



**Addis Ababa University**

**Addis Ababa Institute of Technology  
School of Civil and Environmental Engineering**

**Eastern Nile River Basin Simulation with Grand  
Ethiopian Renaissance Dam / GERD**

Application of distributed hydrological modeling with Mike Hydro modeling and Nile DSS

**BY - Tesfaye Abebe**

**A Thesis Submitted to the School of Postgraduate Studies in Partial  
Fulfillment of the Requirements for the Degree of Master of Science in  
Hydraulic Engineering at Addis Ababa Institute of Technology, Addis  
Ababa University.**

**ADVISOR: Dr. YILMA SILESHI**

**May, 2015**

**Addis Ababa, Ethiopia**



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### I. Abstract

The Ethiopian government has conducted Integrated Water Resource Development Master Plan for the Blue Nile basin in 1998. The master plan has identified various irrigation and hydropower developments in the Sub basin. Since then, few projects have been implemented and some are under construction and the rest are at various levels of studies.

This research is identified to evaluate and simulate the Grand Ethiopian Renaissance Dam hydropower development opportunities in the Easter Nile basin and to assess the impacts on the downstream hydropower generation and irrigation developments and other water use systems.

The thesis compiled recent studies in the basin and meteorological, hydrological and demand data for each hydropower and irrigation schemes have been considered for the analysis. Mike Hydro 2014 model and Nile Basin DSS (preliminary stage) used for the study for simulation of the river water based on the existing water requirement and user priority setting situation. The model is operated by using the monthly based data in both the demand side and supply sides. The water resources availability assessment and the all locations performed by different Scenarios.

The impact of the Grand Ethiopian Renaissance Dam Hydropower generation in the Eastern Nile River Basin is insignificant on the existing hydropower generation (present condition Sc-0) of the Eastern Nile River Basin. The scenario analysis result indicates that, the overall average power production during the 40 years of simulation is increased by more than 50% in the Eastern Nile River Basin. In the Roseri and Sennar, the average power production increased by 15% from the present (SC-0) condition. The Hydropower generation in the Aswan Dam is reduced by 9% from the present (SC-0) condition.

Accordingly, the simulation result showed positive impact on the existing Irrigation development (present condition Sc-0) of the Eastern Nile River Basin. The impact of the Grand Ethiopian Renaissance Dam Hydropower generation in Irrigation development in the Eastern Nile River Basin is significant on the existing Irrigation development on the downstream of Eastern Nile River Basin. The scenarios result illustrates the benefit for downstream courtiers, especially, in Sudan because of increased upstream regulation in Ethiopia. An overall improved coverage of the irrigation water demand (0 month of deficit with GERD, Sc-1, against 10 months of deficit without GERD, present condition Sc-0) in the Eastern Nile Basin.

The average irrigation water demand deficit during the 40 years of simulation is reduced up to zero (no deficit) in the downstream Irrigation Scheme as shown in the simulation results. In the U/S Sennar and D/S Sennar, the average irrigation water demand deficit is reduced significantly up to nil. The irrigation water demand deficit in the Gzeria and downstream of Aswan Irrigation schemes are also reduced accordingly.

The results in this research are preliminary and based on many assumptions. Where it has been possible to verify the simulations the model results are reasonable. Nevertheless, the current results must be treated with caution. The model need to be refined using improved estimates of stream flow data on the major tributaries and better estimates of irrigation demand at all schemes.

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## Table of Contents

I. Abstract.....	iv
II. ACKNOWLEDGEMENT .....	v
III. Acronyms.....	xi
CHAPTER ONE .....	1
1. Introduction.....	1
1.2 Research Problem .....	3
1.3 Research Questions.....	4
1.4 Research Objectives.....	5
1.5 Research Materials and Methodology.....	6
CHAPTER TWO .....	11
2 Description of the Study Area.....	11
2.1 Nile and Eastern Nile River Basin General Overview.....	11
2.1.1 Blue Nile .....	18
2.2 Tekeze-Atbara Sub-basin.....	24
2.3 Sudd, Bahr el Chazal and Sobat.....	30
2.4. Grand Ethiopian Renaissance Dam.....	33
CHAPTER THREE .....	40
3 Literature Review.....	40
3.1 Some of the models used in River Basin Simulation.....	40
3.3 Some of the pre-studies on Eastern Nile River Basin Simulation .....	45
3.4 Result Comparison of Different Studies on Eastern Nile River Basin Simulation.....	60
CHAPTER FOUR.....	61
4 BASELINE MODEL CONFIGURATION.....	61
4.1 Model Selection and Conceptualization.....	61
4.2. Model structure.....	62
4.3 Model Calibration and Validation .....	68
CHAPTER FIVE .....	77

5	SCENARIO DEFINITION AND IMPLEMENTATION.....	77
5.1.	INTRODUCTION .....	77
5.2.	SCENARIO DEFINITION .....	77
5.3	SCENARIO IMPLEMENTATION .....	78
CHAPTER SIX	.....	84
6	SCENARIO ANALYSIS, EVALUATION, RESULTS AND DISSCUSSION .....	84
6.1.	Impact of Grand Ethiopian Renaissance Dam Hydropower generation in the hydropower generation in the Eastern Nile River Basin.....	84
6.2.	Impact of Grand Ethiopian Renaissance Dam Hydropower generation on Irrigation Development in the Eastern Nile River Basin.....	91
6.3	Evaporation loss comparison in different reservoir sites of the river system of Sudan and Egypt99	
6.4	Impact of Grand Ethiopian Renaissance Dam Hydropower generation on the Blue Nile outflow at the border (the Ethio-sudan border) after the construction of Grand Ethiopian Renaissance Dam..	100
7	CONCLUSIONS AND RECOMMENDATION.....	103
7.1	Conclusion .....	103
7.2	Concluding Remarks.....	104
8.	REFERENCES .....	106

LIST OF FIGURES

Fig.2.1: Eastern Nile River Basin by Catchment Area Fraction.....12

Fig. 2.2: Easter Nile Sub basins.....13

Figure2.3: Location of Study Area and Development Potentials.....14

Figure2.4: Map of the Blue Nile basins showing elevation, the main tributaries and key geographic features.....20

Figure2.2.1: Tekeze – Atbara Sub-basin with potential development sites.....26

Fig.2.2.4 Location Map of Great Ethiopian Renaissance Dam and Reservoir.....39

Fig 3.3.1.1 Typical Layout of Mike Hydro 2014.....42

Fig6.3.2.1 Typical layout of NBDSS .....43

Figure4.2.1: Schematic of baseline configuration.....62

Figure 4.2.2: Critical water level (Storage demand rule) for Sennar Dam.....64

Figure 4.2.3: Priority reduction rule for hydropower for the Sennar Dam.....65

Figure 4-3-1: Observed and simulated daily flows for Didessa at Arjo for calibration period (1979-1989).....70

Figure 4-3-2 : Observed and simulated seasonal flows for Didessa at Arjo.....71

Figure 4-3-3 : Standardised flow residuals for calibration period at Didessa.....71

Figure 4-3-4: Observed and simulated daily flows for Abbay at El Deim for calibration period (1969-1979).....72

Figure 4-3-5: Observed and simulated mean monthly flows for Abbay at El Deim for calibration period (1969-1979).....73

Figure 4-3-6: Standardized flow residuals for calibration period at El Deim .....73

Figure 4-3-7: Observed and simulated daily flows at Didessa at Arjo for the validation period (1962-1972).....74

Figure: 4-3-8 Observed and simulated mean monthly flows at Didessa at Arjo for the validation period (1962-1972).....75

Figure: 4-3-9 Observed and simulated daily flows at Didessa at Arjo for the full observed period (1960-1992).....75

Figure: 4-3-10: Standardised flow residuals, validation period at Didessa at Arjo (1962-1972) .....76

Figure 5.1: Schematic of EN configuration for Scenarios 0... .....79

Figure 5-2: Schematic of EN configuration for Scenarios 1.....83

Figure 6-1: Roseries HP Power deficit at SC0 (Before construction of GERD).....85

Figure 6-2: Roseries HP Power deficit at SC1 (After construction of GERD).....86

Figure 6-3: Sennar HP Power deficit at SC0 (Before construction of GERD).....87

Figure 6-4: Sennar HP Power deficit at SC1 (After construction of GERD).....88

Figure 6-5: Aswan HP Power deficit at SC0 (Before construction of GERD).....89

Figure 6-6: Aswan HP Power deficit at SC1 (After construction of GERD).....90

Figure 6-7: Gizeria Irrigation water demand deficit SC0 (Before construction of GERD).....92

Figure 6-8: Gizeria Irrigation water demand deficit SC1 (After construction of GERD).....93

Figure 6-9: U/S Sennar irrigation water demand deficit SC0 (Before construction of GERD)..94

Figure 6-10: U/S Sennar irrigation water demand deficit SC1 (After construction of GERD)...95

Figure 6 -11: D /S Sennar irrigation water demand deficit SC0 ( Before construction of GERD).....96

Figure 6-12: D/S Sennar irrigation water demand deficit SC1 (After construction of GERD)...97

Figure 6-13: Aswan irrigation water demand deficit SC1 (After construction of GERD).....98

Figure 6-14: Monthly Evaporation loss of GERD.....99

Figure 6-15: Ethio-Sudan Border simulated outflow before the project condition (construction of GERD) in m<sup>3</sup>/s.....101

Figure 6-16: Ethio-Sudan Border simulated outflow after the project condition (construction of GERD) in m<sup>3</sup>/s.....102

## LIST OF TABLES

Table 1.5.1: Crop areas and crop types in the Master plan and ENJMP.....	8
Table 1.5.2: Estimates of crop water requirements (Million m <sup>3</sup> ).....	9
Table 2.2.1: Tekeze River Basin runoff in millions of cubic meters per annum.....	24
Table 2.2.2: Drainage area of rivers and tributaries.....	26
Table 2.2.3: Potential Irrigable land by project (in hectares).....	26
Table 2.2.4: Hydroelectric Power Potential.....	26
Table 2.2.5: Tekeze River Basin Existing dams.....	28
Table 2.2.6: Existing hydro-power schemes.....	29
Table: 2.4.2.1 Technical Feature of GERD.....	37
Table 3.4.1: Result Comparison of Different Studies (ENJMP, Deltares and Thesis Findings)...	60
Table 4.1: Irrigation Scheme in Eastern Nile Basin.....	62
Table 4.2: Existing Hydropower plants and reservoirs of the Eastern Nile Basin.....	63
Table 4.3: Reservoir and hydropower generation characteristics - Heightened Roseires.....	64
Table 4.4: Reservoir and hydropower generation characteristics for Sennar Dam.....	64
Table 4-5: Reservoir and hydropower generation characteristics for the Fincha'a.....	65
Table 7.5: Reservoir and hydropower generation characteristics for the Merowe.....	66
Table 7.6: Reservoir and hydropower generation characteristics for the High Aswan Dam.....	67
Table 4.1: Flow gauges for calibration in the Eastern Nile .....	69
Table 4.2: Calibration periods for flow gauges in the Eastern Nile.....	69
Table 4.3: Calibration statistics for Didessa at Arjo.....	71
Table 4.4: Calibration statistics for Abbay at El Deim .....	73
Table 5-1: Eastern Nile simulation with GERD Scenarios.....	78
Table 5-2 Technical feature of GERD.....	80
Table 5-3: Characteristic dam levels and HP parameters for Grand Ethiopian Renaissance Dam – Scenario 1.....	82

### III. Acronyms

#### Key words

Model Validation

Scenario

Mike Hydro

Decision Support System

#### List of Abbreviations

AAIT	Addis Ababa Institute of Technology
AAU	Addis Ababa University
Bm <sup>3</sup>	Billion cubic meters
DEM	Digital Elevation Model
DSS	Decision Support System
EN	Eastern Nile
ENJMP	Eastern Nile Joint Multipurpose Project
ENTRO	Eastern Nile Regional Office
ET	Evapotranspiration
GIS	Geographic Information System
Km	kilometer
Km <sup>2</sup>	Square kilometre
Km <sup>3</sup>	cubic kilometer
M	Million (Mega)
m.a.s.l	mean above sea level
MoWIE	Ministry of Water, Irrigation and Energy
NBDSS	Nile Basin Decision Support System
NBI	Nile Basin Initiative
NMSA	National Metrological Service Agency

# CHAPTER ONE

## 1. Introduction

An integrated approach to the water system and its surroundings is the basis for long-term, sustainable and equitable management of the environment. Multi-sector planning to allocate scarce resources at the river basin level is increasingly needed in the water sector, as water users and governmental agencies become more aware of the trade-offs occurring between water quantity, quality, water reuse, shared investment costs and reliability on water resources.

River basin simulation models are important tools in water management studies of river basins. Such studies often pertain to complex water resources systems, and require the analysis of large amounts of data. (W.N.M. van der Krogt)

River Basin Simulation and Modeling is used to Understanding system behavior river basin, identifying knowledge gaps, analyzing alternatives in a non-destructive environment, estimating future impacts of exogenous factors (e.g. Climate Change) and Forecasting & Early Warning system.

The Eastern Nile River Basin faces a number of challenges that need to be considered carefully in order to realize the growth potential of the Nile River basin. Some of these issues, some of which are interlinked and particularly relevant for the River basin, include: conflicts in resource use; growing population and livestock pressure on land leading to serious land degradation; increasing demand for energy; uncoordinated water resources development; inadequate policy framework and lack of a clear institutional responsibility for their management; inadequate knowledge base and absence of an adequate regulatory framework (coupled with lack of implementation) for the protection of the resources. It is therefore high time for urgent action in the short-term to help manage the current and emerging challenges of the River basin.

The Ethiopian government has conducted Integrated Water Resource Development Master Plan for the Blue Nile basin in 1998. The master plan has identified various irrigation and hydropower developments in the Sub basin. Since then, few projects have been implemented and some are under construction and the rest are at various levels of studies.

The Grand Ethiopian Renaissance Dam is one of the identified hydropower development projects which is under construction.

The Grand Ethiopian Renaissance Dam has an active storage capacity ( $60,000 \text{ Mm}^3$ ) greater than the yearly average inflows ( $49,000 \text{ Mm}^3/\text{yr}$ ) thus the dam stores and regulates more than a

yearly flow at Ethio-Sudan Border. Therefore, different concerns rose about the impact of the Dam on the downstream water users both in Sudan and Egypt.

The objectives of the Eastern Nile River Basin Simulation for existing state in taking account of GERD is to simulate water allocation for major activities, evaluate and to assess the impacts of The Grand Ethiopian Renaissance Hydroelectric Power Project on the downstream hydropower generation, Irrigation development and Evaporation loss.

The Eastern Nile River Basin has a huge potential for the development of water resource infrastructure for hydropower generation, flow regulation to support downstream irrigation abstractions and for flood control. If the Basin operated according to integrated River Basin management, it could provide maximum benefits of development for the entire region.

This research conducted by the integration of hydraulic parameters and hydrological evaluation tools in a GIS interface.

The Mike Hydro 2014 which is developed by Danish hydraulic Institute (DHI). It is customized to suit NBDSS and Eastern Nile River basin model. The Decision support system of the Sub basins was analyzed by Second release of Nile DSS (NB DSS 2014) as preliminary stage and result comparison.

Simulation results consist of performance of reservoirs, hydropower and water balance at the user nodes and river flows at each river node. Simulations have been based on monthly flows data considering specific series of years as representative of a possible future scenario. Simulations are realized at all reservoirs in future conditions (with GERD) based on monthly flows from January 1951 to December 1990. The model was used to simulate selected future scenarios. A baseline scenario is current situation without GERD and the second scenario is considering GERD and other developments on the downstream.

The thesis compiled recent studies in the basin and meteorological, hydrological and demand data for each hydropower and irrigation schemes will be considered for the analysis. Mike Hydro (Mike Hydro 2014) model and Nile Basin DSS used for the study for simulation of the river water based on the existing water requirement and user priority setting situation. The model is operated by using the monthly based data in both the demand side and supply sides. The water resources availability assessment and the all locations performed by different Scenarios.

### 1.2 Research Problem

The Eastern Nile River Basin faces a number of challenges that need to be considered carefully in order to realize the growth potential of the Nile River basin. Some of these issues, some of which are interlinked and particularly relevant for the River basin, include: conflicts in resource use; growing population and livestock pressure on land leading to serious land degradation; increasing demand for energy; uncoordinated water resources development; inadequate policy framework and lack of a clear institutional responsibility for their management; inadequate knowledge base and absence of an adequate regulatory framework (coupled with lack of implementation) for the protection of the resources. It is therefore high time for urgent action in the short-term to help manage the current and emerging challenges of the River basin.

The Ethiopian government is currently concentrating on development of Ethiopia's hydroelectric power potential that generates capacities to meet domestic demand and exports for neighboring countries and provide support to foreign currency income. Related to this, the Abay Basin Integrated Master Plan Study revealed feasible hydropower project sites in the basin. One of these is the Grand Ethiopian Renaissance Dam Project dam i.e. under construction. It occupies an area of land above 500 m elevation designed to rise up to 145 m high from the riverbed to provide effective hydropower reservoir area.

The construction of GERD raises different issues and debates from the downstream countries i.e. Sudan and Egypt. Egypt and Sudan have different questions and concerns on the impacts of the dam on their existing water resource developments. Therefore, this research is identified to evaluate and simulate the GERD hydropower development opportunities in the basins and to assess the impacts on the downstream hydropower generation and irrigation developments and other water use systems.

This research simulates and evaluates the impact of GERD hydropower generation on the Eastern Nile Basin water resources. The research compiles recent studies in the basin and meteorological, hydrological and demand data for each irrigation schemes will be considered for the analysis. Mike Hydro model will be used for the simulation of the river water based on the existing water requirement and user priority setting situation. The model will be operated by using the monthly based data in both the demand side and supply sides.

The need to see previously developed proposals with advanced and recent models will facilitate formulation of other alternatives and optimal water resources allocation for various demands. On other hand such allocation techniques used to minimize the water crises and the conflict among users by predicting future scenarios. The output of such study contributes as the guide line in the River basin to well water management.

The model selected for the study is Mike Hydro 2014 Model that evaluates and simulates a full range of water development management options and takes account of multiple and competing uses of water system.

## 1.3 Research Questions

The research has addressed the following questions:

- ❖ What will be the impact Grand Ethiopian Renaissance Dam Hydropower generation in the hydropower generation in the Eastern Nile River Basin (especially on down Stream Hydropower Schemes)?
- ❖ What will be the impact of Grand Ethiopian Renaissance Dam Hydropower generation on irrigation schemes and Irrigation development in the downstream Countries (Sudan and Egypt) of Eastern Nile River Basin?
- ❖ By how much the out flow of Blue Nile regulated on the Ethio-Sudan Brdr; how much the Blue Nile out flow will be at the Ethio-Sudan B order before and after the construction of the Grand Ethiopian Renaissance Dam (GERD)?
- ❖ What will be the Evaporation loss change in Eastern Nile River Basin system? Evaporation loss comparison in different reservoir sites of the river system of Sudan and Egypt with respect to GERD reservoir.

### 1.4 Research Objectives

#### 1.4.1 General objective

The general objective of this Eastern Nile River Basin Simulation for existing state in taking account of GERD research is to simulate water allocation for major activities, evaluate and to assess the impacts of The Grand Ethiopia Renaissance Hydroelectric Power Project on the downstream hydropower generation, Irrigation development and Evaporation loss. The Eastern Nile River Basin has a huge potential for the development of water resource infrastructure for hydropower generation, flow regulation to support downstream irrigation abstractions and for flood control. If the Basin operated according to integrated River Basin management, it could provide maximum benefits of development for the entire region. This research will be conducted by the integration of hydraulic parameters and hydrological evaluation tools in a GIS interface. The Mike Hydro 2014 modeling applied for hydrological evaluation and hydraulic analysis in a spatial distribution. The Decision support system of the Sub basins will be analyzed by Second release of Nile DSS (NB DSS 2014) as preliminary stage for result comparison.

#### 1.4.2 Specific Objectives

- To evaluate and Simulate the impact of GERD hydroelectric generation on the downstream Hydropower generation of Eastern Nile River Basin
- The impact of GERD on downstream irrigation schemes and development of the Eastern Nile River Basin
- By how much the out flow of Abay regulated on the E thio-Sudan B rder and what would be the impacts on the Downstream Eastern Nile River Basin
- Evaporation loss comparison in different reservoir sites of the river system of Sudan and Egypt with respect to GERD reservoir.

To address the above key questions using Mike Hydro Model and the second release of Nile DSS, the following key indicators will be used:

- Time series of hydropower generation
- Time series of Lake and reservoir water level
- Amount of irrigation water abstracted and deficiency
- Time series of flow at different nodes

### 1.5 Research Materials and Methodology

The materials used in this research include master plan documents performed so far by BCEOM, Hydrological Studies of Eastern Nile River Basin by NBI and ENTRO, Feasibility Studies by Nile Irrigation and Drainage Project, JMP and ENPM by ENTRO and other study documents prepared by local and foreign professionals. Mike Hydro model and Nile Basin DSS utilized to perform the Simulation. The Model user Guide is used as a guideline to operate the model.

The methodology adopted in the study follows literature review, data collection, organization and analysis of data based as per to the requirement of Mike Hydro model and NB DSS. The overall approach of the study will be discussed on data analysis and results discussion parts. Mike Hydro simulation carried out on monthly time step for the available data.

MIKE Hydro operates on the basis of a schematic river network, which is made up of building blocks or objects. These typically included river reaches, water user nodes, reservoir nodes, irrigation nodes, hydrological catchments, hydropower nodes and channels which link the various nodes. The characteristics of the individual building blocks and the interactions between them are governed by user defined operating rules. The wide range of modeling routines embedded in the MIKE Hydro model, allowed the simulation of various multi-purpose water resource project scenarios. The routines which have been the focus of this study relate to reservoir and hydropower operation, irrigation demand modeling, hydrological routing, water allocation rules, rainfall-runoff modelling and evaporation.

MIKE HYDRO -A physical and conceptual model system for catchments, rivers and floodplains developed **without** dependencies on Arc GIS. It is Map-based Graphical User Interface and it has a River and Catchment delineation tool.

Rainfall Runoff modeling NAM and UHM Rainfall Runoff models are available and built-in in MIKE HYDRO model

Basin module for river basin planning and management, featuring: River network definition, Water users, Catchments, Irrigation, Reservoirs, Hydropower

Mike Hydro has a functionalities that could performs Optimizations, Reservoir sedimentation and Macro programming and scripting options and Result layer for processing and presentation of time series results

A DSS is a common computer-based platform for communication, information management and analysis of water resources. It provides a framework for sharing knowledge, understanding

river system behavior, evaluating alternative development and management strategies, and supporting informed decision making.

The Nile Basin DSS as a common analytical platform for the Nile Basin.

### 1.5.1 Data

To achieve the goal of the research most of the data have been collected from the various phase of the Abbay basin master plan document, WRPM NB DSS Meta database, MoWIE and NMA.

The data used in the study includes the stream flow data of main rivers course and 15 tributaries (catchments) gauges were used to estimate the flow at the project site and computation of Grand Ethiopian Renaissance Dam flow volume. The other important data includes the demand data for irrigation and hydropower, location of project sites, relevant reservoir data, precipitation and potential evaporation.

### 1.5.2 Input Data and Data Used

The various types of data needed for the simulations are:

- Monthly time series of rainfall, runoff, and evaporation for different sub-catchments
- Irrigation areas and demands for each scenario and demands, based on assumed cropping patterns
- Characteristics of the hydropower stations (installed capacity, number of turbines, rated heads and discharges, etc.,)
- Reservoir characteristics (area-capacity curves, rule curves, evaporation, seepage rates, irrigation demands, etc.)
- Reservoirs elevation-area-capacity relationship

#### 1.5.2.1 Stream Flow Data

Catchment runoff represents locations in the model where water is introduced directly to the stream system. The hydrological analysis that will be undertaken during the study requires the collection and review of hydrometric data associated with the Eastern Nile River Basin.

These monthly flows were developed through the scoping of the proposed Reservoirs and Interventions. These sites include: Lake Tana and five of its main tributaries, the Jemma tributary downstream of Lake Tana, the Fincha'a and Amenti tributaries and the Didessa, Dabus and Beles tributaries downstream of Kessie. Bahir Dar to Kessie-Incremental, Kessie to

Mendya-Incremental, Mendya to Border/Renaissance Incremental, Morgen White Nile, Atbara wade, Rahad and Dinder. These incremental flows were available for the period from 1951 to 1990 and were developed from simple subtractions of mainstream gauges, therefore incorporating flows from tributaries already known from gauged data.

**1.5.2.2 Water Use Data**

The most common water use in Nile river basin is irrigation water demand. This activity is defined as a Water User and added to the model as a Water User node in MIKE Hydro. The temporal variation in the extraction of water is described by a time series file for each water user node. The temporal variation of return flow of water that is assumed not to be consumed at the water user node can be transferred back to one or more river nodes.

Crop water requirements were estimated using the FAO irrigation module in Mike Hydro based on areas and crop types for the schemes presented in the Ethiopian Master Plan report and ENJMP summarized in Table (1.5.1) and Table

In the current situation, the water system retained for the purpose of this study will assume water requirements for irrigation purposes in Sudan and Egypt. Table 5.1.2 shows irrigation water demands in Sudan and Egypt.

**Table 1.5.1 : Crop areas and crop types in the Master plan and ENJMP**

Irrigation scheme	Crop Types and Crop Areas for Schemes (km <sup>2</sup> )						
	Total area (km <sup>2</sup> )	Groundnut	Sorghum/ Dura	Cotton	Wheat	Beans	Fallow
Upstream Sennar	4141	2071	0	2071	0	0	-
Gezira	3575	894	298	1192	1192	0	1192
Managil	3973	993	331	1324	1324	0	-
Downstream Sennar	1012	506	0	506	0	0	-
Tamaniat-Hassanab	804	134	268	0	268	134	134
Hassanab-Dongola	1247	208	416	0	416	208	208

For determining crop water requirements, rainfall and evaporation data model was used.

Estimates of irrigation water use per scheme are summarized in a table as average monthly and annual values as determined using the FAO irrigation module in Mike Hydro.

**Table 1.5.2 : Estimates of crop water requirements (Million m<sup>3</sup>)**

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Sennar	67.5	66.5	44.7	34.9	35.1	77.1	97.4	93.8	132.4	148.2	141.9	82.8
Gizira	202.3	191.3	118.1	30.8	44.5	180.9	268.6	258.6	337.8	321.8	249.6	185.6
Tamaniat-Hassanab	67	49	0	0	29	38	79	41	63	75	58	65
Hassanab-Dongola	104	76	0	0	44	59	123	64	97	116	90	101
D/S Aswan	4709	3553	4481	4584	4986	1888	5159	5282	4404	2606	3034	3465

### 1.5.3.3 Hydropower Data

Hydropower generation is simulated by inserting a hydropower node and connects it to a reservoir using the channel feature. Return flow back to the river is simulated by connecting the hydropower feature to the river node.

### 1.5.3.4 Reservoir Data

Each reservoir can simulate the performance of specified operating policies using associated operating rule curves. These define the desired storage volumes, water levels and releases at any time as a function of existing water level, the time of the year, demand for water and possibly expected inflows.

Reservoirs can be inserted anywhere on the river branches except on river bifurcation nodes or the most upstream nodes. The reservoir definition is used to describe the reservoir characteristics, operating rules, and upstream- and downstream connections to users and control nodes are specified. Data required to simulate the reservoirs is available from Eastern Nile Technical Regional Office (ENTRO) power toolkit. For the standard reservoir, the time series information required includes bottom, crest, spillway, top of dead storage, and minimum operation pool elevations; minimum and maximum valve releases; precipitation, seepage loss, and evaporation; and flood control and operational rules levels for any water users attached to the reservoir. Though not a time series, the height-volume area relationship describing the reservoir bathymetry is additional input information required for the model.

### **1.5.3.5 Losses and Gains**

Losses and gains were placed at reservoirs locations within the basin to account for reservoirs gains due to precipitation and losses due to Evaporation. These losses represent the difference between gross precipitation on the reservoir and evaporation loss from the reservoir.

### **1.5.3 Time series prepared for river basin simulation**

Time series of rainfall and runoff were prepared for sub-catchments which correspond to a) catchments upstream of hydrometric stations and b) catchments up- and downstream of major existing or potential hydraulic structures, such as diversion weirs and dams. The time series upstream of hydrometric stations were primarily used for calibration of rainfall-runoff models. Rainfall time series for catchments up- and downstream of major hydraulic structures were used in the preparation of runoff time series for river basin simulation.

### **1.5.4 Availability and sources of hydro-meteorological data**

The primary input requirements for the modeling in the Eastern Nile include stream flow time series data, reservoir data, irrigation water requirements, rainfall data and evaporation data. Monthly rainfall data were sourced from the Nile Basin Encyclopedia, the Ethiopian Master plan, the Global FAO Clim database and the WMO GHCN (Global Historical Climatology Network) database. The simulation period for the model is 1951-1990.

### **1.5.5 Data Quality Control, Infilling and Record Extension**

Extensive patching of rainfall data for the whole Eastern Nile Region was undertaken, as described in detail in the Master plan and JMP Data Report. No further checking and/or infilling was carried out for stream flow data as the JMP flows, which have already been patched and quality controlled, were used as a basis for the modeling.

## CHAPTER TWO

### 2 Description of the Study Area

#### 2.1 Nile and Eastern Nile River Basin General Overview

The Nile River is the world's longest river with a length of 6700 km. Nile Basin has an area consisting of 3.2 million sq. km, 10% of Africa. The Basin covers 11 countries: Burundi, DR Congo, Egypt, Eritrea, Ethiopia, Kenya, Rwanda, South Sudan, Sudan, Tanzania, and Uganda.

The whole Nile Basin countries' population is estimated over 400 million; 190 million in the basin. The Basin consists of rich natural and environmental assets and rich historical heritage.

At approximately 6700 km, the Nile River is the longest river in the world. It extends from the Lake Victoria in the south to Lake Nasser (Aswan Dam) in the north with a total catchment area of approximately 3 million km<sup>2</sup> before flowing into the Mediterranean Sea.

The basin comprises a diverse group of different tributaries with relatively small and isolated areas contributing to the significantly to the total flow (Sutcliffe and Parks, 1999). The river traverses the countries of Tanzania, Uganda, Rwanda, Burundi, Zaire, Kenya, Ethiopia, Sudan and Egypt.

The Nile Basin is characterized by two mountainous plateaus, namely the Lake Plateau in the southern part at a level of between 1000 and 2000 masl; and the Ethiopian Plateau forming the eastern part of the basin rising to more than 3500 m asl. The basin descends gradually northwards of the Lake Plateau to the Sudan plains at an altitude of about 500 masl, and then further flattens out in Egypt to the north.

The main parts of the Nile are summarized below and which are described in more detail in the respective

- The Equatorial Lakes comprising Lake Victoria, the Upper Victoria Nile, Lake Kyoga, the Lower Victoria Nile, Lake Albert, Lake Edward and Lake George;
- The Bahr el Jebel Basin – the main feature of this basin are the Sudd swamps and wetlands; · The Bahr el Ghazal Basin;
- The Sobat Basin comprising the Baro and Pibor tributaries;
- The White Nile which extends from the foothills of the lake plateau in the south to the confluence with the Blue Nile, and from the foothills of the Ethiopian Plateau in the east to the Nile-Congo divide in the west;
- The Ethiopian (or Abyssinian) Plateau comprising the Blue Nile and the Atbara Rivers;
- The Main Nile from Khartoum and Aswan and from Aswan to the Mediterranean Sea

The climate of the Nile Basin is extremely variable owing to its geographic extent. The seasonal pattern of rainfall shows bimodal rainfall in the Equatorial Lakes area, to a transitional zone between Lake Albert and Mongalla to a single rainfall season in the Bahr el Jebel basin (Sutcliffe and Parks, 1999). The trend of a shorter rainfall season is apparent to the northern tributaries and lower parts of the basin. Compared to the size of the basin, the total runoff from the Nile is relatively small, with average annual runoff at about 30 mm. However, the distribution of runoff is not uniform and significant flow volumes are generated from relatively small and isolated tributaries, in the Equatorial Lakes region and in the Ethiopian highlands. (NBI-ENJMP)

### Eastern Nile Basin

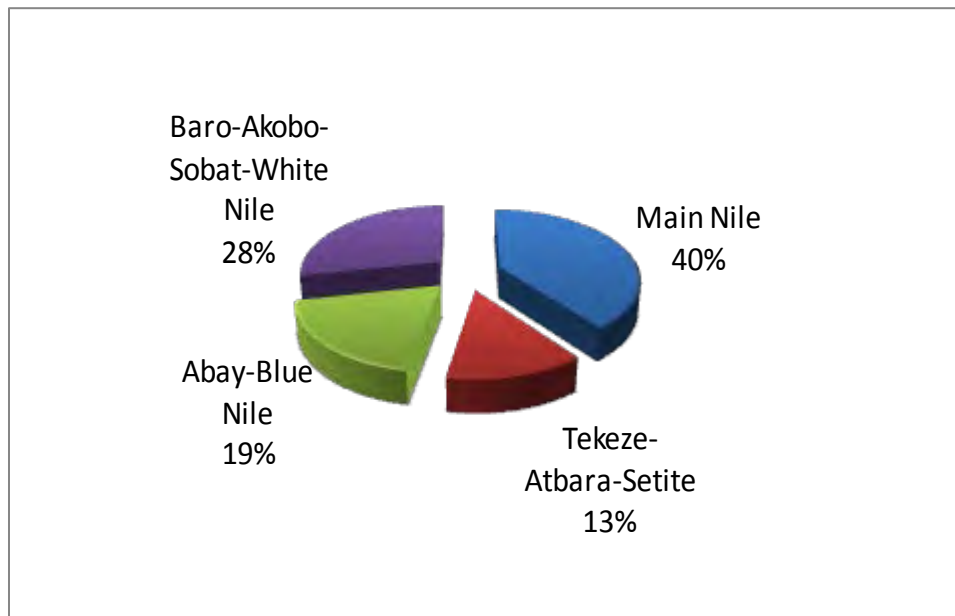
Eastern Nile Basin is a Nile River basin without the Equatorial Lake basin

Eastern Nile Basin has an Area consists of 1.8 million sq.km. The Basin covers 4 countries: Egypt, Ethiopia, South Sudan and Sudan.

The Eastern Nile Basin countries Population estimated over 149 million. The Basin consist Rich natural and environmental assets and Rich historical heritage

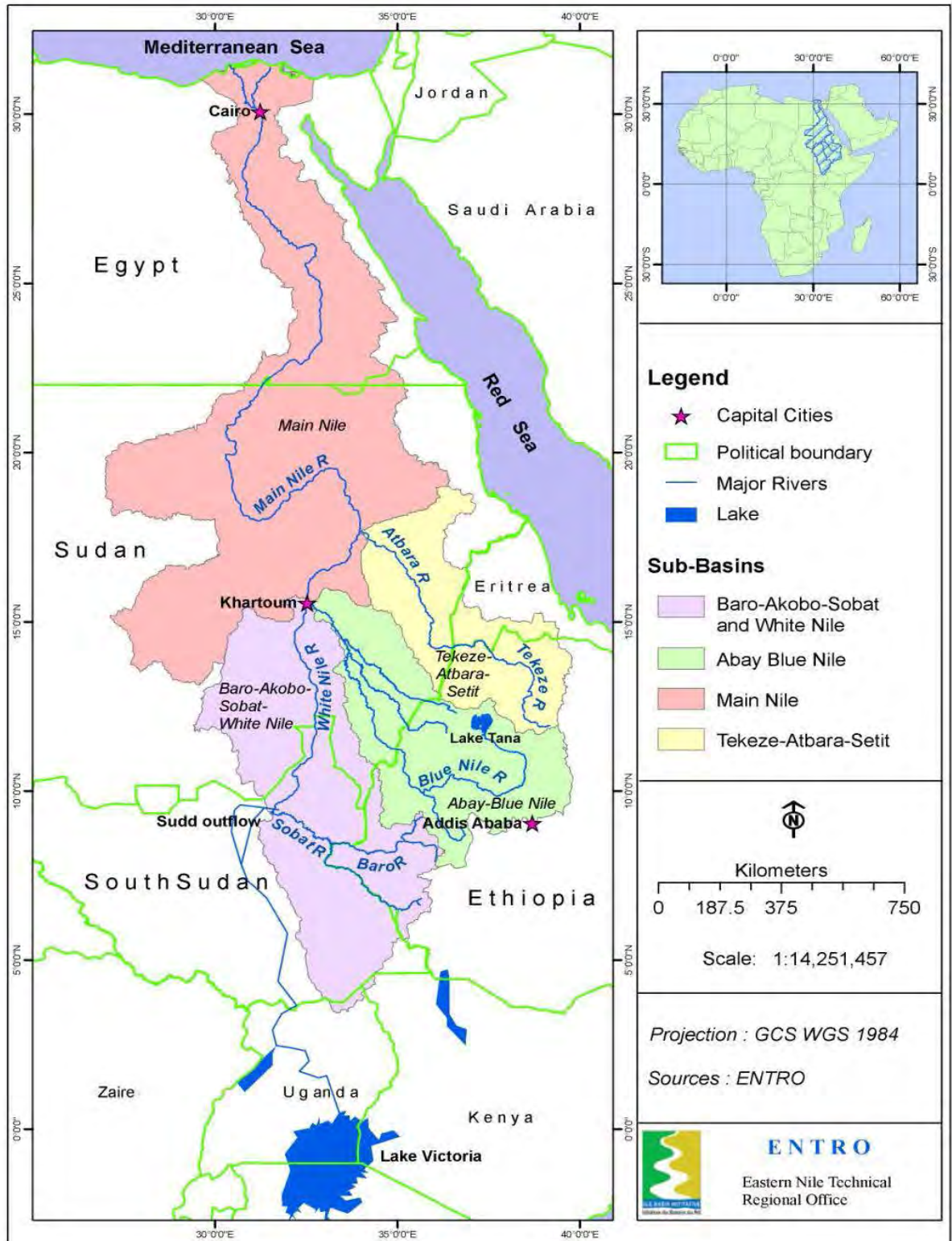
The Eastern Nile Basin Divided into 4 sub-basins:

- Baro-Akobo-Sobat-White Nile,
- Abay-Blue Nile,
- Tekeze-Setit-Atbara and
- Main Nile



**Fig 2.1 Eastern Nile River Basin by Catchment Area Fraction**

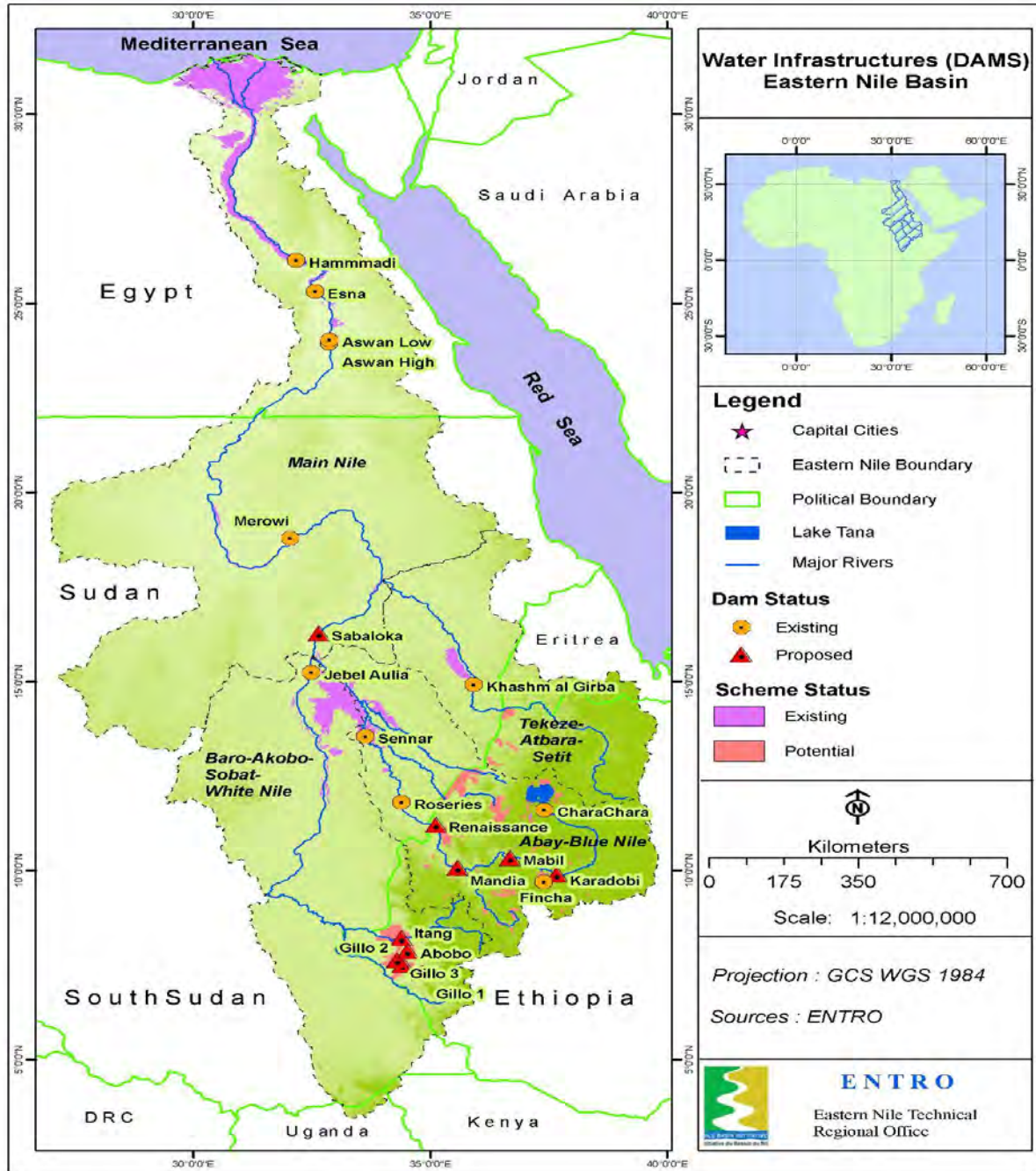
## Easter Nile River Basin Simulation with GERD



**Fig. 2.2 Easter Nile Sub basins**

## Easter Nile River Basin Simulation with GERD

In the Eastern Nile River system there have been identified various irrigation and hydropower developments in the basin. Since then, various projects have been implemented and some are under construction and the rest are at various levels of studies. Fig. 2.3 shows below the Easter Nile Sub basins.



**Figure 2.3: Location of Study Area and Development Potentials**

The Blue Nile River (known as the Abay in Ethiopia) is the most important tributary of the Nile River, providing over 62% of the Nile's flow at Aswan (World Bank, 2006). Both Egypt, and to a lesser extent Sudan, are almost wholly dependent on water that originates from the Nile. This dependency makes the challenges of water resources management in this region an international issue (Waterbury, 2002).

The Blue Nile rises in the Ethiopian highlands in the region of West Gogjam and flows northward into Lake Tana, which is located at an elevation of just under 1,800 m. It leaves the southeastern corner of the Lake, flowing first south-east, before looping back on itself, flowing west and then turning north-west close to the Border with Sudan.

In the highlands, the basin is composed mainly of volcanic and Pre-Cambrian basement rocks with small areas of sedimentary rocks. The catchment is cut by deep ravines in which the major tributaries flow. The valley of the Blue Nile itself is 1,300 m deep in places.

The primary tributaries in Ethiopia are the Beshio, Jema, Muger, Guder, Finchaa, Anger, Didessa and Dabus on the left bank and the Chemoga, Timochia, Bir and Beles on the right bank.

The Blue Nile enters Sudan at an altitude of 490 m .a.s.l and just before crossing the frontier, the river enters a clay plain, through which it flows to Khartoum. The average slope of the river from the Ethiopian frontier to Khartoum is only 15 cm km<sup>-1</sup>. Within Sudan, the Blue Nile receives water from two major tributaries draining from the north, the Dinder and the Rahad, both of which also originate in Ethiopia. At Khartoum the Blue Nile joins the White Nile to form the main stem of the Nile River.

Within the basin rainfall varies significantly with altitude and is considerably greater in the Ethiopian highlands than on the Plains of Sudan. Within Sudan, the average annual rainfall over much of the basin is less than 500 mm. In Ethiopia, it increases from about 1,000 mm year the Sudan Border to between 1,400 and 1,800 mm over parts of the upper basin and exceeds 2,000 mm in some places. The flow of the Blue Nile is characterized by extreme seasonal and inter-annual variability.

At the Ethio - Sudan Border total annual flow varies from approximately 31 Bm<sup>3</sup> to 70 Bm<sup>3</sup>. Typically, more than 80% of the flow occurs during the flood season (July to October) while only 4% of the flow occurs during the dry season (February to May).

Currently Ethiopia utilizes very little of the Blue Nile water, partly because of its inaccessibility and partly because the major centers of population lie outside of the basin. To date only two relatively minor hydraulic structures and one water transfer from Lake Tana to Beles Hydropower have been constructed in the Ethiopian part of the catchment. The two dams (i.e., Chara Chara weir and Finchaa) were built primarily to provide hydropower.

The Beles Hydroelectric Power Plant, sometimes referred to as Beles II or Tana-Beles, is a run-of-the-river hydroelectric power plant in Ethiopia near Lake Tana. The power plant receives water from the lake and after utilizing it to produce electricity; the water is then discharged into the Beles River. The plant will eventually have an installed capacity of 460 MW. It is also expected to help provide water for the irrigation of 140,000 ha (350,000 acres). It was inaugurated in May 2010. The Chara Chara weir regulates outflow from Lake Tana for the downstream Tis Abay power stations.

Agriculture, which is the main occupation of the inhabitants in the basin, is primarily rain fed with almost no irrigation. Although there is some informal small-scale irrigation, currently the only formal irrigation scheme in the Ethiopian part of the catchment is the Finchaa sugar cane plantation (8,145 ha), which utilizes water after it has passed through a hydropower plant. In contrast to Ethiopia, Sudan utilizes significant volumes of Blue Nile water both for irrigation and for hydropower production. Two dams (i.e., Sennar and Roseires) have been constructed on the main river approximately 350 km and 620 km south-east of Khartoum (Table 1). These provide hydropower (primarily for Khartoum) as well as water for several large irrigation schemes, including the Gezira scheme (882,000 ha), which is one of the largest in the World. As well as irrigating land immediately adjacent to the Blue Nile River, some water is diverted from the Blue Nile downstream of the Roseires reservoir to the Rahad River, where it is used to supplement the irrigation of the Rahad irrigation scheme (168,037 ha). The total irrigated area in the Sudanese part of the Blue Nile is estimated to be 1,305,000 ha, for a variety of crops including cotton, sugar cane and vegetables. The installed power capacity at the two dams is 295 MW which represents 25% of the country's total generating capacity (i.e., 1,200 MW from both thermal and hydro power stations).

The Ethiopian Government is currently concentrating on development of Ethiopia's hydroelectric power potential that generates capacities to meet domestic demand and exports for neighboring countries and provide support to foreign currency income. Parallel to this, the Abay Basin Integrated Master Plan Study revealed feasible hydropower project sites in the basin. One of these is the GRAND ETHIOPIAN RENAISSANCE Dam Project is under construction.

The Grand Ethiopian Renaissance Hydroelectric Power Project is located in the Eastern Nile Basin at the foothills of the escarpment of western Ethiopia. Geographically, it is situated

between North  $9^{\circ}50'49''$  and  $11^{\circ}17'21''$  and East between  $35^{\circ}57'25''$  and  $35^{\circ}52'48''$ . It occupies an area of land above 500m elevation designed to rise up to 145 m high from the riverbed to provide effective hydropower reservoir area. The total area of the reservoir where the study has been conducted is 191,546.51ha. It is expected to hold 63 million  $m^3$  of water to generate about 6,000 MW electric power. The dam is proposed to be constructed at a distance of 15 km along the Ethio-Sudanese Border, i.e. at the outlet of Blue Nile River from Ethiopia to the Sudan. The reservoir extends back into Ethiopian territory along the Blue Nile River for about 100 Km. The dam starts at about 500 meters above sea level and with dam height about 145 m. Thus, the vegetation between altitudes from 500 to 645m is expected to be under water. With the formation of a reservoir with extensive surface area, various economic activities are may be attracted and affect the immediate catchment area.

The reservoir water, after dam construction will take up all the existing land cover and land use types occurring in between the lowest ground base 500m and the highest 645m elevation asl. It will enfold all side slopes of river valleys, plains and low isolated hills and hill side slopes of Abay and its major tributaries i.e. Dabus, Didessa and Beles falling in between the lower and upper elevations indicated here above. Henceforth, studying the land cover resources in the reservoir area before dam construction by type and extent help determine the reservoir's impact on the existing natural resources, land use, land users and thus look for alternative actions to be considered ahead of time.

### 2.1.1 Blue Nile

The Blue Nile is located between  $16^{\circ} 2' N$  and  $7^{\circ} 40' N$  latitude, and  $32^{\circ} 30' E$  and  $39^{\circ} 49' E$  longitude. It has an estimated area of 311,437 sq. km. From its source Gish Abbay in West Gojam, Abbay flows northward as the Gilgel Abbay into Lake Tana. The Blue Nile River (also called Abbay River in Ethiopia) exits from the south east of Lake Tana and flows south and then westwards cutting a deep gorge towards the western part of Ethiopia. A number of tributaries joined Abbay River in Ethiopia: Beshilo, Derame, Jema, Muger, Finchaa, Didessa and Dabus from the east and south; and the Suha, Chemoga, Keshem, Dera and Beles from the north. The Dinder and Rahad rise to the west of Lake Tana and flow westwards across the Border joining the Blue Nile below Sennar. In the Sudan, the Blue Nile flows on the plain desert until it reaches the confluence, where it meets with White Nile in Khartoum.

The basin is subdivided into 18 major sub basins namely, Lower Eastern Nile, Upper Eastern Nile, Dinder, Rahad, Tana, Beshelo, Beles, Dabus, Diddessa, Jemma, Muger, Guder, Fincha, Anger, Wenbera, South Gojam, North Gojam and Welaka

The Blue Nile originates from Lake Tana far up in the Ethiopian highlands and spirals down toward Sudan in deep gorges. The distance from Lake Tana to the Ethiopian-Sudanese Border (Diem) is 900 river-kilometers, and the elevation drop is nearly 1300 meters. At the Border, the river enters the Sudanese plains and flows toward Khartoum for another 700 kilometers of mildly Sloped terrain.

The climate of the Ethiopian plateau is influenced by the migration of the Inter tropical Convergence Zone (ITCZ) which produces heavy rains from June to September and dry conditions for the rest of the year. As a result, the Eastern Nile is highly seasonal with most flow occurring from July to October. At Diem the river averages 50 BCM per year, but during exceptionally wet or dry years, it may exceed 70 BCM or fall below 30 BCM per year. Below Diem, Dinder and Rahad add another 4 BCM to the annual flow, but reservoir evaporation and Channel conveyance losses detract 2.5 to BCM (Abay Master Plan)

The Blue Nile, or the Abbay, and its tributaries flow from the Ethiopian Highlands providing most of the flow in to the lower Nile. The Eastern Nile finds its source on the Ethiopian plateau at an elevation of approximately 2000 to 3000 masl. The plateau has varying topography, with broken and hilly areas, grassy uplands, swamp valleys and scattered trees (Sutcliffe & Parkes, 1999). Lake Tana in the upper basin is a shallow lake sitting at an elevation of about 1800 masl and which has a surface area of approximately 3000 km<sup>2</sup>. It has an estimated catchment area of some 12 129 km<sup>2</sup>. The lake tributaries include the Gilgel Abbay, the Gumara, the Ribb and the Megech which are perennial streams that are highly

seasonal. The Eastern Nile flows from the lake through a series of cataracts and the Tis Issat falls where there is a hydropower plant with an installed capacity of 73 MW. The main river is joined by many tributaries in steep valleys including the Jemma, the Muder, the Guder and the Finchaa rivers. Significant contributions are made by the Didessa and Dabus tributaries, which drain the south-western, humid part of Ethiopia. The Beles tributary joins the main river from the north-east just before the site of the proposed Border on the Ethiopia- Sudan Border. The Mean Annual Runoff (MAR) at this site is estimated to be 48 billion m<sup>3</sup>/a. Downstream of El Diem, the Roseires and Sennar dams on the Eastern Nile provide water for the large irrigation schemes further downstream to the confluence with the White Nile at Khartoum. The Gezira irrigation scheme and Managil extension scheme are amongst the largest in the world, covering a combined area of approximately 8000 km<sup>2</sup>. Downstream of Sennar Dam, the Rahad and Dinder tributaries join the Eastern Nile before the confluence with the White Nile near Khartoum. From here, the main Nile flows about 1500 km to Lake Nasser (Aswan Dam) with the only major inflow from the Atbara River some 300 km downstream from Khartoum

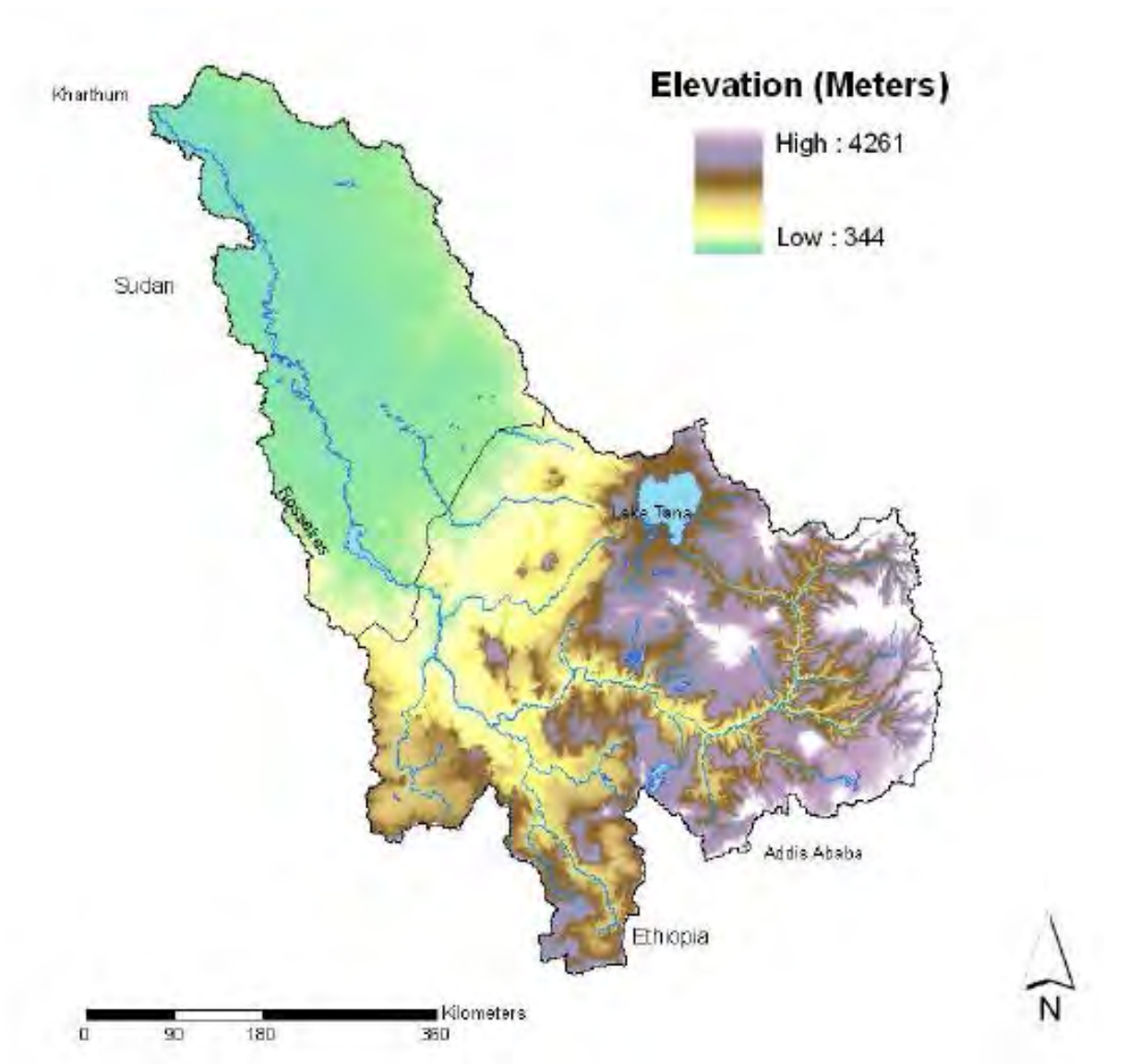
### 2.1.2 Physical Catchment Description

Although the Blue Nile (known as the Abbay in Ethiopia) Basin comprises only 8% of the total Nile Basin catchment area, on average, the Eastern Nile contributes almost 60% of the Main Nile River flow at Aswan Dam in Egypt. Catchment elevation in the Eastern Nile Basin ranges between about 400 m asl at Khartoum to more than 4200 m asl at Mount Ras Dashen in the north-eastern part in Ethiopia. The climate in the basin varies from humid to semi-arid and is mainly dominated by latitude and altitude. This is reflected in the high variability of local climates, ranging from hot and arid in Sudan to temperate at the highlands and even humid-cold at the mountain peaks in Ethiopia.

Within the Blue Nile Basin, there is significant variability in terms of sub catchment sizes, slopes, climatic patterns, topography, drainage patterns, geological formations, soils and vegetation. In general, three broad topographical divisions are identifiable: the highland plateau, steep slopes adjoining the plateau that tilt to the west and the western low lands with gentler topography comprising the remainder of the Basin.

Mean annual rainfall in the Blue Nile Basin varies between less than 400 mm in Sudan close to the confluence with the White Nile to more than 2000 mm in the Ethiopian highlands. Generally, three seasons are defined in Ethiopia: The rainy season from June to September which contributes about 70% of the annual rainfall and which is driven by south-west winds originating from the Atlantic Ocean; the dry season from October to January; and the short

rainy season between February and May, originating from south-east winds from the Indian Ocean.



**Figure 2.4: Map of the Blue Nile basin showing elevation, the main tributaries and key geographic features (Source: Awulachew, 2008)**

The Blue Nile Basin hydrology is characterized by seasonal and annual variability, very steep catchment and channel gradients and rapidly eroding watersheds, which result in very high sediment loads. This is exacerbated by poor agricultural practices, overgrazing and deforestation. The dominant land cover in the Blue Nile Basin is rainfed agriculture, i.e.

cropland (26%) and grassland (25%). Wood and shrub land are minor compared to the other land cover types (Teferi et al., 2010). The dominant soil texture of the Basin is clay. The soil type in the basin is dominated by Vertisol and Nitisol types (53%). The Nitisols are deep non swelling clay soils with favourable physical properties like drainage, workability and structure, while the Vertisols are characterized by swelling clay minerals with more unfavorable conditions. The basin geology is characterized by basalt rocks, which are found in the Ethiopian highlands, while the lowlands are mainly composed of basement rocks and metamorphic rocks such as gneisses and marbles (ENTRO, 2007).

### 2.1.3 Hydrological overview

The Blue Nile, or the Abbay, and its tributaries flow from the Ethiopian Highlands providing most of the flow into the lower Nile. The Eastern Nile finds its source on the Ethiopian plateau at an elevation of approximately 2000 to 3000 masl. The plateau has varying topography, with broken and hilly areas, grassy uplands, swamp valleys and scattered trees (Sutcliffe & Parkes, 1999). Lake Tana in the upper basin is a shallow lake sitting at an elevation of about 1800 masl and which has a surface area of approximately 3000 km<sup>2</sup>. It has an estimated catchment area of some 12 129 km<sup>2</sup>. The lake tributaries include the Gilgel Abbay, the Gumara, the Ribb and the Megech which are perennial streams that are highly seasonal. The Eastern Nile flows from the lake through a series of cataracts and the Tis Issat falls where there is a hydropower plant with an installed capacity of 73 MW. The main river is joined by many tributaries in steep valleys including the Jemma, the Muder, the Guder and the Finchaa rivers. Significant contributions are made by the Didessa and Dabus tributaries, which drain the south-western, humid part of Ethiopia. The Beles tributary joins the main river from the north-east just before the site of the proposed Grand Ethiopian Renaissance Dam on the Ethiopia- Sudan Border. The Mean Annual Runoff (MAR) at this site is estimated to be 48 billion m<sup>3</sup>/a. Downstream of El Diem, the Roseires and Sennar dams on the Eastern Nile provide water for the large irrigation schemes further downstream to the confluence with the White Nile at Khartoum. The Gezira irrigation scheme and Managil extension scheme are amongst the largest in the world, covering a combined area of approximately 8000 km<sup>2</sup>. Downstream of Sennar Dam, the Rahad and Dinder tributaries join the Eastern Nile before the confluence with the White Nile near Khartoum. From here, the main Nile flows about 1500 km to Lake Nasser (Aswan Dam) with the only major inflow from the Atbara River some 300 km downstream from Khartoum.

### 2.1.4 Existing Water Resource Infrastructure Hydropower

There are currently two major dams in the Blue Nile supplying water for irrigation and hydropower. These are the Roseires and Sennar dams in Sudan. The Roseires Dam

downstream of El Diem was completed in 1966. It has a full supply capacity of 2100 million  $m^3$  and is operated primarily for hydropower. It has an installed capacity of 280 MW. The Sennar Dam downstream of Roseires was built in the 1920s and is used primarily for irrigation of the Gezira and Managil irrigation schemes. Two canals from Sennar Dam supply water to the schemes. Sennar dam also generates hydropower with an installed capacity of 15 MW.

The Beles Hydroelectric Power Plant, sometimes referred to as Beles II or Tana-Beles, is a run-of-the-river hydroelectric power plant in Ethiopia near Lake Tana. The power plant receives water from the lake and after utilizing it to produce electricity; the water is then discharged into the Beles River. The plant will eventually have an installed capacity of 460 MW. It is also expected to help provide water for the irrigation of 140,000 ha (350,000 acres). It was inaugurated in May 2010.

The Tis-Abbay II hydroelectric power plant is located on the Abbay River downstream of Lake Tana where the head of the Tis Issat Falls has been used to generate electricity since 1964. Tis-Abbay I have an installed capacity of 11 MW and Tis-Abbay II has increased the installed capacity at this location to 73 MW.

The Fincha'a Dam on the Fincha'a River, a tributary of the Eastern Nile has an installed capacity of 128 MW. It was constructed in 1973 and is now also connected to the Amerti River via a tunnel.

On the Main Nile, there are several irrigation schemes which are supplied from the river, one at Tamaniat–Hassanab and the other at Hassanab-Dongola located upstream and downstream of Merowe Dam respectively. Merowe Dam is located near the 4<sup>th</sup> cataract near the city of Merowe. The main purpose of the dam is for hydroelectricity and it has an installed capacity of 1250 MW.

### 2.1.5 Existing Water Users Irrigation

The major consumptive water user in the Blue Nile catchment is irrigation. The average annual supply for irrigation in the Gezira and Managil Schemes is about 6 Billion  $m^3/a$ . Additional smaller irrigation areas comprise the irrigation areas upstream and downstream of Sennar dam covering an estimated area of 5000  $km^2$ , and the combined average annual supply to these areas is estimated to be 3.6 billion  $m^3/a$ .

Hydropower is generated at Tis Abbay (downstream of Lake Tana), at Roseires Dam, at Sennar Dam, on the Fincha River and in the Beles tributary from Lake Tana.

Although there are numerous local riparian water users within Blue Nile catchment, it has been assumed that the volume of water abstracted for domestic use, livestock watering and subsistence farming is negligible compared to the large scale commercial irrigation water use in the catchment.

### 2.1.5 Present Operation System

Releases are made from Roseires to Sennar in order to maintain the water level in Sennar for irrigation supply to the Gezira and Managil canals. At present Roseires is operated to maintain electrical supply from the dam, although the storage is also reduced in July and August to try to reduce the rate of sedimentation in the dam. The dam is allowed to start filling at the earliest at the beginning of September or when the flow at dam drops to 350 million m<sup>3</sup>/d or at the latest on the 26<sup>th</sup> September and fill for 26 days.

With the exception of two relatively small Sudanese reservoirs (Roseires and Sennar) and a hydroelectric weir below Lake Tana, no other regulation projects exist along the Blue Nile. However, the topography of the basin in Ethiopia can support a series of major hydroelectric and storage projects (U.S. Bureau of Reclamation Study, 1964). The characteristics of these projects (i.e., Lake Tana, Karadobi, Mabil, Mendaia, and Grand Ethiopian Renaissance Dam) and those of Roseires and Sennar are studied and summarized in the Abay Master plan Document. Full hydropower development in Ethiopia could create 62 BCM of combined reservoir storage and 5700 MW of hydroelectric power capacity.

The benefits and implications of such projects are important for Ethiopia and all Nile Basin Nations. Presently, large scale irrigation takes place only in Sudan below Sennar (at the Managil and Gezira irrigation developments) using an estimated 15.3 BCM of water per year. In fact, the primary purpose of Roseires and Sennar is to secure and divert this quantity to the irrigation areas. By contrast, food production in Ethiopia relies mainly on rain-fed agriculture. However, significant expansion of irrigated lands is possible in both countries, and extensive water withdrawals could develop in the near future.

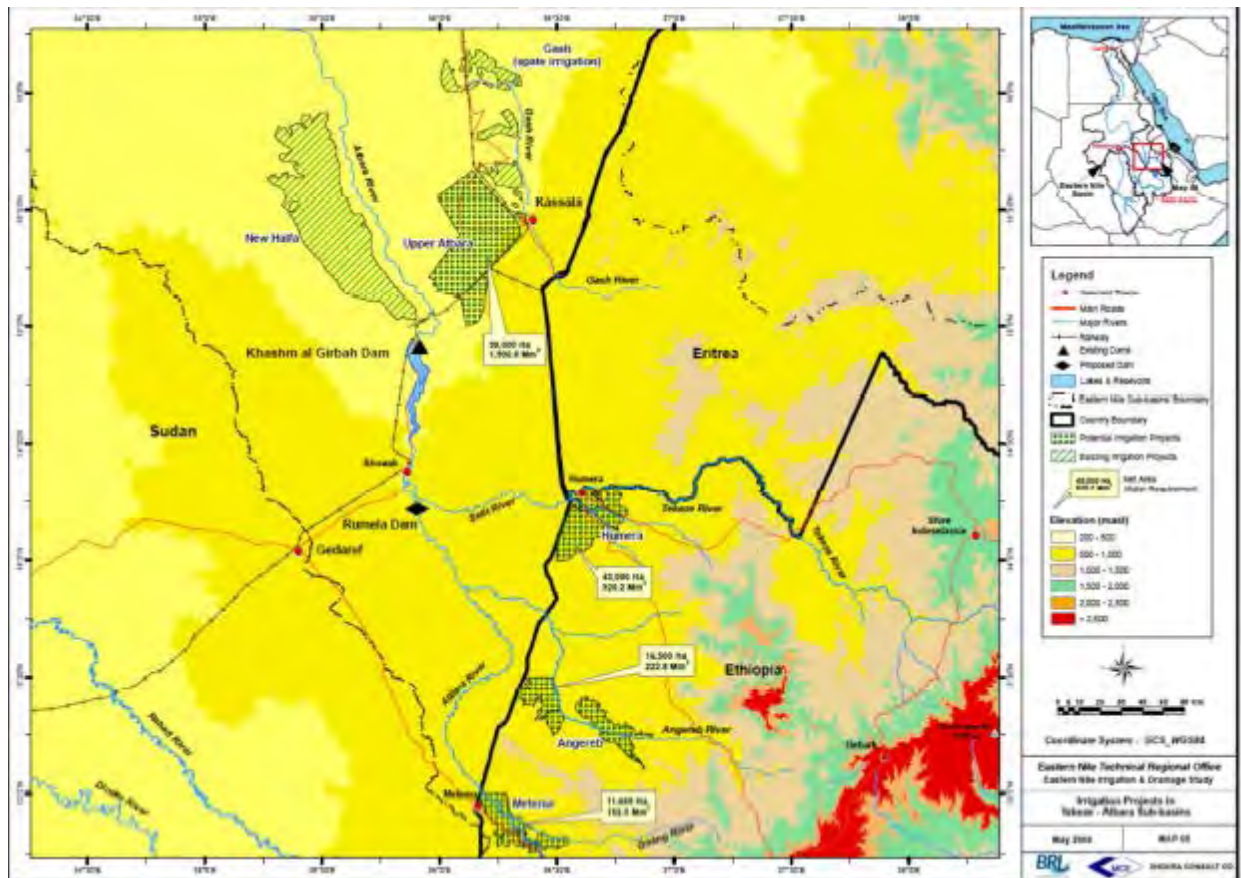
The last tributary of the Nile is the Atbara River which drains parts of Ethiopia (north of Lake Tana), Eritrea, and Sudan. Atbara contributes an average flow of 12 BCM per year in a highly seasonal pattern similar to that of the Eastern Nile. The river provides water for irrigation (at 1.5 BCM annually) and energy generation through the Khashm el Girba reservoir.

## 2.2 Tekeze-Atbara Sub-basin

The Tekeze- Atbara river system rises in the northeastern highlands of Ethiopia. The total river catchments cover some 68,000km<sup>2</sup>, 70% of which lie above elevation 1500 m asl and 40% above elevation 2000m. The Atbara-Tekeze basin has three main tributaries, Angreb and the Goang, which meet inside Sudan to form the Upper Atbara River. The Upper Atbara River joins the Seteit (Tekeze in Ethiopia) branch to form the Atbara River. Extreme variations in the climatic conditions exist across the Atbara-Tekeze river basin. While the average monthly temperatures are in the range of 12°C to 18°C in the highlands the monthly average at the confluence with the main Nile is more than 29°C with minimum and maximum temperatures from 5°C to 46°C. The rainfall varies from 1500mm on the highlands to 500mm at the Border and to less than 100mm at the confluence with the main Nile. The rainy season extend over 8 months on the highlands to 5 months at the border but mainly concentrated in the period June to September. A number of major rivers bisect the basins under consideration. The annual runoffs of these rivers are shown in Table 6.2.1. All rivers flow in the period June to December of every year with flow mainly concentrated in the months of July to September and with peaks in August.

**Table 2.2.1: Tekeze River Basin - Rivers runoff in millions of cubic meters per annum (MM<sup>3</sup>)**

River	Total
Blue Nile at Roseires	50,600
Dinder	3,000
Rahad	1,000
Tekeze-Setit	7,870
Angreb-Goag-Atbara	4,202
Main Atbara	12,072



**Figure 2.2.1: Tekeze – Atbara Sub-basin with potential development sites**

In E thiopian s ide of t he T ekeze ba sin arable l and i s m ore s situated i n t he B order w ith a n identified potential of over 70,000 ha. In Sudan 189,000ha of land is currently under irrigation from Khashem El Girba Dam on the Main Atbara River. Around 135,000ha irrigation area is planned under the Upper Atbara Project. In Sudan land resources is not a limitation. Table 6-2 shows the potential areas planned to be irrigated under different identified projects in Ethiopia and Sudan.

The na ture of t he t opography i n E thiopia o ffers s everal da m s ites for minor to large scale hydroelectric power generation and multipurpose use. The rainfall is poorly distributed over the year with 70% in the months of July to September. Seasonal storage in dams would be necessary for hydroelectric power generation and multipurpose use. A adequate survey of the topography and hydrometrical records would reveal the full extent of the hydropower potential of the basins. This could be combined with the purposes of river regulation, sedimentation reduction, creation of livelihood and protection of the watershed. The long term harnessing of the river could possibly include a cascade like series of several dams with regional power

interconnection programs and irrigation opportunities. The hydropower generation under the identified projects is shown in Table.

**Table 2.2.2: Drainage area of rivers and tributaries**

<i>River</i>	<i>Location</i>	<i>Drainage area km<sup>2</sup></i>
Tekeze-Setiet	At Sudan border	066,100
Angreb	At Sudan border	014,000
Goag-	At Sudan border	006,300
Main Atbara	Girba Dam	100,000

**Table 2.2.3: Potential Irrigable land by project (in hectares)**

<b>Basin</b>	<b>Ethiopia</b>		<b>Sudan</b>		<b>Total</b>
	<b>Existing</b>	<b>Proposed</b>	<b>Existing</b>	<b>Proposed</b>	
Tekeze-Setiet		42,965			42,965
Angreb		16,535			16,535
Goang		11,561			11,561
Atbara Branch				134,628	134,628
Atbara Main			189,000		189,000

**Table 2.2.4: Hydroelectric Power Potential**

<b>No.</b>	<b>Project</b>	<b>Purpose</b>	<b>Status</b>	<b>Reservoir capacity (Million m3)</b>	<b>Installed hydropower (MW)</b>
1	Tekeze-5	Hydropower	Existing	9,200	300
2	Khashm Elgirba	Multipurpose	Existing	650	-
3	Rumela	Multipurpose	Proposed	1300	20
4	TK7	Multipurpose	Proposed	-	-

### 2.2.1 Proposed water Resources Development

The starting point in the search for harnessing the opportunities of the basins is based on the identified water resource projects in the Eastern Nile countries. The options for water resource development could include:

- Irrigation Development
- Hydroelectric power generation and interconnections
- Rural infrastructures development
- Watershed management
- Flood and drought management
- Forests and wildlife

Most of these options have been included in the list of projects that have been identified in each country. The list of major water resources projects for the different sub-basins in Ethiopia and Sudan includes:

In the Atbara-Tekeze-Angreb-Goang Rivers sub-basins in Ethiopia:

- Tekeze Hydropower Dam;
- Humera Irrigation Project;
- Goang multipurpose opportunity;
- Angreb multipurpose opportunity;
- Possible other single or multipurpose in sub-catchments (small scale irrigation);
- In Sudan existing and planned projects on the Atbara-Seteit River are:
- Existing New Halfa irrigation Scheme
- Upper Atbara multipurpose Project

### 2.2.2 Hydrological overview

The Tekeze-Atbara catchment is the most seasonal of the major tributaries of the Nile. It is the last major tributary of the eastern Nile and is located in the northern part of Ethiopia, Sudan and part of Eritrea, draining an area of approximately 68 800 km<sup>2</sup> (Sutcliffe and Parks, 1999). The Atbara drains the mountainous area north of Lake Tana and the plains to the west with a catchment area of about 31 400 km<sup>2</sup> above its confluence with the Tekeze (called the Setit in Sudan). The lower basin in Sudan is quite eroded and is joined by intermittent streams. The Angreb and Goang Rivers join to form the Upper Atbara River in Sudan. The Upper Atbara River joins the Tekeze tributary to form the Atbara River. The Tekeze River has a mean annual runoff of 7870 million m<sup>3</sup>/a and the Angreb-Goang contribution is about 4202 million m<sup>3</sup>/a. The main Atbara River has an estimated mean annual flow of 12 072 million m<sup>3</sup>/a. Mean annual rainfall varies from 1500mm on the highlands to 500mm at the Ethiopia-Sudan Border and to less than 100mm at the confluence with the main Nile. The mean annual rainfall is

estimated to be 950 mm across the catchment, with a shorter rainfall season, concentrated in August and September, than the Blue Nile.

**2.2.3 Existing water resource infrastructure**

Existing bulk water infrastructure comprises the TK5 reservoir in the upper Tekeze which is a multipurpose reservoir providing hydropower and water for irrigation with a high assurance of supply. It has a full supply capacity of 9 km<sup>3</sup>. The Khashm el Girba Reservoir on the Atbara supplies water for irrigation as well as for hydropower generation. It was built in 1964 and originally had a full supply capacity of 1.3 km<sup>3</sup>. Currently, the Upper Atbara Dam Complex, which involves the Burdana Dam on the River Setit and the Rumela Dam on the Atbara River upstream of the Khashm al Girba Dam, is under construction in Sudan

**Table 2.2.5: Tekeze River Basin Existing dams**

Existing							
Khashm el				TK			
Operation : Provides seasonal storage to augment the water supply to the New Halfa Irrigation Scheme. Due to high sediment loads in the flood season the dam is allowed to fill at the start of the flood season and then drawn down suddenly to RL450 over three days (Around about mid July) to try to scour sediment from the dam basin. The dam is filled using the recessionary limb of the flood flows (in August/ September). It is likely that the streamflows in the river are monitored on a daily basis to time the emptying/filling to ensure that the dam can fill. A scour release may not be made if the inflows are insufficient to refill the dam and will				Operation: The target power is adjusted to maximize firm hydro-power.			
	Elevation	Area (km <sup>2</sup> )	Volume (mill m <sup>3</sup> )		Elev (m)	Area (km <sup>2</sup> )	Volume (mill m <sup>3</sup> )
Bottom	44	0	0	DS	975	0.0	0
	44	1.5	5		1000	5.0	69
Dead Storage level (DSL)	45	2.3	14		1010	8.1	13
	45	3	23		1030	21.6	42
	46	6	43		1050	39.6	102
	46	10.8	70		1070	61.8	203
	467.5	35	16		1090	81.9	348
	47	63	30	Min OL for	1096	89.4	404
	473.6	95	58		1110	106	535
max operating level (Max	47	100	65		1130	139.	781
				Max OL	1140	156.	929
					1150	176.	1095
				Tekeze Medium Hydropower Project, Feasibility Report, Final Version Dec 1997, especially			
from reservoirs manager.accdb developed by the NBI unless otherwise							

Table 2.2.6: Existing hydro-power schemes

Dam	Khashm El Girba		TK5
Description	Pump/Turbine to irrigation canal	Turbine	Turbine
Installed capacity (MW)	7.6	10.6	300
Maximum WL	474	474	1140
Tail level	464.6	425	975
Approximate head (m)	9.4	49	165

#### 2.2.4 Water users

The main water user in the T ekeze-Atbara basin is irrigation in the New H alfa irrigation scheme. There are a number of proposed multipurpose projects in the basin which are currently being investigated. Hydropower generation is a non-consumptive water user in the basin. No environmental / compensation releases are currently made from Khashm el Girba Dam.

#### 2.2.5 Present operation system

The T K5 reservoir is operated primarily for hydropower and the water is available for irrigation projects in the surrounding area. There is a high reliability of supply associated with the TK5 hydropower and therefore there is potential for supply to larger irrigation schemes. Khashm el Girba is a multipurpose reservoir which supplies irrigation water through a canal system and also generates a small amount of hydropower. The Khashm el Girba reservoir is drawn down to almost empty before the high flow season in order to reduce sediment build up.

### 2.3 Sudd, Bahr el Chazal and Sobat

Exiting Lake Albert, the Nile flows north to Nimule at the Ugandan-Sudanese Border. From here, it changes name from Albert Nile to Bahr el Jebel, receives the contribution of several tributaries known as Torrents, reaches Mongala, and soon thereafter enters the Sudd. Over the 1913 to 1971 time period, the flow at Mongala varied from a 64 BCM per year maximum to a 15.3 BCM per year minimum, with a 31 BCM per year average. Most of the water comes from Lake Albert with the Torrents contributing an average of 4.8 BCM per year. Much like the Sudd rainfall, the flow of the Torrents is highly seasonal occurring from May to November. Below Mongala, the river enters the Sudd swamps, spills over its banks, and inundates the adjacent flood plains. The extent of the flooded area varies with flow, but in the 1979-1980 periods it was estimated to be 30,000 square kilometers (Sutcliffe and Parks, 1999). In the Sudd, evaporation exceeds rainfall by about 1300 millimeters per year, causing most of the spilled water to evaporate. At Malakal, where the river and its bifurcations emerge from the Sudd, only half of the Mongala flow remains. Specifically, over the 1913-1971 time periods, the flow at Malakal averaged 15.2 BCM per year. The percent reduction of the flow increases in wet years and decreases in dry years. From 1963 to 1971 the average annual flow at Mongala was 55.02 BCM, while the flow at Malakal was 21.4 BCM, representing a 61% reduction.

The seasonal cycle of wetland flooding and drying is a key element of the ecology and the 2-3 economy of the Sudd. Howell et al. (1988) and Sutcliffe and Parks (1999) explain that the swamps are either permanent wetland areas (i.e., wetlands that remain flooded throughout the year) or seasonal wetland areas (i.e., wetlands that are flooded during the rainy season and uncovered during the dry season, from December to April). Seasonal swamps are most valuable to the local economy as they support cattle grazing during the dry season. In 1979-1980 nearly half of the wetlands were seasonal swamps. Permanent wetland areas are habitats of a rich diversity of plant and animal life.

The Jonglei Canal was first proposed (Garstin, 1904) as a water conservation project to reduce evaporation in the Sudd and augment the Nile flow. In Phase II of the project, the Canal would divert up to 43 million cubic meters per day from Bahr el Jebel at Bor, before significant overbank spillage would occur, by-pass the swamps, and discharge into the Sobat River immediately before its junction with the White Nile. From a water conservation standpoint, the canal benefit would depend on its operating rule (partitioning the flow between the Bahr el Jebel and Jonglei) as well as on the flow regulation exercised by Lake Albert. From the standpoint of the local population, the canal should support and enhance Sudd's cattle grazing potential. The Bahr el Ghazal and its tributaries (Bahr el Arab, Lol, Jur, Tonj and others) drain an area of more than 500,000 square kilometers. As in the Sudd, rainfall over the basin occurs

between March and October and generates seasonal runoff (June to November) averaging 11 to 14 BCM per year. Overbank spillage occurs extensively in the basin over a variable wetland area ranging from 4,000 to 17,000 square kilometers (Sutcliffe and Parks, 1999). Wetland evaporation is so significant that when the river joins Bahr el Jebel at Lake No, its flow contribution is minimal (0.4 bcm per year).

Water conservation projects have also been proposed for the Bahr el Ghazal river basin. The potential water benefits from these projects are estimated at 5 to 8 bcm per year (UNDP, 1981, Fahmy and Fahmy, 1981), but these estimates are based on insufficient data. As in the Sudd, the seasonal wetlands of the Bahr el Ghazal enable cattle grazing during the dry season and are crucial for the survival of the local population.

Below Lake No, the river is known as the White Nile and flows eastward until it joins the Sobat River, a few kilometers upstream of Malakal. Sobat's main tributaries, Baro, Akobo, and Pibor, drain portions of Ethiopia and southern Sudan, and contribute an average of 13.7 bcm per year (as estimated by the 1913 to 1971 flow record) to the White Nile. Sobat's rainfall is seasonal from April to October and so is its streamflow (from June to November). Before joining Pibor, Baro spills an average of 2.8 bcm per year to the adjacent M'achar Marshes (Jonglei Investigation Team, 1954). Water conservation projects have been proposed to minimize spillage and augment the flow of the White Nile. However, the impacts of the conservation projects for the local population are not fully understood.

### 2.3.1 Physical Catchment Description

The Baro-Akobo-Sobat (BAS) Basin, as defined for this project, is located in the central part of the Nile basin and extends from the Equatorial forests near Gambella at elevations of 2 000 to 3 000 masl to its confluence with the White Nile at Malakal at 400 masl. The basin includes a complex system of rivers and large seasonal wetlands formed by the seasonal spills of the large rivers. The main rivers in the BAS basin are: Baro, Gila and Akobo, which originate in the Ethiopian Plateau, and the Pibor, which originates in southern Sudan and northern Uganda. Grassland, open shrub lands and open woodland with coverage of 30%, 23% and 17% respectively, are the dominant land cover units in the sub basin. Other significant land cover types in the basin include seasonal and permanent swamps, montane forest, rainfed and some irrigated crops and dense woodland. The grass land predominantly covers the low-lying area of the sub basin.

### 2.3.2 Hydrology

The Baro-Akobo-Sobat region consists of a number of hydrologically dissimilar sub-catchments. Most of the runoff (about  $12 \text{ km}^3/\text{a}$ ) is generated in the mountainous, high rainfall areas in the east which are collected by the Baro River. The slightly drier and less mountainous area of the Gilo and Akobo Rivers also provides runoff (about  $4 \text{ km}^3/\text{a}$ ), while the vast plains south of the Akobo river generate negligible runoff. During high flows, water ponds in the channels and is diverted into adjacent rivers or depressions which complicates flow measurement. The most significant of these transfers (about  $3 \text{ km}^3/\text{a}$ ) is from the Baro River, just upstream of the Pibor confluence, into the M'achar Marshes. The M'achar Marshes is located north of the Baro River before its confluence with the Pibor River in the Sudanese land. It is hydraulically connected to the Baro River during high stage flows (flood flows overtopping the river embankments) from its south and to the ephemeral torrents originated from the foothills of the western highlands of Ethiopia from its eastern side.

### 2.3.3 Climate

The climate of the BAS is featured by mountain ranges in the Ethiopian part, subject to high rainfall, and the flat plains in Sudan with declining rainfall from south to north. The vegetation cover follows rainfall isoheights, ranging from dense forests at the source, to bush and shrub land further downstream. The annual rainfall is around 1500 to 2000 mm/a in the Gambella region, 1000 mm/a in the Pibor area and 700 mm/a at Malakal. The rainfall season extends from May to October in the southern and eastern parts of the basin, and decreases northward to only July, August and September in the northern parts. The rainfall seasonality is reflected by the highly seasonal river discharges of the BAS basin. Similarly, rainfall exhibits large annual variability in particular in the low rainfall region of the basin.

### 2.3.4 Existing Water Resource Infrastructure

The Baro-Akobo-Sobat catchment is largely undeveloped. The only dam in the catchment is the Abobo Dam which must still be developed to fully service the planned 10 400 ha of irrigation.

### 2.3.4 Major Water Users

Apart from the Abobo Irrigation Scheme, there are currently no major water users in the basin in the form of commercial irrigation and/or hydropower installations. Although there is no bulk water infrastructure, water is used from the river for domestic water requirements. This demand is negligible compared to the average daily flows in the river and has not been included in the model.

### 2.4. Grand Ethiopian Renaissance Dam

#### 2.4.1 Grand Ethiopian Renaissance Dam (Master Plan)

The Grand Ethiopian Renaissance Dam project site is located on the Abbay/ Blue Nile River some 30 km downstream of its confluence with the Beles River and 20km upstream of the Ethiopian-Sudan Border. The catchment area to the Grand Ethiopian Renaissance Dam site comprises some 176,918 km<sup>2</sup> of the Abbay River Basin. The head waters of the Abbay River are in the mountains surrounding Lake Tana, the largest tributary of which is the Gilgel Abbay. Lake Tana, at an elevation of approximately EL. 1785 m provides significant regulation of the natural river flow in the upper reaches of the Abbay. The didesa, Dabus and Beles Rivers are the main tributaries which join the Abbay in the reach between Lake Tana and the Grand Ethiopian Renaissance Dam Site.

Much of the upper part of the basin comprises the highland plateau with elevation generally exceeding 2000m. The plateau exhibits extensive level areas with intensive agriculture divided by incised valleys. Mountain peaks rise to over 4000m in the north. The Abbay flows generally within a deeply incised gorge which has a relatively gentle gradient falling some 545m over 600km from an elevation of El. 1030m at Kessie bridge to El. 485m at the Ethio-Sudanese border.

This site is the last possible one on the Blue Nile River and is located near the Sudanese Border. The USBR reference is BN-28, and the co-ordinates, taken from the 1:50,000 maps prepared by S. Pietrangelli for the Tana Beles study are the following: North latitude = 11° 12' 50" and East longitude = 35° 05' 40"

Slight differences occur between the co-ordinates given in the USBR report and the ones calculated from the new maps which are mainly due to the inaccuracy of the USBR maps.

Maps:

- Geological map at 1:250,000: ABU RAMLA (NC 36-4).
- Topographical maps issued from S. Pietrangelli study with the following reference: SH 40 and SH 44 for the reservoir area are with contour lines every 50 m. It corresponds to the EMA national grid number of: 1135-C3 and 1035-A1 which are not yet available.
- Aerial photos available from the USBR study (1960 series at 1:50,000 scale): Nos 9459 and 9460.

##### 2.4.1.1 Regional Geology

The region is a flat pen plain highly eroded. Geologically, the predominant rocks are the old Precambrian series. They have been distinguished as the PGT2 formations which correspond to intrusive granites and other PSGD which are mainly granodiorite. Downstream, near the

Grand Ethiopian Renaissance Dam PTAC are mapped and represent the Tambien group which is mainly phillites, quartzite and other graphitic schist with some marble.

Some volcanic rocks are also present but mainly as remnant deposits on the top of small hills. They have been attributed to the recent quaternary eruptive events of the MAGDALA group and referenced as QATB. They are mainly formed by alkali trachytes and associated basalt.

The regional fracture pattern can be grouped into three main families. The first one is orientated to the N-S or NE-SW direction. The second one is to the E-W direction and the third one to the NW-SE direction. The region is highly affected by the old fracturing system which has marked the old basement complex. The intrusive granite formation may develop around their margin a foliated contact more or less fractured. This could be mapped at a greater scale during the geological survey for the further level of study.

Lateritization is effectively important and may affect the rock in depth. The thickness is not known but may be over 10 meters.

The wide valley up or downstream is also covered by thick alluvium deposits.

### 2.4.1.2 Dam site

#### I. Main geomorphologic and geological features

The site is at the restriction formed by the intrusive granite rocks into the basement complex gneiss rocks. Both abutments rise up 400 meters above the river bed. The two mounts are in a N-S to N-E alignment. Both abutments are formed by steep slopes cutting through into the granite rock.

For an assumed height of about 100 m, the total crest length would reach about 1,250 meters. The general valley corresponds to a large « U » shape with a flat bottom entrenched by the river flowing towards the left bank. The main flood plain is about 300 m wide. Upstream the dam site, the river has cleaned up the rock which is exposed in the stream. Off the river bed, in the flood plain, the rock is covered by silty clay from the flood deposits which may also be the result of lateralization. The total thickness is not known, but is estimated more than 10 meters.

#### II. Structural aspects

The structure is predominantly influenced by the intrusive aspect of the granite formation. Fracturization will have a great importance. 3 main families were already defined for the region. Locally, a few other directions may exist especially around the margin contact with the gneiss formation.

### III. Geotechnical aspects and water tightness

This type of rock is generally considered fairly watertight and no major problems are expected for the foundation.

The weathered zone may vary and without any other geological information, it will be assumed as USBR that it may reach up to 12 to 15 meters in the flat bottom section, and around 3 to 6 meters along the slopes.

The site is considered suitable for a concrete dam.

### IV. Construction material

Impervious material predominantly located in the main flood area, either up or downstream the dam site seems to be abundant while natural sources of gravel and sand for aggregates are not in sufficient quantity. Quarrying the granite or gneiss rock located near the dam site seems to be required to produce the quantities needed for the project.

#### 2.4.2 Current Study of Grand Ethiopian Renaissance Dam Project

EEPCO is currently concentrating on development of Ethiopia's hydroelectric power potential that generates capacities to meet domestic demand and exports for neighboring countries and provides support to foreign currency income. Associated to this, the Abay Basin Integrated Master Plan Study revealed feasible hydropower project sites in the basin. One of these is the Grand Ethiopian Renaissance Dam Project dam construction. It occupies an area of land above 500m elevation designed to rise up to 145 m high from the riverbed to provide effective hydropower reservoir area.

The reservoir water, after dam construction will take up all the existing land cover and land use types occurring in between the lowest ground base 500m and the highest 645m elevation masl. It will enfold all side slopes of river valleys, plains and low isolated hills and hill side slopes of Abay and its major tributaries i.e. Dabus, Didessa and Beles falling in between the lower and upper elevations indicated here above. Henceforth, studying the land cover resources in the reservoir area before dam construction by type and extent help determine the reservoir's impact on the existing natural resources, land use, land users and thus look for alternative actions to be considered ahead of time.

The Great Renaissance Dam Project is situated in the Beneshangul -Gumuz National Regional State of Ethiopia. The Zones in which it falls are Assosa, Kamashi and Metekel and portions of

were taken by the reservoir are: Menge, Oda Bildag, Sherkole, Anglometi, Sirba Abay, Bulen, Dangur, Guba and Wenbera.

Geographically, it is situated between North  $9^{\circ}50'49''$  and  $11^{\circ}17'21''$  and East between  $35^{\circ}57'25''$  and  $35^{\circ}52'48''$  (Location map). The total area of the reservoir where the study has been conducted is 191,546.51 ha. It is expected to hold 63 million  $m^3$  of water to generate about 5,250 MW electric power. The location and reservoir area is shown below in the figure 2.4.1

### 2.4.2.1 Technical Features of GERD

The GERD project is located approximately 750 km northwest of Addis Ababa on the Abbay River, in the Beneshangul Gumuz National Regional State of Ethiopia.

The type of works will mainly consist of a Roller Compacted Concrete (RCC) dam, two powerhouses, a gated spillway and a rock-fill saddle dam.

The main dam which will have a volume of approximately 10MCM, a length of 1780 meters and height of 145 meters, will be a RCC gravity dam, divided in three sections: right bank, central section and left bank.

The central section will be used as a stepped spillway. This will create a reservoir that covers, at full supply level, an area of 1,680 sq. km and hold a volume of 63 Billion cubic Meter (BCM) of water. The normal and minimum operating water levels will be 640 and 590 meters above sea level respectively, and the reservoir volume at minimum operating level is to be 12 BCM.

The two powerhouses will be at the downstream of the main dams: one on the right bank and the other on the left bank. They will accommodate 10 and 5 Francis Turbine Units respectively, with a total installed generating capacity of 5,250MW.

The reservoir area will cover 1,874 square kilometers at full supply level (FSL) of 640 meters above sea level (masl). The total storage volume is 74 billion cubic meters with an active storage volume of 59.2 Billion cubic meters. For a design flow of 4,305 cubic meters per second and a maximum net head of 133 meters and plant factor of 0.31, the expected average energy production per year is 15,692 GWh.

The plant has two surface powerhouses equipped with sixteen power generating units and a Switchyard. The installed power is flexible (base or peak) and the plant has been designed so that the installed capacity may be built in several stage.

The reservoir level will be controlled through three spillways, designed to cater for a probable maximum flood (PMF) of 19,370m<sup>3</sup>/s.

The saddle dam, with a maximum height of 60m and a approximate volume of 17 M CM will have a curved axis and a length of approximately 4,800 meters. The cross section will include an impervious asphalt core with the relevant upstream and downstream transition. The dam body is to be made of material obtained from the spillway excavation, whilst selected rip-rap will constitute the slope protection. A wave protection wall will be placed on the 4m wide crest.

A 500KV double bus-bar switchyard will be set up about 1.4 km downstream of the main dam. The switchyard will include incoming bays from the transformer feeders at the power plant and the outgoing transmission line bays.

The first major step in the schedule will be the diversion of the river through diversion culverts. This will take place at the beginning of the 2012/2013 dry season. The river will be diverted to enable the construction of the central section of the dam and will be carried out using four culverts constructed in the dam body.

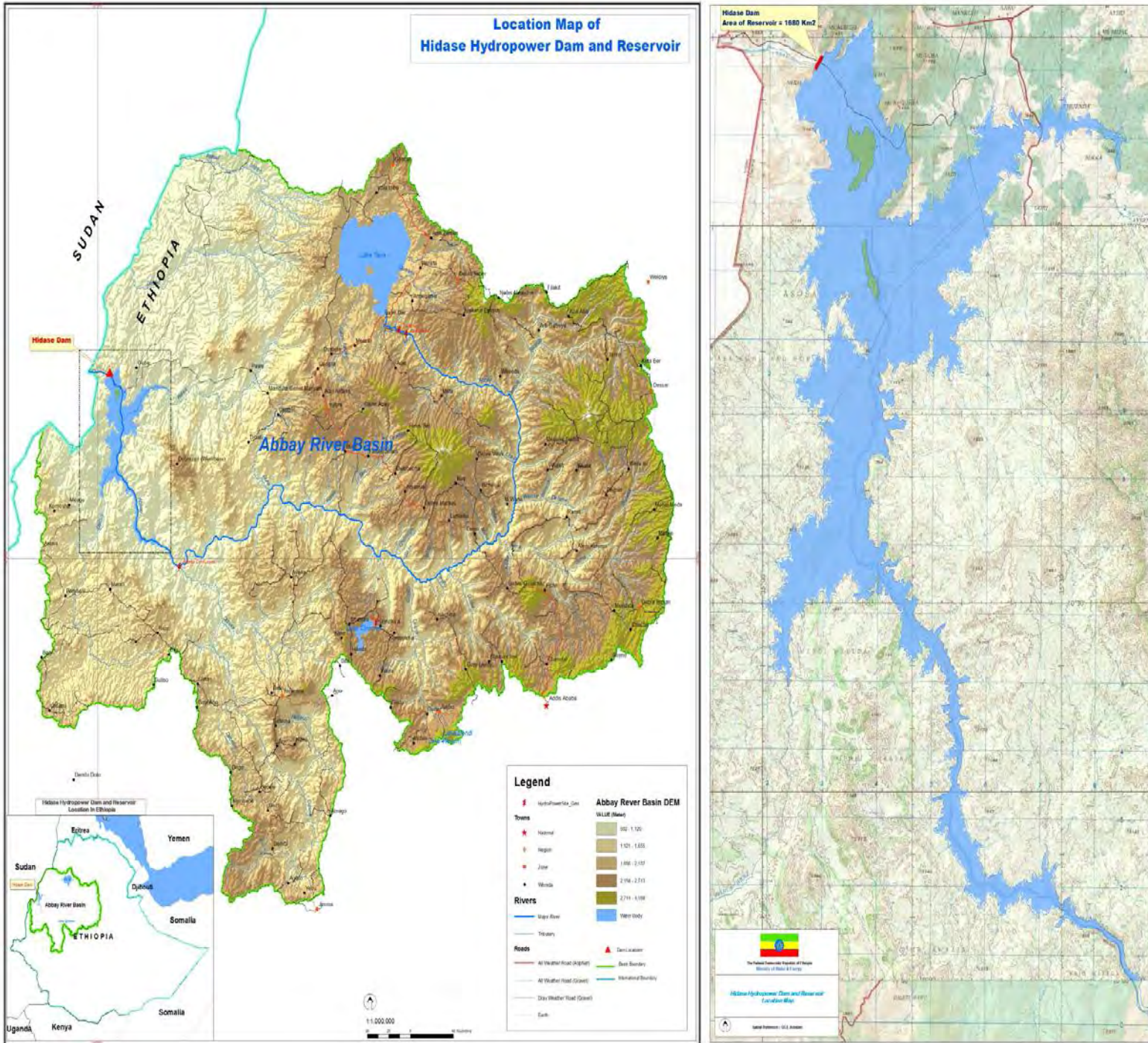
The central section of the dam will be kept lower than the right bank and left bank sections to serve as a spillway and allow for rainy season floods. This arrangement will also allow for the construction of the main dam body to proceed on both river banks during the rainy season.

**Table: 2.4.2.1 Technical Feature of GERD**

<b>Hydrological data</b>	
Catchment area	172,250 km <sup>2</sup>
Mean annual flow	1,547 m <sup>3</sup> /s
<b>Main dam</b>	
Type	Roller compacted concrete (RCC) dam
Max. Height above foundation	145m
Crest e elevation	645 m asl
Crest length	1780m
Dam volume	10.1Mm <sup>3</sup>
<b>Reservoir Data</b>	
Full Supply Level (FSL)	640 masl
Minimum operating level (MOL)	590 masl
Operating range	50m
Total Storage volume	74.01sm <sup>3</sup>
Live storage vol. (Max. regulated capacity)	59.22 8m <sup>3</sup>

## Easter Nile River Basin Simulation with GERD

Dead storage volume	14.79 Bm <sup>3</sup>
Surface area at (FSL)	1, 874 km <sup>2</sup>
Surface area at {MOL)	606 km <sup>2</sup>
10,000 years return peak flood	26,860 m <sup>3</sup> /s
Probable Maximum Flood (PMF)	38,750 m <sup>3</sup> /s
Mean annual sediment yield	207 Mm <sup>3</sup> /y
Length of reservoir at FSL	246 km
<b>Saddle Dam</b>	
Type	Rock Fill Dam with Bituminous Surface Sealing
Height	45m
Crest length	4800m
Crest elevation	644 masl
Wave wall elevation	646 masl
<b>Powerhouse</b>	
Right powerhouse	
Powerhouse type	Outdoor
Un;t# /Type	10/Francis
Installed power	10/375MW
Left power house	
Power house type	Outdoor
un;t#/Type	6/Francis
Installed power	6/375MW
<b>Power and Energy</b>	
Max Net Head	133
Total Installed capacity	6000MW
Avg. annual energy Generation	15692 GWh/yr
Plant factor	0.31



**Fig.2.2.4 Location Map of Grand Ethiopian Renaissance Dam and Reservoir**

## CHAPTER THREE

### 3 Literature Review

#### 3.1 Some of the models used in River Basin Simulation

##### 3.1.1 River Basin Simulation Model-RIBASIM

RIBASIM is generic model package for analyzing the behavior of river basins under various hydrological conditions. The model package is a comprehensive and flexible tool which links the water availability at various locations with the specific water-users in the basin.

RIBASIM enables the user to evaluate a variety of measures environment related to infrastructure, operational and demand management in terms of water quantity and water quality.

RIBASIM generates water distribution patterns and provides a basis for detailed water quality and sedimentation analyses in river reaches and reservoirs. It provides a source analysis, giving insight in the water's origin at any location of the basin.

RIBASIM follows a structured approach to river basin planning and management.

RIBASIM is a dedicated modeling instrument for river basin planning and management. It has a set of outstanding features which make it a state of the art river basin simulation package.

Large and complex river basins can be modeled and simulated with RIBASIM, while previously modeled sub-basins can be combined into one main-basin.

RIBASIM has been developed by WL | Delft Hydraulics and is part of the Delft Software. It can be linked to other WL | Delft Hydraulics software like the HYMOS hydrological database and Modeling system, the SOBEK hydraulic models and the DELWAQ Water quality model.

RIBASIM, The model could be applied at basin/sub-basin scale, (1) to provide an efficient handling and structure analysis of the large amounts of data commonly associated with (complex) water resources systems, (2) to make comprehensive and flexible tool to link the hydrologic inputs of water at various locations to the various water using activities, and (3) to evaluate a variety of measures related to infrastructure and operational management

The model has been applied for more than 15 years in a large number of countries and in a wide variety of projects. Water management organizations worldwide use it to support their world-management and planning activities.

### 3.1.2 WEAP model

Developed by the Stockholm Environment Institute (SEI), the WEAP model is intended to be used to evaluate planning and management issues associated with water resource development. The WEAP model essentially performs a mass balance of flows sequentially down a river system, making allowance for abstractions and inflows. The elements that comprise the water demand-supply system and their spatial relationship are characterized within the model. The system is represented in terms of its various water sources (e.g., surface water, groundwater and water reuse elements); withdrawal, transmission, reservoirs, and wastewater treatment facilities, and water demands (i.e. user-defined sectors, but typically comprising industry, mines, irrigation and domestic supply) (SEI, 2007; Yates *et al.*, 2005).

The Water Evaluation and Planning System (WEAP) aims to incorporate these values into a practical tool for water resources planning. WEAP is distinguished by its integrated approach to simulating water systems and by its policy orientation. WEAP places the demand side of the equation--water use patterns, equipment efficiencies, re-use, prices and allocation--on an equal footing with the supply side--stream flow, groundwater, reservoirs and water transfers. WEAP is a laboratory for examining alternative water development and management strategies.

WEAP is comprehensive, straightforward and easy-to-use, and attempts to assist rather than substitute for the skilled planner. As a database, WEAP provides a system for maintaining water demand and supply information. As a forecasting tool, WEAP simulates water demand, supply, flows, and storage, and pollution generation, treatment and discharge. As a policy analysis tool, WEAP evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

### 3.1.3 Summarized MIKE Hydro River Basin model

MIKE HYDRO is the common Graphical User Interface framework for Water Resources products of MIKE by DHI without dependencies on Arc GIS. (WGS1984)

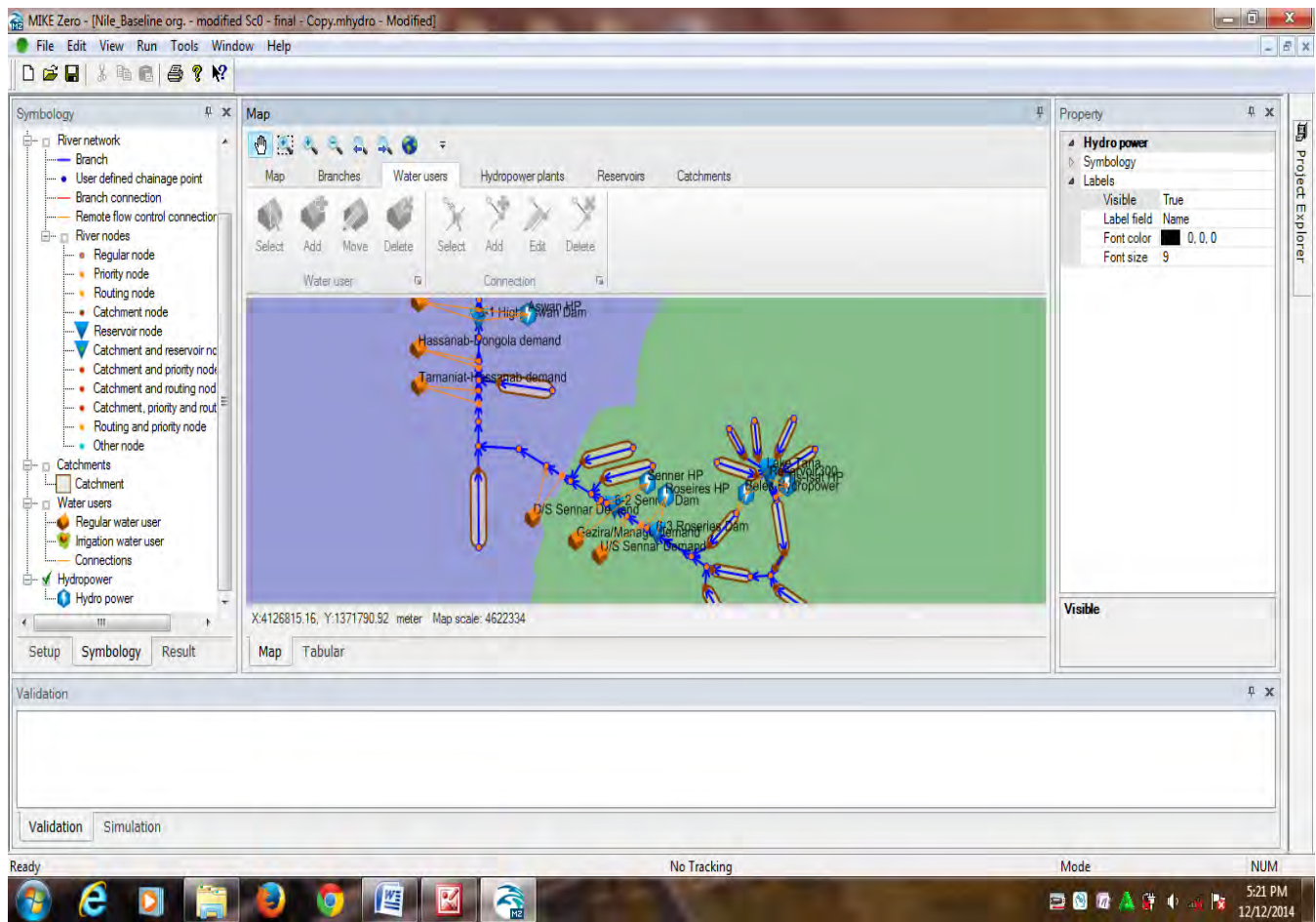
MIKE HYDRO Basin is a versatile and highly flexible model framework for a large variety of applications concerning Simulation, Allocation, and Management and planning aspects of water resources within a river basin.

MIKE HYDRO offers a state-of-art, map centric user interface for intuitive model build, parameter definition and results presentation for water resources related applications

MIKE HYDRO Basin models generally utilize a river network and sub catchments within the specific river basin as basic model-data. On top of this, a number of features can be applied depending on the type of application.

MIKE HYDRO Basin is the successor of DHI's former product for integrated water resources management and planning; 'MIKE BASIN'.

MIKE HYDRO has been used in Nile Basin for Eastern Nile Joint Multipurpose project and NELSAP with the interface of NBDSS.



**Figure: 3.3.1.1 Typical Layout of Mike Hydro 2014**

### 3.1.3.1 Mike Hydro and Decision Support System

A DSS is a common computer-based platform for communication, information management and analysis of water resources. It provides a framework for sharing knowledge, understanding river system behavior, evaluating alternative development and management strategies, and supporting informed decision making.

The Nile Basin DSS comprises of an Information Management System, a regional river basin modeling system, and a suite of analytical tools to support multi-objective analysis of investment alternatives.

The main goal is to support an informed, scientifically based rational cooperative decision making. The objective is to improve the overall net benefit from harnessing the Nile River, and to develop economically efficient, equitable, environmentally compatible and sustainable

## Easter Nile River Basin Simulation with GERD

The Nile Basin DSS interface with Mike Hydro and comprises of an Information Management System, a regional river basin modeling system, and a suite of analytical tools to support multi-objective analysis of investment alternatives.

The main goal is to support an informed, scientifically based rational cooperative decision making. The objective is to improve the overall net benefit from harnessing the Nile River, and to develop economically efficient, equitable, environmentally compatible and sustainable.

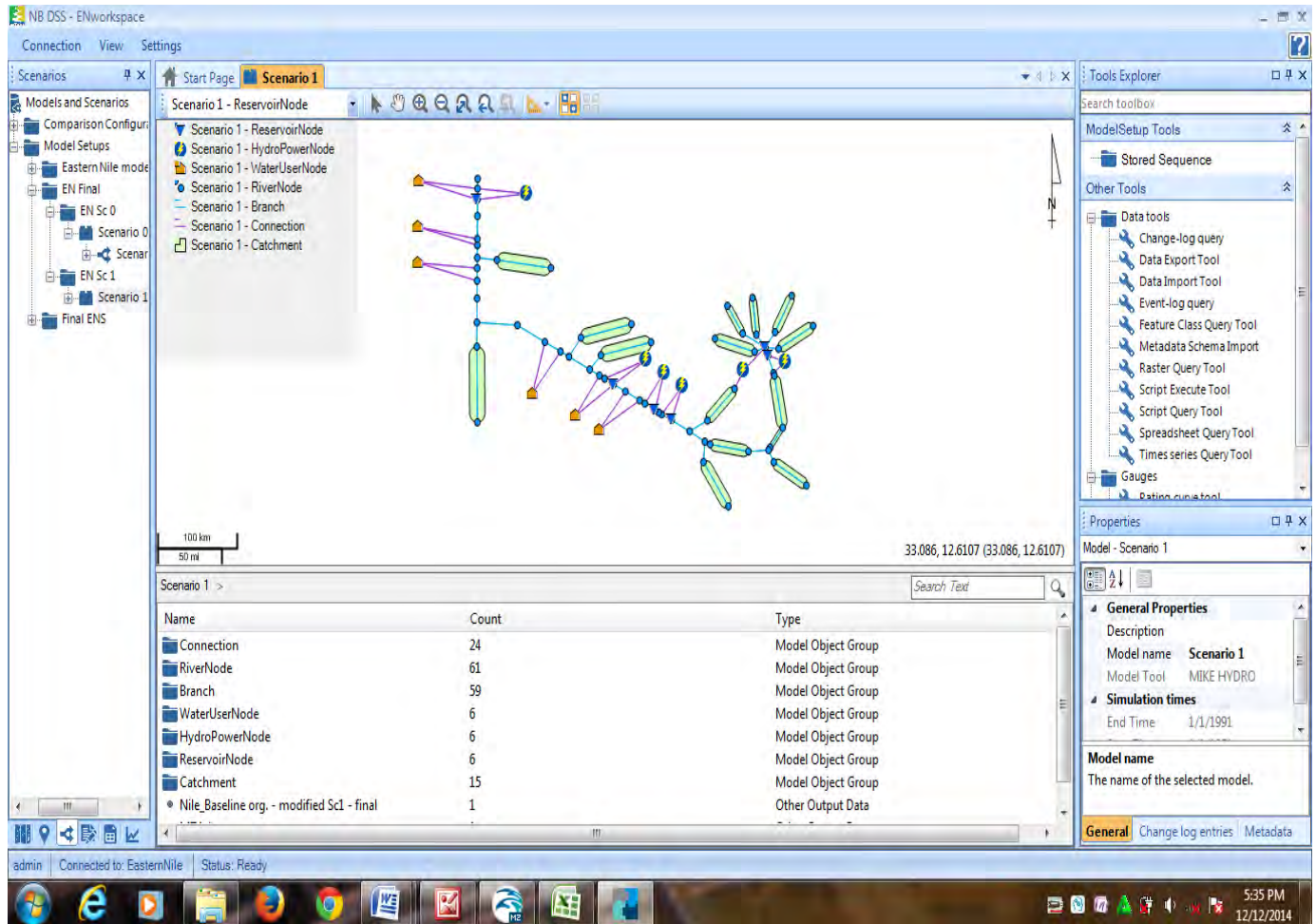


Figure: 3.3.2.1 Typical layout of NBDSS

### 3.2 Choosing the best model for a Simulation

As discussed in the above section, different hydrological models are available. These models differ in terms of their process representation, spatial and temporal representation, data requirements, and their ability to answer various what if questions. Therefore, choosing a best model for a particular application is a difficult task. Beven (2001) outlined the following key steps to be considered while choosing a model: a) is a model readily available, or could it be made available if the investment of time (and money!) appeared to be worthwhile?; b) does the model predict the variables required by the aims of a particular project?; c) are the assumptions made by the model likely to be limiting in terms of what you know about the response of the catchment you are interested in?; and d) can all the inputs required by the model, for specification of the flow domain, for the boundary and initial conditions and for the specifications of the parameters values, be provided within the time and cost constraints of a project?. Blöschl (2006) argued that the best model is not the most accurate one but the one that serves best the purpose of reaching a consensus among the players.

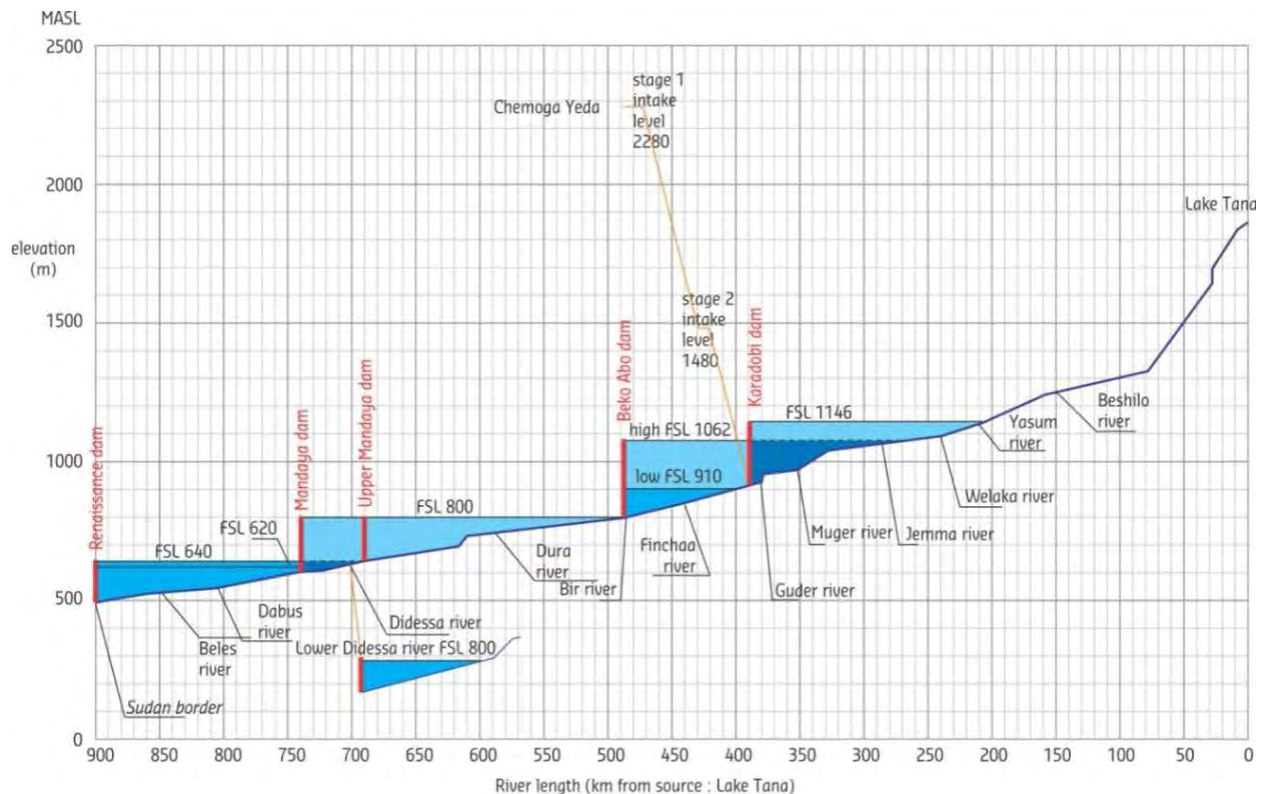
After the careful study and evaluation of some of the above-mentioned hydrological models, Mike Hydro Model considered as a good choice for the purpose of this study. While the hydrological models described earlier can simulate the hydrological process with varying degrees of representation of the physics of the hydrological processes, very less to detailed data needs and simple to complex parameterizations, each of these models do not offer the possibility of integrating with the NBDSS and hydrology with broader range of water management and DSS issues. Mike Hydro is well suited to water resource modeling in the Eastern Nile basins. The model specializes in assessing the potential for water resources development, particularly hydropower and irrigation by determining likely impacts of different water resources development scenarios and optimization of water allocation schemes.

### 3.3 Some of the pre-studies on Eastern Nile River Basin Simulation

#### 3.3.1 Insights in the water-energy-food nexus in the Nile Basin with the new Eastern Nile Water Simulation Model

Wil N.M. van der Krogt, Henk J.M. Ogink

The Most recent comprehensive study on the Eastern Nile River basin Simulation has been done by Deltares using RIBASIM. The model is based on the 41 years of flow series (1963-2003) by using HEC-5 software and defining four scenarios.



The study presents Options for the Abay Blue Nile reservoir cascades:

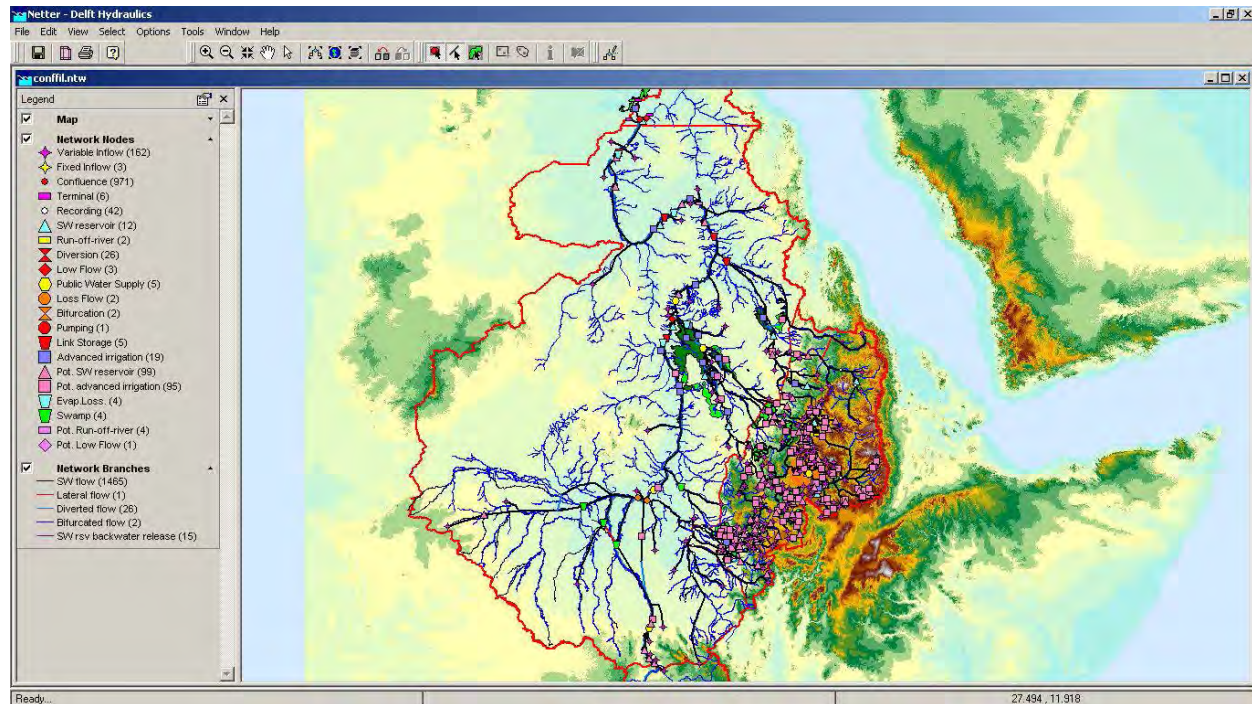
- Renaissance FSL 640: under construction
- Various cascade combinations of Karadobi, Beko Abo Low / High, Lower / Upper Mandaya and Renaissance FSL 640 / 620 dams

For the model, they considered all current and planned water use and Infrastructure, among others:

- 162 sub-catchments

- 111 dams: 11 existing and 100 under construction
- 114 Irrigation areas: 18 existing and 96 potential
- 3 potential wetland by-passes
- Lakes, swamps, domestic water use etc.

### Complete Water Balance Model-By Deltares



Complete EN network schematization for ENWSM (RIBASIM7) with map

### Strength of the study

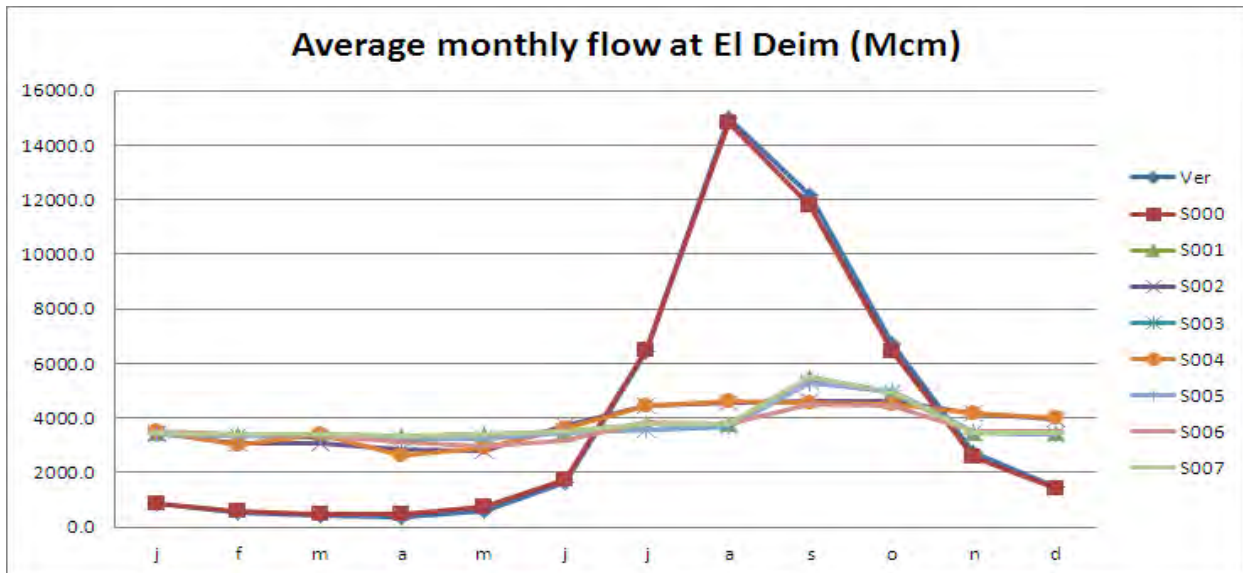
- It has been developed at ENTRO, Addis Ababa, a **joint cooperation** of the 4 EN countries
- It has been based on **data from the ENTRO library and public domain**
- It is the latest and presently most **complete water balance model** of the
- Eastern Nile (EN), covering all users and infrastructure
- It uses **unique hydrological time series** with length of 103 years (1900-2002)

The model Verification case: Nile natural flow, no structures and no users, check recorded and simulated river flows at the 42 recording stations (1900-2002)

**Table 3.3.1 Simulation cases in the illustrative analysis**

<b>Case</b>	<b>Combination of measures</b>
8001	<ul style="list-style-type: none"> <li>•Renaissance640</li> <li>•Beles dam + Dinder and Beles irr. (Et)</li> <li>•High Roseires + Kenana irr. (8u)</li> </ul>
8002	<ul style="list-style-type: none"> <li>•Abbay dams cascade A of Karadobi + Beko Abo Low + Mandaya + Renaissance620.</li> <li>•Beles dam + Dinder and Beles irr. (Et)</li> <li>•High Roseires + Kenana irr. (8u)</li> </ul>
8003	<ul style="list-style-type: none"> <li>•Abbay dams cascade B of Karadobi - Beko Abo Low- Madaya Upper- Renaissance dam640</li> <li>•Beles dam + Dinder and Beles irr. (Et)</li> <li>•High Roseires + Kenana irr. (8u)</li> </ul>
8004	<ul style="list-style-type: none"> <li>•Abbay dams cascade C of Beko Abo High (1062) + Mandaya + Renaissance620</li> <li>•Beles dam + Dinder and Beles irr. (Et)</li> <li>•High Roseires + Kenana irr. (8)</li> </ul>
8005	<ul style="list-style-type: none"> <li>•Abbay dams cascade D of Beko Abo High (1062) + Mandaya Upper+ Renaissance640</li> <li>•Beles dam + Dinder and Beles irr. (Et)</li> </ul>

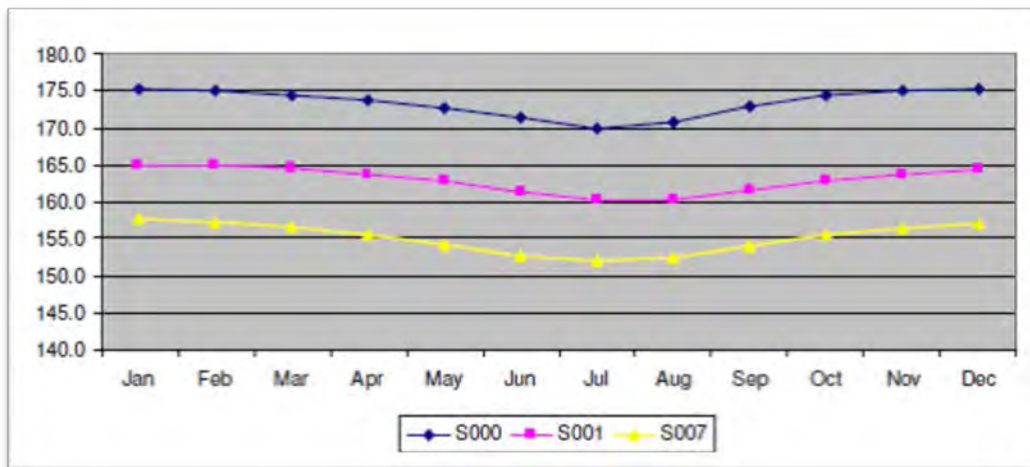
### Results: change in flow regime



Compared to present (S000):

- ❖ Monthly flow variation flattened out almost completely: beneficial for Sudan irrigation
- ❖ Inflow to Lake Nasser reduces by about 9-11%
- ❖ Sediment inflow to Roseires reduced

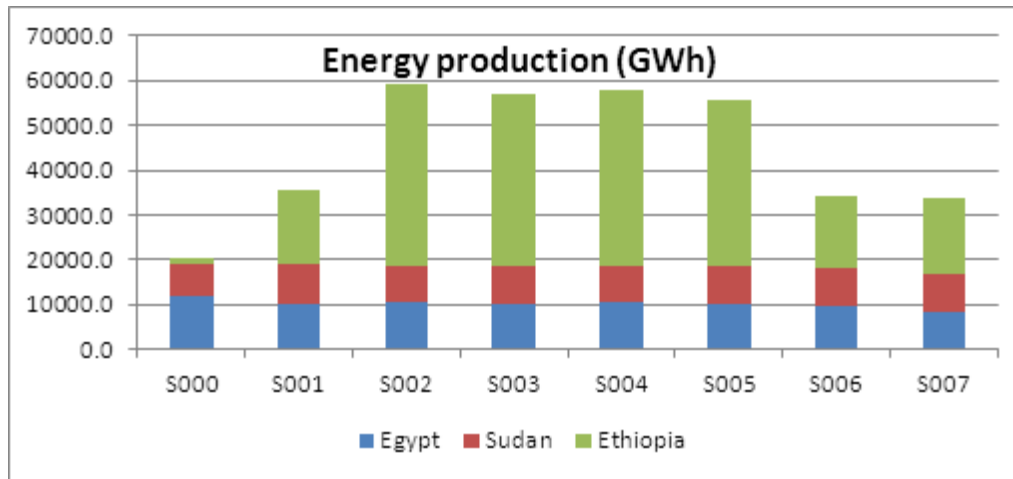
### Results: change in Lake Nasser water level



Compared to present (S000):

- ❖ Average monthly level of Lake Nasser reduces,
- ❖ Toshka spilling reduces,
- ❖ Lake Nasser open water evaporation losses reduces by 31% (S001),
- ❖ Toshka pumping energy consumption increases by 26% (S001)

**Results energy: change in production**



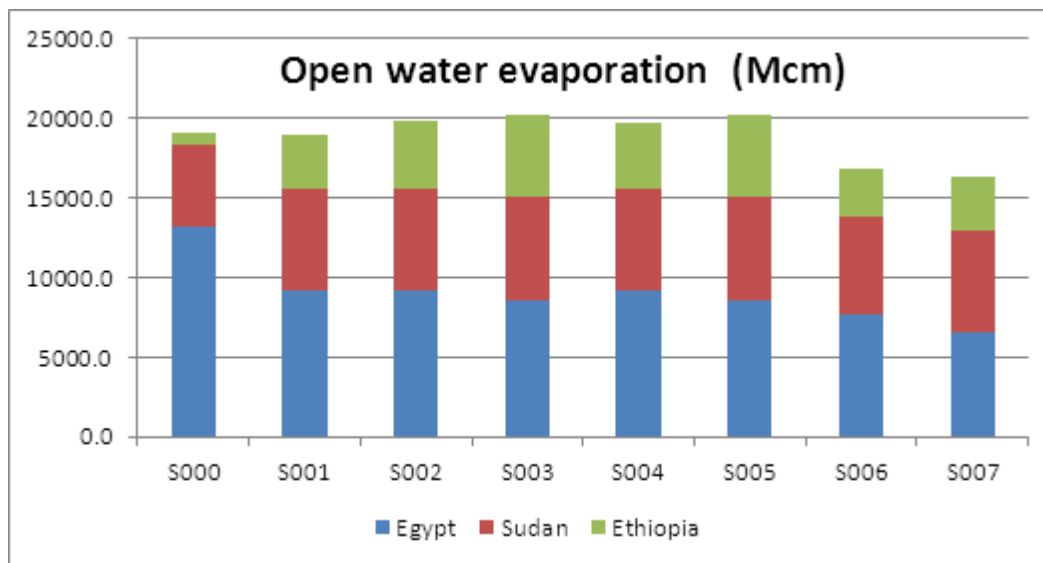
Compared to present (S000):

- ❖ Overall energy production increases by 75-190%
- ❖ Energy production in Sudan increases by 14-18%
- ❖ Power production at Aswan reduces by 13-15%

According to the above result of Deltares - Construction of GERD (S001) compared to present (S000):

1. The Overall energy production of EN increases by 75%
2. The Energy production in Sudan increases by 14%
3. The Power production at Aswan reduces by 13%

**Results water: change in open water evaporation**



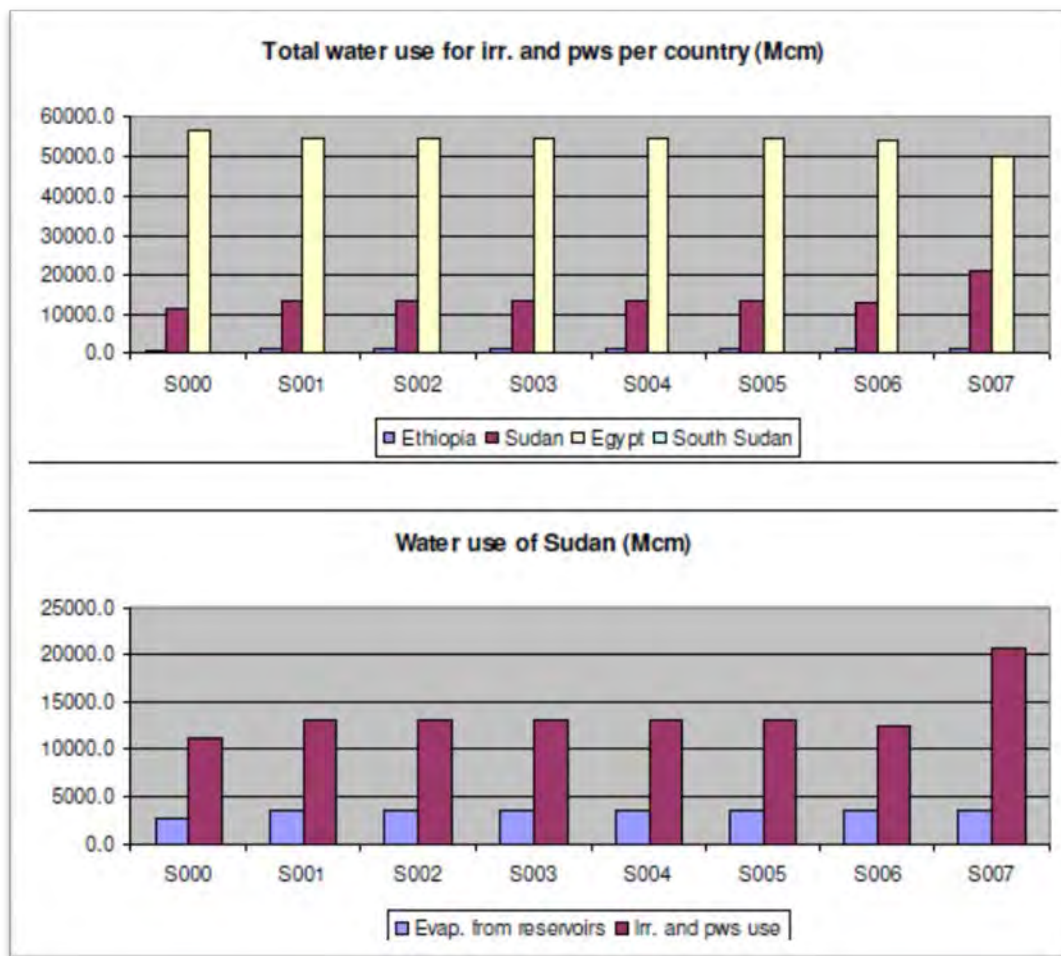
Average annual open water evaporation (Mcm) from reservoirs Compared to present (S000):

1. Lake Nasser open water evaporation losses reduces,
2. Open water evaporation in Sudan and Ethiopia increases
3. Overall open water evaporation the same (S001) and slight increase cascade cases

According to the above result of Deltares Average annual open water evaporation (Mcm) from reservoirs- Construction of GERD (S001) compared to present (S000):

1. Lake Nasser open water evaporation losses reduces,
2. Open water evaporation in Sudan and Ethiopia increases
3. Overall open water evaporation the same (S001)

### Results food: Irrigation and DMI water use



### Conclusion

According to Deltares Illustrations, the overall simulation results show that new dams in Ethiopia benefit Ethiopia's power production but also well increase the benefits of Sudan's irrigation water use from the regulated flow.



### 3.3.2 SCENARIO ANALYSIS REPORT: Eastern Nile Joint Multipurpose Programme: Blue Nile

#### OBJECTIVES OF THE STUDY

The primary objective this study is “...to serve as a shared knowledge base, provide analytical capacity, and support stakeholder interaction, for cooperative planning and management decision making for the Nile River Basin... As such the Nile Basin DSS is expected to be an agreed upon tool that will be accepted and used by all riparians in the management of the shared Nile water resources”. The primary objective of the WP2 Stage 2 consultancy therefore is to help ensure that the NB-DSS becomes a reliable and sustainable software system by demonstrating and showcasing the DSS capabilities within the context of trans boundary integrated water resource planning and management. Within this context, the objective of this pilot case application is to undertake scenario evaluation using the NB-DSS. This involves:

- Configuration, calibration and validation of a relevant baseline model for representing the present state of water resource development for the pilot application case
- Defining scenarios and a set of economic, environmental and social evaluation criteria (indicators)
- Using the configured model to implement scenarios in the NB-DSS
- Using the MCDA tools and associated functionalities embedded in the NB-DSS to evaluate scenarios based on the quantification of economic, environmental and social indicators

#### GENERAL APPROACH AND METHODOLOGY OF THE STUDY

The water balance and most of the operational management scenarios for the Blue Nile system have been configured and simulated with the MIKE Basin software, while a flood damage scenario using MIKE 11 has also been set up and analyzed.

MIKE Basin operates on the basis of a schematic river network, which is made up of building blocks or objects. These typically included river reaches, water user nodes, reservoir nodes, irrigation nodes, hydrological catchments, hydropower nodes and channels which link the various nodes. The characteristics of the individual

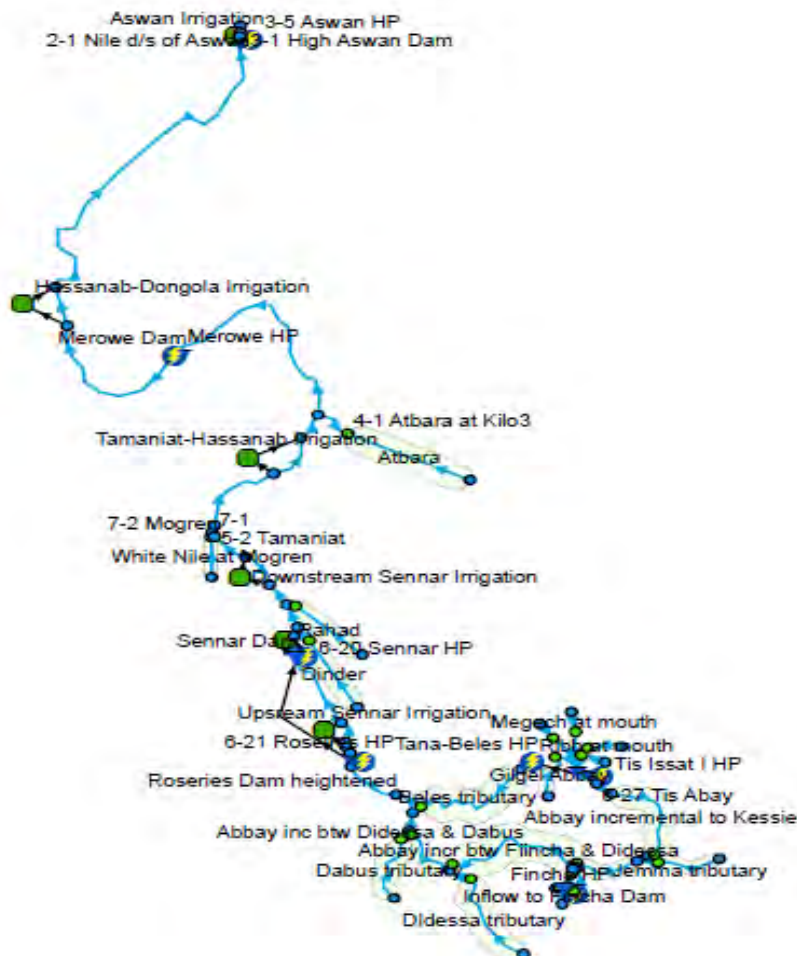
building blocks and the interactions between them are governed by user- defined operating rules. The wide range of modeling routines embedded in the MIKE Basin model, allowed the simulation of various multi-purpose water resource project scenarios. The routines which have been the focus of this study relate to reservoir and hydropower operation, irrigation demand modeling, hydrological routing, water allocation rules, rainfall-runoff modelling and evaporation.

### Availability and sources of hydro-meteorological data

The Study Monthly rainfall data were sourced from the Nile Basin Encyclopaedia, the Ethiopian Master plan, the Global FAO Clim database and the WMO GHCN (Global Historical Climatology Network) database. The observed flow data was sourced from the Nile Encyclopaedia and the Ethiopian Master plan and no updated data was available since the Stage 1 round of modeling.

### Model structure

A schematic of the baseline model configuration is shown in Figure



## Easter Nile River Basin Simulation with GERD

Eastern Nile Joint Multipurpose Programme (Blue Nile) Scenarios are shown in the table below

Scenario	Development	Management Option	Climate Change
SC0	Baseline	Current	None
SC1	Border Dam	Maximize hydropower generation at Border	None
SC2	Border Dam Mandaya Dam	Maximize hydropower generation at Border and Mandaya dams	None
SC3	Border Dam	Maximise hydropower generation at all dams along Blue Nile River; Maintain irrigation supply	None
SC3a	Mandaya Dam		Blue Nile SRES A2 – CNRM CM3
SC4	Border Dam	No flood control operation	N.A.
SC4a		Operate Border Dam for flood mitigation downstream	N.A.

### Scenario Results of the Study

The results of ENJMP for the Blue Nile Summarized in the tables below:

**Table: Summary of Social Indicator Result**

Indicator	Name	Unit	SC1	SC2	SC3	SC3a
SO1 Blue Nile ds Border	Water availability	% change from baseline	1	504	470	311
SO1 Blue Nile outflow			27	510	475	167
SO1 Main Nile ds Blue Nile			2	61	55	26
SO2 Border Dam	Malaria endemicity	% of population	23	23	23	23
SO2 Mandaya Dam			15	15	15	15
SO3 Blue Nile ds Border	Pest disease	Index	-4	-5	-5	-5
SO3 Blue Nile outflow			-2	-5	-5	-5
SO3 Main Nile ds Blue Nile			-2	-4	-5	-5
SO4 ds Khartoum	Urban pollution	Time decay (h)	-102	-110	-107	-104
SO81 Blue Nile ds Border	Recession Agric - floodplain	% change from baseline	-49	-53	-60	-60
SO81 Blue Nile outflow			-31	-33	-70	-71
SO81 Main Nile ds Blue Nile			-27	-30	-63	-65
SO81 Main Nile ds Merowe			-39	-43	-50	-50
SO91 Aswan	Fish production - dams and wetlands	ton/a	16361	16593	16586	16731
SO91 Border			1192	1034	1336	1297
SO91 Mandaya Dam				2579	2822	2767
SO91 Merowe			1720	1720	1720	1720
SO91 Roseires			2613	2678	2678	2678
SO91 Sennar			293	324	870	870
SO92 Blue Nile ds Border	Fish production - river	% change from baseline	47	57	45	43
SO92 Blue Nile outflow			0	6	44	46
SO92 Main Nile ds Blue Nile			1	7	31	30
SO10 Border Dam	Loss in productive land	km <sup>2</sup>	2131	2131	2131	2131
SO10 Mandaya Dam				14	14	14
SO12 Border Dam	Physical displacement	No households	502	502	502	502
SO12 Mandaya Dam			-	2111	2111	2111

**Table: Summary of Economic Indicator Result- Blue Nile**

Indicator	Name	Unit	SC1	SC2	SC3	SC3a
EC1 Lower Blue Nile	Navigation	change from baseline	51	73	100	90
EC21 Aswan	Average energy produced	GWh/a	8147	8431	8388	4825
EC21 Border			6866	6805	7599	6987
EC21 Mandava Dam				14454	14720	13895
EC21 Merowe			6633	6936	7207	6704
EC21 Roseires			1502	1507	1730	1509
EC21 Sennar			86	96	117	109
EC22 System			Average Energy produced -	GWh/a	28111	43105
EC31 Aswan	Open water evaporation loss	million m3/a	11429	11436	11294	11926
EC31 Border			795	609	807	801
EC31 Mandava Dam				855	945	1008
EC31 Merowe			1213	1193	1149	1108
EC31 Roseires			1172	1185	1474	1589
EC31 Sennar			197	226	295	300
EC32 System			Open water evaporation loss - total system	million m3/a	20555	21253
EC51 ds Sennar	Change in Food production - existing scheme	ton/a	0	0	0	0
EC51 Gezira			0	0	0	-80475
EC51 Tamaniat			0	0	0	0
EC51 Aswan			0	0	0	0
EC51_Hassanab			0	0	0	0

### Conclusions and Recommendations of the Study

The Blue Nile basin has significant potential for development of hydropower.

The improved regulation afforded by the construction of Border and Mandaya dams will enable further expansion of the existing irrigation schemes along the lower Blue Nile River.

Although there are numerous socio-economic benefits associated with the construction of Mandaya and Border dams, these dams are also linked to serious environmental and social impacts, both at the dam sites and along the downstream river reaches, which will have to be managed and mitigated in order for the development to be sustainable.

The construction of Mandaya and Border dams will have negligible impact on existing irrigation schemes and hydropower installations along the Blue Nile and Main Nile rivers and will also only slightly reduce inflow volumes into Aswan Dam.

Based on the CNRM CM3 GCM, the assessment of climate change impacts on the Blue Nile system, after construction of Border and Mandaya dams, showed that the mean annual volume that is discharged by the Blue Nile River into the Main Nile will reduce by 9.5% due to climate change. Further expected climate change related impacts include increased open water evaporation loss in the Blue Nile basin of about 0.8 billion m<sup>3</sup>/a, a 7% reduction in hydropower at the four main dams along the Blue Nile River, a slight reduction in fish production (-3%) and a significant decrease in dry season low flows along the lower Blue Nile River.

### 3.3.3 Application of the Water Evaluation and Planning (WEAP) Model to Simulate Current and Future Water Demand in the Blue Nile

Matthew McCartney<sup>1</sup>, Yosif A. Ibrahim<sup>2</sup>, Yi Ima Sileshi<sup>3</sup> and Seleshi Bekele Awulachew<sup>1</sup>

This study followed a method for the model is first configured to simulate a –baseline year, for which the water availability and demands can be confidently determined. It is then used to simulate alternative scenarios to assess the impact of different development and management options. The model optimizes water use in the catchment using an iterative Linear Programming algorithm, the objective of which is to maximize the water delivered to demand sites, according to a set of user-defined priorities. When water is limited, the algorithm is formulated to progressively restrict water allocation to those demand sites given the lowest priority.

In this study, the model was set-up to simulate three scenarios: i) the natural situation with no abstractions, ii) the current situation and iii) future demand in approximately 2015. Time series of monthly naturalized flow data for the period 1960-1992, obtained from the Abay Basin Master Plan (BCEOM, 1998), were used as input data. Estimates of current irrigation and hydropower demand were derived from data provided by government ministries and agencies or from previous studies. This included information on water passing through the turbines of the power stations and water diverted for irrigation. It was necessary to make a lot of assumptions, particularly about return flows from irrigation schemes. In some cases demand estimates were derived based on demand at similar irrigation schemes, and simply weighted by the ratio of the scheme areas. Irrigation demand was allowed to vary slightly depending on rainfall determined for the rain gauge located closest to the scheme. Hence, in higher rainfall years, irrigation demand was reduced slightly. Net evaporation from Lake Tana and the reservoirs was estimated using data from the nearest meteorological station.

For the 2015 scenario, the size of planned hydropower and irrigation development was derived from the basin master plans for Sudan and Ethiopia. This included both new schemes and proposed extension of existing schemes (Table 2). In Sudan it is planned to raise the height of the Roseires dam by 10m, to increase the area irrigated at several locations and to construct several new irrigation schemes. It is estimated that the total irrigated area will increase to approximately 2,126,000 ha. In Ethiopia it is planned to transfer water from Lake Tana to the Beles River (a tributary of the Blue Nile) for hydropower generation, to extend the Finchaa irrigation scheme and to develop several new irrigation schemes, in the vicinity of Lake Tana as well as in other sub-basins. It is estimated that the total formally irrigated area will increase to approximately 210,000 ha. In addition, it is planned to construct a very large dam (storage capacity 40.2 Bm<sup>3</sup>) on the main stem of the Abay, at Karadobi, for hydropower.

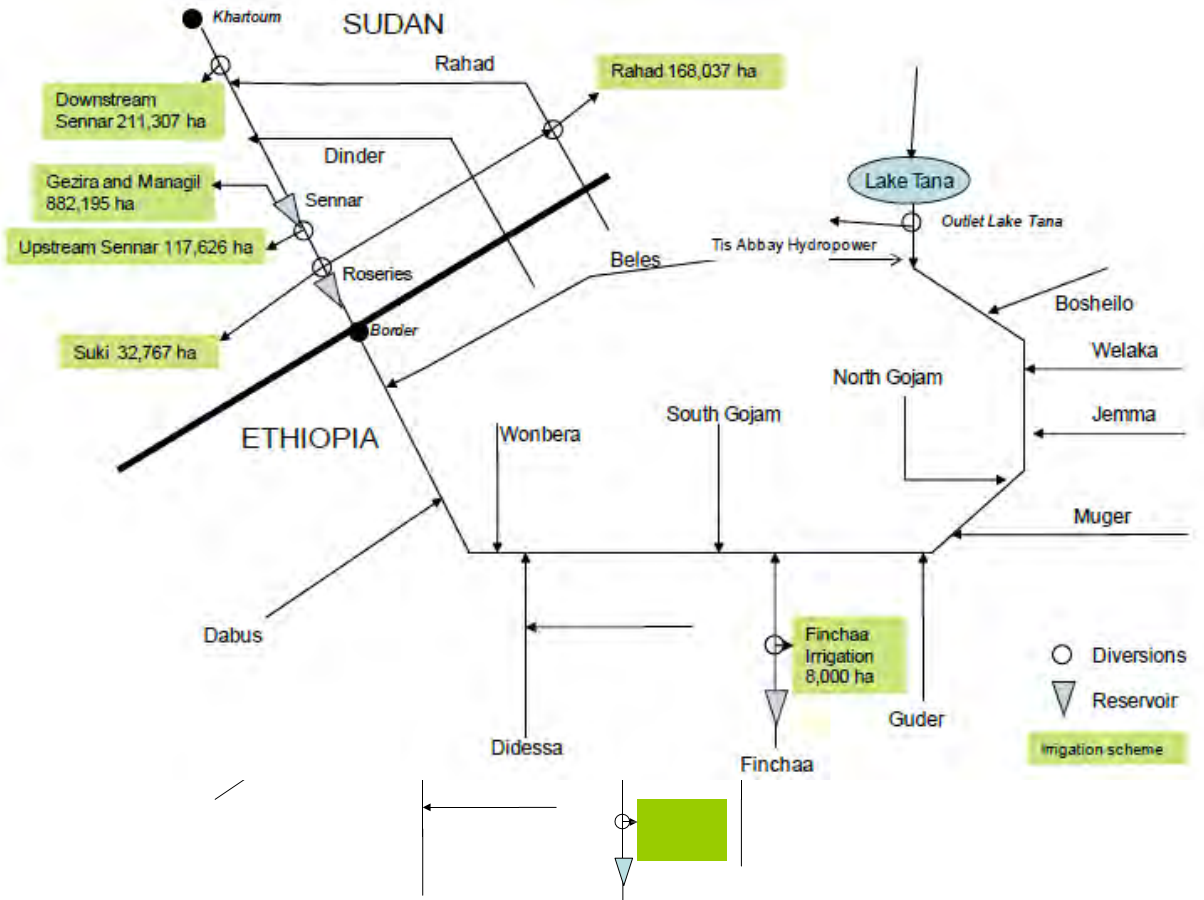


Figure: Schematic of the model configuration for the current situation

The water demand for new schemes was derived from basin master plans and, where available, feasibility studies. Where it is planned to extend irrigation schemes the demand was estimated based on current demand, but weighted by the new area. Again for the irrigation schemes some variability was simulated to allow for differences in rainfall.

## Results

The Study shows the simulated and observed flows at the Ethiopia-Sudan border and at Khartoum for the current situation. These results indicate that the WEAP simulation is reasonably good. At Khartoum, observed data (obtained from the Global Data Runoff Centre) were only available for the period 1960-1982. Over this period the percentage error in the simulated mean annual flow was 3.7%. As a result of current abstractions, primarily for irrigation in Sudan, the flow at Khartoum is estimated to be approximately  $7.5 \text{ Bm}^3 \text{ y}^{-1}$  less than would occur naturally (i.e.  $41.7 \text{ Bm}^3 \text{ y}^{-1}$  rather than  $49.3 \text{ Bm}^3 \text{ y}^{-1}$ ). At the border there are two flow gauging stations. One is operated by the government of Ethiopia and just a few kilometers downstream another is operated by the government of Sudan. Possibly because of differences in periods of missing data, observed flows at these two stations differ and there is a 10% difference in mean annual flow;  $50.6 \text{ Bm}^3$  measured by

## Easter Nile River Basin Simulation with GERD

Ethiopia and 45.6 Bm<sup>3</sup> measured by Sudan. Without detailed analysis, which was beyond the scope of the present study, it is not possible to know which of the two flow series is the more accurate. The WEAP model simulation actually lies between the two, but is closest to the Sudanese estimate with a mean annual discharge of 45.8 Bm<sup>3</sup>.

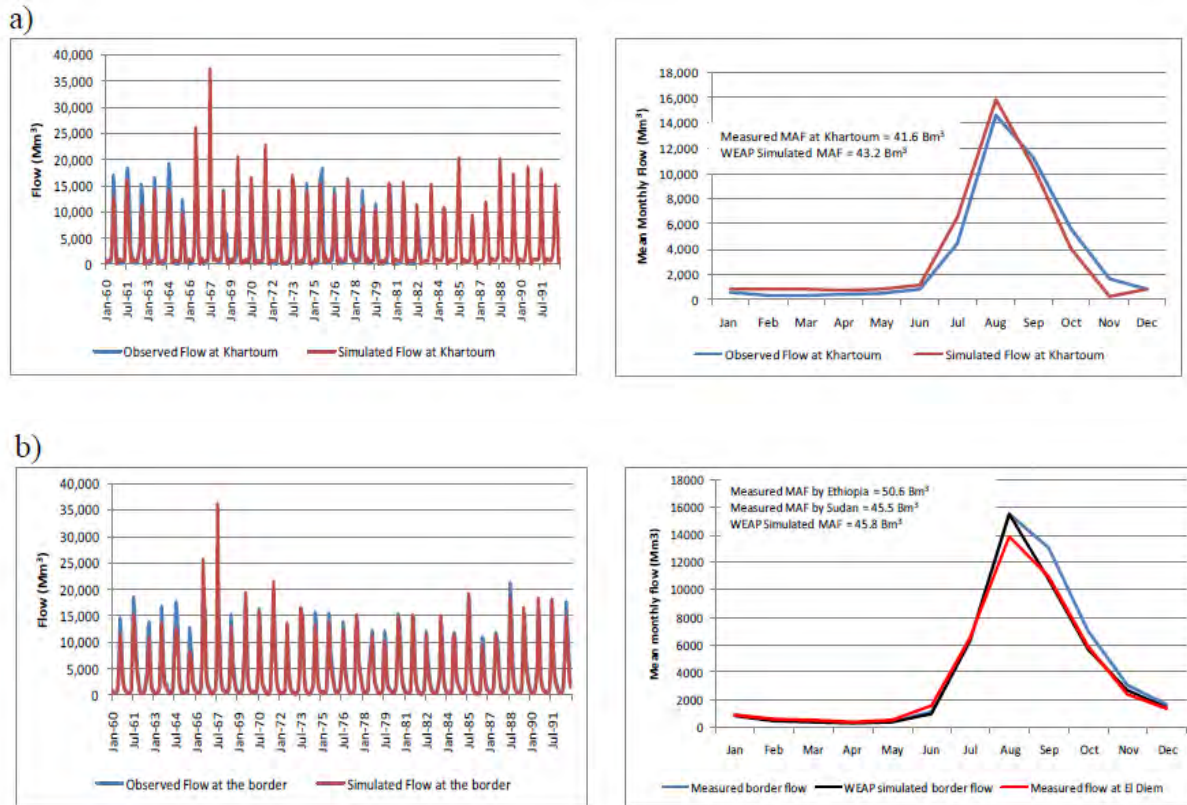


Figure: Simulated and observed flow series and mean monthly flows for the Blue Nile at: a) Khartoum and b) the Ethiopia-Sudan border

	Current		2015	
	Ethiopia	Sudan	Ethiopia	Sudan
<b>Formal irrigation area (ha)</b>	<10,000	1,305,000	210,00	2,126,000
<b>Hydropower</b>				
Installed capacity (MW)	218	295	2,194	295
Production (Gwhyr <sup>-1</sup> )	1,298	c.a. 1,000	9,930	ca 1,000

Table Comparison of current and future (2015) irrigation and hydropower in the Ethiopian and Sudanese parts of the Blue Nile

### Concluding Remarks of the study

In the study WEAP model has been configured to simulate the impacts of water resource development in the Blue Nile basin. Currently Ethiopia utilizes very little water but does regulate some flow for hydropower production. In contrast Sudan uses some water for hydropower production but also abstracts large volumes for irrigation. Both countries plan to develop water resource infrastructure substantially in the near future. By approximately 2015 it is estimated that the total annual consumptive demand is likely to be  $17.12 \text{ Bm}^3\text{y}^{-1}$  (i.e. 35% of the natural flow at Khartoum). Of this  $3.69 \text{ Bm}^3\text{y}^{-1}$  will be consumed in Ethiopia and  $13.43 \text{ Bm}^3\text{y}^{-1}$  in Sudan.

### 3.4 Result Comparison of Different Studies on Eastern Nile River Basin Simulation

Based on their results, the two studies ((ENJMP, Deltares) and the thesis findings have been compiled and summarized below

**Table 3.4.1: Result Comparison of Different Studies (ENJMP, Deltares and Thesis Findings)**

Selected Nodes/Schemes	Name	Unit	ENJMP	Deltares	Thesis finding
Blue Nile D/S GERD	Water availability	% change from baseline(Sc0)	1	-	12
Blue Nile outflow			27	-	12
Main Nile D/S Blue Nile			2	-9	-9
Aswan	Average Energy produced	% change from baseline(Sc0)	Negligible	-13	-9
Merowe			Negligible	14	15
Roseires			Negligible	14	15
Sennar			Negligible	14	15
Over all System	Average Energy produced - total system	% change from baseline(Sc0)	Negligible	75	50
Aswan	Open water evaporation loss (Sc1)	million m <sup>3</sup> /a	11429	9000	9500
GERD			795	3000	1200
Merowe			1213	6000	6500
Roseires			1172		
Sennar			197		
Over all System	Open water evaporation loss - total	million m <sup>3</sup> /a	20555	18000	17200
ds Sennar	Reduction of Irrigation water Demand deficit	% change from baseline(Sc0)	100	100	100
Gezira			100	100	100
Tamaniat			100	100	100
Aswan			100	-	100
Hassanab			100	100	100

## CHAPTER FOUR

### 4 BASELINE MODEL CONFIGURATION

#### 4.1 Model Selection and Conceptualization

One of the most important elements in the modeling process is the selection of the model which should be based on a clear understanding of the purpose of the model and in turn what output is required from the model including the following considerations (Dingman S.L., 2002):

- The type of information required;
- The required accuracy and precision of output
- The locations for which output is required
- Temporal requirements.

Model conceptualization is also informed by the available information about the system that is being modeled as well as the availability of input data.

In this study, the Mike Hydro modelling software was selected to model the Eastern Nile River Basin. Mike Basin is “...a powerful multi-purpose modeling package for professionals working with water resource projects’. It provides a package that supports the following components of hydrological analysis” (DHI, 2010):

- water allocation scenario modeling,
- reservoir and hydropower operation,
- hydrological modeling,
- irrigation demand and yield assessment,
- in-stream nutrient modeling,
- catchment nutrient load assessment,
- Time series data management and analysis.

The Mike Hydro 2014 model was set up to represent the Eastern Nile catchment from its source in the Ethiopian Highlands to its confluence with the White Nile at Khartoum in Sudan, and downstream to Lake Nasser. All major tributaries of the Eastern Nile are represented in the model. In the model configuration of the Eastern Nile pilot application case (ENJMP) was used as a reference for the layout of the modeling and refined. This refinement included modeling of irrigation water requirements using the FAO methodology in Mike Hydro 2014 and undertaking rainfall-runoff modeling in NAM. The Mike Hydro 2014 model, observed monthly flows are used as inflow boundary conditions for the White Nile at Mogren and for the Atbara. Major reservoirs, irrigation schemes and hydropower projects currently operating in the Eastern Nile catchment were included in the model configuration.

4.2. Model structure

A schematic of the baseline model configuration is shown below in Figure 7.2.1. The model includes Lake Tana and five of its main tributaries, the Jemma tributary downstream of Lake Tana, the Fincha’a and Amerti tributaries and the Didessa, Dabus and Beles tributaries downstream of Kessie. Existing reservoirs in the Eastern Nile at Fincha’a, Roseires and Sennar as well as Merowe and High Aswan Dam on the Main Nile downstream of the confluence with the Blue Nile are included with hydropower. Tana-beles Hydropower gets its water from a natural lake reservoir i.e. water transferred from lake Tana. Irrigation water requirements were calculated for the demands upstream of Sennar, the Gezira & Managil Schemes and for the demands downstream of Sennar, as well as for the irrigation water requirements on the Main Nile downstream of Khartoum at Tamaniat, Dongola and Aswan.

Table 4.1: Irrigation Scheme in Eastern Nile Basin

Sub-Basin	Irrigation Scheme	
	Existing (ha)	Potential (ha)
Baro-Akobo-Sobat	1,125,636	630,535
Abay-Blue Nile	644,087	1,364,639
Tekeze-Atbara-Setite	244,047	164,893
Main Nile	3,636,499	-
<b>Total</b>	<b>5,650,269</b>	<b>2,160,067</b>

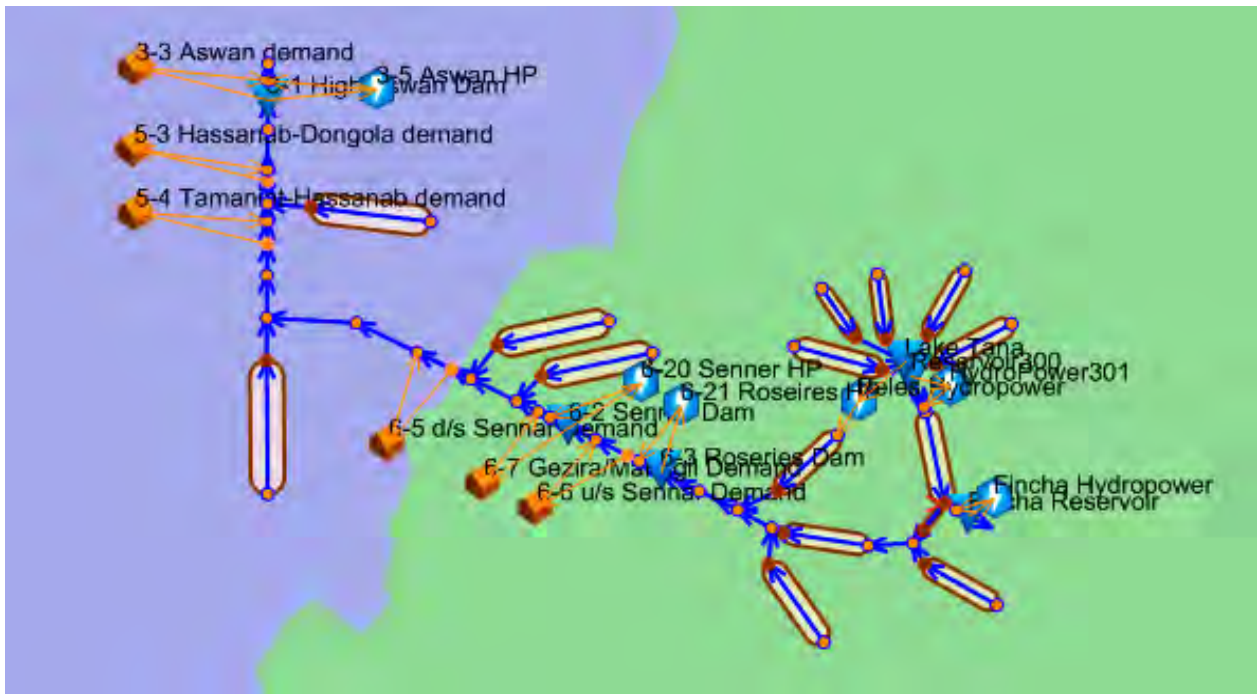


Figure 4.2.1 : Schematic of baseline configuration

The reservoirs in the Eastern Nile system were represented as rule curve reservoirs, with a hydropower node at each reservoir, and an irrigation node at Sennar. The installed capacities at Roseires and Sennar were 280 MW and 15 MW, respectively. An efficiency loss of 75% was used for the hydropower nodes. For each reservoir, a constant target demand was assumed, with target power of 280 MW and 15 MW respectively for Roseires and Sennar.

The priority reduction rules that were defined, with levels reduced seasonally to allow the early part of the flood through the reservoir (to avoid excessive sedimentation), before storing as much flood water as possible to be released during the dry season, were assumed initially. This sedimentation rule was refined and is now represented as a storage demand rule between Roseires and Sennar, which is driven by the levels in Sennar (Figure). For Sennar, the irrigation demand was assigned first priority at all levels, with levels for the hydropower rule being drawn down from a maximum of 421.6 m to 417.3, with a reduction factor of 0.8 for the first 6 months of the year (1 otherwise).

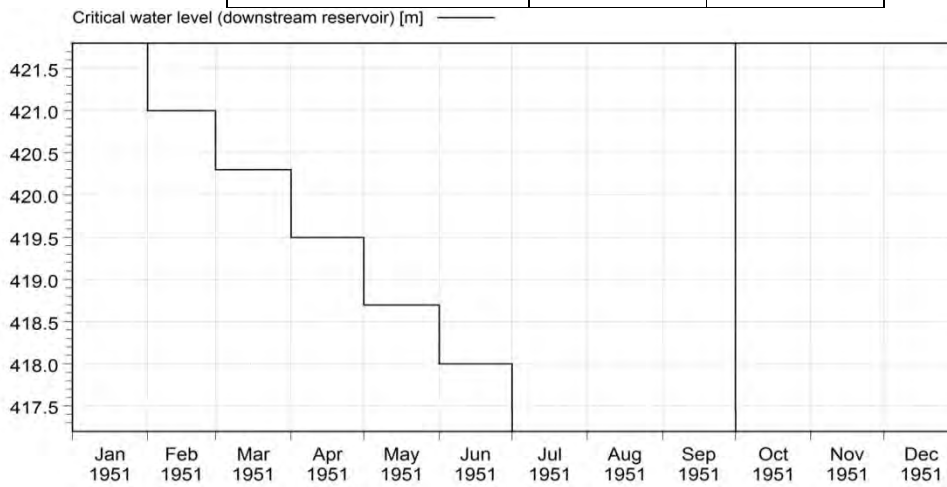
**Table 4.2: Existing Hydropower plants and reservoirs of the Eastern Nile Basin**

Name	Country	River	Live storage <i>Mm</i> <sup>3</sup>	Capacity MW
Fincha	Ethiopia	Blue Nile	Run-of-river	134
Tis Abbay I & II	Ethiopia	Blue Nile	Run-of-river	85
Beles MPP	Ethiopia	Blue Nile	Run-of-river	460
Tekeze	Ethiopia	Blue Nile	9200	300
Roseires	Sudan	Blue Nile	2200	275
Sennar	Sudan	Blue Nile	370	15
Kashim EL Gibra	Sudan	Atbara	600	17
Jebel Aulia	Sudan	White Nile	3000	30
Merowe	Sudan	Main Nile	8300	1250
High Aswan Dam	Egypt	Main Nile	105900	2100
Old Aswan Dam	Egypt	Main Nile	Run-of-river	500
Esna	Egypt	Main Nile	Run-of-river	90

The reservoir and hydropower generation characteristics for Heightened Roseires and Sennar dams in the model configuration are presented in Table 4.3 and Table 4.4 respectively.

**Table 4.3: Reservoir and hydropower generation characteristics - Heightened Roseires Dam**

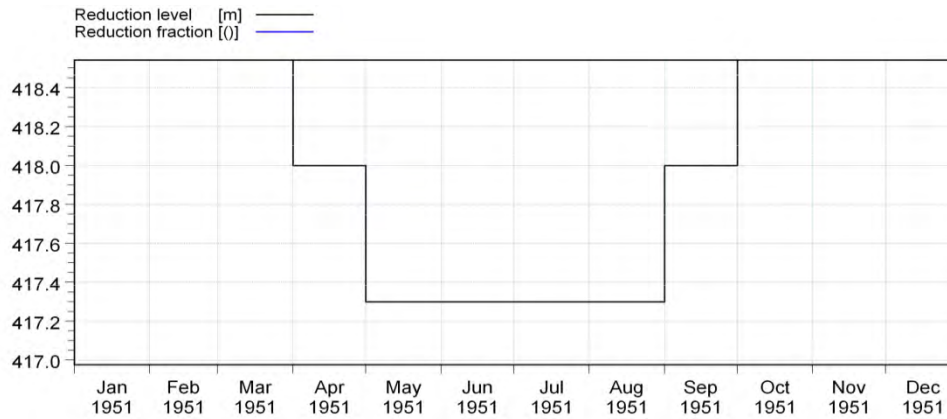
Variable/rule	Units	Value
Dam crest level	masl	490
Flood control level	masl	490
Top of dead storage	masl	467
Bottom level	masl	465
HP target power	MW	280
HP installed capacity	MW	280



**Figure 4.2.2 : Critical water level (Storage demand rule) for Sennar Dam**

**Table 4.4 : Reservoir and hydropower generation characteristics for Sennar Dam**

Variable/rule	Units	Value
Dam crest level	masl	422
Flood control level	masl	421.8 (Oct-Jul) 417.2 (Aug-
Top of dead storage	masl	415
Bottom level	masl	412
HP target power	MW	15
HP installed capacity	MW	15



**Figure 4.2.3: Priority reduction rule for hydropower for the Sennar Dam.**

For the outflows from Lake Tana, the spillway function as calibrated with  $K = 125$  and  $b = 1.5$ . A short distance downstream of Lake Tana, a small power station called Tis-Abbay I was constructed in 1964, to capture the hydropower potential from high head differences at a waterfall location. In 2001, Tis-Abbay II was installed. This was implemented in the model, using a small ‘virtual’ reservoir to represent the heads with a small amount of storage. The station capacity is now 73 MW. As there is little storage at this location, it has a negligible effect on the water balance of the system

Fincha’a Dam is represented as a rule curve reservoir with a hydropower node. The installed capacity at the hydropower node is 130 MW. An efficiency loss of 75% was used. A constant target demand of 70 MW was assumed. A constant reduction priority level of 2214 m asl was assumed. A summary of the reservoir and hydropower characteristics for Fincha’a is presented in Table. There is a tunnel that connects the adjacent Amerti River to the Fincha’a Dam to supplement the water supply when the levels in Fincha’a are low. There is also a reservoir on the Amerti River as part of this scheme. However, further detail on the operation of these two reservoirs is required.

**Table 4.5: Reservoir and hydropower generation characteristics for the Fincha’a Dam**

Variable/rule	Units	Value
Dam crest level	masl	2219
Flood control level	masl	2219
Top of dead storage	masl	2213
Bottom level	masl	2212
HP target power	MW	70
HP installed capacity	MW	130

Along the main Nile from Khartoum to Lake Nasser, the only major inflow is from the highly seasonal Atbara tributary. There are some irrigation abstractions from the river included in the model at Tamaniat and Hassanab upstream of the Atbara confluence, and at Hassanab and Dongola downstream of Merowe Dam. Estimates have been made, based on flow records, of seepage and evaporation losses from the river.

Merowe Dam is represented as a rule curve reservoir with a hydropower node. The installed capacity at the hydropower node is 1250 MW. An efficiency loss of 75% was used. A constant target demand of 625 MW was assumed. A constant reduction priority level of 285 masl was assumed. A summary of the reservoir and hydropower characteristics for Merowe is presented in Table 4.6.

**Table 4.6: Reservoir and hydropower generation characteristics for the Merowe Dam**

Variable/rule	Units	Value
Dam crest level	masl	300
Flood control level	masl	300
Top of dead storage	masl	285
Bottom level	masl	250
HP target power	MW	625
HP installed capacity	MW	1250

Rainfall at the High Aswan Dam is almost negligible in comparison with evaporation, which represents the main volumetric loss from the lower Nile. As inter-annual variation in evaporation rate is relatively constant, a fixed seasonal cycle of monthly evaporation rate was used with volumetric evaporation losses being calculated based on the reservoir surface area.

The High Aswan Dam is represented as a rule curve reservoir with a hydropower node. The installed capacity at the hydropower node is 2100 MW. A constant target demand of 720 MW was assumed. A constant priority reduction rule of 183 masl was assumed. However, the HAD is operated primarily to regulate downstream releases for irrigation demand, with hydropower generation being a secondary benefit. The FAO irrigation module was used to estimate the irrigation water requirements from Aswan for downstream users based on documented irrigation areas and assumed crop types which were presented in the previous

section. As historical information on reservoir operation was not available, the average monthly irrigation water requirements were routed through the hydropower node and the shortfall was abstracted directly from the reservoir.

**Table 4.7: Reservoir and hydropower generation characteristics for the High Aswan Dam**

Variable/rule	Units	Value
Dam crest level	masl	183
Flood control level	masl	183
Top of dead storage	masl	146
Bottom level	masl	107
HP target power	MW	720
HP installed capacity	MW	2100

### 4.3 Model Calibration and Validation

For any model to be credible and gain acceptance among its users and stakeholder groups, it is imperative to have a well-defined and defensible model calibration and validation process that illustrates the model's ability to simulate changes in hydrologic conditions and water management options accurately.

The calibration and validation of the Eastern Nile model has been done at selected flow gauging stations representing key sub-catchments (main tributaries) and incremental catchments as indicated table 4.3.1

#### 4.3.1 Model acceptance criteria

The criteria described below were considered when comparing simulated and observed model output at key locations for the acceptance of model calibration. With both the visual and the quantitative criteria, a good overall agreement of simulated flows compared to the observed is desirable. These will include the following:

- A good agreement between the average simulated and observed catchment runoff (a good water balance);
- A good overall agreement of the shape of the hydrograph;
- A good agreement of the peak flows with respect to timing rate and volume;
- A good agreement for low flows.

Additional measures to gauge the acceptability of the model include:

- Overall long-term water balance: difference between simulated and observed total flow over the simulation period, expressed as a percentage of total observed flow.
- Cumulative water balance: a cumulative plot of the observed and simulated flows over the period of record to reveal any systematic deviations.
- Model Efficiency: expressed as  $R^2$  values for simulated flows and lake/reservoir levels
- Visual inspection and assessment of relevant aspects of hydrographs. This will include, for example, checks of flood peaks, seasonal cycles, and flow variability
- Semi-quantitative checks of other model outputs against other available information, for outputs where some information is available but is subject to high levels of uncertainty

### 4.3.2 Model calibration

The sub-catchments in the Eastern Nile as listed in Table were selected for model calibration.

**Table 4.1 : Flow gauges for calibration in the Eastern Nile**

Flow Gauge	Observed M AR (Mm3/a)	Catchment area (km2)	MAP (mm)	Runoff coefficient
Gumara at Bahir Dar	852	1394	1274	48%
Abbay at Kessie (incremental)	10899	49789	1092	20%
Didessa at Arjo	4027	9981	1186	34%
Dabus at Asossa	4894	10139	1735	28%
Abbay at Border Deim (incremental)	33915	109786	1307	24%

#### 4.3.2.1 Selection of calibration and validation periods

The selection of calibration periods was based on the longest period of observed record that contained the fewest missing values from the Abay Master plan. Wherever possible a minimum flow record length of 10 years was selected to calibrate on. Table presents the calibration periods that were selected.

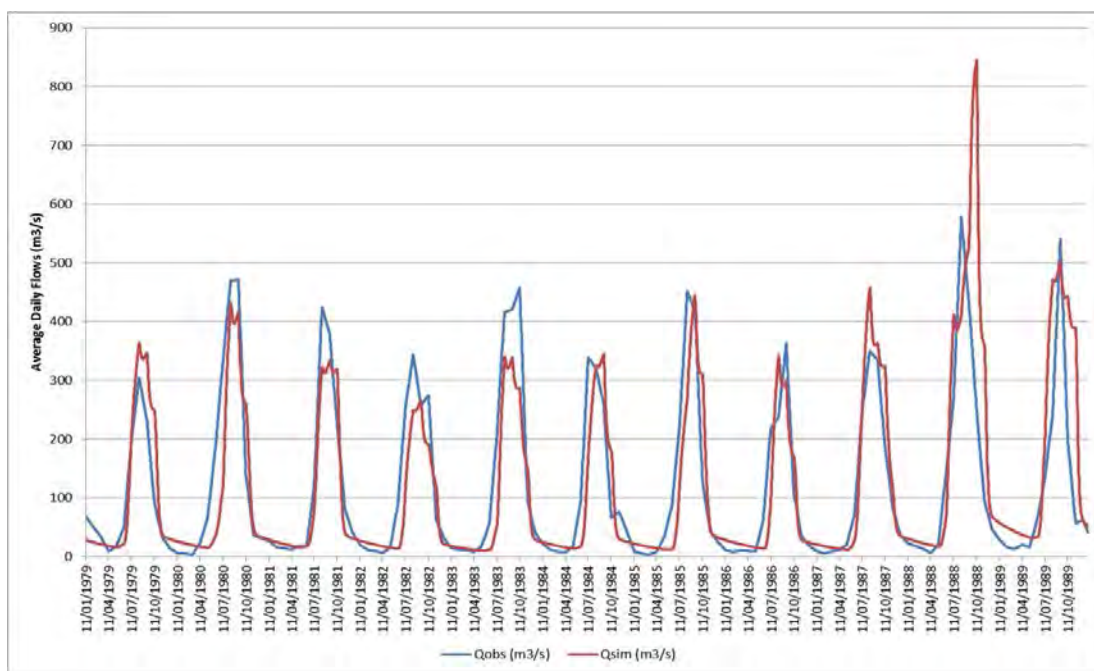
**Table 4.2 : Calibration periods for flow gauges in the Eastern Nile**

Flow gauge	Record period	% Patched / Infilled values	Calibration period	Validation period
Abbay at Kessie (incremental)	Jan 1960 – Dec 1990	5%	1960 - 1968	1972 – 1982
Didessa at Arjo	Jan 1960 – Dec 1990	27%	1979 - 1989	1962-1972
Dabus at Asossa	Jan 1963 – Dec 1979	3%	1963 - 1974	1975-1980
Abbay at Border /El Deim	Jan 1961 – Dec 1979	8%	1969 -1979	1961-1968

### 4.3.2.1 Calibration results

#### Didessa at Arjo

The results of the incremental calibration for the Didessa at Arjo are summarized in Figure 4-3-1, Figure 4-3-2, Figure 4-3-3 and Table 4-3 below. Overall there is a good agreement between simulated and observed daily flows, except for the over simulation of the peak in October 1988. The seasonal variation shows a fairly good agreement between high flows and low flows, but the rise of the hydrograph appears to be a bit delayed and the corresponding fall. The parameters for this tributary were transferred to the rest of the Didessa catchment to the confluence with the Abbay.



**Figure 4-3-1: Observed and simulated daily flows for Didessa at Arjo for calibration period (1979-1989)**

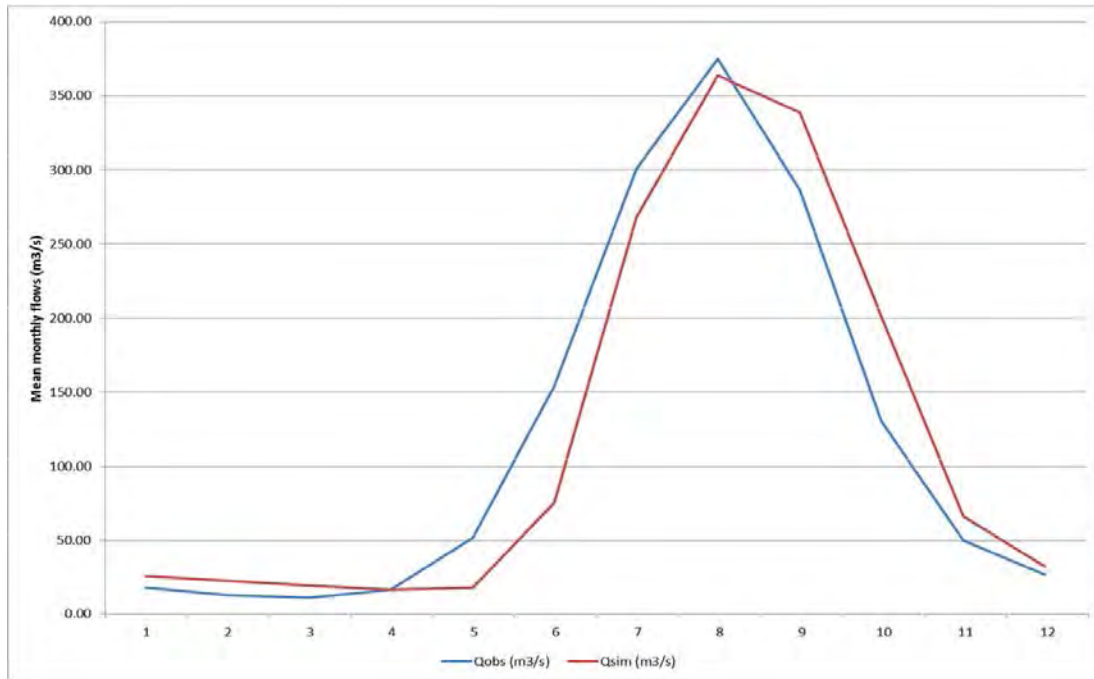


Figure 4-3-2 : Observed and simulated seasonal flows for Didessa at Arjo

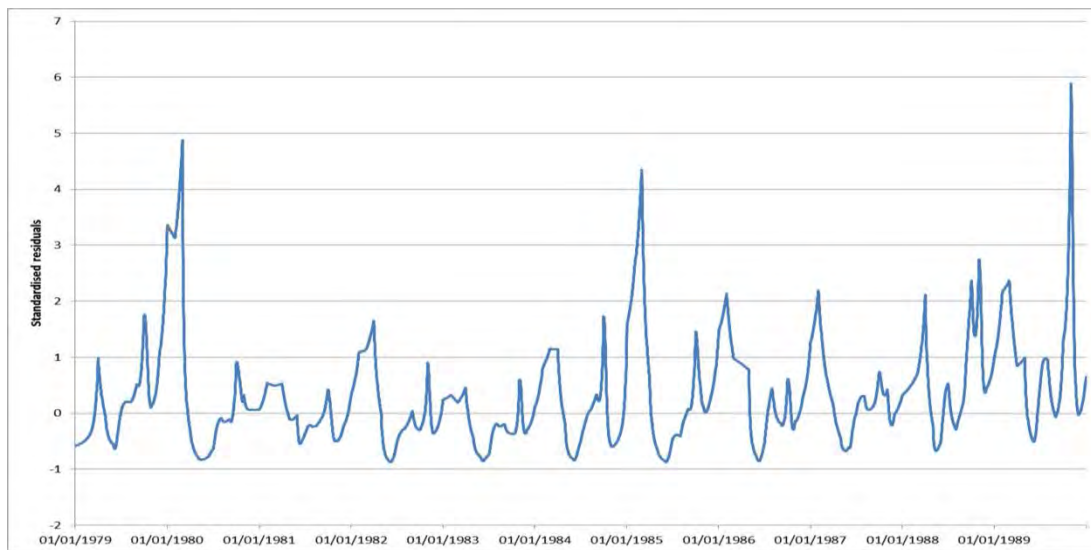


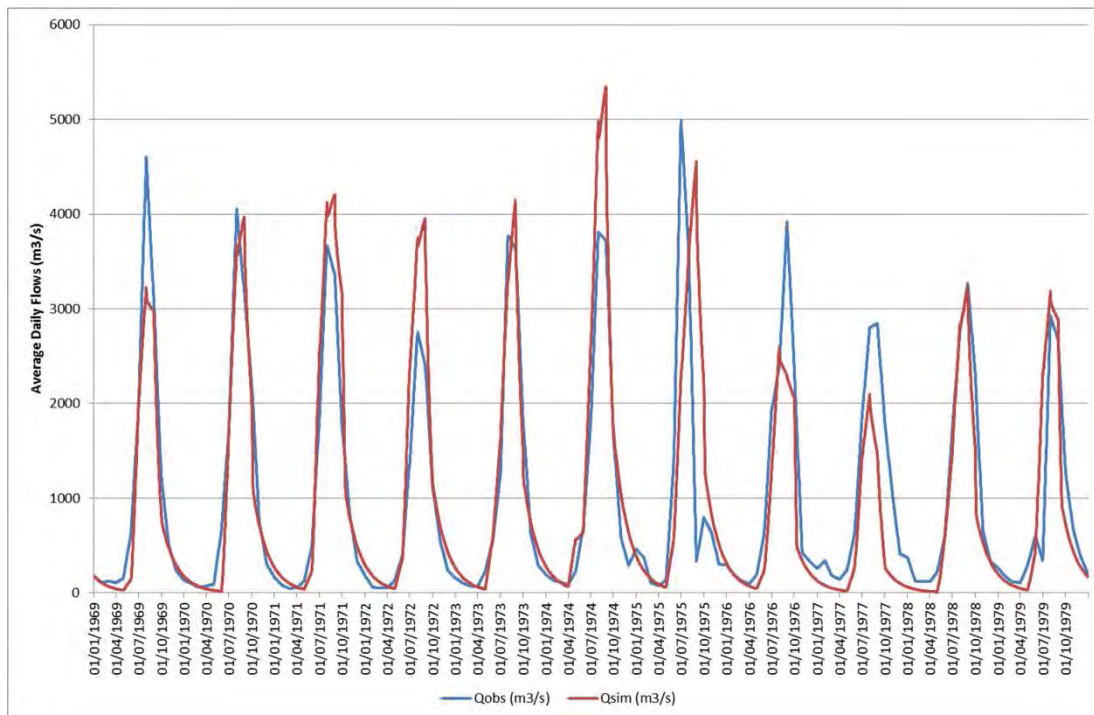
Figure 4-3-3 : Standardised flow residuals for calibration period at Didessa

Table 4.3 : Calibration statistics for Didessa at Arjo

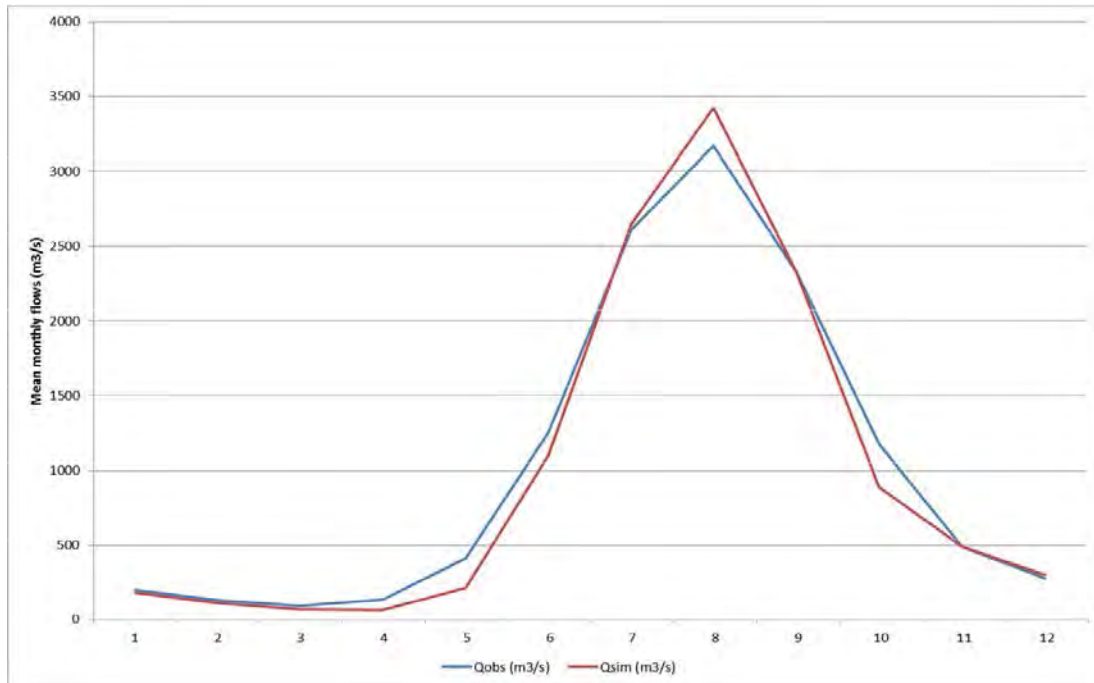
	Observed	Simulated	Difference
1979-1989			
MAE (million	3796	3833	1%
Std.Dev. (m <sup>3</sup> /s)	137	149	8%
R <sup>2</sup> = 65%			

### Abbay at Border El Deim

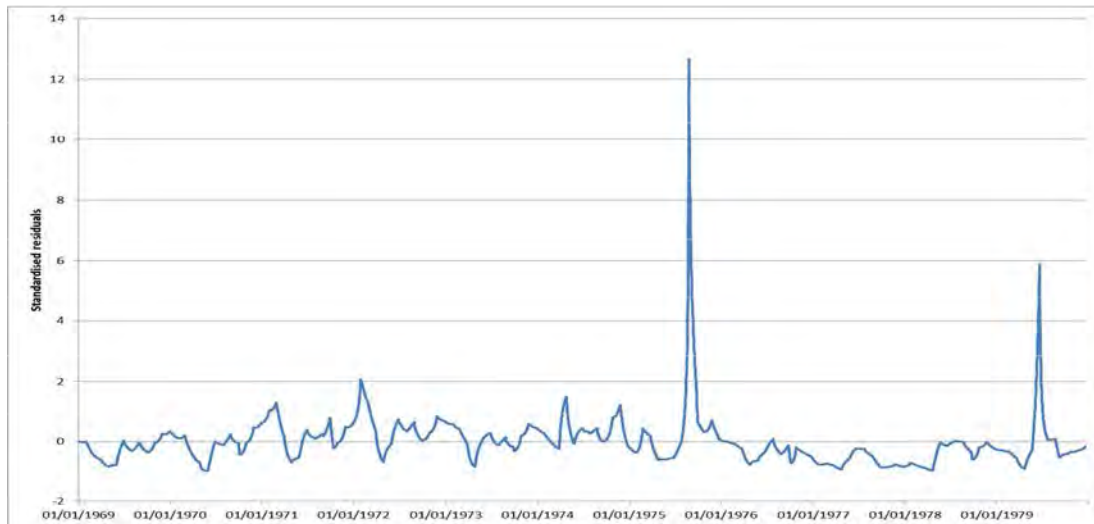
The results of the incremental calibration for the Abbay at El Deim are shown in Figure 4-3-4, Figure 4-3-5, Figure 4-3-6 and Table 4-4 below. Overall there is a good agreement between simulated and observed daily flows, and only 2% difference between annual flows. The seasonal variation shows fairly good agreement between observed and simulated high and low flows, but the simulated high flows are slightly delayed compared to the observed.



**Figure 4-3-4: Observed and simulated daily flows for Abbay at El Deim for calibration period (1969-1979)**



**Figure 4-3-5: Observed and simulated mean monthly flows for Abbay at El Deim for calibration period (1969-1979)**



**Figure 4-3-6 : Standardised flow residuals for calibration period at El Deim**

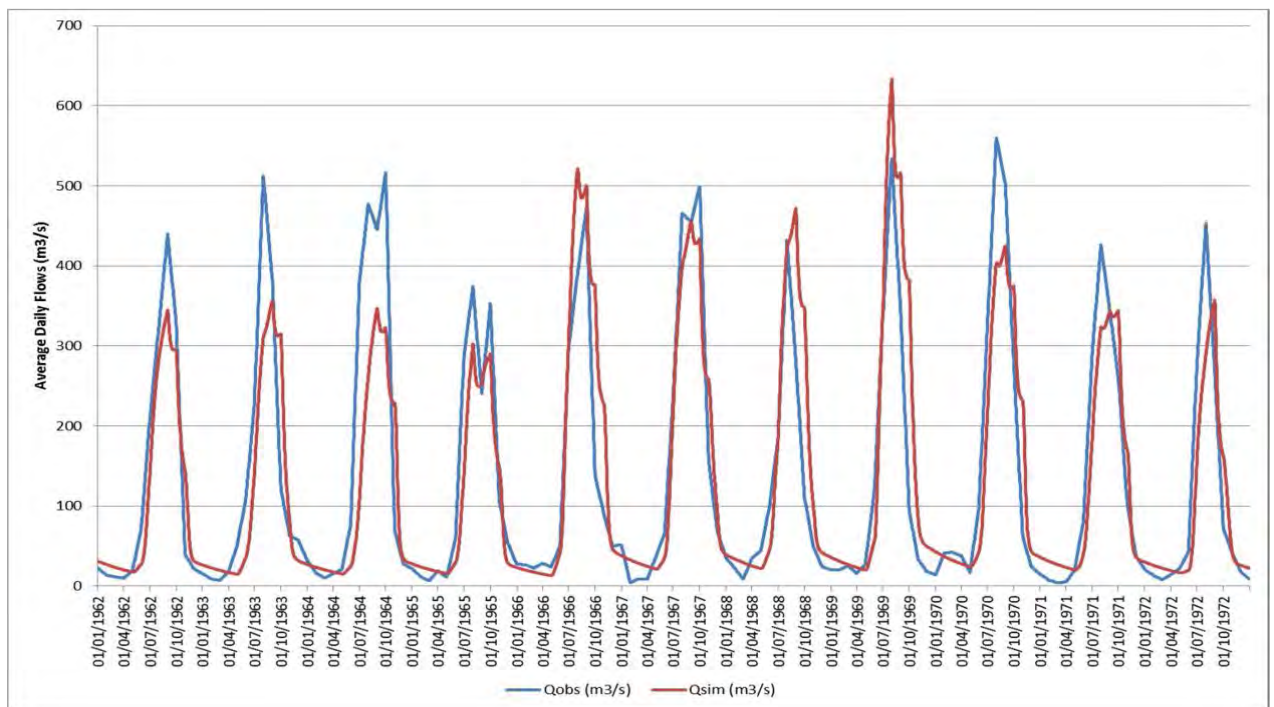
Table 4.4 : Calibration statistics for Abbay at El Deim

1969-1979	Observed	Simulated	Difference
MAE (million)	3251	3133	-4%
Std.Dev. (m <sup>3</sup> /s)	1155	1220	6%
R <sup>2</sup> = 74%			

### 4.3.3. Validation results

#### Didessa at Arjo

The validation results for the period 1962-1972 for the Didessa at Arjo are summarized in Figure 4-3-7, Figure 4-3-8, and Figure 4-3-9 and Figure 4-3-10 below. Overall, the simulated flows for the validation period compare well with the observed flows but there is some variation which is evident in the seasonal plot and the standardized residuals plot.



**Figure 4-3-7: Observed and simulated daily flows at Didessa at Arjo for the validation period (1962-1972)**

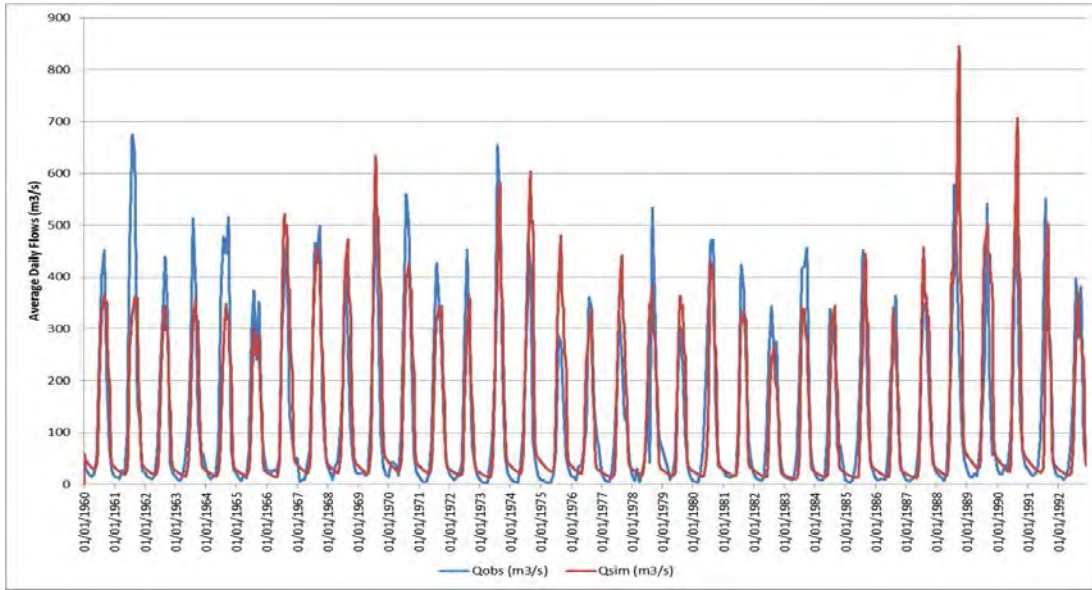


Figure: 4-3-8 Observed and simulated daily flows at Didessa at Arjo for the full observed period (1960-1992)

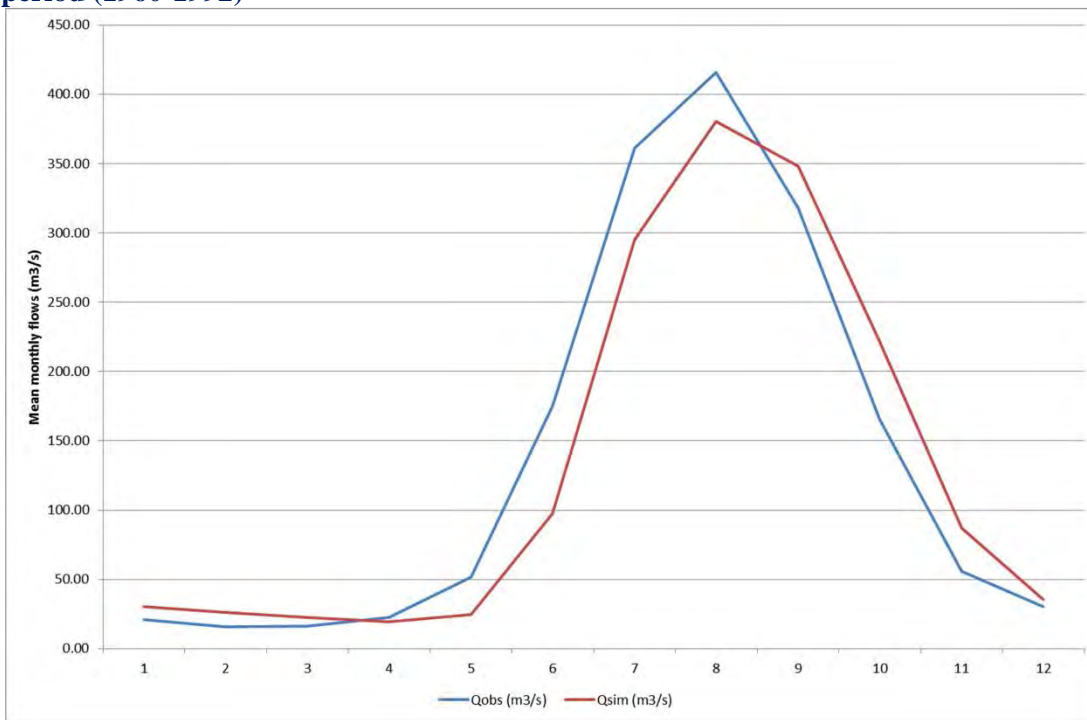
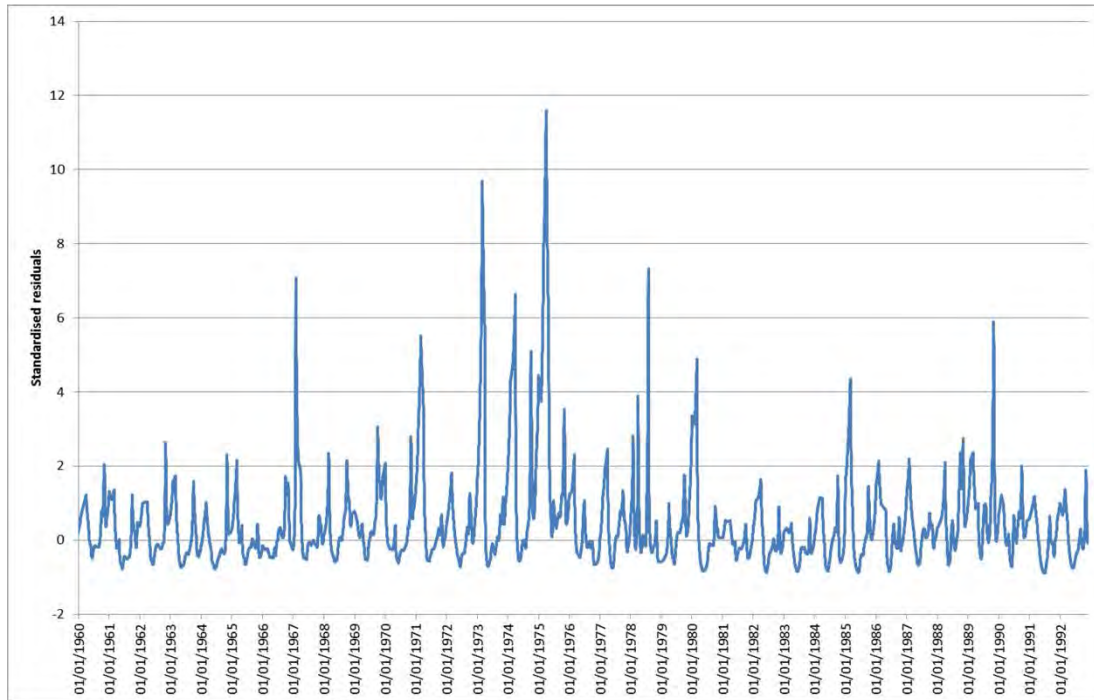


Figure: 4-3-9 Observed and simulated mean monthly flows at Didessa at Arjo for the validation period (1962-1972)



**Figure: 4-4-10: Standardised flow residuals, validation period at Didessa at Arjo (1962-1972)**

## **CHAPTER FIVE**

### **5 SCENARIO DEFINITION AND IMPLEMENTATION**

#### **5.1. INTRODUCTION**

Scenarios are used to compare various “what if” cases and provide a structured method of thinking about possible future water resource development and management options, opportunities and risks, and how these might interact. The results are useful for consensus building and decision making. Within the context of this research, a scenario is defined as “a contemplated state of the Eastern Nile Basin induced either through targeted human intervention (e.g. combinations of development and management interventions) or through externalities (e.g. climate change, economic policies etc.)”.

#### **5.2. SCENARIO DEFINITION**

The prioritization of water management issues in the Eastern Nile, the identification of various potential development interventions and management options to address these issues and the definition of possible scenarios, were undertaken with respect to the implementation of the Grand Ethiopian Renaissance Dam in this research. In essence, the scenarios are based on one future development interventions on the Eastern Nile in Ethiopia, i.e. the construction of Great Ethiopian Renaissance Dam, an optimization scenario, a development scenario and a flood damage scenario.

As seen from above, considering the large number of potential development projects, a different combination of scenarios could be developed in order to assess the impact of individual projects on the downstream projects. Currently the identified potential projects are at various levels of studies and some are under implementation. To compare and analyze different development options, two scenarios are considered based on the existing state and development of the Great Ethiopian Renaissance Dam. The number of scenarios and sequences of developments could vary as required by planners and decision makers in the future. The scenarios considered by now are: Base line scenario i.e. existing state condition (developments up to 2012) and scenario considering the implementation of the Grand Ethiopian Renaissance Dam (future) on the existing condition of the Eastern Nile Basin.

### 5.3 SCENARIO IMPLEMENTATION

The approach that was adopted for scenario implementation essentially involved the formation baseline model, if necessary modification of the NBI and EN-JMP as appropriate, for representation of the various development and management options being considered in each scenario.

A simulation period of 1951 to 1990 was used for all scenarios.

#### 5.3.1 Scenario Model Development

All the Eastern Nile countries Ethiopia, Sudan and Egypt plan to increase development of the Blue Nile water resources significantly in the near future. This research investigates the use of the Mike Hydro 2014 model and NBDSS to investigate scenarios of water demand in the basin and to evaluate the likely implications of GERD Hydropower development on downstream water availability. Water use was simulated over a 32-year period of varying rainfall and flow. The results reported here are preliminary results derived from initial model runs.

##### 5.3.1.1 Scenario 0: Baseline

The development and implementation of the MIKE Hydro model representing the baseline (current) Eastern Nile system is shown below

So is the Base Case scenario, representing the present conditions without GERD. The development and implementation of the Mike Hydro model representing the baseline (current) Eastern Nile system is detailed in Section

**Table 5-1 : Eastern Nile simulation with GERD Scenarios**

Scenario	Development Intervention	Management Option
SC0*	Baseline(Existing up to 2012)	Current
SC1	Grand Ethiopian Renaissance Dam Dam/GERD	Future

\*Includes heightening of Roseires Dam

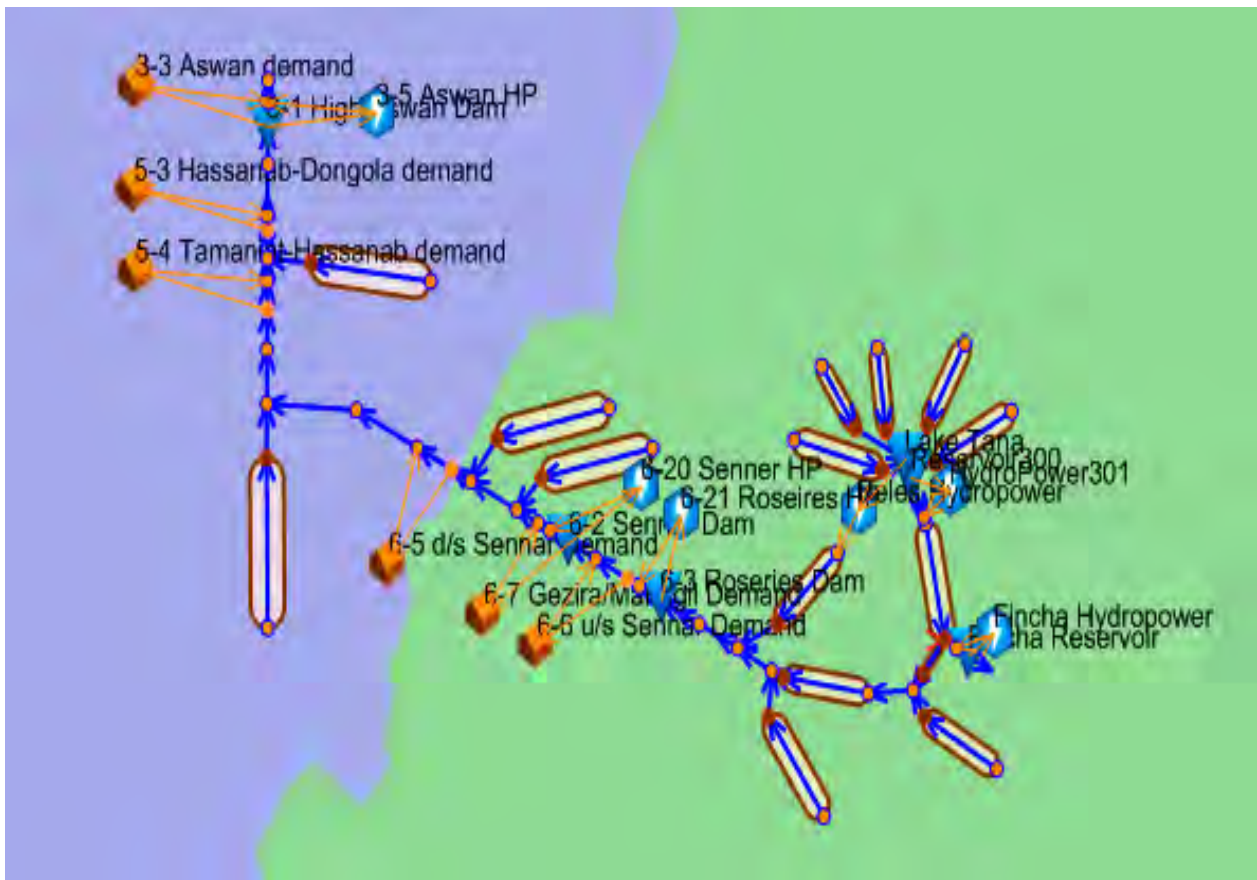


Figure 5.1 : Schematic of EN configuration for Scenarios 0

### 5.3.1.2 Scenario 1: Grand Ethiopian Renaissance Dam

The main dam which will have a volume of approximately 10MCM, a length of 1780 meters and height of 145 meters, will be a RCC gravity dam, divided in three sections: right bank, central section and left bank.

The central section will be used as a stepped spillway. This will create a reservoir that covers, at full supply level, an area of 1,680 sq. km and hold a volume of 63 Billion cubic Meter (BCM) of water. The normal and minimum operating water levels will be 640 and 590 meters

above sea level respectively, and the reservoir volume at minimum operating level is to be 12 BCM.

The two powerhouses will be at the downstream of the main dams: one on the right bank and the other on the left bank. They will accommodate 10 and 5 Francis Turbine Units respectively, with a total installed generating capacity of 5,250MW.

The reservoir area will cover 1,874 square kilometers at full supply level (FSL) of 640 meters above sea level (masl). The total storage volume is 74 billion cubic meters with an active storage volume of 59.2 Billion cubic meters. For a design flow of 4,305 cubic meters per second and a maximum net head of 133 meters and plant factor of 0.31, the expected average energy production per year is 15,692 GWh.

The plant has two surface powerhouses equipped with sixteen power generating units and a Switchyard. The installed power is flexible (base or peak) and the plant has been designed so that the installed capacity may be built in several stage.

The reservoir level will be controlled through three spillways, designed to cater for a probable maximum flood (PMF) of 19,370m<sup>3</sup>/s.

The saddle dam, with a maximum height of 60m and approximate volume of 17 MCM will have a curved axis and a length of approximately 4,800 meters. The cross section will include an impervious asphalt core with the relevant upstream and downstream transition. The dam body is to be made of material obtained from the spillway excavation, whilst selected rip-rap will constitute the slope protection. A wave protection wall will be placed on the 4m wide crest.

A 500KV double bus-bar switchyard will be set up about 1.4 km downstream of the main dam. The switchyard will include incoming bays from the transformer feeders at the power plant and the outgoing transmission line bays.

Technical feature of GERD considered in this scenario is given below in the table.

**Table 5-2 Technical feature of GERD**

<b>Hydrological data</b>	
Catchment area	172,250 km <sup>2</sup>
Mean annual flow	1,547 m <sup>3</sup> /s
<b>Main dam</b>	

## Easter Nile River Basin Simulation with GERD

Type	Roller compacted concrete (RCC) dam
Max. Height above foundation	145m
Crest e elevation	645 m asl
Crest length	1780m
Dam volume	10.1Mm <sup>3</sup>
<b>Reservoir Data</b>	
Full Supply Level (FSL)	640 masl
Minimum operating level (MOL)	590 masl
Operating range	50m
Total Storage volume	74.01sm <sup>3</sup>
Live storage vol. (Max. regulated capacity)	59.22 8m <sup>3</sup>
Dead storage volume	14.79 Bm <sup>3</sup>
Surface area at (FSL)	1, 874 km <sup>2</sup>
Surface area at {MOL)	606 km <sup>2</sup>
10,000 years return peak flood	26,860 m <sup>3</sup> /s
Probable Maximum Flood (PMF)	38,750 m <sup>3</sup> /s
Mean annual sediment yield	207 Mm <sup>3</sup> /y
Length of reservoir at FSL	246 km
<b>Saddle Dam</b>	
Type	Rock Fill Dam with Bituminous Surface Sealing
Height	45m
Crest length	4800m
Crest elevation	644 masl
Wave wall elevation	646 masl
<b>Powerhouse</b>	
Right powerhouse	
Powerhouse type	Outdoor
Un;t#/Type	10/Francis
Installed power	10/375MW
Left power house	
Power house type	Outdoor
un;t#/Type	6/Francis
Installed power	6/375MW
<b>Power and Energy</b>	
Max Net Head	133
Total Installed capacity	6000MW
Avg. annual energy Generation	15692 GWh/yr
Plant factor	0.31

The characteristics for Grand Ethiopian Renaissance Dam used in this research are based on the recommended a full supply level of 640 m. Following the approach used, all excess water was assumed to spill (i.e. no spillway function was defined). The reduction factor applied for energy production due to friction losses or electrical efficiency losses was assumed to be 0.86. The operating rules for Grand Ethiopian Renaissance Dam, and the other existing dams on the Eastern Nile River, were dictated by the regulation of seasonal river flows for flood control and irrigation, maintaining minimum flow releases, maintaining operational head levels for hydropower generation, and maintaining storage capacity by flushing to control sedimentation.

The hydropower operating rule that was adopted for Grand Ethiopian Renaissance Dam assumed that the dam would be used as a “peak” dam in order to maximize energy production during some months of the year. This involved setting the target power equal to the installed capacity, combined with a relatively limited active storage (i.e. a high minimum operating level) in order to maximize head availability. This ensured very high energy production annually during the main rainfall season.

Operational levels as well as hydropower characteristics for Grand Ethiopian Renaissance Dam are summarized below.

**Table 5-3: Characteristic dam levels and HP parameters for Grand Ethiopian Renaissance Dam – Scenario 1**

Variable/rule	Units	Value
Dam crest level	masl	640
Flood control level	masl	640
Minimum operation level	masl	622
Top of dead storage	masl	550
Bottom level	masl	500
HP target power	MW	6000
HP installed capacity	MW	6000

With the heightening of Roseires Dam, the additional capacity available will provide water required for the extension of the Rahad and Kenana irrigation schemes downstream of

Roseires that fall into the lumped demand upstream of Sennar. The irrigation area will increase to approximately 6424 km<sup>2</sup>. It has been assumed that the crop mix will stay the same and increase proportionally. In addition to the increased irrigation scheme area, the installed hydropower capacity will be increased to 415 MW.

A schematic of the Mike Hydro model configuration that was used to implement Scenarios 1 is presented in Figure below

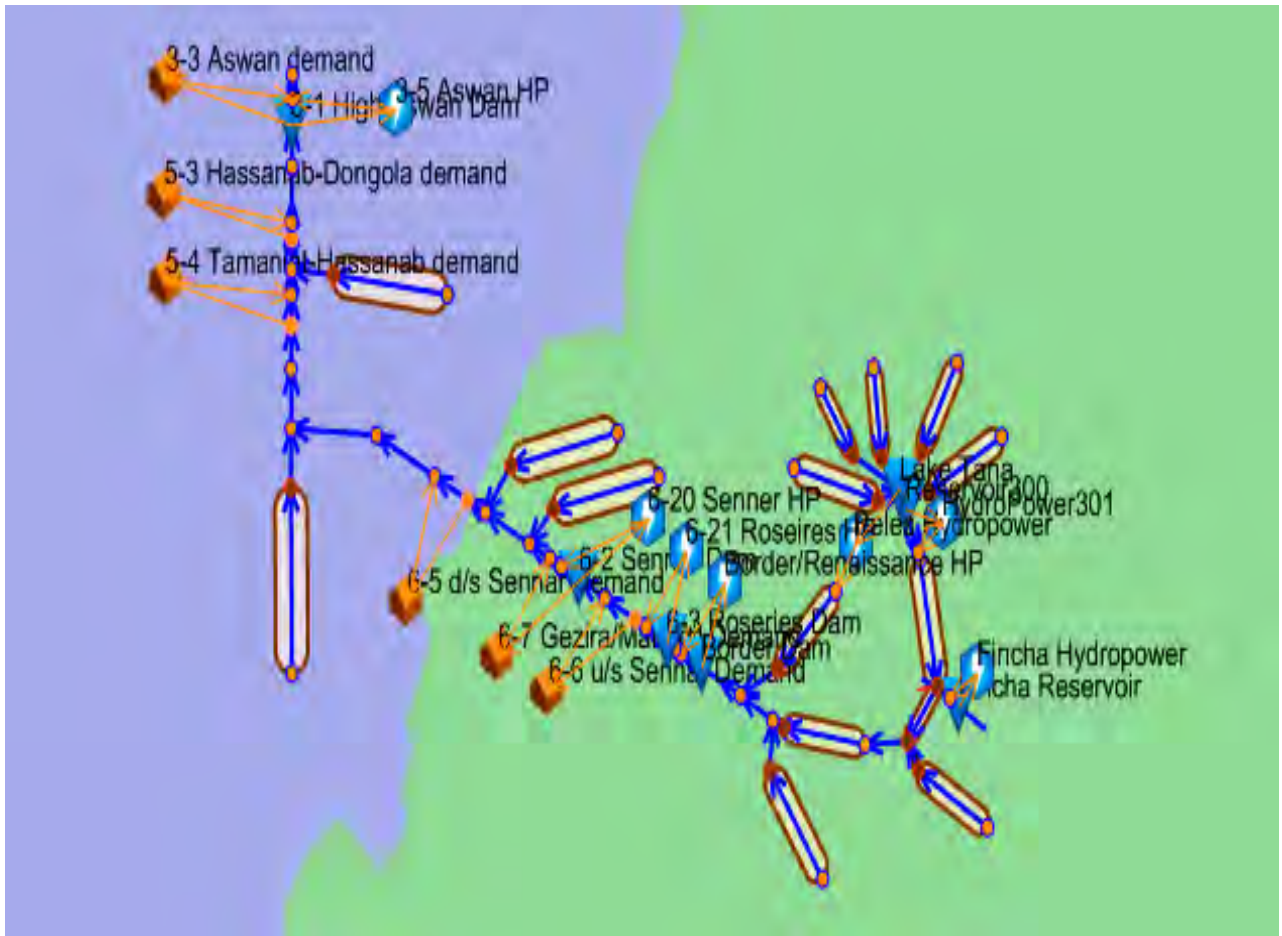


Figure 5-2 : Schematic of EN configuration for Scenarios 1

## CHAPTER SIX

### 6 SCENARIO ANALYSIS, EVALUATION, RESULTS AND DISCUSSION

#### 6.1. Impact of Grand Ethiopian Renaissance Dam Hydropower generation in the hydropower generation in the Eastern Nile River Basin

The impact of the Grand Ethiopian Renaissance Dam Hydropower generation in the hydropower generation in the Eastern Nile River Basin is significant on the existing hydropower generation of the Eastern Nile River Basin scenario 1, SC-1. In this scenario, the overall average power generation during the 36 years of simulation is increased by more than 50% in the Eastern Nile River Basin. In the Roseri and Sennar, the average power production increased by 15% from the present (Sc0) condition. The power generation in the Aswan Dam is reduced by 9%.

After construction and full production capacity of GERD the Eastern Nile Basin will be benefited with a total installed capacity of more than 11,000 MW instead of the present 5,000 MW. The Energy generation in the Eastern Nile River Basin will increase from the present 8,153 GWh/yr to 22,401 GWh/yr, which is more than 50%, when GERD will be at full production.

.Therefore, the impact on the GERD is significant in existing development scenario on the downstream Eastern Nile Basin. But for the full development on the basin should be analyzed and modeled by other scenarios.

The mean monthly power generation deficit at Roseries, Sennar and High Aswan Dam hydropower before and after GERD construction is shown in the figure below.

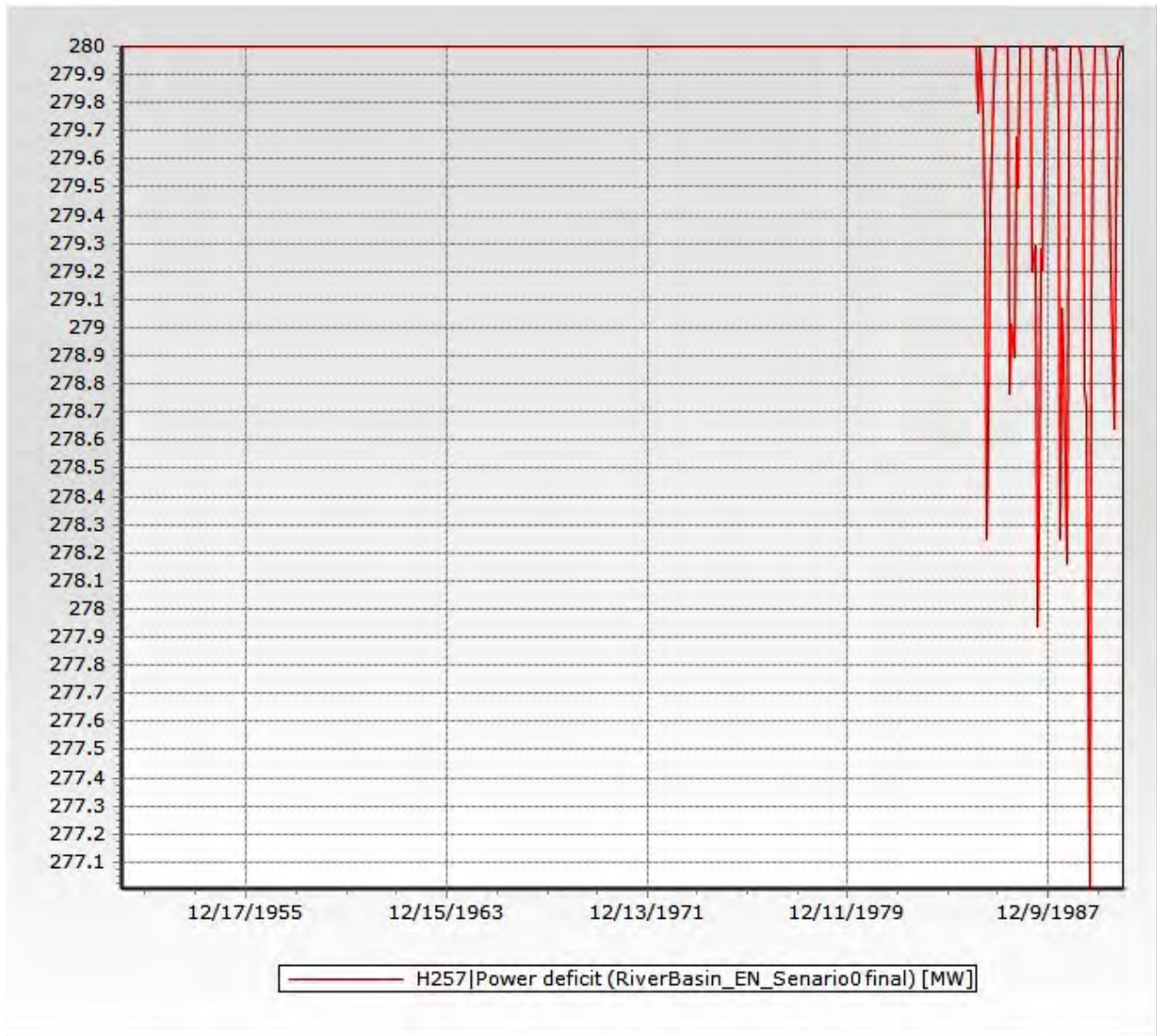
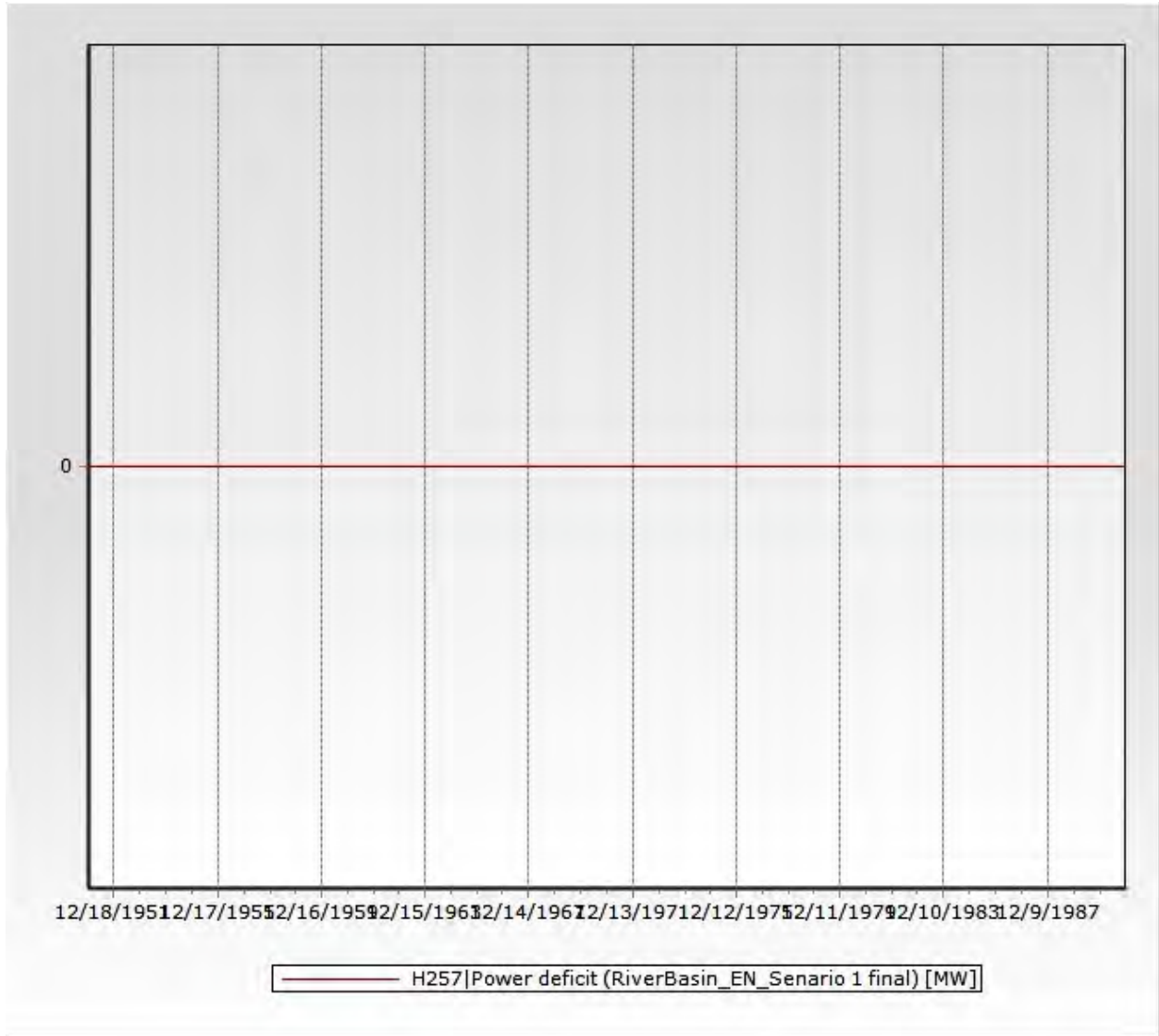


Figure 6-1: Roseries HP Power deficit at SC0 (Before construction of GERD)



**Figure 6-2: Roseries HP Power deficit at SC1 (After construction of GERD)**

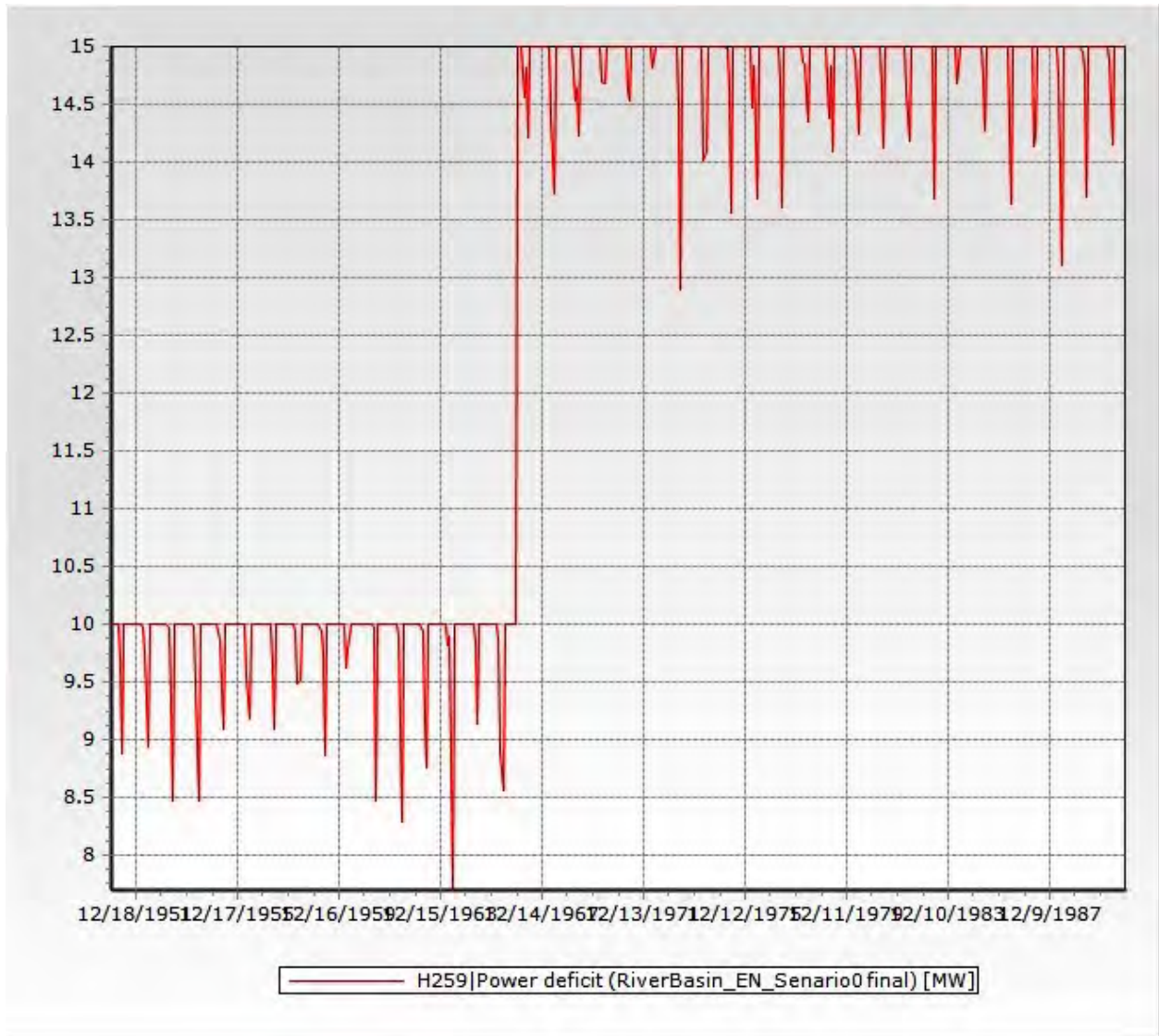


Figure 6-3: Sennar HP Power deficit (MW) at SC0 (Before construction of GERD)

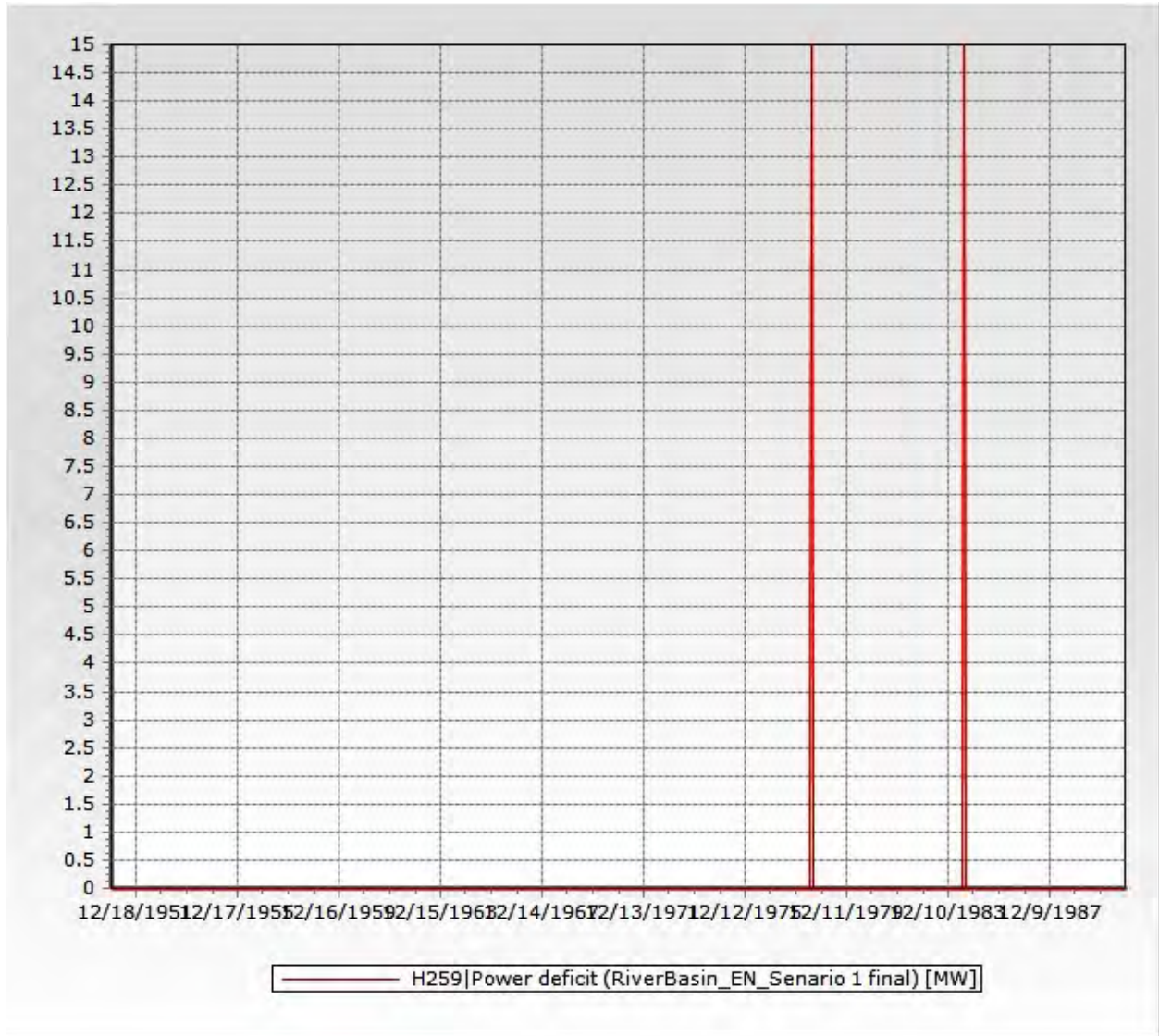


Figure 6-4: Sennar HP Power deficit (MW) at SC1 (After construction of GERD)

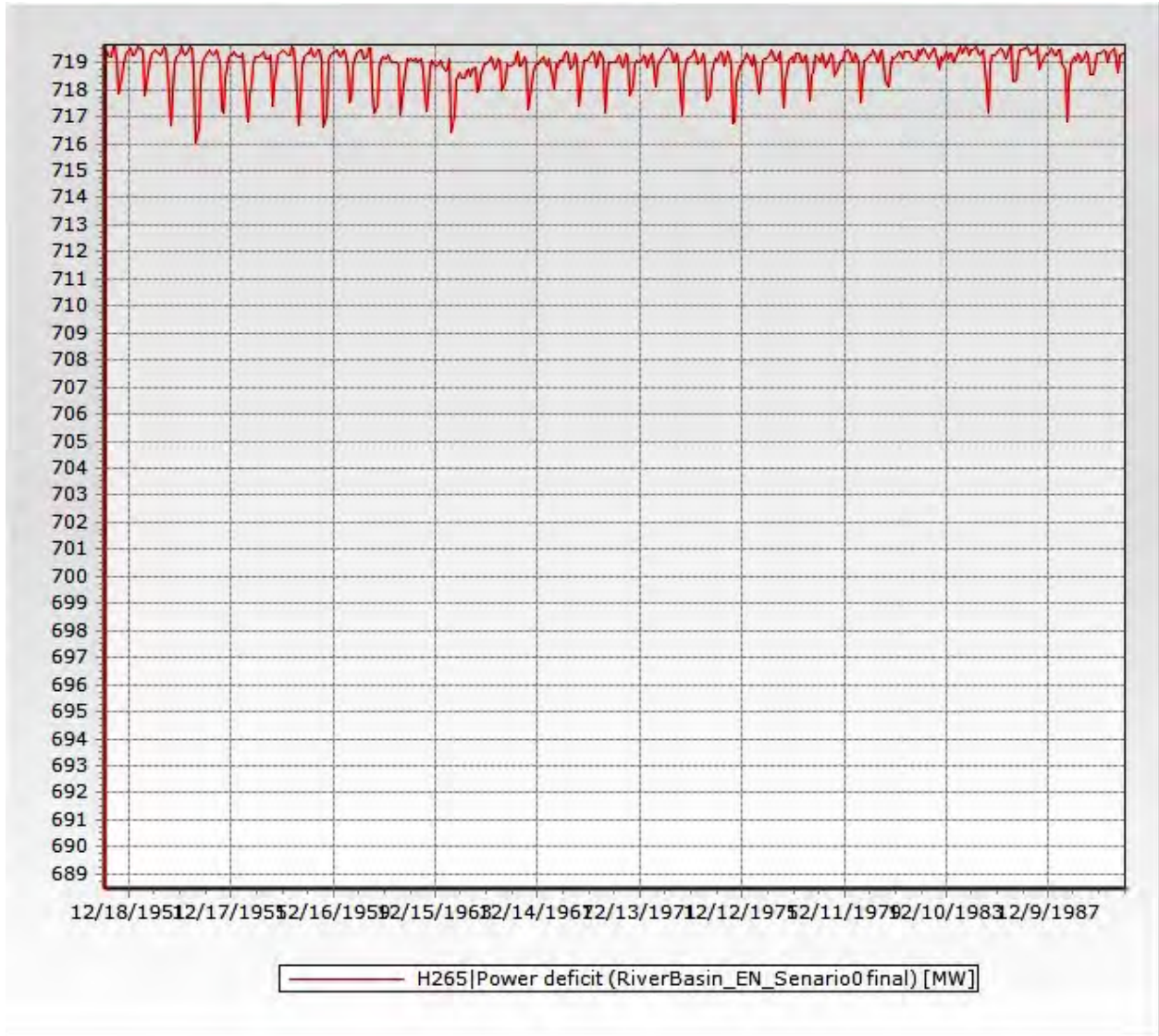


Figure 6-5: Aswan HP Power deficit (MW) at S0 (Before construction of GERD)

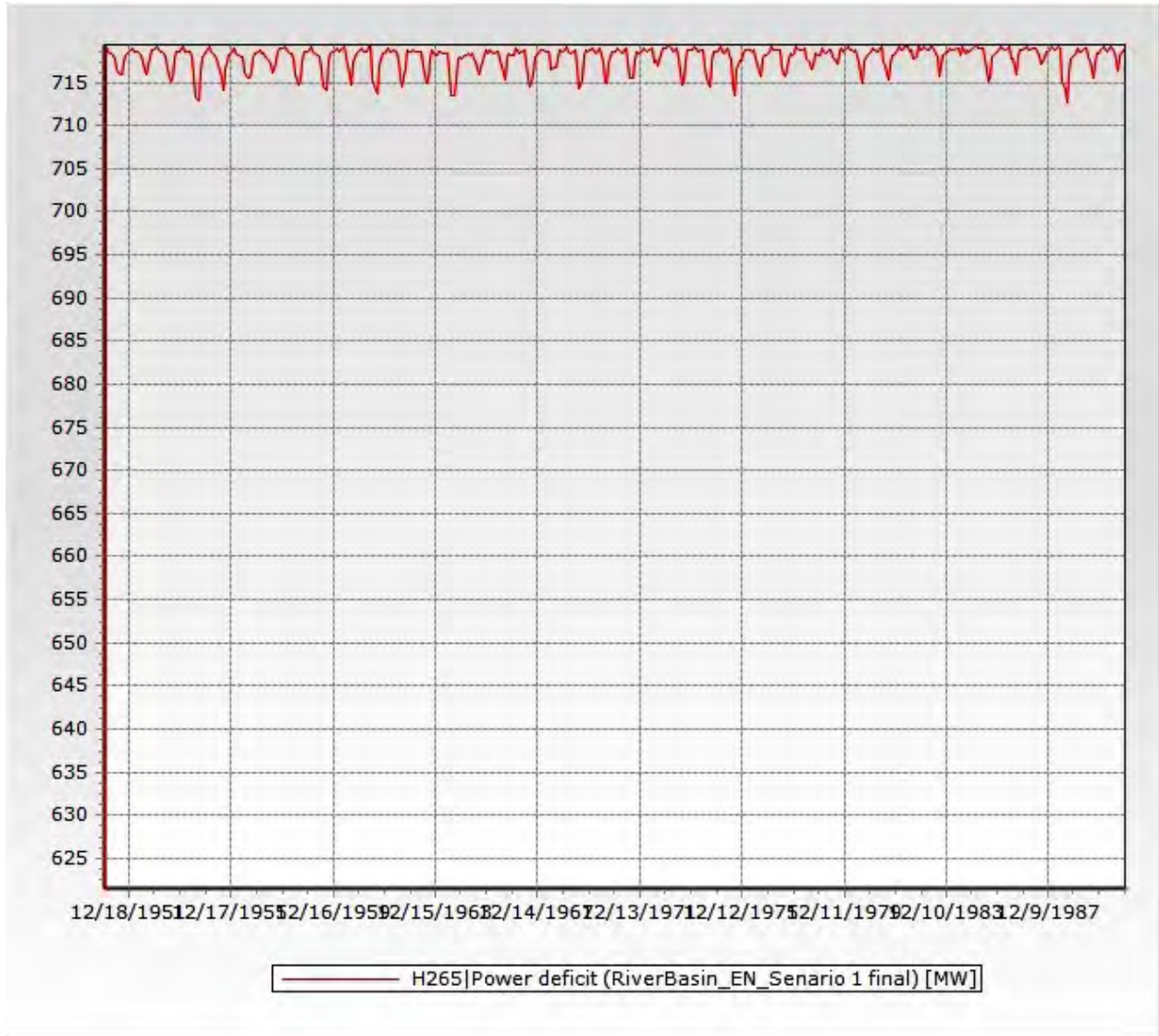


Figure 6-6: Aswan HP Power deficit (MW) at SC1 (After construction of GERD)

### **6.2. Impact of Grand Ethiopian Renaissance Dam Hydropower generation on Irrigation Development in the Eastern Nile River Basin**

The impact of the Grand Ethiopian Renaissance Dam Hydropower generation in Irrigation development in the Eastern Nile River Basin is significant on the existing Irrigation development on the downstream of Eastern Nile River Basin scenario 1, SC-1. The scenarios illustrate the benefit for downstream countries, especially, in Sudan because of increased upstream regulation in Ethiopia. An improved coverage of the irrigation water demand (0 month of deficit against 10 months of deficit without GERD) in the Eastern Nile Basin. This is highlighted by the simulated irrigation water demand deficit in the downstream Irrigation development as shown in the figure below.

In this scenario, the average irrigation water demand deficit during the 36 years of simulation is reduced up to zero (no deficit) in the downstream Irrigation Scheme as shown in the simulation results below. In the u/s Sennar and d/s Sennar, the average irrigation water demand deficit is reduced significantly up to nil. The irrigation water demand deficit in the Gezira scheme is also reduced accordingly.

In the downstream Reservoirs which shows in scenario 1 (after construction of GERD) that it is possible to fill and empty the downstream reservoir in all years. This contrasts with the current situation when in some years there is insufficient flow to fill the reservoir and is despite the fact that raising the downstream dams will substantially increase the reservoir storage and irrigation demands will also have increased greatly.

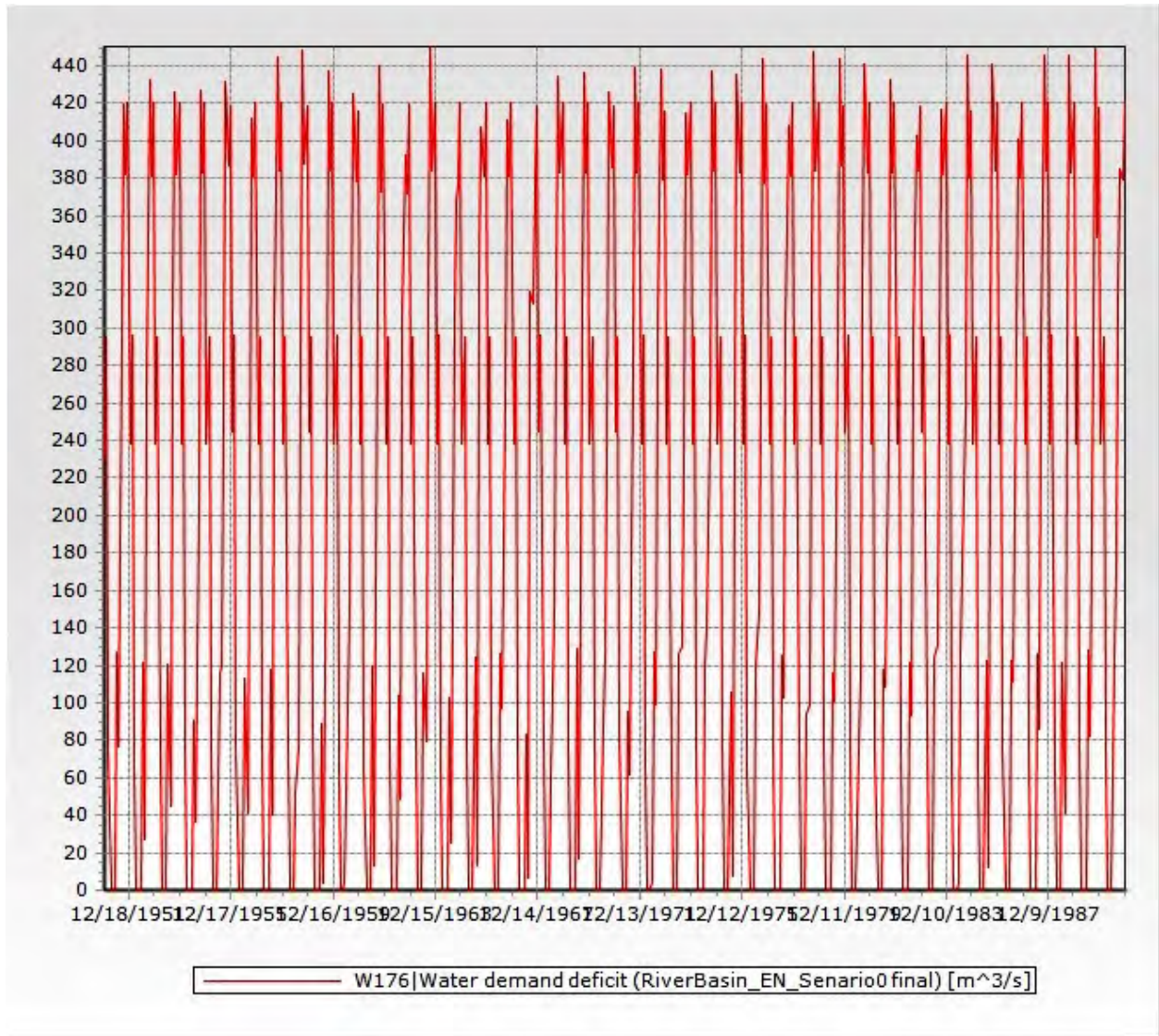


Figure 6-7: Gizeria Irrigation water demand deficit SC0 (Before construction of GERD)

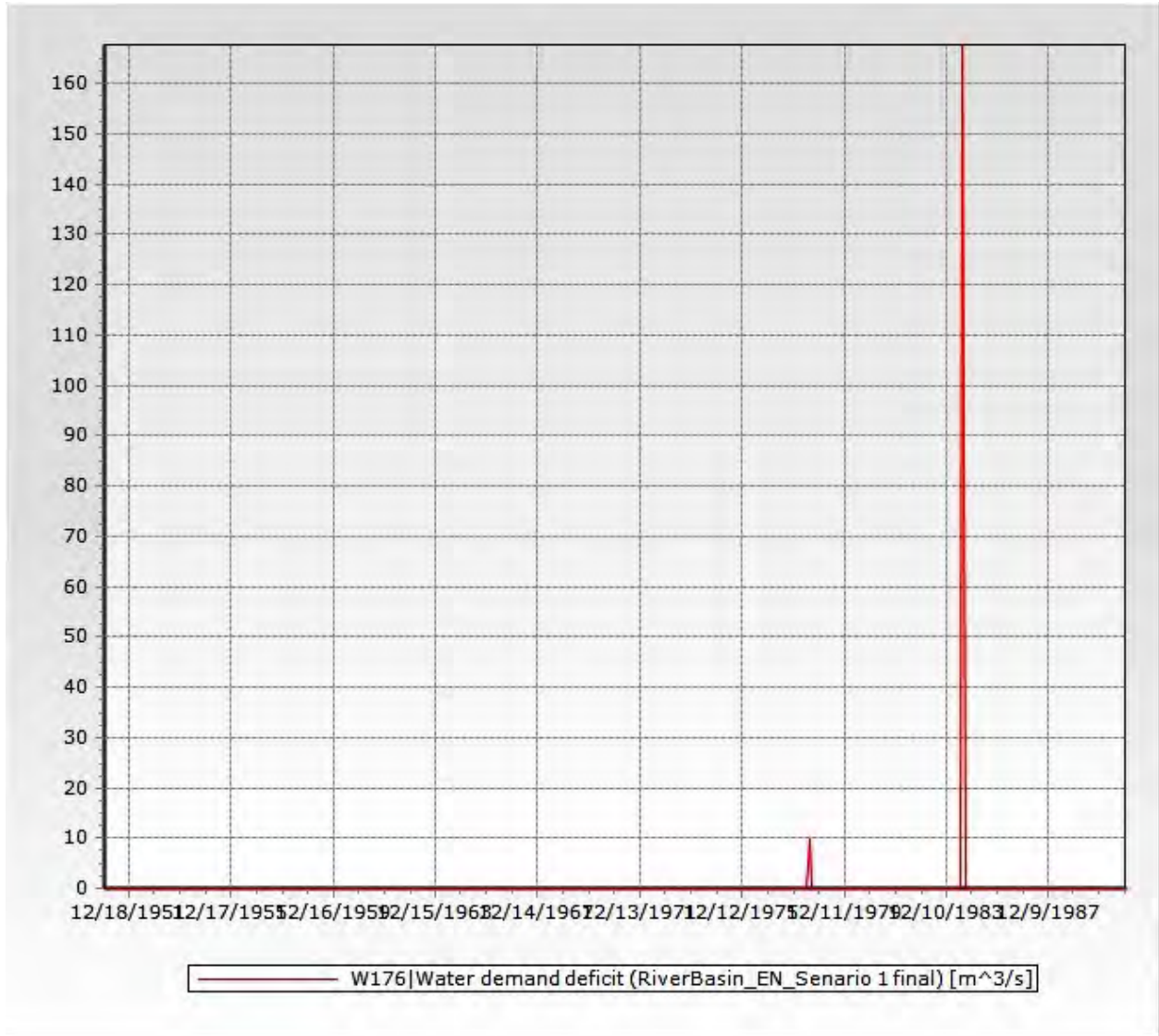
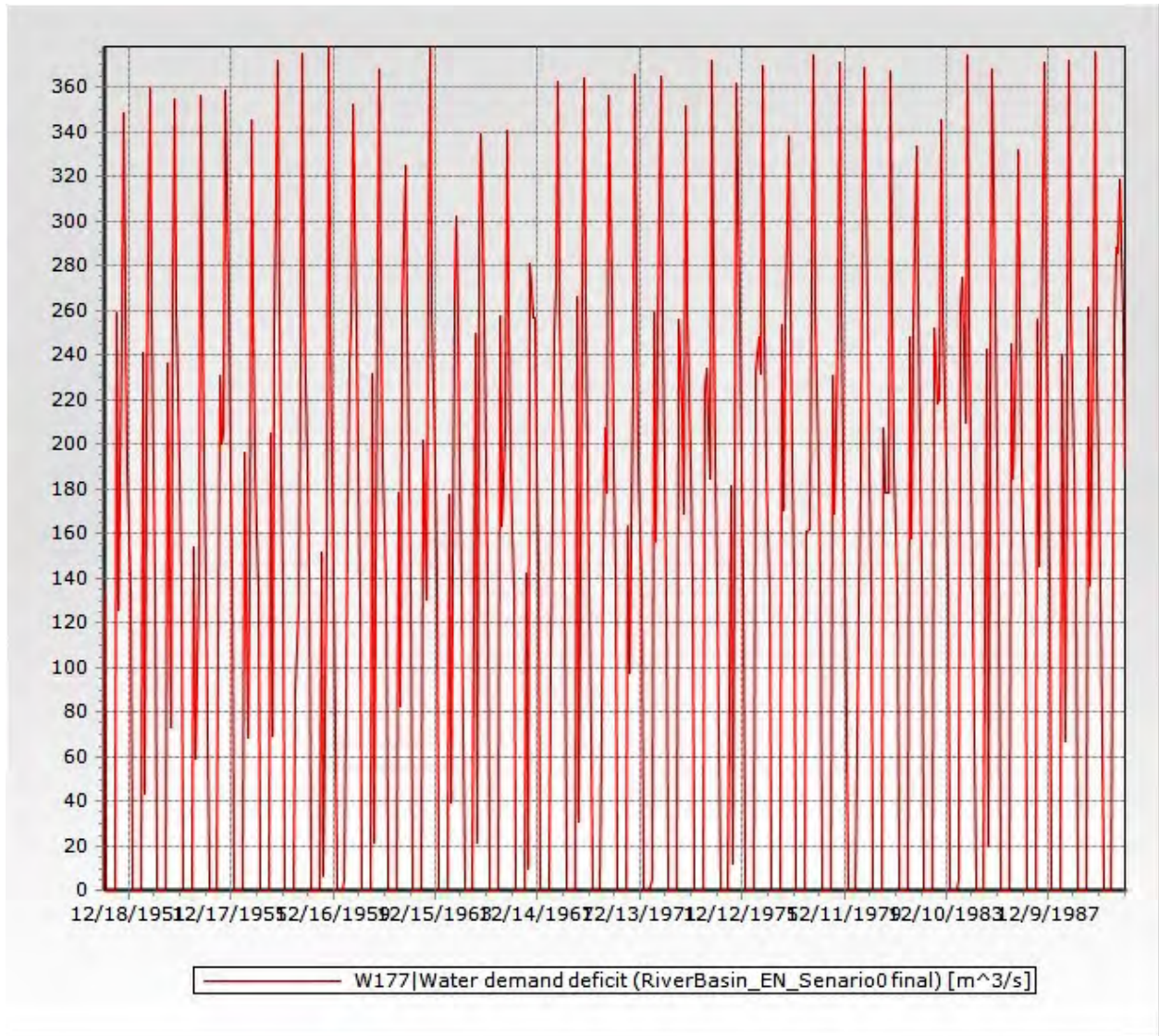
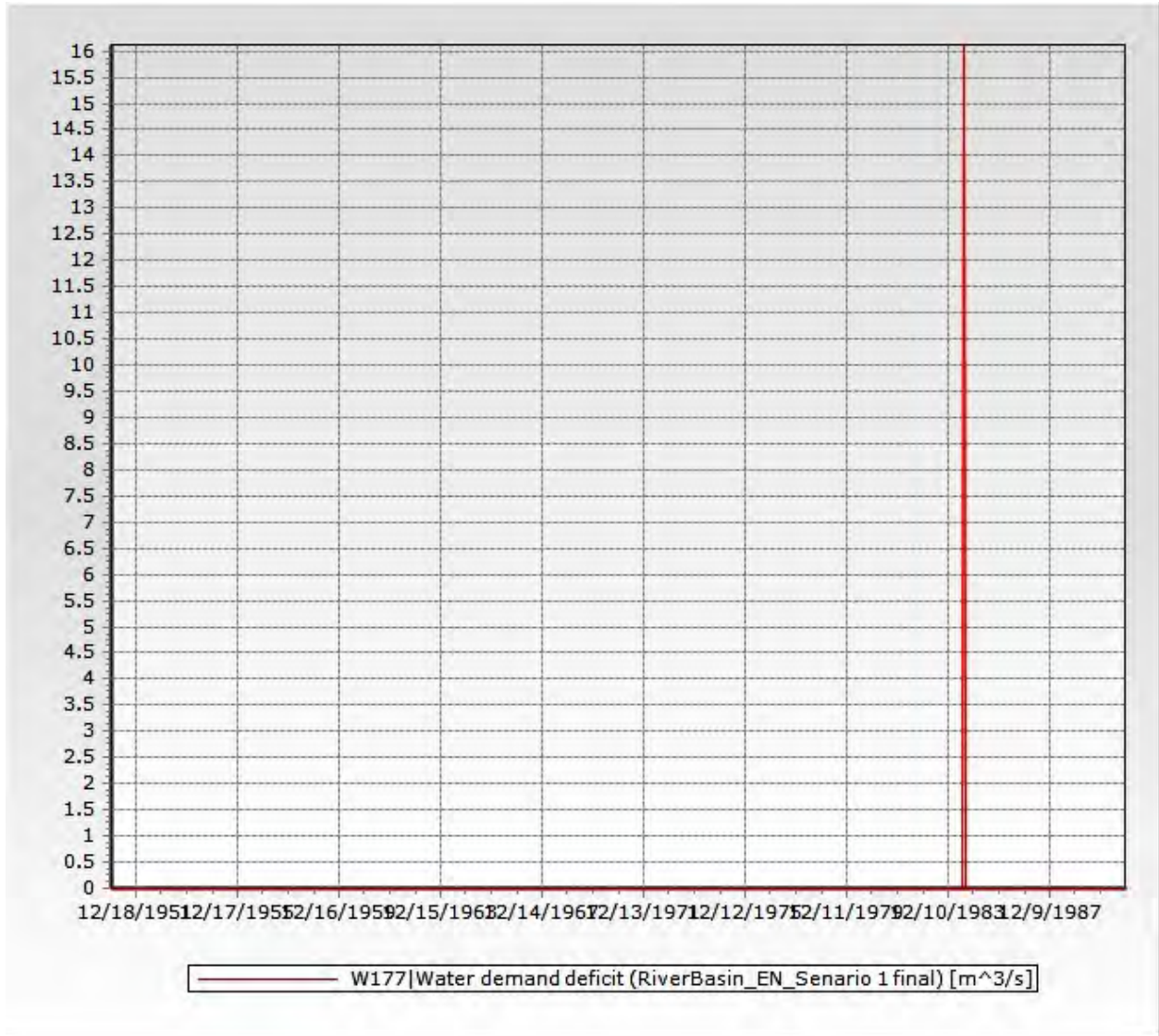


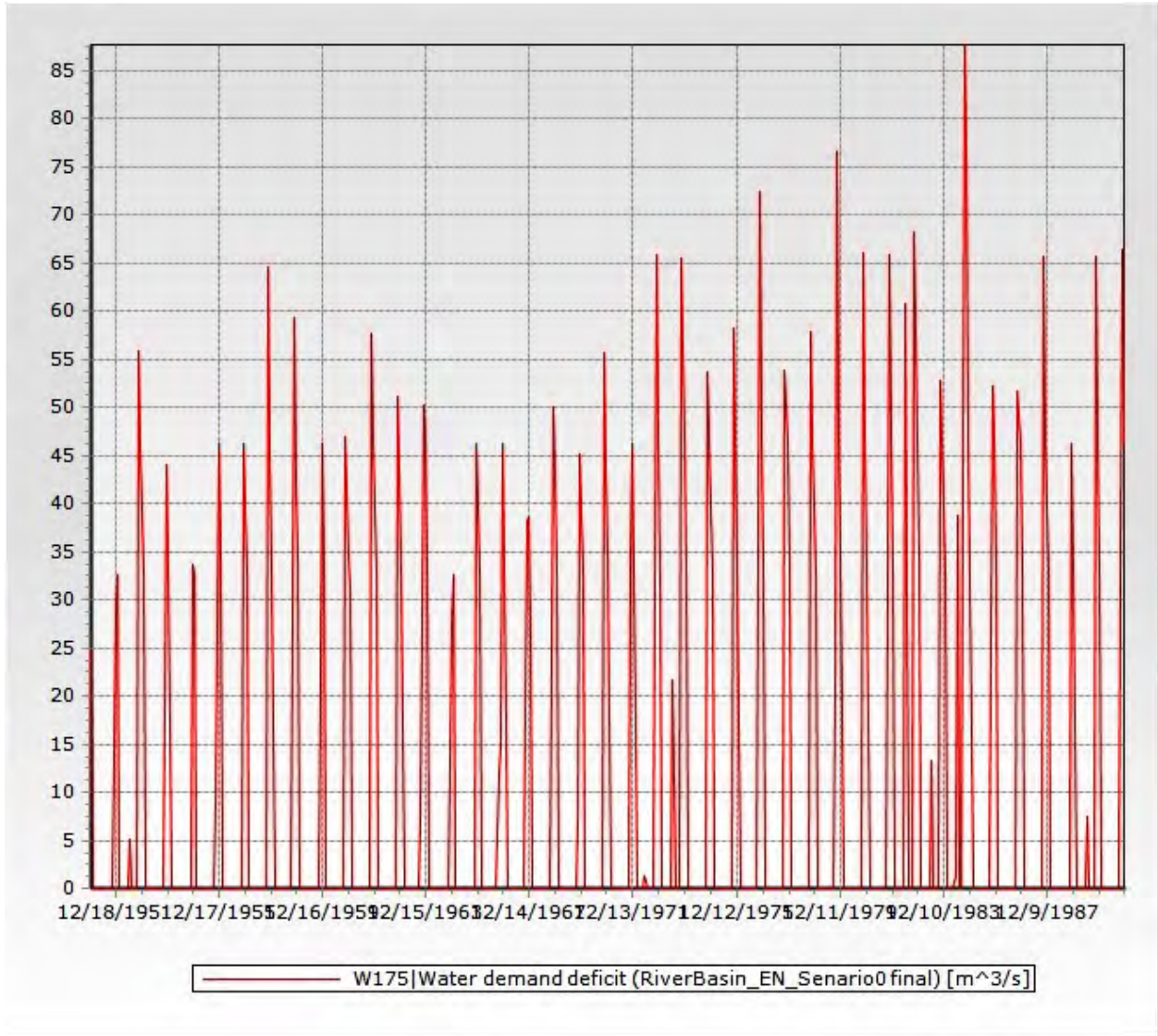
Figure 6-8: Gizeria irrigation water demand deficit SC1 (After construction of GERD)



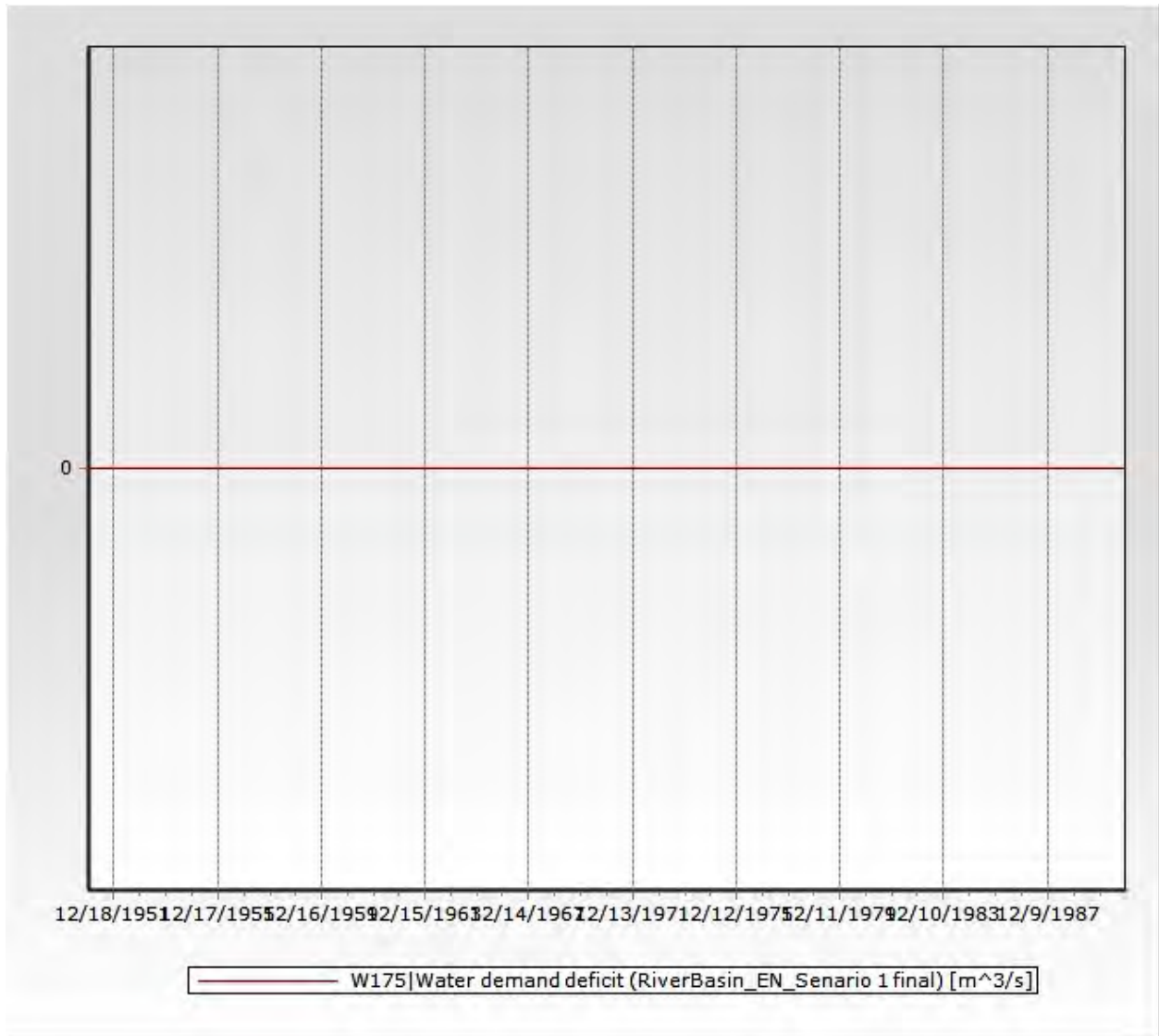
**Figure 6-9: U/S Sennar irrigation water demand deficit ( $\text{m}^3/\text{s}$ ) SC0 (Before construction of GERD)**



**Figure 6-10: U/S Sennar irrigation water demand deficit SC1 (After construction of GERD)**



**Figure 6-11: D/S Sennar irrigation water demand deficit SC0 (Before construction of GERD)**



**Figure 6-12: D/S Sennar irrigation water demand deficit SC1 (After construction of GERD)**

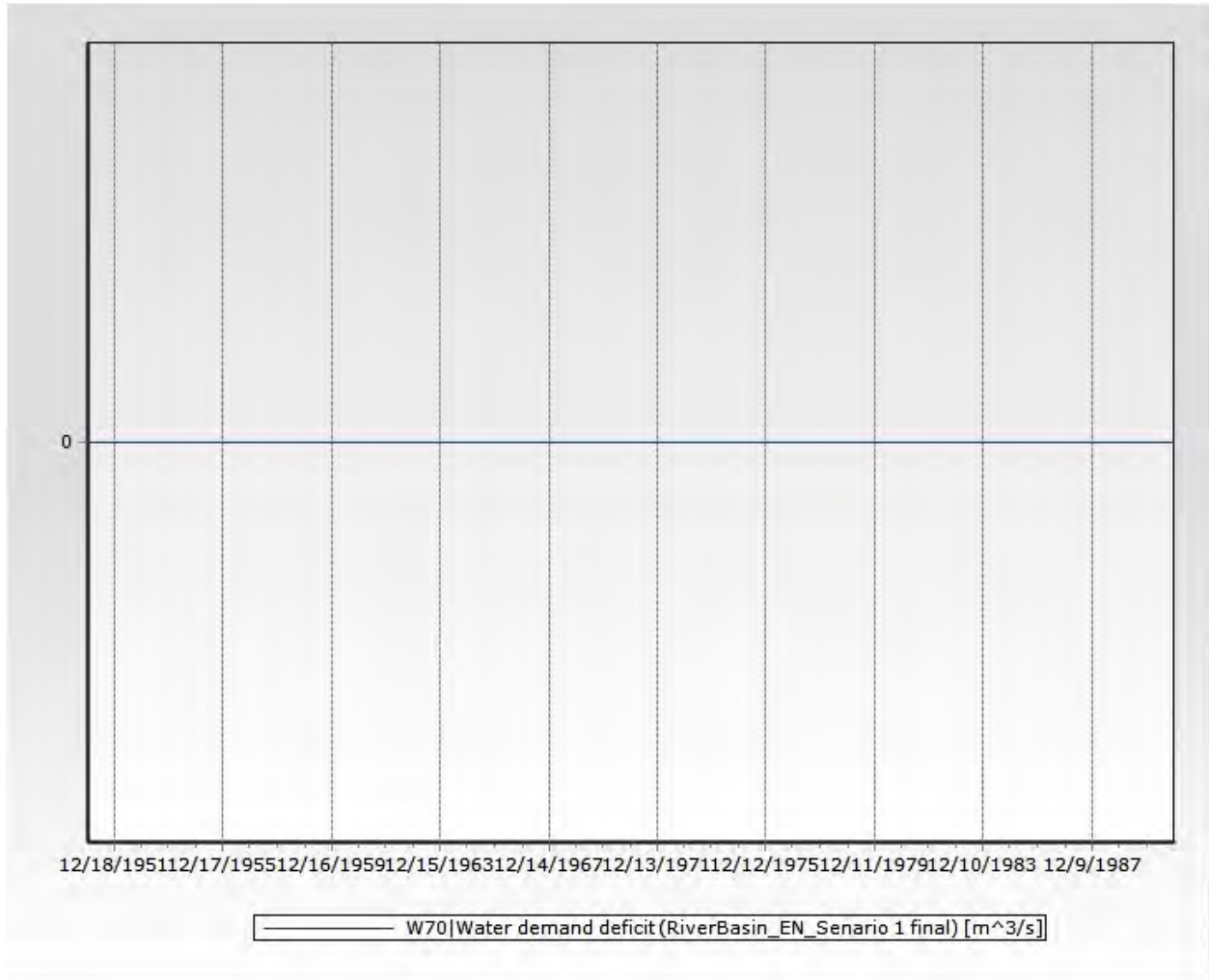


Figure 6-13: Aswan irrigation water demand deficit SC1 (After construction of GERD)

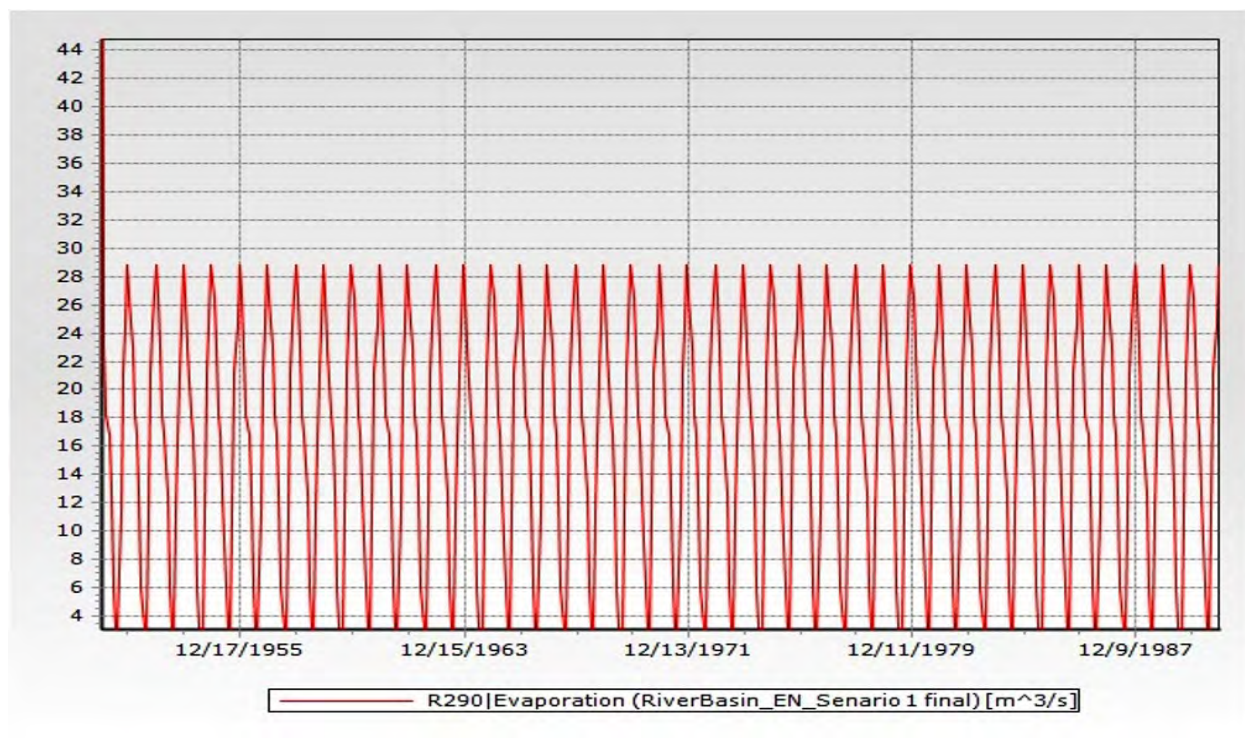
### 6.3 Evaporation loss comparison in different reservoir sites of the river system of Sudan and Egypt

The impact of Great Grand Renaissance Dam Hydropower generation in reducing Evaporation loss in the Eastern Nile River Basin is significant on the existing development on the downstream of Eastern Nile River Basin by saving significant amount of water on the Highland of the basin when compared to the existing downstream reservoirs in Sudan and Egypt reservoirs evaporation losses.

The Overall open water evaporation in the Eastern Nile River Basin remains the same (after construction of GERD-Sc1). The specific simulation result shows that the Lake Nasser open water evaporation losses reduce but open water evaporation in Sudan and Ethiopia slightly increases.

With GERDP dam operating upstream, average annual HAD losses are equal to 9.5 BCM/year instead of 10.8 BCM/year in case of HAD alone. Evaporation losses are reduced by 12 % comparing to HAD alone situation.

The scenarios illustrate the benefit for Sudan and Egypt of increased upstream regulation in Ethiopia by saving significant amount of water.



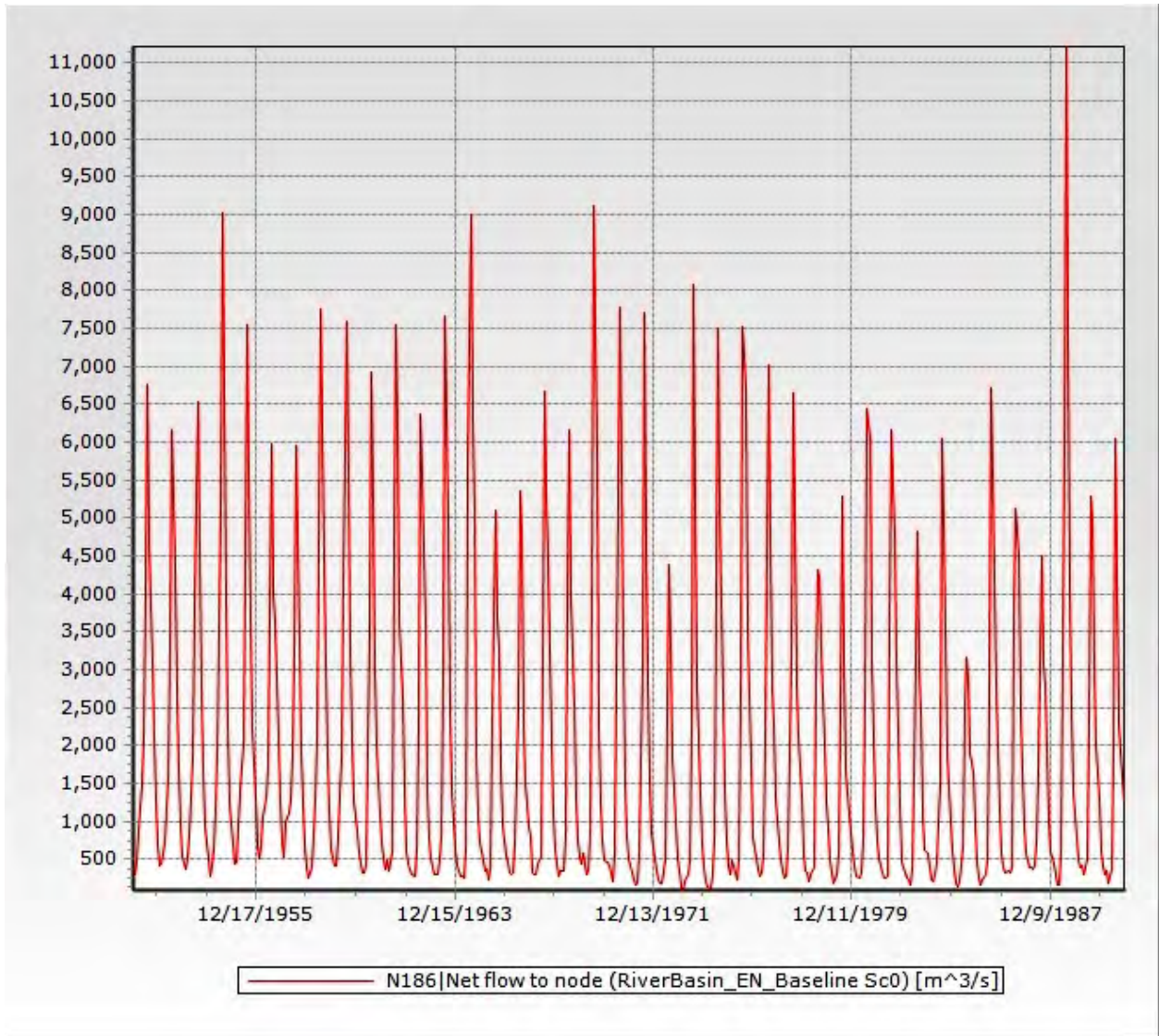
**Figure 6-14: Monthly Evaporation loss of GERD**

#### **6.4 Impact of Grand Ethiopian Renaissance Dam Hydropower generation on the Blue Nile outflow at the border (the Ethio-sudan border) after the construction of Grand Ethiopian Renaissance Dam**

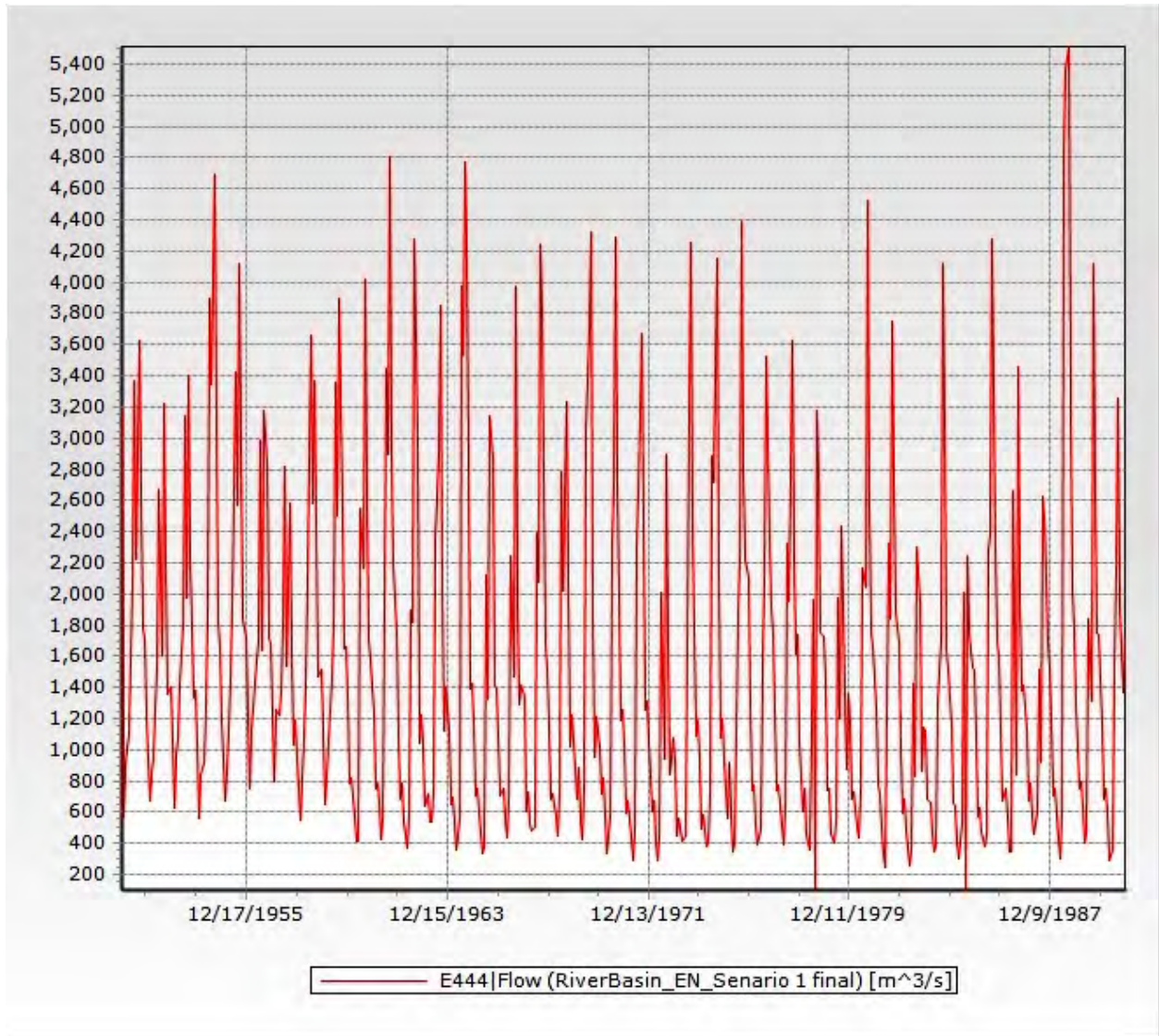
The stream flow data of 4 main river course and 15 tributaries gauges were utilized for the computation of Grand Ethiopian Renaissance Dam flow volume. The mean monthly flows obtained from the historical records that are converted in to specific discharges for suitability of the model. Bahir Dar, Kessie, and Grand Ethiopian Renaissance Dam and 14 gauged tributaries were utilized. Based on these data, the overall stream flow volume at each gage sites on the mainstream and tributaries was computed by MIKE Hydro. As indicated on Figure below the mean out flow was found to be  $1549.5 \text{ m}^3/\text{s}$ . The mean annual flow of Abbay was found to be 48.865 BCM at the downstream of Great Ethiopian Renaissance Dam/ and 3.8 BCM at Bahir Dar below the outlet of Lake Tana. The value of Grand Ethiopian Renaissance Dam flow obtained from this analysis is almost equal to the one which is estimated on the master plan, which is 50.6BCM.

More regular flows are provided downstream GERD (in Sudan and Egypt). The simulation result indicates that, at Ethio- Sudanese border, floods on the Blue Nile are controlled and reduced by GERDP (reduction of 40 % of the maximum monthly flow) while low flows are significantly increased

In average, the whole inflow volumes are regulated: annual out flows are equal to annual inflows once losses are deducted (approximately the difference in GERDP water levels at the beginning and at the end of the simulated period). Compared to natural conditions, the monthly repartition of flows is modified with a smoothing effect: outflows decrease during the wet period (July to October) and increase significantly during the rest of the year (as shown in the Figure 6-15).



**Figure 6-15: Ethio-Sudan Border simulated outflow before the project condition (construction of GERD) in m<sup>3</sup>/s**



**Figure 6-16: Border simulated outflow after Construction of GERD (Scenario 1) in m<sup>3</sup>/s**

## CHAPTER SEVEN

### 7 CONCLUSIONS AND RECOMMENDATION

#### 7.1 Conclusion

The impact of the Grand Ethiopian Renaissance Dam Hydropower generation in the hydropower generation in the Eastern Nile River Basin is significant on the existing hydropower generation of the Eastern Nile River Basin. Based on the scenario analysis result, the overall average power generation during the 36 years of simulation is increased by more than 50% in the Eastern Nile River Basin. In the Roseri and Sennar, the average power production increased by 15% from the present (SC 0) condition. The average power generation in the Aswan Dam is reduced by 9%.

After the construction and full production capacity of GERD; the Eastern Nile Basin will be benefited with a total installed capacity of more than 11,000 MW instead of the present 5,000 MW. The Energy generation in the Eastern Nile River Basin will increase from the present 8,153 G Wh/yr to 22,401 G Wh/yr, which is more than 50%, when GERD will be at full operation.

The impact of the Grand Ethiopian Renaissance Dam Hydropower generation in Irrigation development in the Eastern Nile River Basin is significant on the existing Irrigation development on the downstream of Eastern Nile River Basin. The scenarios illustrate the benefit for downstream countries, especially, in Sudan because of increased upstream regulation in Ethiopia. The scenario analysis result showed an improved coverage of the irrigation water demand (0 month of deficit against 10 months of deficit without GERD) in the Eastern Nile Basin.

In this analysis, the average irrigation water demand deficit during the 36 years of simulation is reduced up to zero (no deficit) in the downstream Irrigation Scheme as shown in the simulation results. In general, on the U/S Sennar and D/S Sennar, the average irrigation water demand deficit is reduced significantly up to nil. The irrigation water demand deficit in the Gzeria scheme is also reduced accordingly.

In the downstream Reservoirs which shows in scenario 1 (after construction of GERD), it is possible to fill and empty the downstream reservoir in all years. This contrasts with the current

situation when in some years there is insufficient flow to fill the reservoir and is despite the fact that raising the downstream dams will substantially increase the reservoir storage and irrigation demands will also have increased greatly.

The impact of Grand Renaissance Dam Hydropower generation in reducing Evaporation loss in the Eastern Nile River Basin is significant on the existing development on the downstream of Eastern Nile River Basin by saving significant amount of water on the Highland of the basin when compared to the existing downstream reservoirs in Sudan and Egypt reservoirs evaporation losses.

The Overall open water evaporation in the Eastern Nile River Basin remains the same (after construction of GERD-Sc1). The specific simulation result shows that the Lake Nasser open water evaporation losses reduce but open water evaporation in Sudan and Ethiopia slightly increases.

With GERD dam operating upstream, average annual High Aswan Dam losses are equal to 9.5 BCM/year instead of 10.8 BCM/year in case of HAD alone. The Evaporation losses are reduced by 12 % comparing to HAD alone situation.

The overall mean annual flow from the mean monthly data of the main stream gauges was estimated to be 48.865 BCM at the Sudan Border. It is a bit less as compared to the result of scenario 1 of the master plan to irrigate a command area of 440,804 ha and to generate 9,519 GWh,. On the other hand the mean annual flow 50BCM given on the master plan is a bit more than the recent result 48.865 BCM

The construction of GERD results in positive impact by providing more regular flows throughout the year to the downstream countries (Sudan and Egypt). The simulation result indicates that, at Ethio- Sudanese border, floods on the Blue Nile are controlled and reduced by GERD (reduction of 40 % of the maximum monthly flow) while low flows are significantly increased.

## 7.2 Concluding Remarks

The Mike Hydro 2014 has been configured to simulate the impacts of water resource development in the Eastern Nile basin with account of GERD. Currently Ethiopia utilizes very little water but does regulate some flow for future hydropower production on the main Abay River. In contrast Egypt and Sudan uses some water for hydropower production but also

abstracts large volumes for irrigation. Accordingly, all Eastern Nile countries plan to develop water resource infrastructure substantially in the near future.

GERD reservoir will provide more constant flows than in the present natural conditions. The monthly flow with an exceedance frequency of 95 % at the Sudan Border will become greater than 3,000 Mm<sup>3</sup>/month. Sudan will be less vulnerable by drought periods with this important stored water volume and more regular provided flows.

Other benefits include water conservation. The GERD will minimize the evaporation loss from dams located in less favorable downstream countries. A total of close to 19 billion cubic meters (BCM) of water evaporators from the Aswan High Dam and other dams in Sudan (of this evaporation from Aswan alone amounts to 14.3 BCM) annually. Evaporation at the Jebel Aulia dam in Sudan amounts to 3.5 BCM annually from 1.75 BCM storage capacity. By contrast evaporation loss from the full development of the GERD is likely to be no more than 0.4 BCM.

The GERD will reduce and alleviate the Sediment transport from Ethiopian highlands = 157 to 207 million MT/yr. High cost of dredging from irrigation infrastructures, e.g. Maintenance and dredging cost of Rosaries reservoir = USD 7.5 million/yr. Irrigation scheme and HP generation underperformance: with less sediment entering Sudan HP generation gains would amount to USD 88 million worth of electricity per annum.

Current and projected Eastern Nile Basin energy demand exceeds by far available supply from GERD compared to the existing condition of the Eastern Nile Basin.

It would be wise that the Eastern Nile River Basin countries (Egypt, Ethiopia and Sudan) could closely cooperate to have shared vision and to optimize the whole Nile Basin water management system. Creating and developing an integrated system will be significantly beneficial for each country by interconnected projects could provide additional energy to Sudan and Egypt from surplus of GERD energy generation.

The results in this research are preliminary and based on many assumptions. Where it has been possible to verify the simulations the model results are reasonable. Nevertheless, the current results must be treated with caution. The model need to be refined using improved estimates of stream flow data on the major tributaries and better estimates of irrigation demand at all schemes. In addition, it is better to use the NB DSS all features in the next researches when the NB DSS fully utilized and publicized by including MCA and CBA. It needs to plan to simulate another scenario based on anticipated water resource development in full development of the Basin.

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