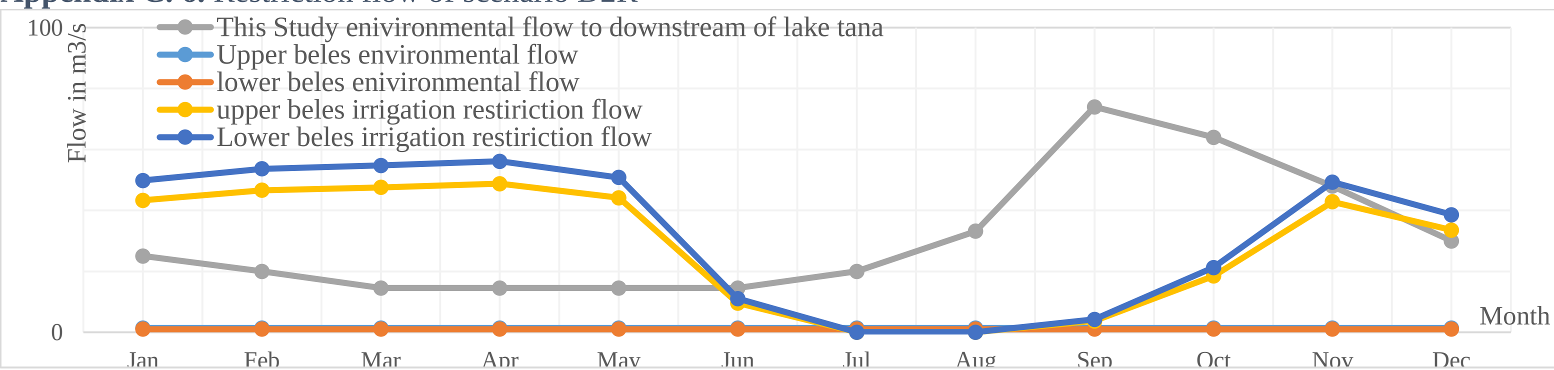
**For details of scenario refer section 5.2.1.2*

Appendix C. 5-2. Ranking computations of scenarios

Scenarios	Through flow (1) Mm3	Power Generation (2) GWh	Water Diverted for Irrigation (3) Mm3	Max Water needed for Irrigation (4) Mm3	Irrigation coverage %	Rank	(3)/(1)	Rank	(2)/(1)	Rank
Scenario D1	2968.5	2365.5	1965.4	2805.7	70.05	4	0.66	4	0.797	4
Scenario D1R	2958.4	2991.3	1990.8	2805.7	70.96	2	0.67	2	1.011	3
Scenario D2	2968.5	2365.5	1972.0	2805.7	70.29	3	0.66	3	0.797	4
Scenario D2R	2957.3	3634.3	1998.4	2805.7	71.23	1	0.68	1	1.229	1
Scenario D3	2968.5	2365.5	1867.4	2805.7	66.56	6	0.63	6	0.797	4
Scenario D3R	2962.3	3293.7	1878.2	2805.7	66.94	5	0.63	5	1.112	2

**For details of scenario refer section 5.2.1.2*

Appendix C. 6. Restriction flow of scenario D2R



Appendix C.7. Monthly water requirement in irrigation per hectare

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	**Annual Averages**
water requirement l/s/ha	0.93	1.07	1.13	1	0.83	0.13	0	0	0.05	0.25	0.58	0.72	**0.56**

**Source: Halcrow-GIRD, 2010*

Appendix C. 8. Water Budget nMAG model results of each scenario

Scenario D1

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

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WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD1.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2968.5	706.6	272.6	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4687.8	3383.5	1304.3	0.0	0.0
4	UBI	0.0	1304.3	0.0	1304.3	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
7	LB Control Point	0.0	3921.5	3260.1	661.4	0.0	0.0
8	LBI	0.0	661.4	0.0	661.4	0.0	0.0
10	Sky	0.0	1965.7	1965.7	0.0	0.0	0.0
20	blue nile	0.0	4239.3	4239.3	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)
AVER. INFLOW TO SYSTEM : 6205.0
ACTUAL INFLOW TO SYSTEM : 6205.0
RESERVOIR EVAPORATION : 0.0
INITIAL RESERVOIR LEVEL : 9870.9
FINAL RESERVOIR LEVEL : 9870.9
RES. CHANGE per YEAR : 0.0
OUTFLOW : 6205.0

Scenario D1R

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

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WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD1R.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2958.4	706.6	272.2	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4677.7	3373.4	1304.3	0.0	0.0
4	UBI	0.0	1304.3	0.0	1304.3	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
6	Dangurahp	0.0	3911.4	1149.9	0.0	401.6	25.9
7	LB Control Point	0.0	1551.4	865.0	686.5	0.0	0.0
8	LBI	0.0	686.5	0.0	686.5	0.0	0.0
10	Sky	0.0	1990.8	1990.8	0.0	0.0	0.0
20	blue nile	0.0	1843.8	1843.8	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)
AVER. INFLOW TO SYSTEM : 6205.0
ACTUAL INFLOW TO SYSTEM : 6205.0
RESERVOIR EVAPORATION : 2370.4
INITIAL RESERVOIR LEVEL : 14203.2
FINAL RESERVOIR LEVEL : 14203.4
RES. CHANGE per YEAR : 0.0
OUTFLOW : 3834.6

Scenario D2

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

Print

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WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD2.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2968.5	706.6	272.6	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4687.8	4217.4	470.4	0.0	0.0
4	UBI	0.0	470.4	0.0	470.4	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
7	LB Control Point	0.0	4755.4	3253.8	1501.6	0.0	0.0
8	LBI	0.0	1501.6	0.0	1501.6	0.0	0.0
10	Sky	0.0	1972.1	1972.1	0.0	0.0	0.0
20	blue nile	0.0	4233.0	4233.0	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)
AVER. INFLOW TO SYSTEM : 6205.0
ACTUAL INFLOW TO SYSTEM : 6205.0
RESERVOIR EVAPORATION : 0.0
INITIAL RESERVOIR LEVEL : 9870.9
FINAL RESERVOIR LEVEL : 9870.9
RES. CHANGE per YEAR : 0.0
OUTFLOW : 6205.0

Scenario D2R

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

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Close

WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD2R.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2957.3	706.6	272.2	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4676.7	4206.2	470.4	0.0	0.0
4	UBI	0.0	470.4	0.0	470.4	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
6	Dangurahp	0.0	4744.2	2535.9	0.0	176.8	6.5
7	LB Control Point	0.0	2712.6	1184.6	1528.0	0.0	0.0
8	LBI	0.0	1528.0	0.0	1528.0	0.0	0.0
10	Sky	0.0	1998.5	1998.5	0.0	0.0	0.0
20	blue nile	0.0	2163.5	2163.5	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)
AVER. INFLOW TO SYSTEM : 6205.0
ACTUAL INFLOW TO SYSTEM : 6205.0
RESERVOIR EVAPORATION : 2043.1
INITIAL RESERVOIR LEVEL : 14172.8
FINAL RESERVOIR LEVEL : 14172.8
RES. CHANGE per YEAR : 0.0
OUTFLOW : 4161.9

Scenario D3

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

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WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD3.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2968.5	706.6	272.6	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4687.8	3814.8	873.0	0.0	0.0
4	UBI	0.0	873.0	0.0	873.0	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
7	LB Control Point	0.0	4352.8	3358.4	994.4	0.0	0.0
8	LBI	0.0	994.4	0.0	994.4	0.0	0.0
10	Sky	0.0	1867.4	1867.4	0.0	0.0	0.0
20	blue nile	0.0	4337.6	4337.6	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)

AVER. INFLOW TO SYSTEM	: 6205.0
ACTUAL INFLOW TO SYSTEM	: 6205.0
RESERVOIR EVAPORATION	: 0.0
INITIAL RESERVOIR LEVEL	: 9870.9
FINAL RESERVOIR LEVEL	: 9870.9
RES. CHANGE per YEAR	: 0.0
OUTFLOW	: 6205.0

Scenario D3R

Result: WATER BUDGET FOR EACH MODULE IN THE SYSTEM:

Print
Close

WATER BUDGET FOR EACH MODULE IN THE SYSTEM:
DATASET : one year. File: C:\nMag2004\TanaD3R.set
RUN : Tana Beles Hydropower Project
SIMULATION FOR YEARS 1983 TO 2002

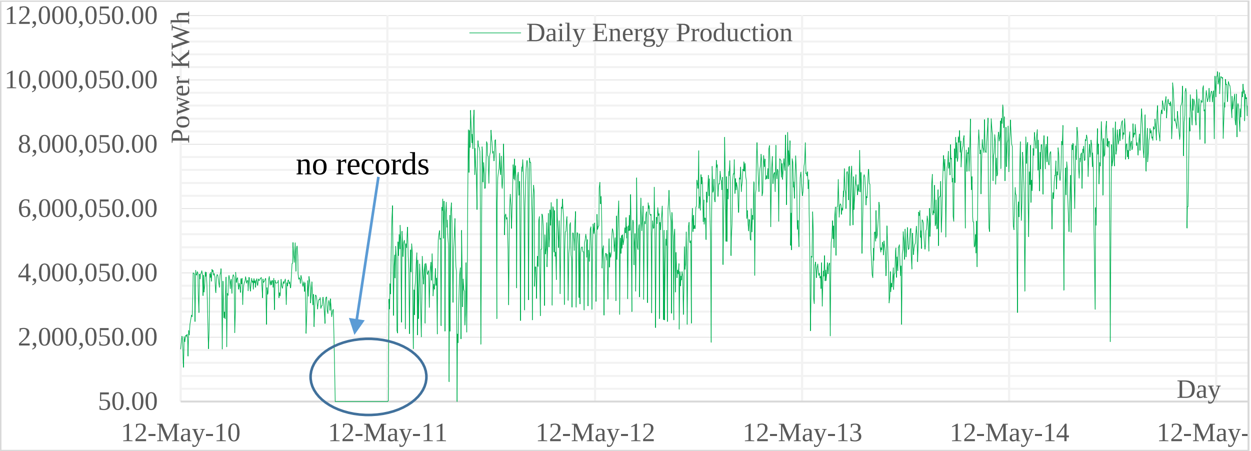
NO	MODULE NAME	QLOCAL Mm3	QTOTAL Mm3	THROUGH Mm3	BYPASS Mm3	SPILL Mm3	SPILL %
1	Tanahp	3947.7	3947.7	2962.3	706.6	272.2	6.9
3	UBR	1719.3	1719.3	1462.3	0.0	257.1	15.0
2	US Control point	0.0	4681.6	3808.6	873.0	0.0	0.0
4	UBI	0.0	873.0	0.0	873.0	0.0	0.0
5	LBR	538.0	538.0	424.6	0.0	113.4	21.1
6	Dangurahp	0.0	4346.6	1709.1	0.0	372.2	17.9
7	LB Control Point	0.0	2081.3	1076.0	1005.2	0.0	0.0
8	LBI	0.0	1005.2	0.0	1005.2	0.0	0.0
10	Sky	0.0	1878.3	1878.3	0.0	0.0	0.0
20	blue nile	0.0	2054.9	2054.9	0.0	0.0	0.0

FINAL WATER BALANCE CONTROL (Mm3)

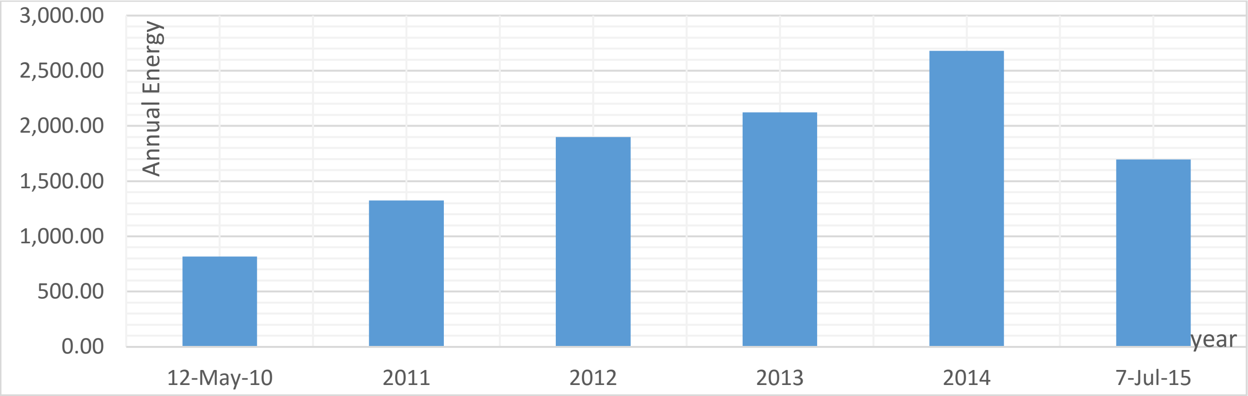
AVER. INFLOW TO SYSTEM	: 6205.0
ACTUAL INFLOW TO SYSTEM	: 6205.0
RESERVOIR EVAPORATION	: 2271.9
INITIAL RESERVOIR LEVEL	: 14317.9
FINAL RESERVOIR LEVEL	: 14317.6
RES. CHANGE per YEAR	: 0.0
OUTFLOW	: 3933.1

Appendix D. Power Production

Appendix D. 1. Existing daily power production of Tana Beles power plant, May 2010- July 2015



Appendix D. 2. Annual energy production of Tana Beles power plant in GWh



Appendix D. 3. Existing power production and turbine discharge