Modeling of Tekeze Hydropower Reservoir Operation with HEC – ResSim

By

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Addis Ababa University

March, 2012

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A thesis submitted and presented to the school of graduate studies of Addis Ababa University in partial fulfillment of the degree of Masters of Science in Civil Engineering (Major Hydropower Engineering)

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Advisor

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Addis Ababa University
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April, 2012

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Approval by Board of Examiners

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Advisor	Signature
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Internal Examiner	Signature
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External Examiner	Signature
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Chairman (Department of Graduate Committee)	Signature

CERTIFICATION

I, the undersigned, certify that I have read and here by recommended for acceptance by the Addis Ababa University a dissertation entitled: **Modeling of Tekeze Hydropower Reservoir operation with HEC - ResSim** and here by recommend for acceptance by the Addis Ababa University in partial fulfillment of the requirements of the degree of Masters of Science in Hydropower Engineering.

Dr. Bayou Chane
(Supervisor)

Date

DECLARATION AND COPY RIGHT

I, Mebrahtom G/mariam Kebedew, declare that this is my own original work and that it has not been presented and will not be presented to any other University for similar or any degree award.

Signature________________________________

Date_________________________________

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April, 2012

Dedication

This work is dedicated to the memory of my mother Abeba Asgedem

ACKNOWELEDGEMENT

My deep appreciation goes to my advisor Dr. Bayou Chane of Addis Ababa University for his encouragement, advice, support and, his valuable guidance and lectures throughout the course of this study and, above all his unselfish contribution to this thesis. His trust and confidence makes me to work on my interest topic.

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Abstract

The main purpose of this study is to model the optimal operation of Tekeze hydropower reservoir for generation of energy and downstream water demand activities considering different scenarios on the power units by accurately determining the reservoir inflow using HEC-ResSim model. The main input data to the model; reservoir physical characteristics, operational characteristics, total monthly irrigation water requirement at downstream of the dam and the hydrological inputs to the reservoir (net evaporation, surface inflow to the reservoirs) are collected and configured. Tekeze dam is located about 80 km west of Mekelle city at coordinates 13° 21' North and 38° 45' East.

To model Tekeze hydropower plant, simulation is performed under three scenarios: (i) the four Francis turbines units are operational, (ii) only three units are operational and (iii) only two units are operational. For each simulation three alternatives are defined on the gate arrangement of the low level outlets to obtain the best alternative that can generate maximum energy. Taking the best alternative, the simulation give for scenario one an average energy of 3669.8MWh and a maximum energy of 7200MWh, for scenario two an average of 3770.7MWh and a maximum energy of 5532.1MWh and for scenario three an average of 3278.1MWh and a maximum of 3641.2MWh. The reservoir level will be almost full in second and third scenario while in the first scenario reservoir level will be below the minimum operating level in the dry season. However, a unique reservoir operation rule curve and power guide curve as operated with the proposed model is developed in this study.

Due to the regulation of flow in Tekeze dam, 70.5% in scenario one, 75.5% in scenario two and 81.3% in scenario three of flood occurred in the rainy season is retained by the construction of the dam. Therefore, there is a smooth release throughout the year. Hence irrigation development is possible in the lowland areas of Tekeze which has a total of 42965 hectares net irrigable area. Accordingly the minimum monthly power plant release 58.0m^3/s, 98.1m^3/s and100.6m^3/s when all the four units, only three units and only two units are operational respectively is greater than the monthly peak irrigation demand (45.5m^3/s). Therefore irrigation can be developed without affecting power generation to shorten the payback period of the dam and to increase the national economy.

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List of Acronyms

GIS	Geographic information system
HEC	Hydraulic engineering center
HEC-ResSim	Hydraulic engineering center reservoir simulation
HEC-DSS	Hydraulic engineering center data storage service
DEM	Digital elevation Model
EEPCO	Ethiopian electric Power Corporation
ETO	Potential Evapo - transpiration
FSL	Full supply level
MoWE	Ministry of water resource and energy
MOL	Minimum operating Level
m.a.s.l	meter above sea level
Mm^3	million cubic meters
MW	Mega watt
MWh	Mega watt hour
NMA	National meteorological Agency
RN	Reservoir network
SC	Scenario
Alt	Alternative
AVG	Average
CMS	Cubic meter per second
GMT	Greenwich Mean Time
GUI	Graphical user interface
GWH/Y	Giga Watt Hours per year
ICS	Inter Connected Systems
PPT	Precipitation
SCS	Self Contained Systems
USBR	United States Bureau of Reclamation
VOL	Volume
WAPCOS	Water and Power Consultancy Services
NEDCO	Netherlands Engineering Consultant

1 INTRODUCTION

1.1 Back ground

Reservoir operation is a complex problem that involves many decision variables, multiple objectives as well as considerable risk and uncertainty (Oliveira and Loucks, 1997). In addition, the conflicting objectives lead to significant challenges for operators when making operational decisions. Traditionally, reservoir operation is based on heuristic procedures, embracing rule curves and subjective judgments by the operator. However, Water management planning for reservoir systems normally ends with an optimization of reservoir operation to satisfy the benefit of different water users or objectives.

Reservoir operation provides general operation strategies for reservoir releases according to the current reservoir level, hydrological conditions, water demands and the time of the year. Established rule curves, however, do not allow modification and hence simulation or optimization of the operations in response to changes in the prevailing conditions is necessary. Therefore, it would be valuable to establish an analytic and more systematic approach to reservoir operation for single or multi-purposes, based not only on traditional probabilistic or stochastic analysis, but also on the information and prediction of extreme hydrologic events and advanced computational technology in order to increase the reservoir's efficiency for balancing the demands from different users and there is an increasing awareness of the need to operate the reservoir systems to optimize the benefits from flood protection, irrigation, hydropower development and dawn stream requirement.

Applying simulation or optimization techniques for reservoir operation is not a new idea. Various techniques have been applied in an attempt to improve the efficiency of reservoir operation for different purposes. These techniques include simulation technique (E.g., Using HEC-ResSim Software simulation technique), WEP (Water Evaluation and Planning Model), Linear Programming (LP); Nonlinear Programming (NLP); Dynamic Programming (DP). In reservoir operation, LP is well known as the most favored optimization technique with many advantages over the other. It is easy to understand and does not require any initial solution. Even though, optimization techniques are very important, now a day's simulations of reservoir are becoming more essential.

Simulation model helps as to answer what if questions regarding the performance of alternative operational strategies. They can accurately represent system operations and are useful for operational analysis in examining long-term reliability of proposed operating strategies. They are ill-suited, however, to prescribing the best or optimum strategies when flexibility exists in coordinated system operations. Prescriptive optimization models offer an expanded capability to systematically select optimal solutions, or families of solutions, under agreed upon objectives and constraints. (Journal of Water resources planning and management © Asce/March, 2004)

The proper management of the hydropower scheme will require the establishment of reservoir operating rules. The purpose of such rules is to facilitate the medium-term planning of hydropower production in the light of changing hydrological circumstances, From day to day, week to week and month to month, the operators are faced with the problem of deciding how much power to produce. The general objective will be the reliable production of firm energy. However, the operators need a set of rules to assist them in deciding whether or not to generate secondary energy and if so how much. The opportunity for the secondary energy generation occurs when reservoir levels are high and rising due to high river inflows. The opposite problem occurs when the reservoir level is low and falling due to low river flow. Under these conditions the problem is to determine how long the generation of firm energy can be maintained and when to introduce cut backs in energy production in such a way that optimal use is made of the available resource while minimizing the probability of complete failure.

Typical reservoir operating rules consist of charts in which reservoir storage is plotted against time of year. The storage is divided into a number of zones, the size of each of which may vary from month to month or in every time step. The number of zones is determined as a result of a study of the particular circumstances of a given reservoir. However, three or more zones may be expected. In this situation, the central zone which we call conservation storage will be concerned with normal operation. While storage remains within this zone firm energy is produced. If the storage should rise into the upper zone, then secondary energy may be produced without presenting any risk to the long-term production of firm energy. On the other hand, should storage fall into the lower zone it becomes necessary to introduce cut backs in energy production.

HEC-ResSim model which was most recently introduced by U.S. Army Corps of Engineers is an interesting tool for reservoir simulation either for single or multipurpose reservoir operation. Hence, HEC-ResSim model is proposed and applied for Tekeze hydropower reservoir operation. This model is used to simulate the operational analysis of the reservoir for hydropower, the possibility of dawn stream irrigation development, dawn stream flow requirement and quantify the amount of flood retained by the construction of the dam. Generally, this study attempts to develop optimal reservoir operation modeling based on maximizing power production, including downstream irrigation demand and other activities by developing operational scenarios at different alternatives.

1.2 Statement of the problem

Reservoir operation study is a complex process that must consider the inter-related hydrological, physical and operational parameters which directly or indirectly affect the water resource activities downstream of the reservoir. In general, there is no universal solution for reservoir operation problems. Hence, a small improvement in the operating rule can lead to large benefits or high efficiency**,** whereas, improper and insufficient reservoir operation fails to meet desired large benefit.

Most reservoir operations in our country lack clear policy that considers the benefit of all potential users of the reservoir water. Consequently, most reservoirs do not serve the expected purpose. Tekeze hydropower reservoir is one of such reservoirs which is not serving as it should. Therefore, a detailed modeling for optimal operation is studied here by creating different scenarios on the power plant units and also analyzing the effect of this operation on the downstream area.

Tekeze river basin is one of the large river basins in Ethiopia which is not well developed yet. At this time, except small micro dams near and around the main river, only Tekeze Hydropower is constructed on the main river. Tekeze reservoir is the source of water for the Tekeze power plant and the downstream activities at this time. The reservoir water is impounded by a concrete arch dam and its storage volume is controlled by low level outlet spillway embedded in the body of the dam. This outlet is controlled by 4 radial gates to operate the flood storage zone. However improper operation of this zone can lead to flooding of the downstream area.

Tekeze reservoir power-intake release considers only the power generation pattern of the Tekeze hydropower plant, which indeed depends on the load share given from the national power grid system.

The power plant release is simply released to downstream of the dam. However, according to the previous studies there is a large area which is suitable for agricultural development. Even though there is suitable area for irrigation there is no enough water which satisfies the irrigation demand in the downstream area since the construction of the dam. Even after the construction of the dam, a detail study between the release from the reservoir and demand for irrigation in the downstream area is not yet studied.

1.3 Objective of the study

The main objective of this study is to model Tekeze Hydropower reservoir for optimal operation to generate power considering downstream activities. To full fill the main objective the study considers the following specific objectives:

- To model reservoir operation of Tekeze hydropower based on number of functional power units taking different scenarios using HEC-ResSim model.
- To establish water release rules for different scenarios of the simulation
- To develop average reservoir pool level for each scenarios based on the simulation period
- To establish power guide curve for different scenarios
- To compare power plant release of each scenarios with the downstream irrigation demand in order to propose irrigation development in the downstream areas

1.4 Description of the Study area

1.4.1 Location

Tekeze River basin is situated in the northwest of Ethiopia between 11° 40' and 15° 12' N, and 36° 30' and 39° 50' E. Tekeze hydropower project particularly the dam is located at coordinates 13° 21' North and 38° 45' East, approximately 80 km west of Mekelle town. It is bordered by the Mereb River basin and by Eritrea in the north, by Atbara River plains in Sudan in the west, by Abay River basin in the south and by Danakil basin in the east. The basin has a total area of 86,510 km^2; a relatively small part of the basin (4,160 km^2) is situated in Eritrea. The basin of Tekeze in side Ethiopia has an average elevation of 1,850m.a.s.l and a catchments area of 59,306 km^2. The length of the Tekeze River from its source at springs near Lalibela down to Sudanese border is more than 600km (MoWR, 1998)

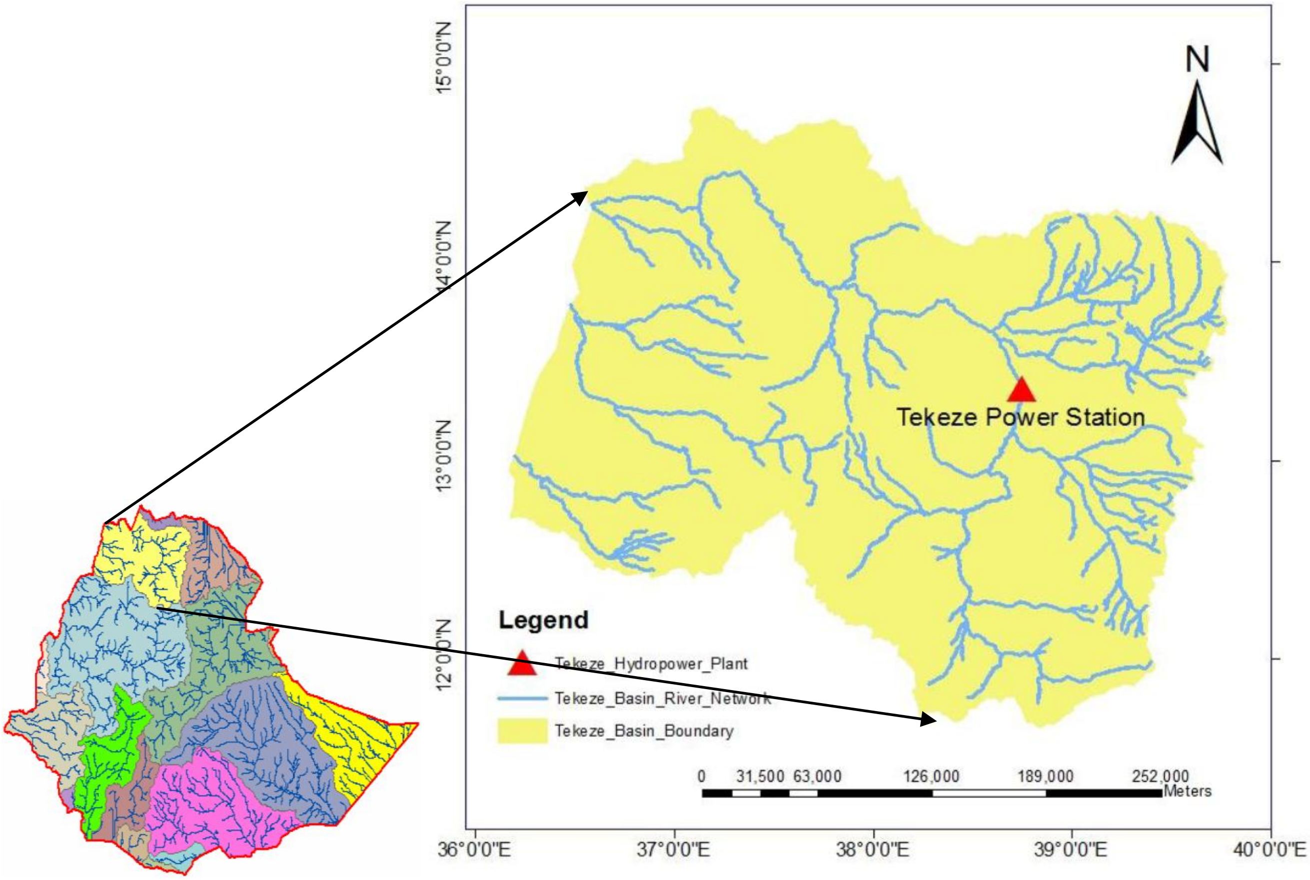


Figure 1: Location of Tekeze river basin

1.4.2 Topography

Tekeze River is a major tributary of the river Atbara that in turn flows into the Nile downstream of the confluence of the Blue and White Nile at Khartoum (MOWR and NEDECO, 1996). The low land part of the Tekeze river basin consists of about 1500km^2 areas, which is almost flat land. Observation of topographic map indicates that the above area has high irrigation potential in view of the water availability from Tekeze and its tributaries. About 70% of the basin lies in the high lands at an altitude of over 1500 m.a.s.l. The area of land above 2000 m.a.s.l covers about 40% of the total basin. The arable land in the highland part of the basin is found in the plateaus and valleys. In those areas there is a significant elevation difference between the major riverbed level and the agricultural fields. The cross sections are typical of all rivers in the high land where the riverbed is very deep compared to the nearby agricultural fields. At some potential dam sites, the riverbed is below 80m from the nearby field (COSAERT and WAPCOS, 2001).

1.4.3 Climate

The climate of the basin can be divided into two: the west region of the Simien Mountains with wet season and the east region with dry (small rainy) and wet (main rainy) seasons. The mean temperatures in the basin vary from 10^0C in the Simien Mountains, to 22^0C in the highlands and to 26^0C in the lowlands. Minimum and maximum temperature ranges are 3-21^0C and 19-43^0C respectively. Rainfall decreases from south to north from 1,200 to 600mm. The mean annual rainfall is 600mm in the lowlands and 1,300mm in the Simien Mountains. These climatic differences resulted in the classification of the basin into four agro-ecology zones namely Wurch, Dega, Woina Dega and Kolla (ENMSA, 1989).

1.4.4 Soil and Geology

The soils of the basin are Eutric Vertisols on the level lands; Eutric Leptosols, Eutric Vertisols, Eutric and Calcric Cambisols and Halpi Luvisols on the sloping lands; Eutric Leptosols on the steep lands; and Leptosols on composite landforms. Eutric Vertisols is difficult to cultivate. Euric Vertisols with soil depths of more than 50cm are dominant on the level lands while Leptisols are the most common soils on the sloping lands. Moderately deep soils are less than 5% (MoWR, 1995).

The dam site is located in the north of Ethiopia, on the Ethiopian plateau, and is about 150km to the west of the Ethiopian rift valley system. The basement of the plateau consists of Precambrian rocks, with various levels of metamorphism. These basement rocks composed mainly of limestones, slates, dolomites and schists, have been folded, stretched and foliated during the Pan African Orogeny (about 500-600 million years ago). Mesozoic sediments then deposited on the Precambrian rocks, before the uplift of the Afro-arabian dome led to out pouring of flood lavas, known as the Trap series. Following the volcanic activity, during the Oligocene period started the rifting phase which is still active.

The rocks in the dam site area are from the upper member of the Precambrian basement composed of lime stones and slates that have been subject to severe tectonic deformation. The dam site itself consists of a steep-sided gorge approximately 350 m deep extending for a distance of some 1.5 km and composed of sub-vertical thinly bedded limes tones. The total thickness of the anticlinal stratigraphic column observed within the gorge exceeds 600 m. The dam axis is located just upstream from the heart of the anticline.

The rock quality of the massive to laminated lime stones forming the foundation of the dam can be stated as good, in terms of shear strength and elastic moduli. In addition, no significant and penetrative weathering has been observed so far. The foundations are expected to be adequately strong to support a high arch dam and underground excavations for the waterways and the powerhouse.

Owing to the nature of the rocks constituting the future reservoir (slates and marls) and to the deep seating of the river below the plateau, it is considered that the water tightness of the reservoir is effective and that the potential leakages have to be controlled in the close vicinity of the dam (MOWR and NEDECO, 1996).

1.4.5 Reservoir area

Tekeze reservoir is one of the biggest man made body of water in Ethiopia, with a total water storage capacity of 9,230 Million cubic meters. Lying on the eastern side of the Simen Mountains range, the reservoir will be almost 70km long at full supply level, with two main branches reaching almost to Sekota in the east. It has a catchment area of over 30,000 square kilometers, with a long term average annual inflow of 3,750 Mm^3. At this rate of inflow, the reservoir would take almost three years to fill completely. However the average annual inflow recorded during the years 2008 and 2009 was abnormally low, so the reservoir was only 52% full up to the end of the 2009 wet season.

Figure 2: Reservoir area of Tekeze Dam (image from Google Earth)

Silent features of Tekeze Hydropower from EEPCO

Hydrology and Reservoir	
Total storage	9.3 Bm^3
Maximum retention level	1140 m.a.s.l
Minimum operation level	1096 m.a.s.l
Surface area at MRL	147 km^2
Live Storage	5.3 B m^3
Dead Storage	4.0 B m^3
Catchment area	30,000 km^2
Annual inflow	3.75B m^3
Sedimentation	30 M m^3/year
Arch dam Features	
Height	188
Crest length	420
Crest elevation	1145
Thickness at base of crown cantilever	27
Thickness at cret	5.6
Power Plant features	
Powerhouse type	Under ground
Turbine number and type	4 Francis
Total installed capacity	300MW
Maximum net head	162.8m
Minimum net head	120m
Maximum discharge	220m3/s

Although the catchment area is highly susceptible to erosion, this sediment load will largely be suspended and deposited at far end of the reservoir where most of the tributaries are located and where flood velocity approaches zero, so will not have any significant effect on the reservoir live storage volume for a great many years to come (from feasibility study of Tekeze hydropower).

1.4.6 Land use and land cover

The land use and land cover of the basin includes 27% of cultivated land, 35.1% of shrub land, 0.3% of wooded grassland, and 32.5% of bushy/open wood land; shrub by grass land and sparsely vegetated shrub land/exposed rock/soil. Most of the climax vegetation of the basin has disappeared and only little of the original vegetation is evident while only little of the lowland woodlands and bush lands in the western and northern parts of the basin are nearer to climax. However, the Afro-alpine and sub-afro-alpine heath vegetation lies above 3700 to 3900 m.a.s.l around Simien Mountains.

Most of the climax vegetation has been disappeared and only little of the original vegetation is evident. It is only the lowland woodlands and bush lands in the western and northern parts of the basin, which are nearer to the natural vegetation with a local use is often left on arable lands. Species of Ficus, Croton, Macrostachys, Acacia albida, balasites aegiptiaca and Zizyphs spina christis are among the dominant tree species retained in the farmlands with average density being 150 trees per kilometer square. This vegetation is mainly found in elevations below 1000 m.a.s.l. The vegetation cover accounts for 10,52617 ha out of which about 77% are woodlands, 10% is bush lands and 13% is wooded grassland. Afro-alpine and Sub-Afro-alpine heath vegetation is also found above 3,700 to 3,900 m.a.s.l around Semen Mountains (MoWR, 1995).

1.5 Organization of the Thesis

The thesis has organized to have six chapters. General overviews of each chapter are discussed as follows.

Chapter 1 contains introduction, problem statement and objectives of the study, description of the study area and organization of the thesis.

Chapter 2 contains literature review on previous studies that are made in this area, hydropower potential and the states of hydropower development in Ethiopia, reservoir operation theories, applications and problems, and the irrigation potential in Tekeze basin downstream of Tekeze reservoir. It represents different simulation and optimization models for reservoir operation. HEC -ResSim model which is applied in this research work is presented in greater detail in this chapter.

Chapter 3 contains methodology and data configuration for the model. All the necessary data are identified, their availability checked and they are organized for t further analysis. Thus, physical and operational data, open water evaporation from the reservoirs surface and inflow to the reservoir are analyzed. Reservoir simulations considering various alternatives are given in Chapter 4.

Chapter 5 contains results and discussions for each of the three scenarios

Chapter 6 contains conclusion and recommendations.

Chapter 7 contains references and appendices.

2 LITRATURE REVIEW

2.1 Previous studies in Tekeze basin

The river basin is not yet well developed however preliminary water resource assessments are carried before the construction of Tekeze hydropower project.

2.1.1 Preliminary Water Resources Development Master Plan for Ethiopia

The Ethiopian Valleys Development Studies Authority commissioned Water and Power Consultancy Services (India) Limited (WAPCOS) to undertake the Preliminary Water Resources Development Master Plan for Ethiopia. WAPCOS submitted their report in 10 volumes in June 1990. The Master Plan covered all aspects of water resource development, including domestic, agricultural and industrial use, hydropower, navigation, flood control, environmental aspects and fisheries in the whole of Ethiopia by dividing for the purpose of the study into 14 basins. The main objects of the study were to:

- quantify the available water resources
- propose future allocation of water resources
- identify and rank water resource development schemes

According to this Master Plan development study the following forecast were done for the future demand of electrical energy for the whole country:

Table 1: Energy forecast according to WAPCOS

Year	Energy demand (1000Gwh/year)
1990	5.5
2000	13.4
2010	35
2020	53.4
2030	72.7
2040	93.7

Accordingly to this forecast, WAPCOS identified ten potential hydropower sites on the Tekeze river with ‘technical potential' energy of 5588 Gwh/year, as follows:-

Table 2: Potential hydropower sites in Tekeze basin as studied by WAPCOS

Dam site	Flow (m³/s)	Head (m)	Power(MW)	Energy (Gwh)
TK1	44	100	43.1	264.3
TK2	67.3	100	65.9	404.2
TK3	89	100	87.2	534.8
TK4	96.8	100	94.9	581.7
TK5	101.3	100	99.3	608.9
TK6	114.8	100	112.5	689.5
TK7	130.8	90	115.4	707.9
TK8	154.2	90	136.1	834.4
TK9	167	75	122.7	752.4
TK10	175	20	34.3	210.3

2.1.2 Tekeze River Basin Development Master Plan Study

The Water Resources Development Authority commissioned NEDECO to carry out an integrated development master plan for the Tekeze river basin, the reconnaissance phase report of which was submitted in October 1995. The Master Plan is intended to encompass all development sectors: agriculture, livestock and fisheries, utilities including hydropower and water supply, transport, tourism and industry. To accomplish this wide range development, an overview was to be taken on the natural resources, both physical and human of the basin, the prevailing environmental and socio-economic conditions. In this report water resources of the basin are quantified, quality of the data is assessed and recommendations made for further study activities to improve the reliability of the data.

According to this study river Tekeze is yet completely undeveloped. In addition to this, hydropower potential of the basin is quite large, the Rivers are quite steep and some have deep gorges, which makes ideal dam construction sites easer. However, the drawbacks are; steep drops and high flows for the short rainy season and the presence of high variability over years. This study estimates the potential for irrigation to be 450,000 ha for small scale and 207,781 ha for large scale in the low land part of the basin. Such irrigation scheme would get its water from reservoir dams to be built for hydropower generation after the study.

The major development potentials of the basin include: -

- Presence of deep gorges and steep slopes for hydropower development,
- Large-scale irrigation potentials,
- The river channels have the potential for fish production,
- Farm forestry practices is currently at its pace in the basin,
- Good potential in the lowlands to grow incense and gum trees and
- Closure of degraded lands is welcomed thus indicating the knowledge of the resource base.

The major limitations or constraints for development of the basin are:

- Absence of steep drops and high flow for short period associated with rain
- annual variability of river flows
- Insufficient quantity and poor quality of feed supply
- Infectious diseases and parasites
- Shortage of skilled manpower
- Undeveloped selection and breeding practices
- Lack of pricing and marketing policies
- Lack of information on livestock productivity and breed characteristics ,diseases and feed supply
- Low level of technology employed in tapping, collecting, sorting and grading activities
- Encroachment of forest areas by the local population for agricultural and construction purposes, and
- Weakness of government organizations at local level to organize forest protection and management.

2.2 Overview of Hydropower states in Ethiopia

Hydroelectric power is the cheapest source of power whenever the natural resources are readily available. Ethiopia has plenty of favorable sites where hydroelectric power can be economically generated. The exploitation and development of these untapped hydropower resources of the country need careful planning (short and long term), proper timing, coordinated efforts among all relevant government bodies, technical assistance, and most of all financial resources in order to transform the hydropower potentials into reality. The following table describes the major hydropower dams in Ethiopia which have a major influence in the national economy of the country.

Table 3: Major Hydropower dams in Ethiopia
(Source: MoWR)

Name	Installed capacity	Commissioning	Basin	Contractor	Financing	Cost
Fincha	134 MW	1973	Fincha (Blue Nile)			
Gilgel Gibe I	180 MW	2004	Gilgel Gibe River	Salini (bid)	World Bank	$331M
Tekeze	300 MW	2009	Tekeze (Atbara)	Sino-hydro Corporation (bid)	Chinese Government	$365M
Beles	460 MW	2010	Lake Tana (Blue Nile)	Salini (no bid)	Ethiopian Government	
Gilgel Gibe II	420 MW	2010	Omo River (no dam, fed by GGI)	Salini (no bid)	Italy and EIB	Euro 370M
Gilgel Gibe III	1,870 MW	2012-13	Omo River	Salini (no bid)	Italy	Euro 1.55 billion
Fincha Amerti Nesse (FAN)	100 MW	planned	Fincha (Blue Nile)	China Gezhouba Group Co. (CGGC)	Exim Bank of China	$276M
Halele Worabese	440 MW	2014	Omo River	Sino-hydro Corporation	Fair-Fund?	Euro 470M

Gilgel Gibe IV	2,000 MW	2014	tributary of the Omo River	Sino-hydro Corporation	Chinese	$1.9 billion
Chemoga Yeda	278 MW	2013	Tributary of the Blue Nile, near Debre Markos	Sino-hydro Corporation	Chinese	$555M
Genale Dawa III	256 MW	awarded in 2009	between Oromo and Somali state	Chinese CGGC	Chinese	$408M
Millennium Dam	5,250 MW	2014	Blue Nile River	Salini	Government	Euro 4.8 billion

2.3 Reservoir operation

Reservoir operation is the technique used to allocate water stored in the reservoir among different upstream and downstream users. This is an important element in water resources planning and management which consists of several control variables that defines the operation strategies for guiding a sequence of releases to meet a large number of demands from stakeholders with different objectives, such as: hydropower generation, irrigation demand, and flood control, environmental releases for downstream ecosystem and allocation of water to different users. A major difficulty in the operation of reservoirs is the often conflicting and unequal objectives. Therefore, it is necessary to optimize reservoir operation in determining balanced solutions between the conflicting objectives.

A reservoir operation policy is a sequence of release decisions in operational periods (such as a month), specified as a function of the state of the system. The state of the system in a period is generally defined by the reservoir storage at the beginning of a period and the inflow to the reservoir during the period. Once the operating policy is known, the reservoir operation can be simulated in time with a given inflow sequence. A number of optimization algorithms have been developed for deriving reservoir operational policies. However, the most common policy implemented in practice is the so-called Standard operational policy, Optimal Operational Policy Using Linear Programming and Stationary Policy Using Dynamic Programming. (Vedula, S. and Mujumdar, P.P, 2006)

2.3.1 Standard Operational Policy

The standard operational policy aims to best meet the demand in each period based on the water availability in that period. It thus uses no foresight on what is likely to be the scenario during the future periods in a year. Let D and R represents demand and Release respectively in a period and K is capacity of the reservoir. Then the available water in any period is the sum of the storage, S, at the beginning of the period, and the inflow Q during the period. In other words, the release in any time period is equal to the availability, S+Q, or demand, D, whichever is less, as long as the availability does not exceeds the sum of the demand and the capacity. Once the availability exceeds the sum of the demand and the capacity, the release is equal to demand plus excess available over the capacity. It is to be noted that the releases made as per the standard operation policy are not necessarily optimum as no optimization criterion is used in the release decisions. For highly stressed system (system in which water availability is less than the demand in most periods), the standard operation policy performs poorly in terms of distributing the deficits across the periods in a year. With evaporation loss E included, the standard operating policy may be expressed as

$$R_t = D_t \text{ if } S_t + Q_t - E_t \geq D_t \ldots\ldots (2.1)$$
$$= St + Qt - Et, \text{ otherwise}$$

$$O_t = (S_t + Q_t - E_t - D_t) - K \text{ if positive} \ldots\ldots (2.2)$$
$$= 0 \text{ otherwise}$$

With R_t and O_t determined as above

$$S_{t+1} = S_t + Q_t - E_t - R_t - O_t \ldots\ldots (2.3)$$

Where: S_t = the storage at the beginning of the period t

Q_t = the inflow during the period t

D_t = the demand during the period t

E_t = the evaporation loss during the period t

R_t = the release during the period t, and

O_t = the spill (overflow) during the period t.

Note that $S_{t+1} = K$ if $O_t > 0$.

2.3.2 Optimal operating Policy using LP

One of the classical problems in water resources systems modeling is the derivation of an optimal operating policy for a reservoir to meet a long term objective. Modeling techniques are used but, depends on whether the reservoir inflows are treated deterministic or stochastic. In the case of deterministic, given a reservoir of known capacity K, and a sequence of inflow, the reservoir operation problem involves determining the sequence of release R_t, that optimizes an objective function. In general, the objective function may be a function of the storage volume and/ or the release.

Linear Programming formulation: Consider the simplest objective of meeting the demand to the best extent possible (the same objective as considered in the Standard operating Policy), such that the sum of the demands met over a year is maximum. This may be formulated as a Linear Programming problem as follows:

$$\text{Max } \sum_t R_t \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (2.4)$$

Subject to: $S_t = S_t + Q_t - R_t - E_t - O_t$ ………………………………………………….. (2.5)

$R_t \leq D_t$ ……………………………………………………………………….. (2.6)

$S_t \leq K$ ……………………………………………………………………….. (2.7)

$R_t \geq 0$ ……………………………………………………………………….. (2.8)

$S_t \geq 0$ ……………………………………………………………………….. (2.9)

$S_{T+1} = S_1$ ……………………………………………………………………….. (2.10)

Where: - T the last period in the year

The constraint (2.6) restricts the release during a period to the corresponding demand, while the objective function (2.4) maximizes the sum of the releases. Thus the model aims to make the release as close to the demand as possible over the year. To ensure that the overflows O_t assume a non zero value, the solution should be only when the storage at the end of the period is equal to the reservoir capacity K. Constraint (2.10) makes the end of the year storage equal to the beginning of the (next) year's storage, so that a steady state solution is achieved.

When the initial storage at the beginning of the first period is known, an additional constraint of the dam, $S_1 = S_0$ may be included, where S_0 is the known initial storage, in which case the sequence of releases obtained would be optimal only with respect to the particular initial storage. The end of the year storage,S_{T+1}, may be set equal to the known initial storage(2.10), if a steady state solution is desired, or may be left free (i.e. last constraint is excluded) if only the release sequence for one year, with known initial storage, S_0, is desired.

Stationary Policy using Dynamic Programming: A general reservoir operation problem is to derive a stationary policy for a repeated sequence of inflow (Q) every year, where t is a 'within year' period, i.e. less than one year. The stationary policy, which may be derived using DP, specifies the release as a function of the storage in a period. The objective is to derive an operating policy which results in the maximized annual net benefit in the long run (steady state).The computation starts at some distant year in the future in the last period, T. The choice of this year is such that the computations yield a steady state solution at the end. The following are the main requirements of operation in this model:

1. There are no boundary conditions. The initial (the beginning of the year) or the final (end of the year) storage values are not specified, and we seek the policy for all possible states.
2. The computation extends beyond the one year horizon, with the stage index n continuously increasing from n = 1, 2, …T, T=1, T=2,…, and the period index, t, keeping track of the position of the particular stage with in the year, t=T,T-1,…1
3. The computations are carried out until the solution reaches a steady state. The steady state is said to be reached at stage n, when the annual net benefit given by $[f_t^{n+T}(S_t) - f_t^n(S_t)]$ converges to a constant value, for all S_t, where $f_t^n(S_t)$ is the accumulated net benefit up to (and including) stage n. This implies that the net benefit over the next T periods from stage n is a constant for all possible initial storages at that stage.

The general recursive equation is written as:-

$$f_t^n(S_t) = \max[B_t(S_t, R_t) + f_{t+1}^{n-1}(S_t + Q_t - R_t)]$$

$$= 0 \le R_t \le S_t + Q_t$$

$$= S_t + Q_t - R_t \le K$$

Where: - B_t (S_t, R_t) = the objective function value in period t for specified storage, S_t at the beginning of the period t, and

R_t = the release during period t,

K = the known reservoir capacity and

Q_t = the inflow during period t.

2.4 Reservoir Operation Models

Numerous Researchers have developed computer models for the operation of reservoirs and river systems. Now-a-day the majority of the reservoirs planning and operations are undertaken using simulation and optimization models. Different types of reservoir operation techniques that have been applied to dam operation are presented in Sec.2.4.1.

2.4.1 Optimization Techniques

Although simulation model can accurately represent system operation and are useful in examining long term reliability of operating exists in coordinated system operation, instead of optimization model are often used to systematically the optimal solution under specified objective and constraints. In all mathematical optimization techniques the problem of reservoir operation is formulated as a problem the objective of which is to maximize or minimize a set of benefits over time, subjected to a set of constraints. The most widely used techniques are linear programming, dynamic programming, non-linear programming, optimal control theory, fuzzy logic and artificial neutral network. Simulation models for the operation of reservoirs have been applied for many years. Many models are customized for particular system. However, more recently, the trend has been to developed general simulation models that can be applied to any basin or reservoir system (Mc Cartnery, 2007).

2.5 Simulation Techniques

Simulation model still remain the primary tool for reservoir operation studies. It is an abstraction of reality and replicates the physical behavior of the system on a computer. The key characteristics of the system (i.e. the main system process and variability) are reproduced by mathematical or algebraic descriptions.

Simulation is different from the mathematical programming techniques, which finds an “Optimal solution” for the system operation meeting all system constraints while maximizing and minimizing some objective (Yeh, 1985). In contrast, simulation models provide the response of the system to specified input under a given condition or constraints. Hence, the simulation model enables the analysts to test the alternative sceneries (For instance, different operation rules) and examines the consistency before actually implementing them. The main drawback of simulation is that it requires prior specification of the system operation policy. In consequence, the only way to locate optimal policy is through subsequent trials. Many researchers have employed optimization method with in simulation models. These techniques do not result in an optimal solution but rather facilitate compliance with the predefined operating rules, (Everson and Moseley, 1971) some of the common and the most applicable reservoir operation models are:

HEC-5: - The program simulates the sequential period-by-period operation of a multiple-purpose reservoir system for inputted sequences of unregulated stream flows and reservoir evaporation rates. Multiple reservoirs can be located in essentially any stream tributary configuration. The program uses a variable time interval. For example, monthly or weekly data might be used during periods of normal or low flows in combination with daily or hourly data during flood events. The user specifies the operating rules in HEC-5 by inputting reservoir storage zones, diversion and minimum in stream flow targets, and allowable flood flows.

RRFM: - is the reservoir release-forecasting model that used to test different reservoir operation alternative, developed by the water resource development. The software can be used both for operational and planning mode. Under the deterministic operational mode the RRFM captures varies input variables, including inflow forecasts from the appropriate models. Through application of the flood control and downstream release rule, it provides forecasts of release rates and reservoir refill mechanism.

RESOP: - Reservoir Operation Study computer program developed by SCG. It assists in the planning, design, and evaluation of reservoir. This must meet water supply and demand requirements. RESOP used to compute monthly water balance for a reservoir system based on inflow, outflow and reservoir storage data. The RESOP output contains detailed information on each of the water balance aspect for each reservoirs and year of operation such as storage and deficit at the end of the month. Spill from the reservoir at the end of the month and the optimized demand computed by the program.

WEAP: - Water evaluation and Planning Model. It is a simulation model develops to evaluate planning of management issue associated with water resource development. WEP can be applied to both Municipal and agricultural systems and can address a wide range of issues including: Sector demand analysis, Water conservation, Water right and allocation priorities, stream flow simulations Reservoir operation and project cost benefit analysis.

MIKE BASIN: - MIKE BASIN runs within and is an extension to ArcView which is a geographical information system (GIS) software product available from ESRI (Environmental System Research Institute). MIKE BASIN integrates GIS capabilities with reservoir/river system modeling. Features also facilitate interconnected use of Microsoft Excel with MIKE BASIN. The model simulates multipurpose, multi-reservoir systems based on a network formulation of nodes and branches. Although the time step is user-selected, solutions are stationary for each time station withoutflowrouting dynamics. Thus, a monthly time step is common. Time series of inflows from catchments to each branch of the stream system are normally provided as input. However, the model can also be connected to watershed precipitation-runoff capabilities provided by the MIKE11.

2.5.1 HEC-ResSim (HEC-Reservoir Simulation model):

According to the user Manual, HEC-ResSim 3.0 is used to simulate reservoir operations including all characteristics of a reservoir and channel routing decision support systems. The criteria for reservoir release decisions, an operation set, are drawn from a set of discrete zones and rules. The zones divide the reservoir by elevation and contain a set of rules that describe the goals and constraints that should be followed when the reservoir pool elevation is within the zone. In this model reservoirs are a key focus point of the software. A reservoir is composed of a pool and a dam. HEC-ResSim makes the assumption that the pool is level and defined by an elevation-storage-area table. The dam element in the model of the reservoir forms an outlet hierarchy. The modeler can describe the different outlets of the reservoir in as much detail as is available or required. Both controlled and uncontrolled outlets are supports. An uncontrolled outlet, such as an overflow spillway, has no control structure to control flow. Controlled outlets can be used to represent any outlet capable of regulating flow, such as a gate or valve. ResSim also incorporates advanced outlet types - power plant and pump, with additional features to represent their special purposes. HEC-ResSim has incorporated over time, advanced features such as outlet prioritization, scripted state variables, and conditional logic.

HEC-ResSim is unique among reservoir simulation models because it attempts to reproduce the decision making process that human reservoir operators must use to set releases. The program represents the physical behavior of reservoir systems with a combination of hydraulic computations for flows through control structures, and hydrologic routing to represent the lag and attenuation of flows through segments of streams. It represents operating goals and constraints with an original system of rule-based logic that has been specifically developed to represent the decision-making process of reservoir operation (U.S. Army Corps of Engineers, 2010).

ResSim offers three separate sets of functions called Modules that provide access to specific types of data within a watershed. These modules are *Watershed Setup, Reservoir Network*, and *Simulation*. Each module has a unique purpose and an associated set of functions accessible through menus, toolbars, and schematic elements.

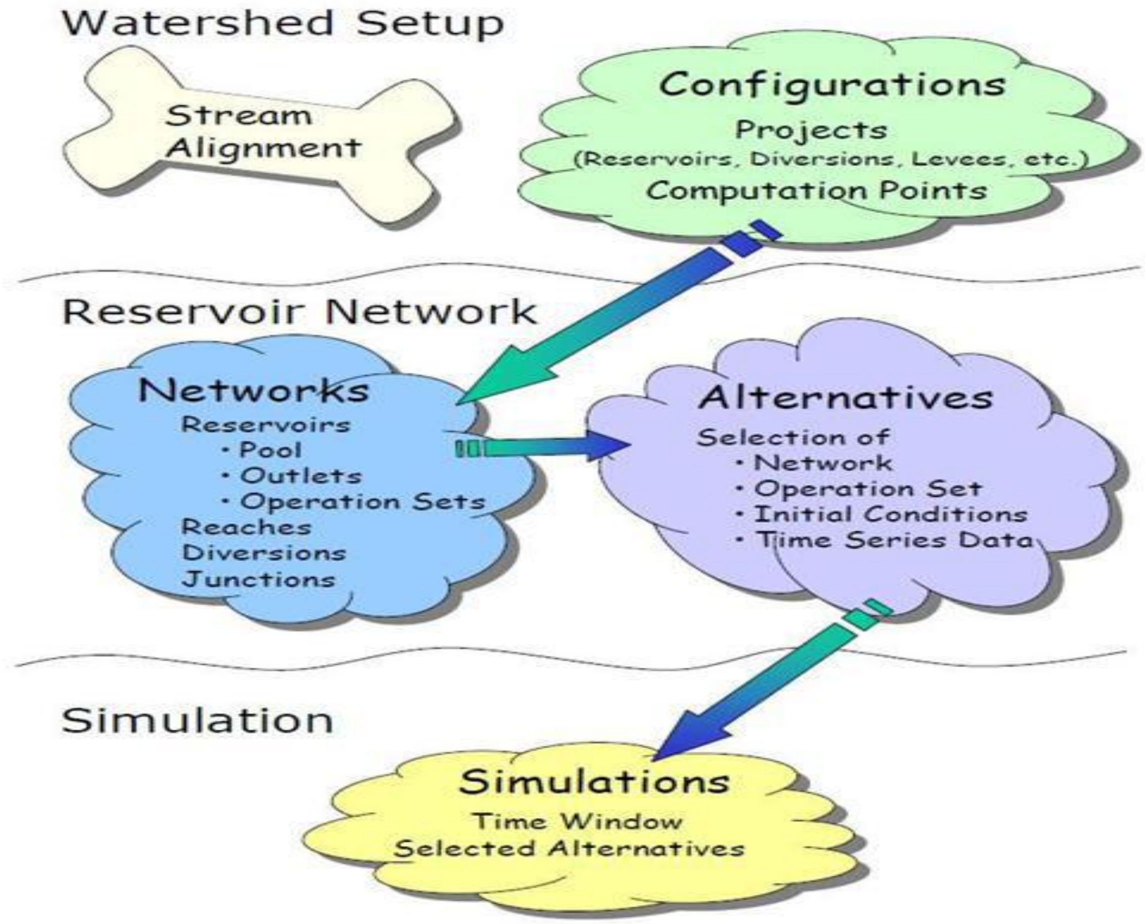


Figure 3: General model setup

Watershed Module Setup: - A watershed is associated with a geographic region for which multiple models and area coverage can be configured. A watershed may include all of the streams, projects (e.g., reservoirs, levees), gage locations, impact areas, time-series locations, hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework.

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

Simulation Module: - The purpose of the Simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the Simulation module is used to configure the simulation. The computations are performed and results are viewed within the Simulation module (HEC-ResSim user guide manual)

2.6 Irrigation Potential in Tekeze Basin

The importance of irrigation in the Tekeze basin has been recognized many generations back according to members of the indigenous irrigation schemes. The existing perennial streams in the Tekeze basin, is not dependable sources of irrigation water due to their limitations in their number and flow rate. Thus, harvesting of the seasonal surface runoff is the strategic option to promote irrigation in the Tekeze basin (UNDP/ECA/FAO, 1994). In accordance with this COSAERT and Commission for Sustainable Agriculture and Environment Rehabilitation in Tigray (COSAERAR), in Tigray and Amhara, respectively, have been established in 1996 with the mandate of study, design and construction of irrigation schemes.

Due to the fact that rain fall is concentrated in few months of the year only few streams are perennial, allowing stream diversion to be the bases for irrigation development. According to Tekeze master plan three potential irrigation sites are selected in the lower Tekeze basin humera, angereb and metama sites. From these sites humera irrigation site is dawn stream the reservoir and can take water from the hydropower dam. The irrigation potential at humera site has a gross potential area of 50547 hectares and 42965 hectares net irrigable area and its full development stage is 9 years according to the master plan study (Tekeze Master Plan Project, Main Report, 1995).

3 METHODOLOGY

3.1 General framework of the study

Framework is a skeleton of any work which shows clear steps of your work. In order to achieve the objectives of the study different type of data has been collected from respective organizations and master plan prepared for the study area. Data obtained from these sources are analyzed and configured for the model. After all data are configured, simulation is performed and results are discussed. Based on the simulation results and objectives of the study, different conclusions and recommendations are drawn. The following flow chart is designed to show all these steps clearly as shown in Fig.4 below.

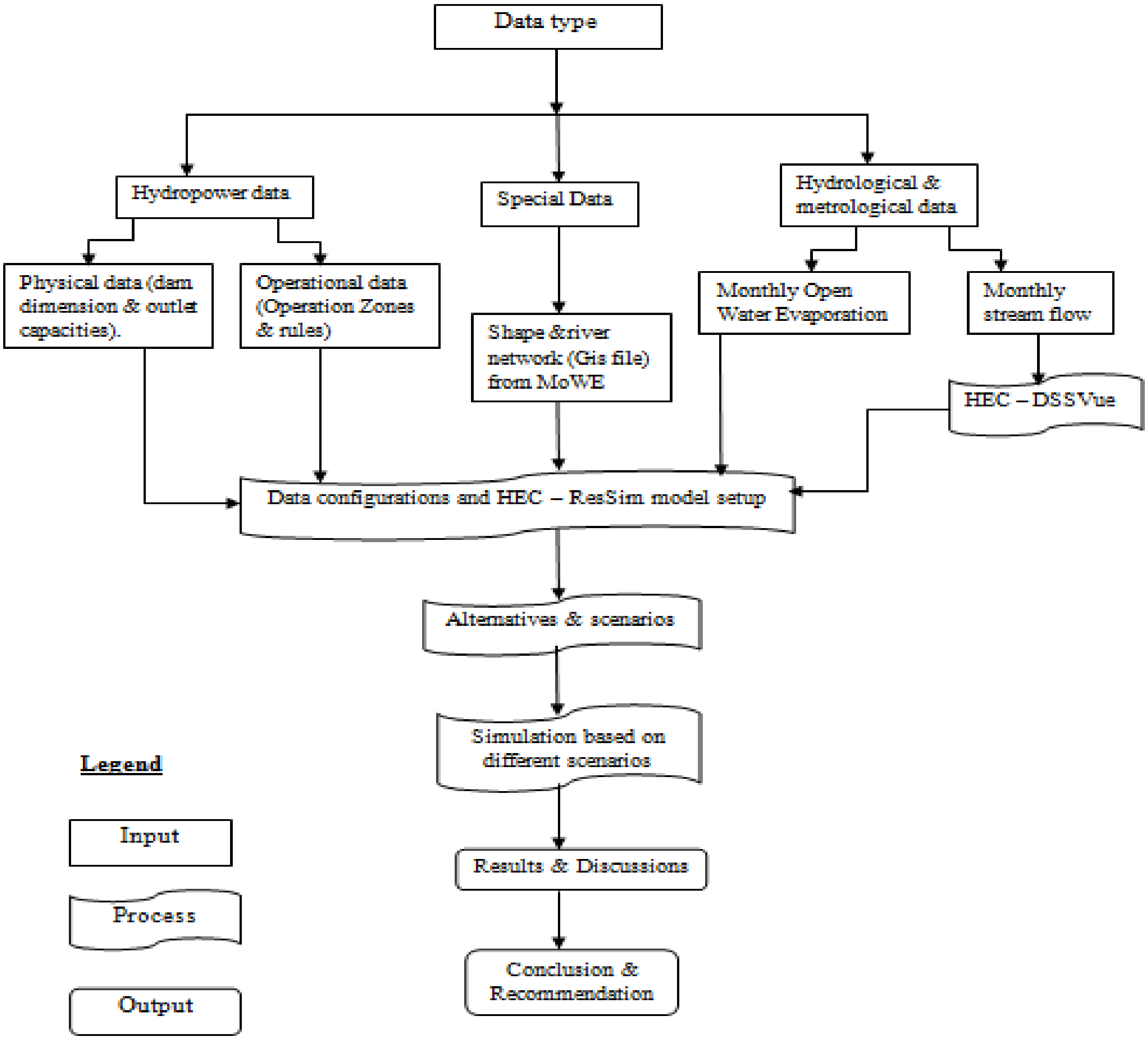


Figure 4: Flowchart of the study

3.2 HEC-ResSim model setup

In this study the Corps of Engineers software, HEC-ResSim model is used to perform the operational modeling or simulation analysis of Tekeze reservoir. HEC-ResSim is the reservoir simulation program developed by the Hydrologic Engineering Center of the Corps of Engineers available on line (USACE, HEC-ResSim, 2007, http://www.hec.usace.army.mil/software/hec-ressim/hecressim-hecressim.htm). HEC-ResSim is a graphical user interface (GUI) soft ware. Its hydropower simulation capabilities include analysis of run - of - river generation, peak power generation, pumped storage and system power operation. To simulate hydropower operation, the reservoir releases are determined to meet power production goals which may vary on a monthly, daily, or hourly basis. Additionally, the hydropower component takes into account the penstock capacity and losses, as well as leakage parameters.

The model allows the user to define alternatives and run simulations simultaneously to compare results. Schematic elements in HEC-ResSim allow the representation of watershed, reservoir network and simulation data visually in a geo-referenced context that interacts with associated data. In addition to that, HEC-ResSim is compatible with Arc-GIS shape files, which can be used as a background layer and facilitate the better representation of the physical system. Watershed boundaries, reservoirs, channel networks, diversions, etc. can be superimposed over the shape file.

HEC-ResSim program is divided into three modules which are the watershed setup, the reservoir network definition and the simulation scenario management respectively.

3.2.1 Watershed Setup Module

The purpose of this module is to provide a common framework for watershed creation and definition. A watershed is associated with a geographic region for which multiple models and layers of information (DEM, area coverage in Arc-GIS) can be configured. A watershed may include all of the streams, projects, e.g., reservoirs, levees, gage locations, impact areas, time series locations, and hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework.

In Tekeze water shed set up, the unit is set to SI unit and the time zone is set to international time zone of the area, GMT+ 3 Africa/ Addis Ababa. The physical arrangement of the streams net work is imported from Arc-View GIS file of the basin. After importing the stream network, stream alignment and, configuration are created. Project elements such as reservoir and computational points are placed in to the configuration, using their respective mouse tools provided in the water shed set up module of the software. The water shed setup is shown in Fig 5.

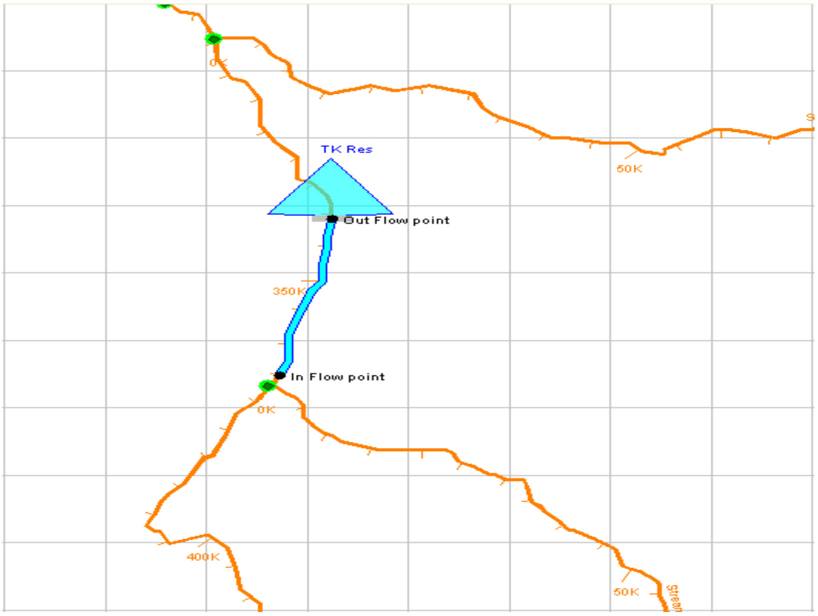


Figure 5: Water shed setup

3.2.2 Reservoir Network Module

The purpose of the Reservoir Network module is to isolate the development of the reservoir model from the output analysis. This module facilitates creation of the network schematic, description of the physical and operational elements of the reservoir model, and definition of the management alternatives to be analyzed. Reservoirs are further divided into multiple technical elements such as the pool, the dam, and one or more outlets. The criteria for reservoir release decisions are drawn from a set of discrete pool heights, power production levels and release rules. Reservoirs are connected to the river network as well as to diversions or junctions. After finalizing the connecting network schematic, physical and operational data for each network element are defined. Management alternatives are created to compare results using different model schematics, i.e. physical properties, operation sets, inflows, and/or initial conditions. Fig. 6 shows reservoir net work set up for Tekeze Hydropower including its setup parameters.

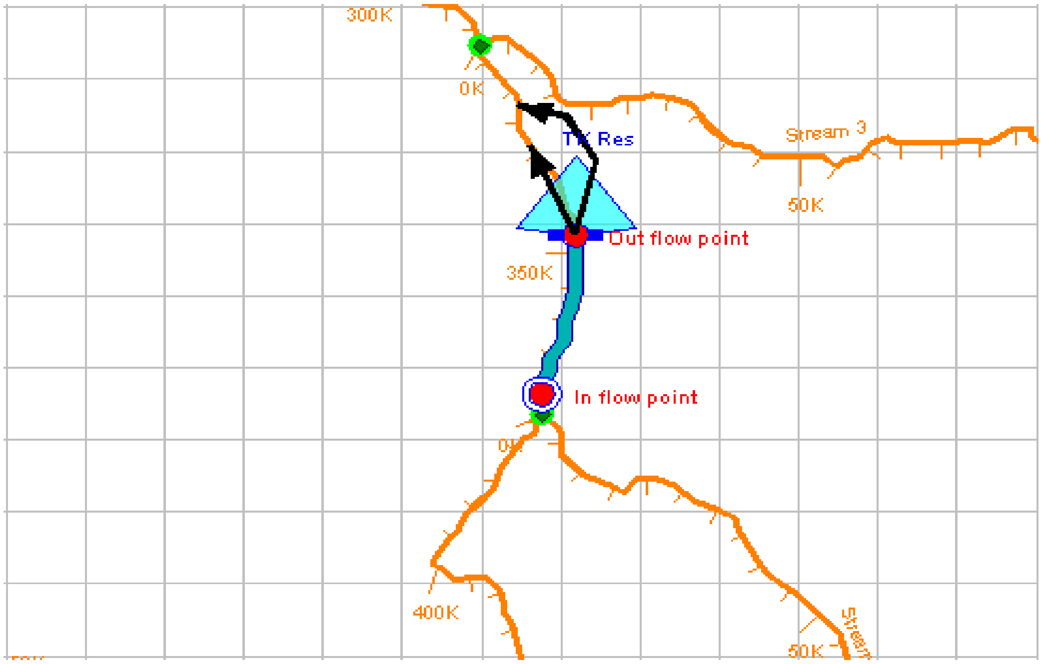


Figure 6: Reservoir net work setup

3.2.3 The Simulation Model

The purpose of the simulation module is to separate output analysis from the model development process. Once the reservoir modeling is completed and the alternatives have been defined, the simulation module is used to configure the simulation. Computations are performed and results are interpreted within the simulation module.

During running the simulation it is necessary to specify a simulation time window, a computation interval, and the alternatives to be analyzed. For the present case, the time widows given are starting, lock back, and end time of simulation. Then, ResSim creates a directory structure within the base folder of the watershed that represents the simulation. Within this simulation tree, there will be a copy of the watershed which includes only those files needed by the selected alternatives. A DSS file called simulation.dss also created in the simulation, which will ultimately contain all the DSS records that represent the input and output data for the selected alternatives. Additionally, elements can be edited and saved for subsequent simulations.

3.3 Hydrological Data Configuration

Historical stream flow records at the diversion point or inflows to a reservoir are the basic information required for hydropower plant development or operation studies. The proper time interval for the hydrological data depends on factors such as the type of plant and the characteristics of stream flows. Monthly average stream flows are often used for preliminary or even advanced studies if the stream flow does not change significantly from day to day. The degree of at-site and upstream regulation is also important in the selection of time intervals. Water losses due to evaporation from the reservoir and leakage through or around the dam and other appurtenant facilities should also be considered. In addition to water losses from the reservoir, water that is diverted for consumption or water that is reserved for operation of navigational locks or fish passage facilities should also be taken into account when estimating losses of the hydropower system.

Hydrology Department, the Ministry of Water and Energy (MoWE) operates and maintains all gauging stations in Ethiopia, and undertakes flow gauging at key sites. Flows required for this thesis are collected from different stations. But the scarcity of hydrological data for the region has been the main constraint in the estimation of the necessary hydrological parameters for this research. All the stations have no enough record, so that generation of daily stream flow data is difficult. Finally averages monthly inflow data of 30 years given in table 4 are taken from EEPCO. This inflow data was used to design Tekeze hydropower dam.

Table 4: Yearly average inflow data

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Inflow (m3/s)	6.6	4.2	6.9	9.4	17.3	47.7	495.9	799.2	321.9	66	22.1	12.9

Inflow data is one of the major inputs of HEC-ResSim operational modeling. However, this inflow data should be first configured in to HEC-DSS data storage system.

The Hydrologic Engineering Centre of the U.S. Army Corps of Engineers has developed the Hydrologic Engineering Centre Data Storage System (HEC-DSS). This software has been used for Tekeze reservoir inflow modeling study. It is a database system designed to efficiently store and retrieve scientific data that is typically sequential. HEC-DSS not only permits the plotting, tabulation and editing of data, but also the manipulation of stored data using a collection of mathematical functions. Apart from database management, it also provides a large number of mathematical functions which can be applied in order to modify and combine the stored time series data; such as: arithmetic function, general function, time conversion and hydrologic function. In this paper a 30 years monthly inflow data is created in the HEC-DSS system.

When converting time series data in to HEC-DSS format it is important that the time series should be continuous, after converting the time series data to this file format, it can be used in the simulation by setting the path to DSS-path for this inflow points to the reservoirs in the alternative editor.

3.4 Physical and Operational Data Configuration

The general data requirements for this model included the physical and operational characteristics of Tekeze Hydropower reservoir. The physical reservoir data is described through the use of the stage – area – volume curves, evaporation loss from the reservoir and the type and capacity of each outlet. The operational data includes, the zone or pool level definitions along with the rules governing the operations in each zone. Tekeze Hydropower reservoir has three major water management zones or pools. These are the inactive zone, the conservation zone and the flood control zone. The inactive pool is often referred to as dead storage since this is water that is below the elevation of the lowest outlet in the dam. The conservation zone holds water that is set aside for environmental release and hydropower production. The flood control zone is storage that is a set aside for the capture of inflow from precipitation events to manage potential downstream flooding. In addition to the above zones five pool levels are fixed at 1053m.a.s.l (inactive level), 1096m.a.s.l (minimum operating level), 1140m.a.s.l (conservation level), 1144m.a.s.l (flood control level) and 1145m.a.s.l (maximum flood level) to serve as a base line data for reservoir operation of this study.

(a). Reservoir Stage - Area – Volume Relation

The main reservoir physical data which are input for the pool include the reservoir surface area mainly used to compute the reservoir evaporation loss and the storage are used to estimate the stage at any time based on storage equation. The reservoir stage-area-storage data for Tekeze hydropower dam is shown in Table 5 and Fig. 7 and 8 (EEPCO, Feasibility report volume III, 1997).

Table 5: Capacity - Elevation- Area data for Tekeze Hydropower Reservoir

Elevation(m.a.s.l)	Area(km^2)	Volume(Mm^3)
975	0.39	1
1000	5.034	69
1010	8.074	134
1020	14.015	245
1030	21.561	423
1040	29.463	678
1050	39.601	1023
1060	50.551	1474
1070	61.798	2036
1080	72.56	2707
1090	81.934	3480
1100	92.851	4354
1110	106.922	5353
1120	122.42	6499
1130	139.702	7810
1140	156.876	9293
1150	176.126	10958

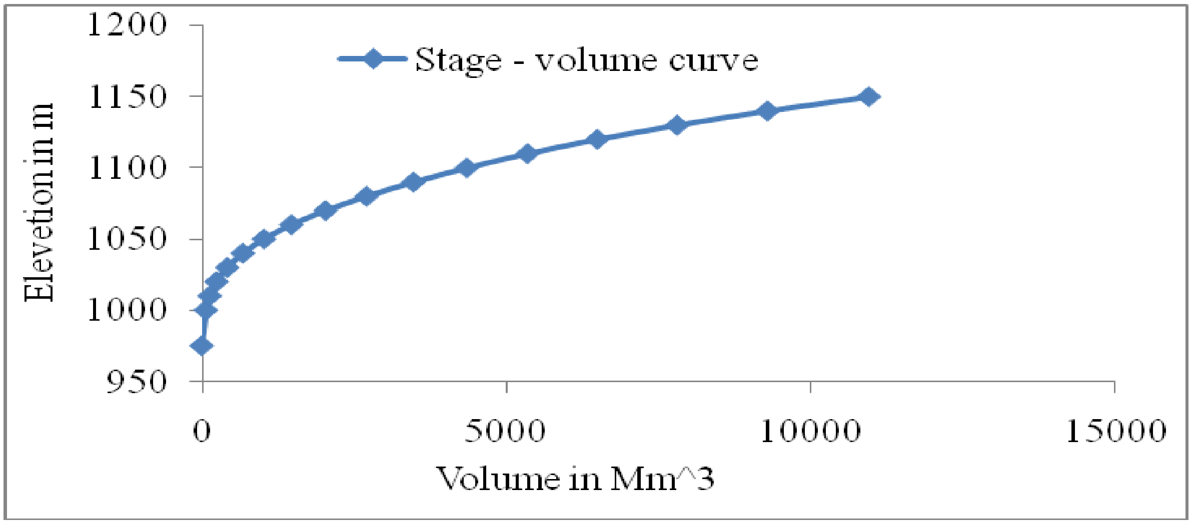


Figure 7 : Stage – Volume curve

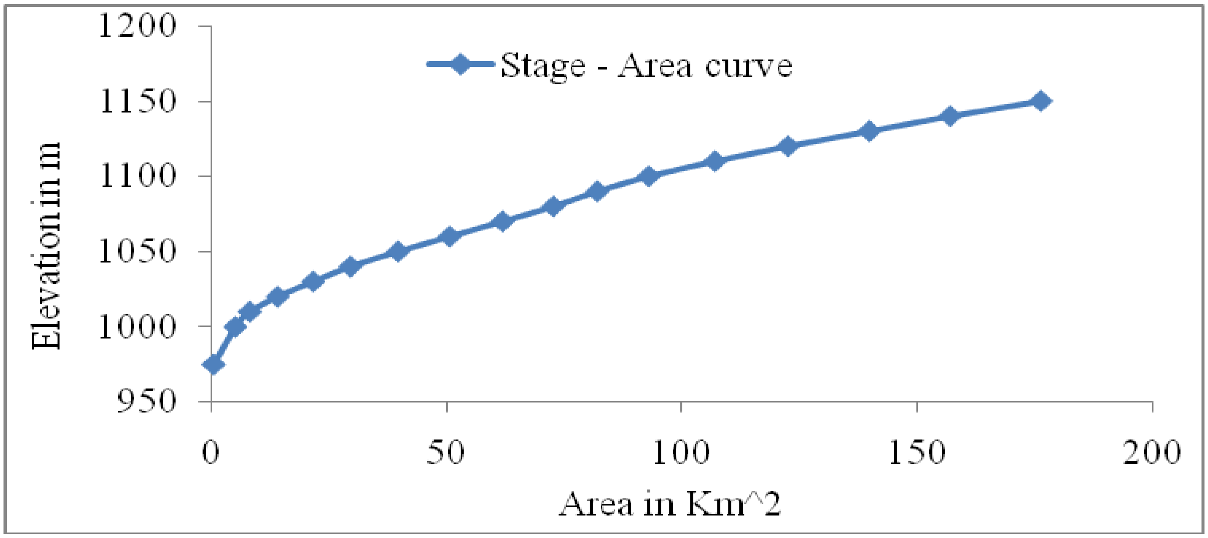


Figure 8 : Stage – Area curve

(b). Reservoir evaporation loss

The loss of water by evaporation from the reservoir must be considered for two main aspects. The first, evaporation from an open water surface Eo, which is the direct transfer of water from lakes, reservoirs and rivers to the atmosphere. This can be relatively easily assessed if the water body has known capacity and does not leak. The second form of evaporation loss occurs due to transpiration (evapo – transpiration) from vegetation, ETo. Evaporation can be estimated using different methods such as; Water balance, Energy balance, Aerodynamic, Penman and Pan Evaporation methods being the most common (Ven Te Chow, 1988). Each method here needs data like: temperature (maximum, minimum and average), relative humidity, sun shine hour and wind speed. However there is limited data of these input parameters. Fortunately, mean monthly evaporation data for the reservoir was obtained from feasibility study of Tekeze medium hydropower document and is shown in Fig. 9 below.

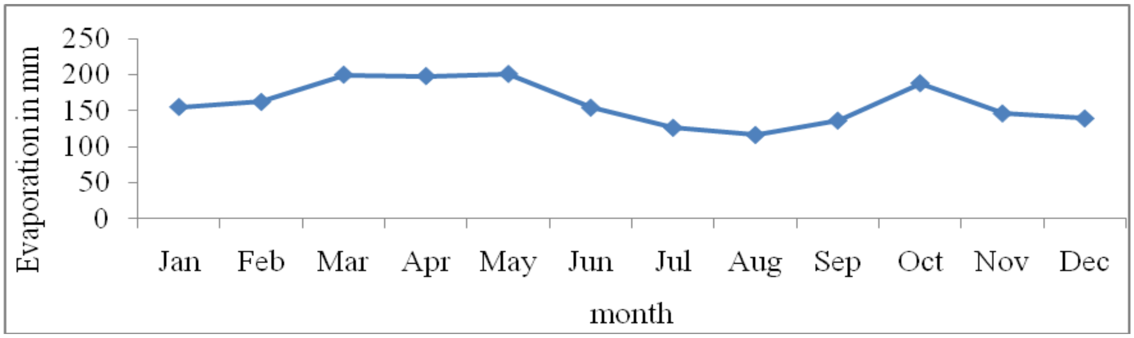


Figure 9 **:** Mean monthly evaporation data of Tekeze reservoir

(c). Dam: The Tekeze hydropower dam performs two major functions. It creates the head and storage necessary to move the turbines, and the storage used to maintain the daily or seasonal flow release. It has a crest elevation of 1145m at maximum flood level and a crest length of 420m (EEPCO, Feasibility report volume II, December, 1997).

(d).Spillway: It consists of four low level gated outlets, located in the central part of the dam. The main function of the outlet is to evacuate the inflow during floods but they can also be used to empty a part of the reservoir in case of emergency for dam safety or to enable exceptional maintenance for the power and spillway intakes, which are located above the low level outlets. They have a total capacity of 4420 m3/s at maximum pool level (FSL) and discharge the water in to the river axis. Elevation versus maximum capacity relation for the main spillway of Tekeze dam for the various elevations above the spillway crest with 4 gates opening was adopted directly from EEPCO, Tekeze medium Hydropower design report.

The spillway operates as a free overflow spillway for low discharges and orifice flow for high discharges. Generally, the orifice flow condition sets in for heads over the crest that is in excess of about 1.7 D, where D is the height of the orifice opening. Under this condition, the discharge over the orifice spillway considering the gates fully open is computed by:

$$Q = Cd\, n\, A\sqrt{2g\left(Hd - \frac{D}{2}\right)}$$

Where: Cd - Coefficient of discharge

n - Number of spans A - Area of orifice opening

Hd - Design head D - Height of the orifice opening

The coefficient of discharge (Cd) varies from 0.70 – 0.83 (USBR, Design of Small Dams, 1984). Table 6 shows elevation – discharge data for the spillway rating curve (Fig. 10) with 4 gates opened.

Table 6: Elevation – discharge data

Reservoir Level(m.a.s.l)	Q(cms) 4 Gates open
1057	0
1065	1091.560
1075	1890.637
1085	2440.802
1096	2928.963
1110	3451.816
1120	3781.275
1130	4084.244
1140	4366.240
1145	4500.617

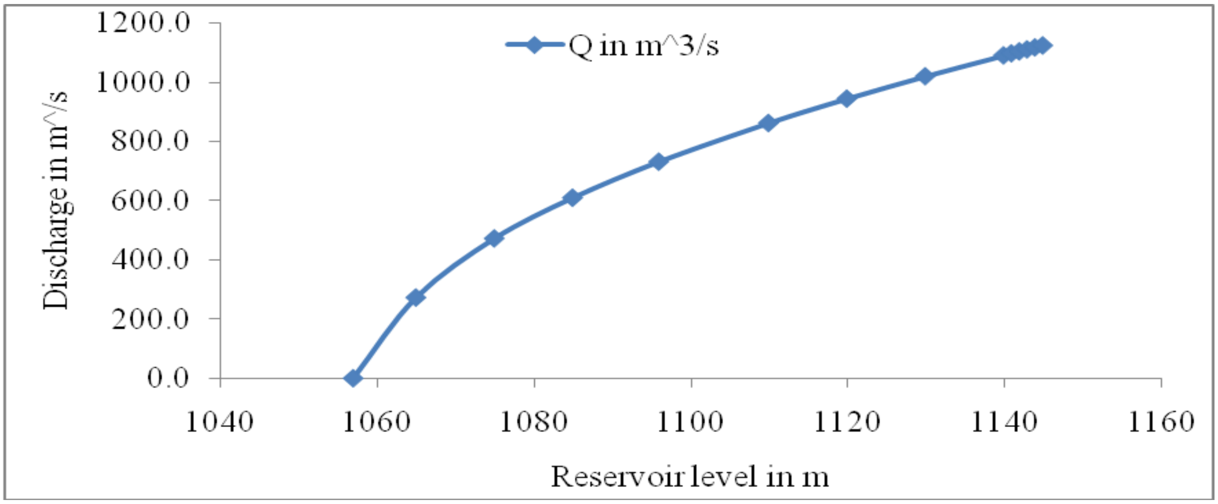


Figure 10: Spill way rating curve

(e).Intake: Intake structures direct water from the reservoir into the penstock or power conduit. Gates or valves are used to cut off the flow of water to permit emergency unit shutdown or turbine and penstock maintenance. Racks or screens prevent trash and debris from entering the turbine units. Where the powerhouse is integral with the dam, the intake is part of the dam structure. The powerhouse and intake are integral part of the dam.

The power intake structure conveys water from the Tekeze reservoir through the 7.25m diameter penstock, to one of the four `turbines in the powerhouse. The intake structure is positioned on the northern side of the reservoir. It is 70 m tall standing from (El. 1075.5m to 1145.0m). The water passes through a set of sixteen steel lined trash racks. Behind the wheel gate water passes immediately into a single concrete lined headrace tunnel which feeds water across a surge shaft manifold bifurcation to a set of four steel penstocks and four inlet valves.

(f).Bottom outlet: Bottom outlet works are required to lower the reservoir level in order to carry out repairs and also to release compensation flows during first filling and when the power plant is not operating. The function of drawing down the reservoir is ensured by the low level outlets whose main function is the flood spillage. In addition, a compensation outlet is provided in the dam and designed to regulate flows from 0 to 30m^3/s. The flow is controlled with an electric-actuator operated butterfly valve as a guard, and an energy dissipating sleeve type valve as a discharge regulator.

The compensation outlet provides minimum releases in the event of a plant shutdown or during maintenance of the intake structure when the reservoir level would be drawn down to elevation of 1078.8m.a.s.l. The compensation flow outlet is located below the low level outlet, with the intake on the right vertical wall of the spillway water passage. The intake comprises a 2m x 2m steel lined bell mouth opening with the centre line set at elevation of 1054m.a.s.l. This outlet has a capacity of 30m^3/s.

The bottom outlet is necessary to maintain environmental flow required for maintenance of d/s fauna and flora close to the intake area until the flow returns back to the stream and also they maintain the minimum flow.

3.5 Minimum Release for Downstream Water Requirements

According to EEPCO design report for Tekeze Hydropower project, a minimum flow for maintaining downstream river flow is provided to satisfy the environmental requirement for fauna and flora close to the intake area until the flow returns back to the stream at or above a minimum level. The criteria adopted for the minimum downstream flow in any given month is based upon the flow which is exceeded 95% of the time under natural conditions at the dam site for the month in question, known as the Q_{95} value. This is subject to the constraint that if the calculated Q_{95} for the month is greater than 60 Mm^3, the required compensation release is limited to 60 Mm^3. When turbine releases are inadequate to meet the prescribed flow, compensation releases must be made from the reservoir regardless of the level of storage (EEPCO, Feasibility report volume III, 1997).

3.5.1 Downstream Irrigation Water Requirement

A few streams are potential in Tekeze basin because rain fall is concentrated in same months of the year. These rivers allow stream diversion to be the bases for irrigation development. According to Tekeze master plan study, three potential irrigation sites are selected in the lower Tekeze basin where Humera, Angereb and Metama sites are found. Among these sites Humera irrigation site is downstream the reservoir and can take water from the hydropower dam.

The irrigation potential at Humera site has a gross potential irrigable area of 50,547 hectares and net irrigable area 42,965 hectares. The size of the potential has been calculated on the bases of data on mean annual regulated flow from the reservoir in the river. According to the master plan study its full development stage is 9 years. The overall irrigation efficiency is 60% this is a high value which attainable only with sophisticated management in the future; the estimated efficiency for present standards is at 50%.Monthly crop water requirement (CWR) of the area is given in the table below

Table 7: Monthly crop water requirement (CWR) for Humera potential irrigation area

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
CWR (l/s/ha)	0.8	1.06	0.96	0.9	0.9	0.7	0.3	0.4	0.78	0.9	0.71	0.6
CWR (m^3/s)	32.7	45.5	41.2	39.1	40.4	31.4	13.3	15.9	33.5	39.5	30.5	24.9

Maximum net irrigation water requirement is estimated to be 129mm/month based on the CWR of February; the peak month which needs high crop water requirement. This is translated in unit flows of 1.07l/s/he over 24hrs or 2.14l/s/he over 12hrs irrigation time taking 50% overall efficiency of the system (Master Plan study, 1995).

4 ALTERNATIVES AND RESERVOUR OPERATION SIMULATION

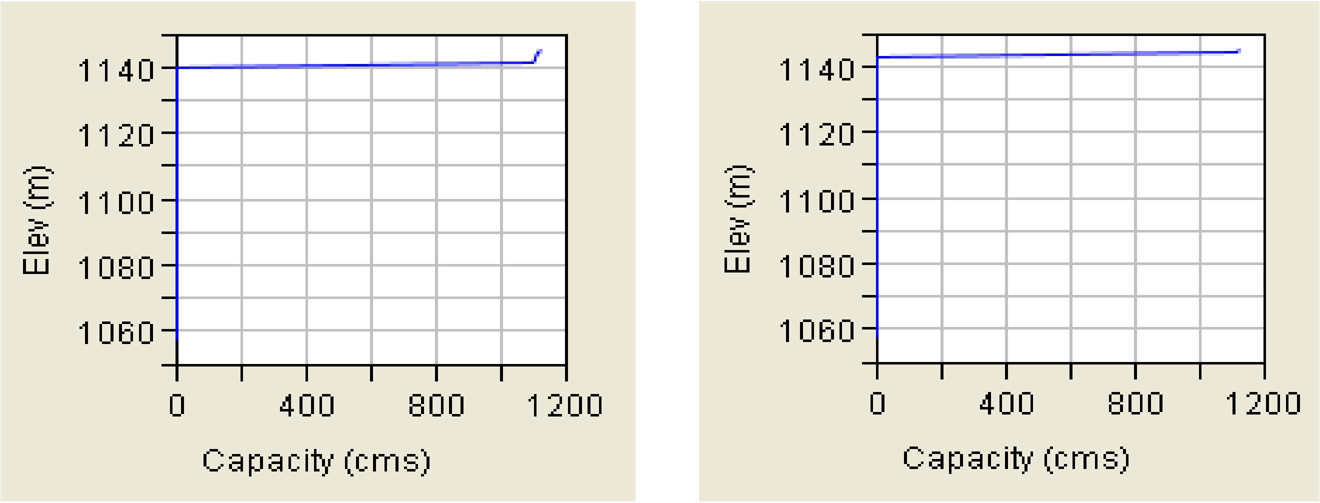
4.1 Alternatives

An alternative consists of a reservoir network (previously created from a configuration) and an operation set for the reservoir network, a definition of initial (lock back) condition and a mapping of all time-series records to identify local inflows. To develop an alternative in HEC–ResSim, an alternative editor that represents the combination of reservoir network is constructed, an active operation set for the reservoir in the network is selected, and the starting or look back conditions and inflow time – series data for the network as specified.

In this paper the simulation alternatives were performed by the arrangement of four low level outlet gates under operation so that we can observe elevation difference in the reservoir and also the downstream water release. These radial gates setting were arranged as:

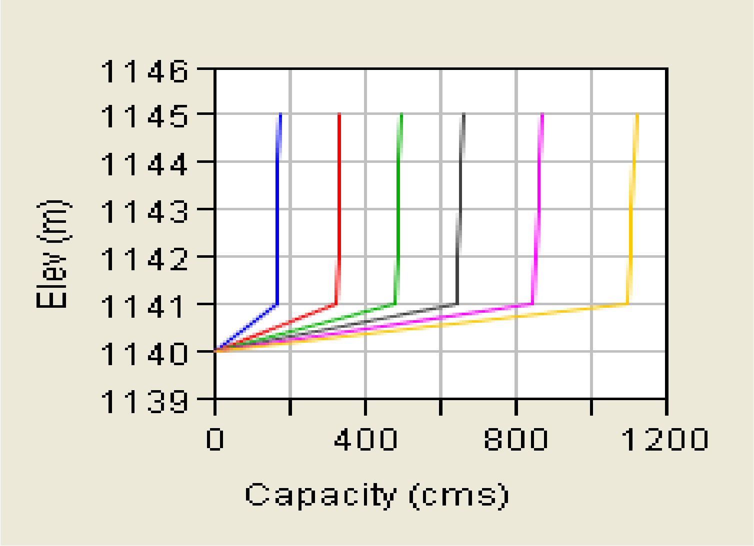
- Low level outlet gate at specific maximum capacity only opened at 1140m (Alt F)
- Low level outlet gate at specific maximum capacity only opened at 1144m (Alt C)
- Low level outlet gate at specific capacity at specific gate opening (partial gate opening) (Alt P)

Fig. 11 shows the gates setting arrangement.



a) Maximum gate opening at 1140m

b) Maximum gate opening at 1144m



c). Partial gate opening at specific gate capacity

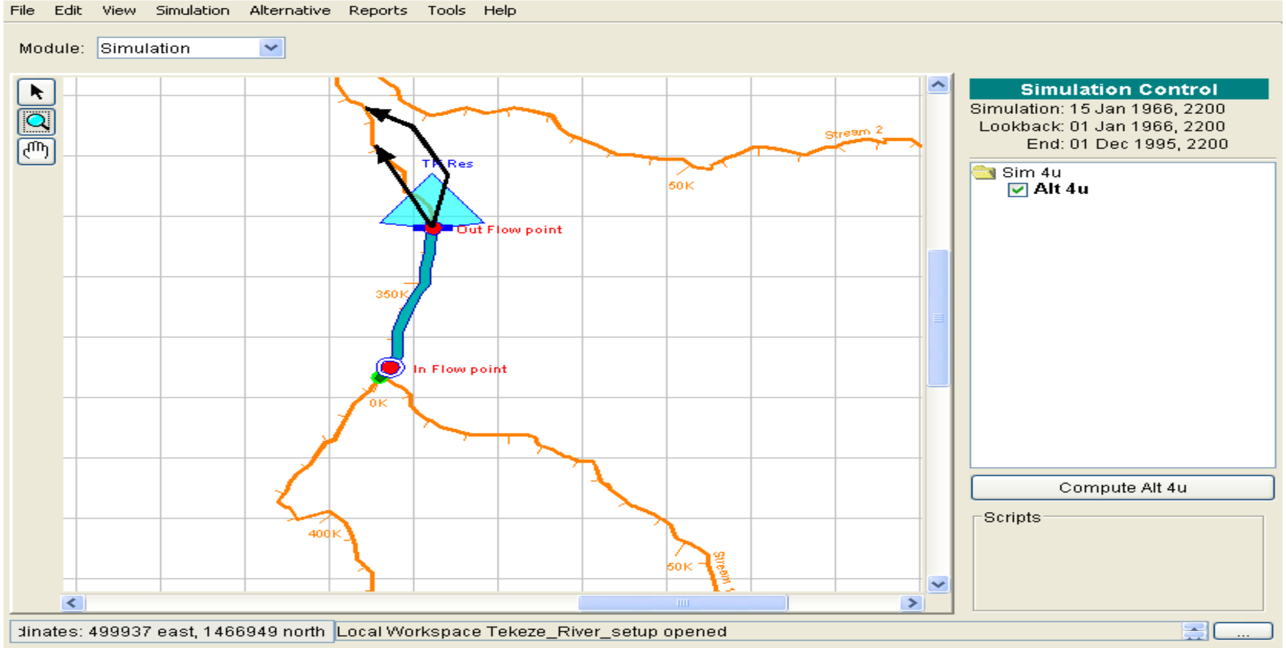
Figure 11: Low level outlet opening arrangements for different alternatives

4.2 Reservoir Operation Simulation

The purpose of the Simulation module is to separate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the simulation module is designed to facilitate the analysis phase of reservoir modeling used to configure the simulation **(**HEC-ResSim – User's Manual. Version 3.0, August 2007).

In this paper operation of Tekeze hydropower reservoir is performed under three scenarios (all the four power units or Francis turbines are operational, only three units are operational and finally only two units are operational). Simulation is performed for each alternative of the three scenarios and a successive trials or iteration steps are analyzed to configure the dynamic characteristics of the reservoir, and to determine the optimal solution which can generate maximum energy. Through each iteration step, the simulation method enables the behavior of the reservoir water level, the power generation output pattern and downstream water release rule. Each scenario is discussed under the three alternatives and simulation is performed by specifying simulation time.

Fig. 12 shows the reservoir simulation set up



Module: Simulation

Simulation: 15 Jan 1966, 2200
Lookback: 01 Jan 1966, 2200
End: 01 Dec 1995, 2200

dinates: 499937 east, 1466949 north
Local Workspace Tekeze_River_setup opened

Figure 12: Simulation time window of HEC-ResSim model

4.3 Assumptions of Reservoir Operation

Simulation of Tekeze hydropower for optimal operation in this paper made a number of assumptions to simplify the complexity of the actual operation system. Some of the basic assumptions are:

1. Constant reservoir effective storage
2. Seepage through the reservoir and the body of the dam is neglected.
3. Seepage and evaporation through any reach are negligible and assumed to be zero
4. Only free water surface evaporation loss is accounted in this study.
5. Constant gross monthly irrigation demand are used at dawn stream of the reservoir in the irrigation area.
6. Multiple gate setting alternative (i.e., the radial gate opening depends up on the water level in the reservoir) and single gate setting alternatives (i.e., maximum at the time of opening and zero otherwise).
7. The initial condition level for minimum and maximum level for gate operations are:

- ➢ The minimum reservoir level for gate operation is at 1140m.
- ➢ The Conservation reservoir level for gate operation is at 1140m.
- ➢ Maximum reservoir operation level for gate operation is at 1144m.

4.4 Steps of Reservoir Operation Simulation

Tekeze Hydropower reservoir modeling for optimal operation consists of the following steps:

1. Preparation of the time series stream flow data and storing the data set in to the HEC Data Storage System (HEC-DSS).
2. From watershed module of HEC-ResSim, drawing of the river network, Tekeze reservoir, river junctions, diversion outlet, computational points and nodes are arranged. (i.e. Water shed setup)
3. From the reservoir network module, draw reaches, diverted outlet, computational points and defining physical data such as reservoir data (stage – area – volume curve), dam data (spill way capacity curve, power plant data, bottom outlet, tail water rating curve)
4. From the reservoir network module, fixing the operational data which are reservoir elevation for the inactive, conservation and the flood storage zones constant top elevation zone is assumed in this study.
5. Adding the diverted outlet for power intake, additional Zones (if necessary) and adding the parameter for controlled outlet, power plant efficiency, head loss and tail water elevation.
6. At the operation window of reservoir network module, set the operational rules at each zone of reservoir.
7. Assigning the required information or data for each Zone and rule, that specifying the constraints of each zone.
8. After correctly defining the reservoir network, creating an alternative to locate the time series data from the HEC-DSS in the appropriate place.
9. Conduct the simulation or run the model and repeating step 8 until you get the best alternative which can give the optimal result for maximum power generation, at the same can able to satisfy the irrigation demand at the downstream site and also the one which have minimum spillage loss, minimum operating storage level and will not have risk of flooding is selected.
10. Finally analyzing the optimal result and determining the final selected alternative based on all gate setting patterns and detail discussion of the result is done.

5 RESULTS AND DISCUSSIONS

5.1 General

Simulation was performed for the period of 1966 - 1995 using the monthly time series inflow data, by dividing the total storage zone in to maximum flood zone, flood control zone, conservation zone, minimum operation zone and the inactive storage zone. In this paper the four operation zones have fixed reservoir level and their elevations are located at 1145m, 1144m, 1140m, 1096m and 1053m m.a.s.l respectively, which are directly adopted from EEPCO. Each zone has its own operation rule for flood control, power generation, environmental and for any additional activity either downstream or within the dam body.

The simulation was also performed under three scenarios, scenario one (when all the four power units are operated), Scenario two (when the three power units are operated), scenario three (when only two power units are operated). Different alternatives were tested for each scenario to select the one which has optimal power generation considering the other activities.

In this study, low level outlet (used mainly as a spill way in Tekeze hydropower), diverted outlet (power plant in this paper) and bottom outlet (compensation outlet in Tekeze hydropower), are used to manage the quantity of water released from the corresponding zone of the reservoir. During the set up of the model; release is made as a function of model variable, power as a function of total monthly Mega Watt Hour operated as schedule (the expected minimum installed capacity). The alternatives were based on the priority given to the operation rule of the gates. The dam body has different gate settings at different outlets, the first at the spillway with 4 gates, the second at the bottom outlet with one gate and the other at power intake also with one gate.

The following Power characteristics are used in the simulation of Tekeze hydropower for optimal operation. Those are; 0.60 plant factor, 300MW installed capacity, zero station use 4.6m total head loss, 85.4% overall efficiency and 972 m.a.s.l average tail water elevation which are directly adopted from the design report of the hydropower plant.

5.2 Scenario One

In this scenario all the four power units are considered to generate power as per the design and simulation is carried out. The result of this simulation is analyzed and discussed considering downstream users, pattern of energy generation, water release rule, power guide curve and irrigation.

5.2.1. Impact of Tekeze Hydropower on Downstream Areas

The main purpose of the construction of Tekeze dam on the Tekeze River is to generate electric energy so that, partially fulfill the energy requirement of the country. In addition, the dam makes regulated flow possibly throughout the year instead of the highly variable seasonal flows that used to occur before the construction of the dam. This has created high potential for downstream irrigation activities and these increases the performance of downstream irrigation activities which is not yet developed.

According to this study 70.5% of the flood is retained by the dam in scenario one, similarly 75.5% in scenario two and 81.3% in scenario three of flood are retained by the construction of the dam Fig. 13. Hence Tekeze Hydropower is also very important in flood control aspect. The natural flow in the river has a large difference between the wet and dry seasons. From the analysis of this study the hydropower dam increases the flow of the driest month (February) from an average monthly flow of $4.2m^3/s$ to $110.7m^3/s$, $137.3m^3/s$ & $134.6m^3/s$ in the first, second & third scenario respectively. This increases the development activities such as irrigation development on the lower part of the basin.

Fig. 13 shows the amount of flood decrease and the available water increase in downstream of the dam due to the construction of Tekeze dam based on monthly average values for the three scenarios while Fig. 14 shows the relation between cumulative inflow and outflow or release from the dam. Table 8 shows the amount of regulated and unregulated flow before and after the construction of the dam in every month of the year with percentage of change of each month. As it is seen from the graph or from the table, the flow is increased in the dry season while decreases in the wet season after the construction of the dam and the amount is quantified by using graphs and tables from the output of the model. Next to this the release is going to compared with the irrigation water requirement of the downstream potential area in section 5.6.

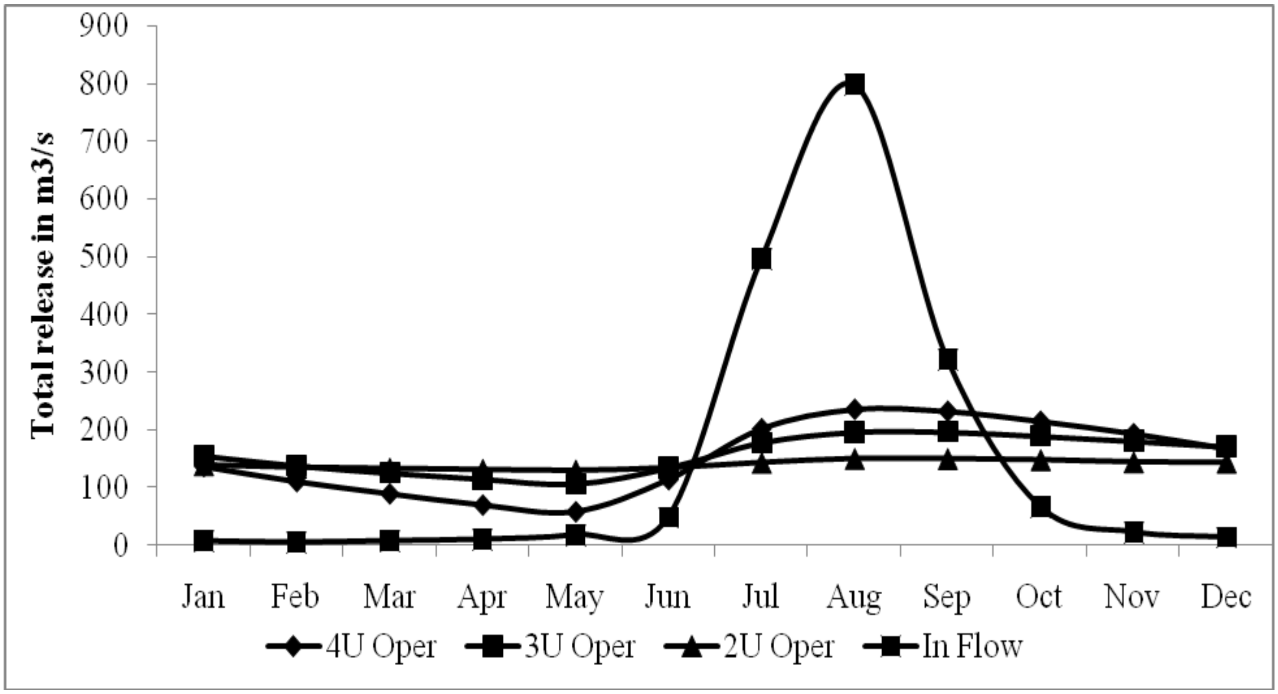


Figure 13: Inflow hydrograph at Tekeze dam site before and after the construction of the dam

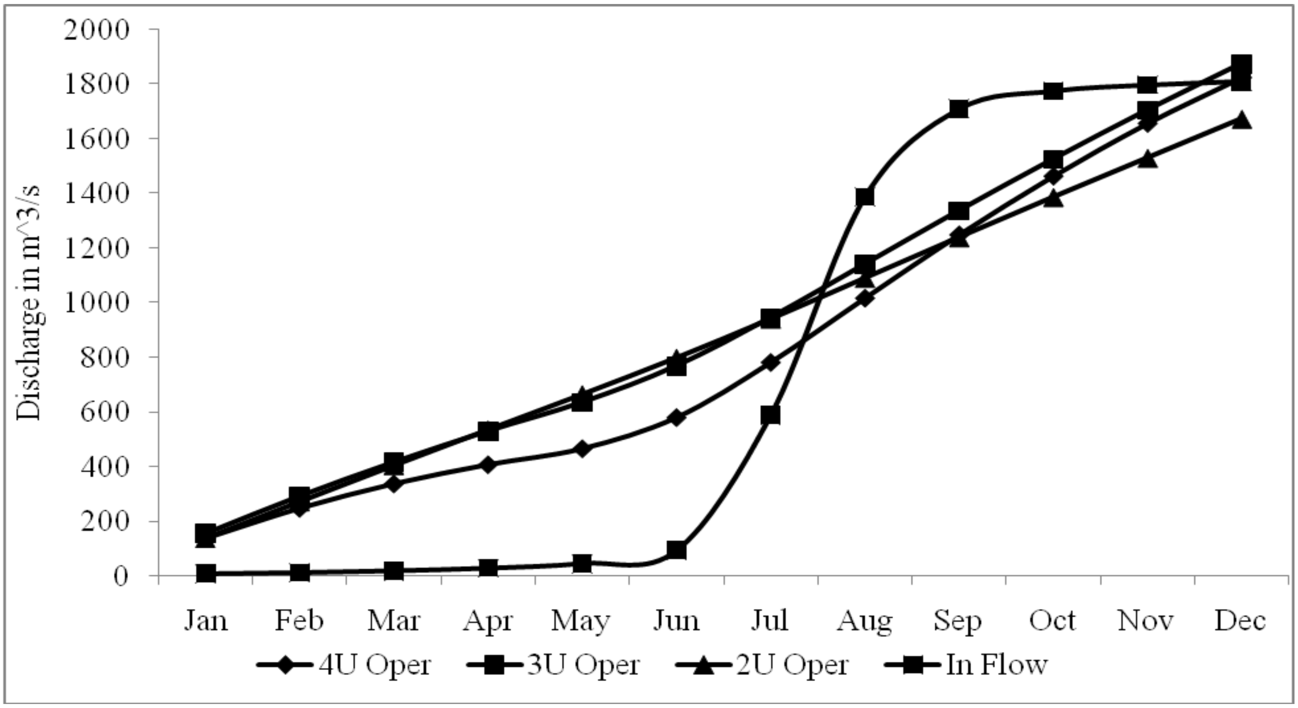


Figure 14: Cumulative Inflow – Outflow relation before and after the construction of the dam

Table 8: Natural flow versus regulated flow of Tekeze dam

Months	Inflow	Regulated Flow Release			Change (%)		
		4U Opr	3U Opr	2U Opr	4U Opr	3U Opr	2U Opr
Jan	6.6	136.8	154.4	138.4	1972.7	2238.6	1997.0
Feb	4.2	110.7	137.3	134.6	2535.7	3169.0	3103.6
Mar	6.9	89.7	124.5	132.6	1199.3	1703.6	1821.7
Apr	9.4	70.2	114.0	130.7	646.8	1112.2	1290.4
May	17.3	58.6	105.5	129.2	238.7	509.8	646.8
Jun	47.7	114.1	133.2	133.7	139.1	179.2	180.2
Jul	495.9	201.8	177.3	142.7	-59.3	-64.3	-71.2
Aug	799.2	235.4	195.6	149.3	-70.5	-75.5	-81.3
Sep	321.9	232.1	195.8	149.2	-27.9	-39.2	-53.7
Oct	66.0	214.8	188.6	147.2	225.4	185.7	123.0
Nov	22.1	193.4	179.8	143.6	774.9	713.6	549.8
Dec	12.9	167.8	170.2	143.1	1200.8	1219.0	1008.9

5.2.2 Power and Energy Production for the Three Alternatives

Power and energy production in the model are generated from the power data input to the reservoir. HEC-ResSim model gives the maximum, average and minimum amount of power in Mega Watt, Energy in Mega Watt Hour, efficiency in percent, turbine flow in meter cubic per second, plant factor and power head in meter. The basic data requirements include: generation requirements, installed capacity, an over load factor, overall efficiency, head loss and tail water level. To find the optimal power generation different iteration steps should be taken by changing the gate setting arrangements and the initial level of the reservoir. Finally the output of scenario one for three alternatives is given in Table 9.

Table 9: Power summary report HEC-ResSim output for scenario one

Alternative	Location/Parameter	Output		
		Average	Maximum	Minimum
1	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	120.6	165.9	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3669.8	7200	0
	Power Generated (MW)	152.9	300	0
	Plant Factor	0.5	1	0
	Flow for power generation (cms)	143.3	220	0
2	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	120.6	163.5	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3653.7	7200	0
	Power Generated (MW)	152.2	300	0
	Plant Factor	0.5	1	0
	Flow for power generation (cms)	143	220	0
3	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	120.4	163.5	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3653.7	7200	0
	Power Generated (MW)	152.2	300	0
	Plant Factor	0.5	1	0
	Flow for power generation (cms)	143	220	0

The best alternative among the three is the one which gives maximum energy generation. Hence, Maximum power generating option among the three alternatives is alternative one. So, it is considered as best alternatives and all the results obtained under this scenario and alternative is discussed below.
As shown in table 9 the following general reports are obtained for alternative one.

Maximum Energy generated (MWh)/year = 7200
Average Energy generated (MWh)/year = 3669.8

Maximum power generated = 300MW

Average power generated = 152.9MW

Average Generation efficiency = 0.9 and Maximum = 0.9

Average Power head = 120.6m and Maximum head = 165.9m

Hydraulic loss Max = average = 4.6m

Average plant factor = 0.5 and maximum = 1.0

Average flow = 143.3m^3/s and Maximum = 220m^3/s are obtained.

Power generation pattern is plotted below from the output of HEC – ResSim model. In the 30 years analysis period of power generation, Tekeze Hydropower almost attained its full power production capacity.

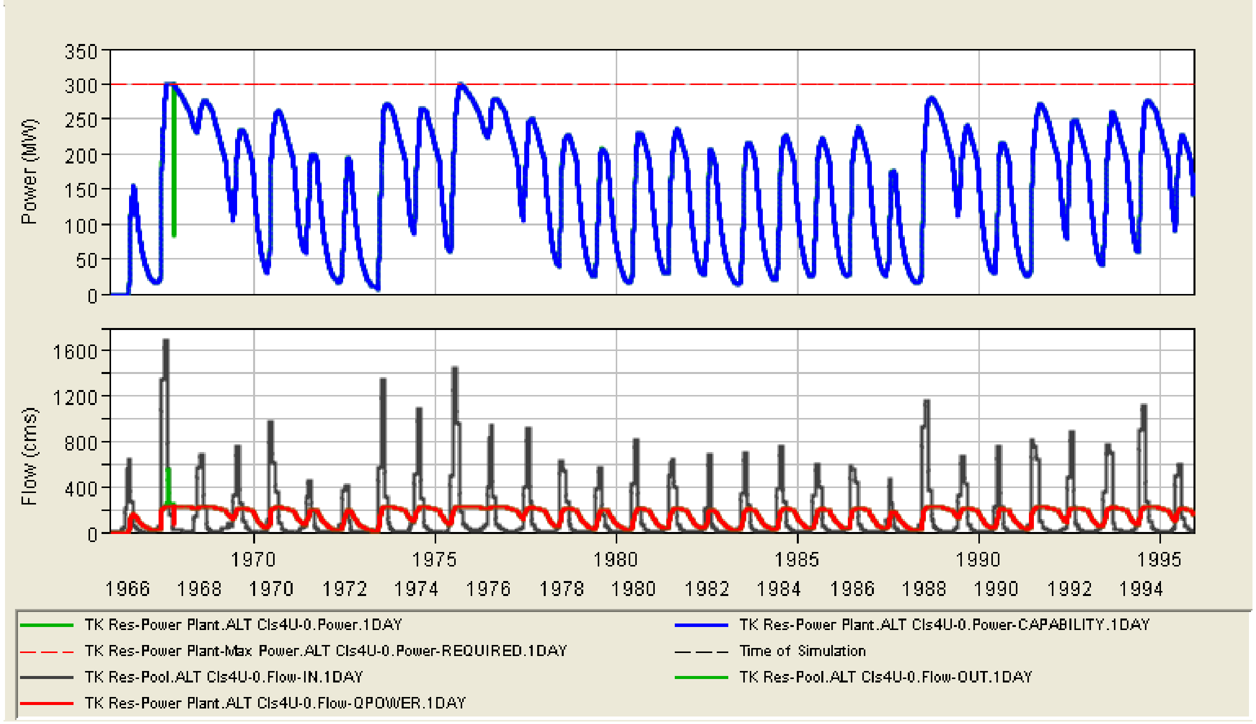


Figure 15: Power generation simulation result from HEC-ResSim Model

5.2.3 Reservoir operation

Fig.16 shows Tekeze reservoir operation obtained by the ResSim model for 30 years of simulation period.

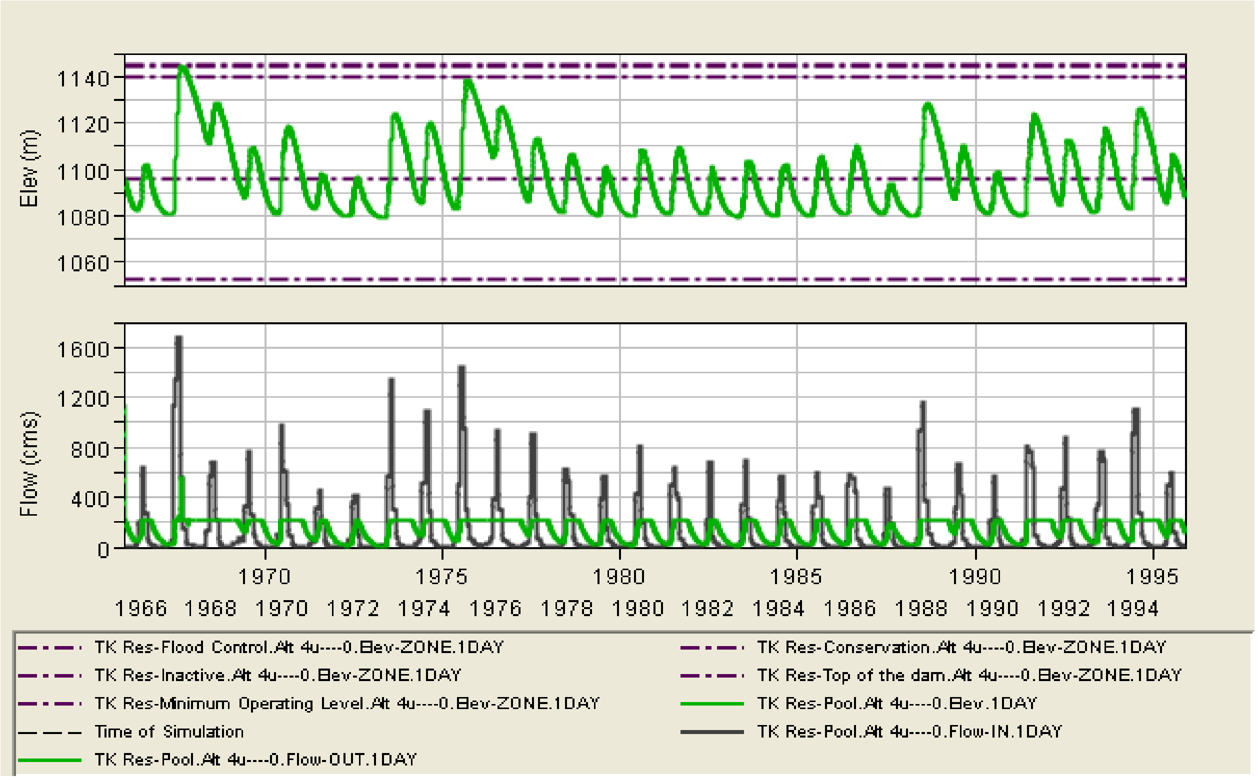


Figure 16: Reservoir operation Model output alternative one of scenario one

Fig. 16 gives the fluctuation of reservoir level in alternative one between the inactive zone and flood control zone throughout the operation time. In dry session the reservoir level will be below the minimum operating level (1096m). This indicates that power production throughout the operation period is impossible if all the four turbines are operated throughout the year or that there is no enough amount of available water in the reservoir to operate the four units continuously throughout the year for production of power. The graph below illustrates the maximum, average and minimum level of the reservoir under the operation of four turbines throughout the year.

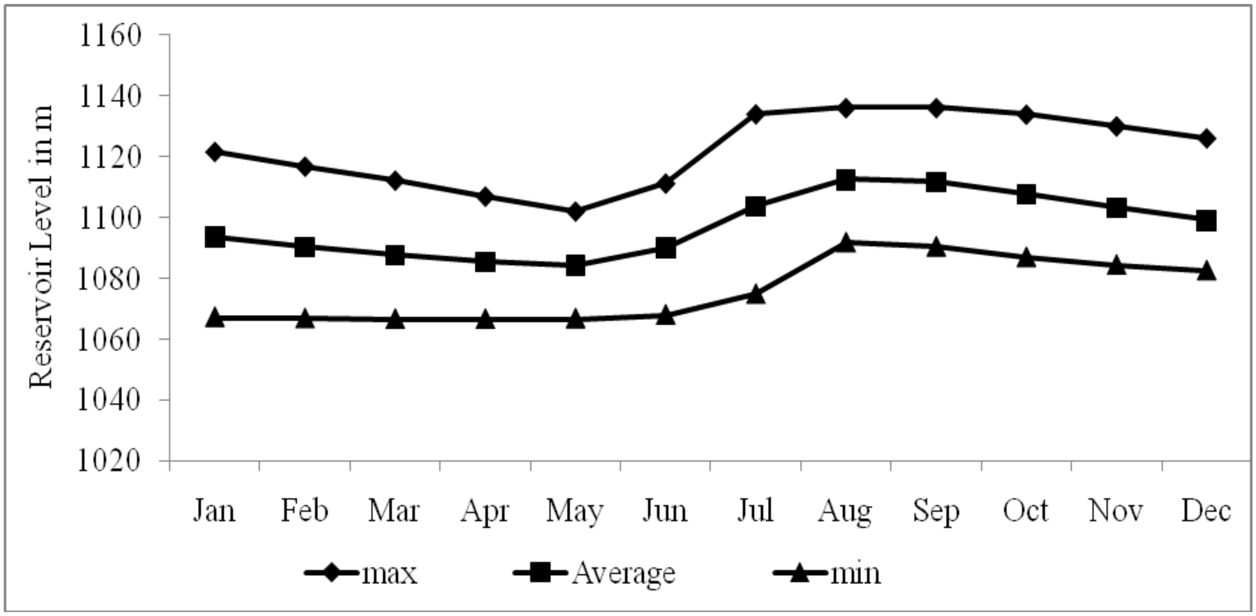


Figure 17: Maximum, average and minimum reservoir levels

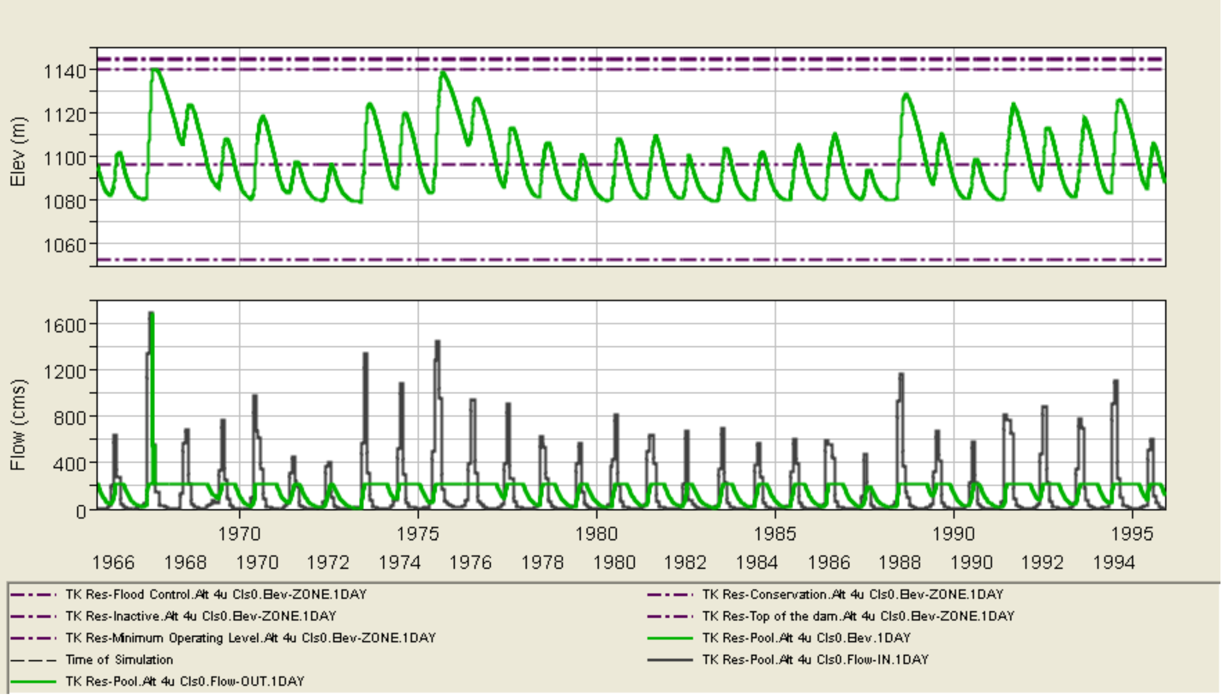


Figure 18: Reservoir operation Model output Alternative two of scenario one

Fig. 18 gives the reservoir level in Alternative two when the low level outlets are opened at 1140m normal condition. This case is also the same with the above condition like the alternative one. But in this case, as reservoir level reaches 1140m m.a.s.l the low level outlet are instantly opened as a result of this more water is discharged as flood in high flow conditions. In comparison of alternative one with the other alternatives it is better to impound the water up to the maximum flood level (1144m m.a.s.l). This is because the high version between the dry and wet season flow.

5.2.4 Reservoir Release Rule

Fig. 19 shows Tekeze reservoir release obtained from the model output in the simulation period.

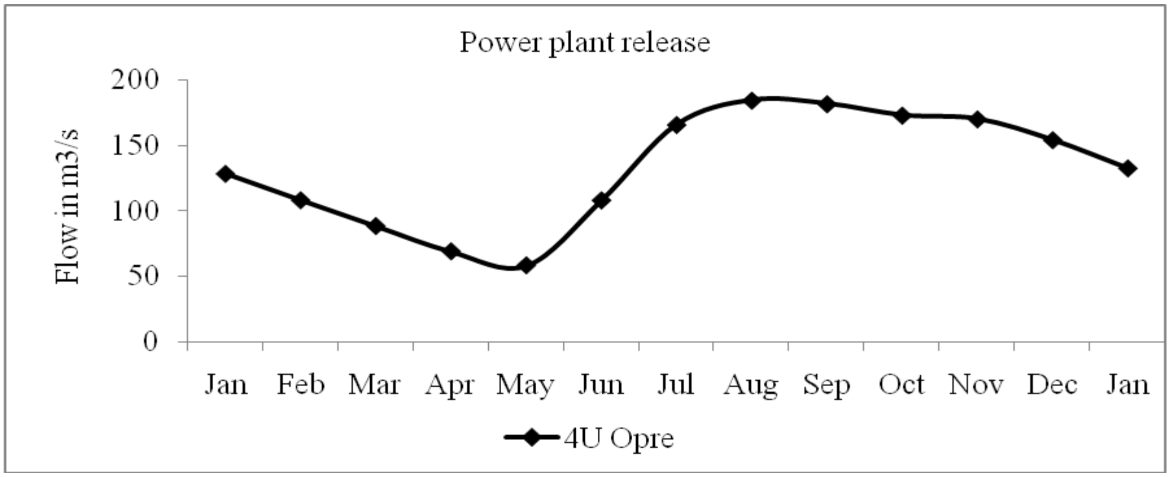


Figure 19: Power Plant release rule model output for scenario one

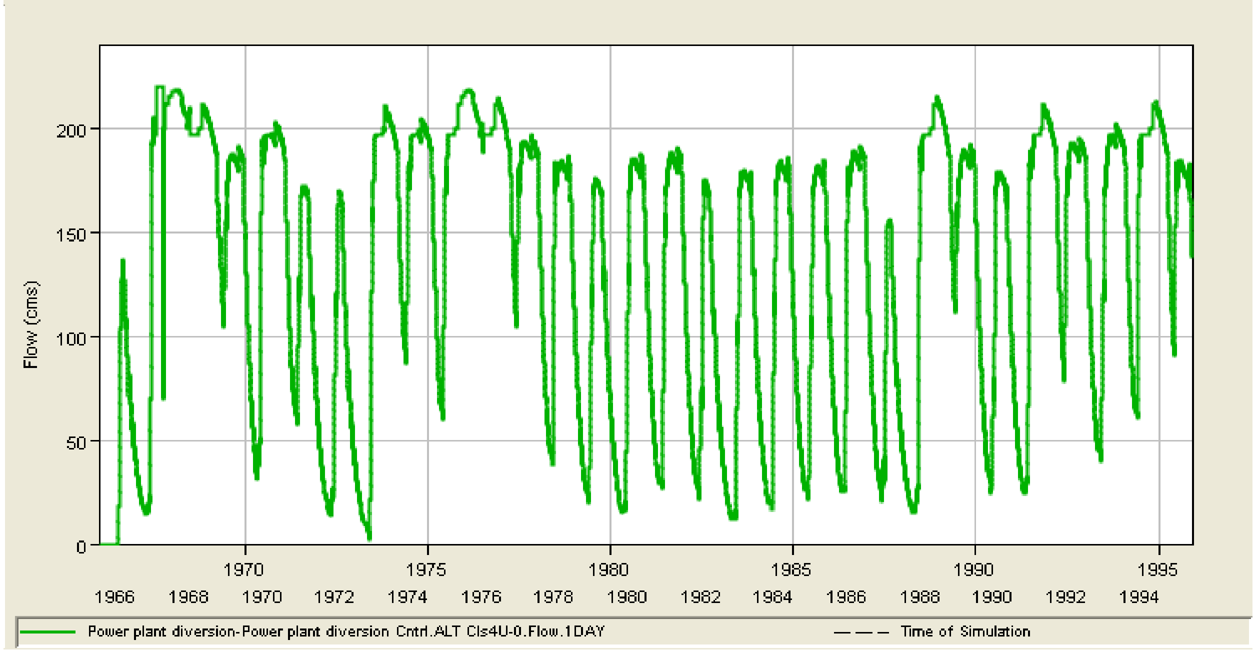


Figure 20: Power plant release model output Alternative one of scenario one

Fig. 20 shows the amount of discharge released from power plant at monthly time step. Minimum release is in the dry season while the maximum release is in the wet season.

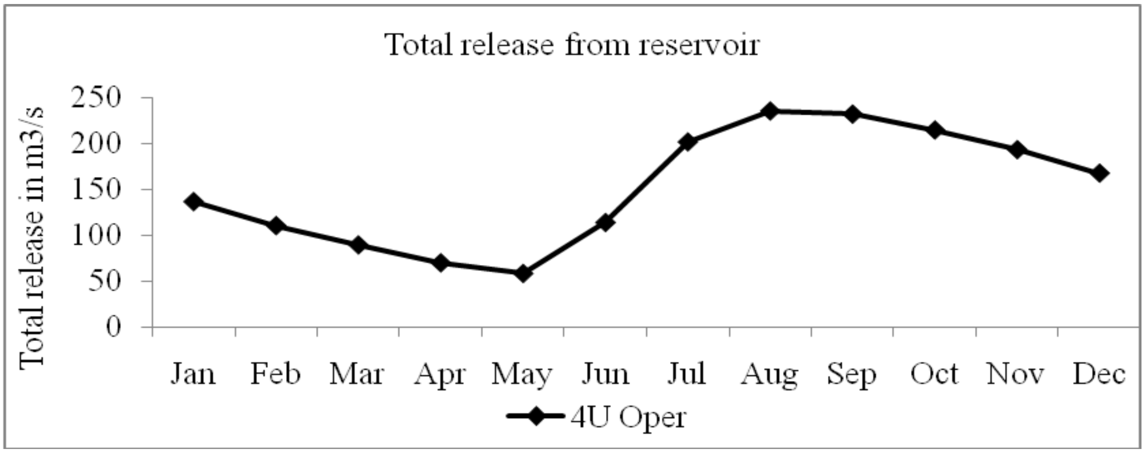


Figure 21: Total water release rule model output of scenario one

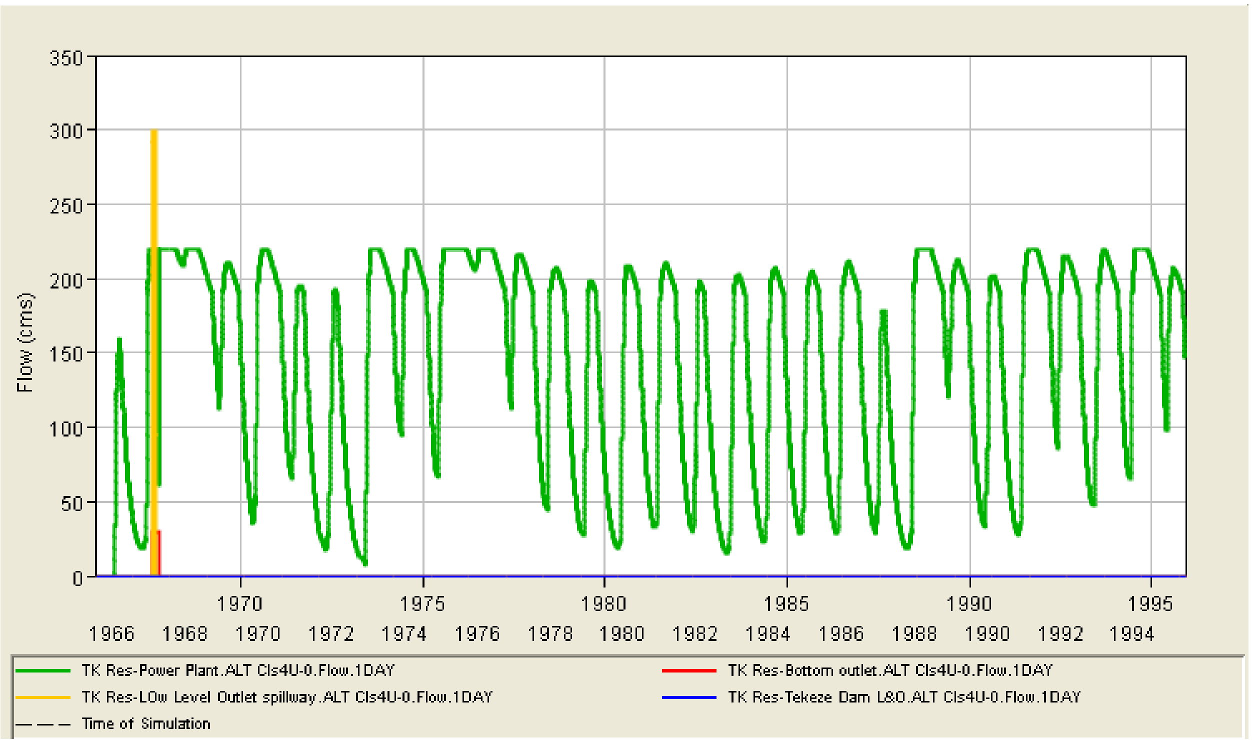


Figure 22: Total release model output Alternative one of scenario one

From Fig. 22 the low level outlets are set for flood discharge. But are opened only once in this simulation period.

5.3 Scenario Two

In this scenario only three power units are assumed to be operational. Taking this in to consideration simulation was carried out and the results are discussed below. In a similar fashion to the first scenario the simulation was carried out in to three alternatives and the best alternative is the first which has maximum power generation. The table below shows the general report of the simulation output.

Table 10: Power summary report from HEC-ResSim model at scenario two

Alternative	Location/Parameter	Output		
		Average	Maximum	Minimum
1	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	130.1	166.9	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3770.7	5532.1	0
	Power Generated (MW)	157.1	230.5	0
	Plant Factor	0.5	0.8	0
	Flow for power generation (cms)	139.3	165	0
2	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	129.1	163.9	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3721.5	5433.4	0
	Power Generated (MW)	155.1	226.4	0
	Plant Factor	0.5	0.8	0
	Flow for power generation (cms)	138.6	165	0
3	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	129.1	163.9	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3721.5	5433.4	0
	Power Generated (MW)	155.1	226.4	0
	Plant Factor	0.5	0.8	0
	Flow for power generation (cms)	138.6	165	0

From the above table the best alternative among the three is the one which has more energy generation. Hence, Maximum power is generated in alternative one. So, it is considered as best alternatives and all the result obtained under this scenario are considered as maximum result. Fig. 23 shows the power generation capacity when only three turbines are working.

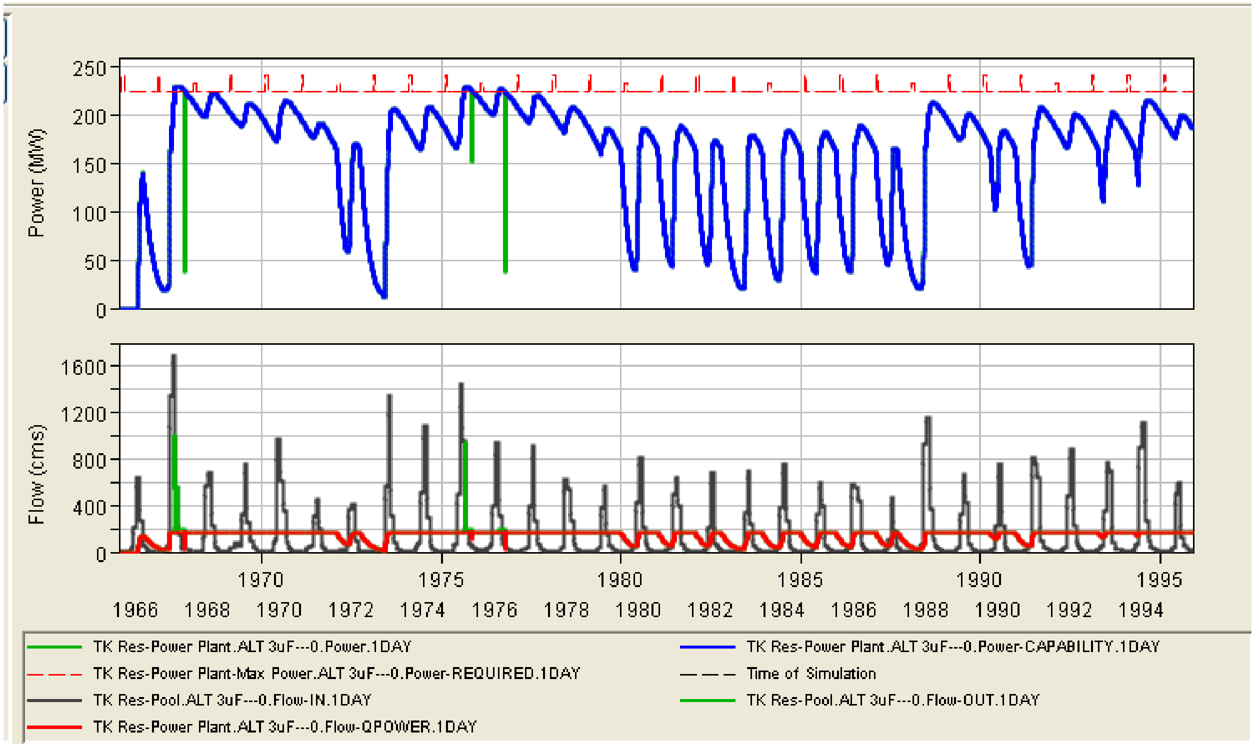


Figure 23: Power generation model output Alternative one of scenario two

Optimal reservoir operation for this scenario is whether to spill the water above 1140m.a.s.l or surge it up to 1144 m.a.s.l and to use it in a safe way without over tapping the dam. As anyone can observe from the inflow hydrograph there is a great variation between the dry and wet season. Therefore, it is better to store the water up to 1144m. The result of HEC-ResSim model show that, the dam will not over top even if the low level outlets are not opened up to 1144m.a.s.l which implies that dam is still safe. The best alternative is now the first alternative which generates maximum power and hold large volume of water that can be smoothly used in the dry period.

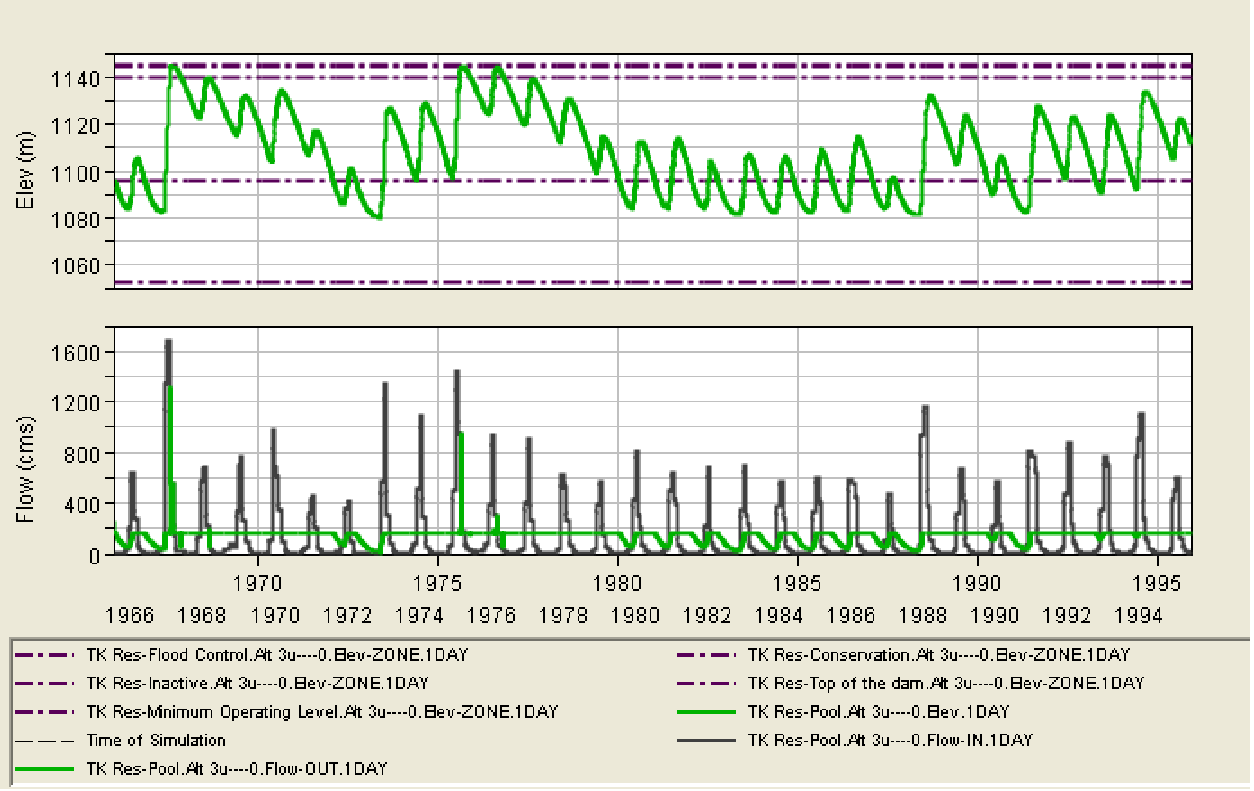


Figure 24: Reservoir operation model output Alternative one of scenario two

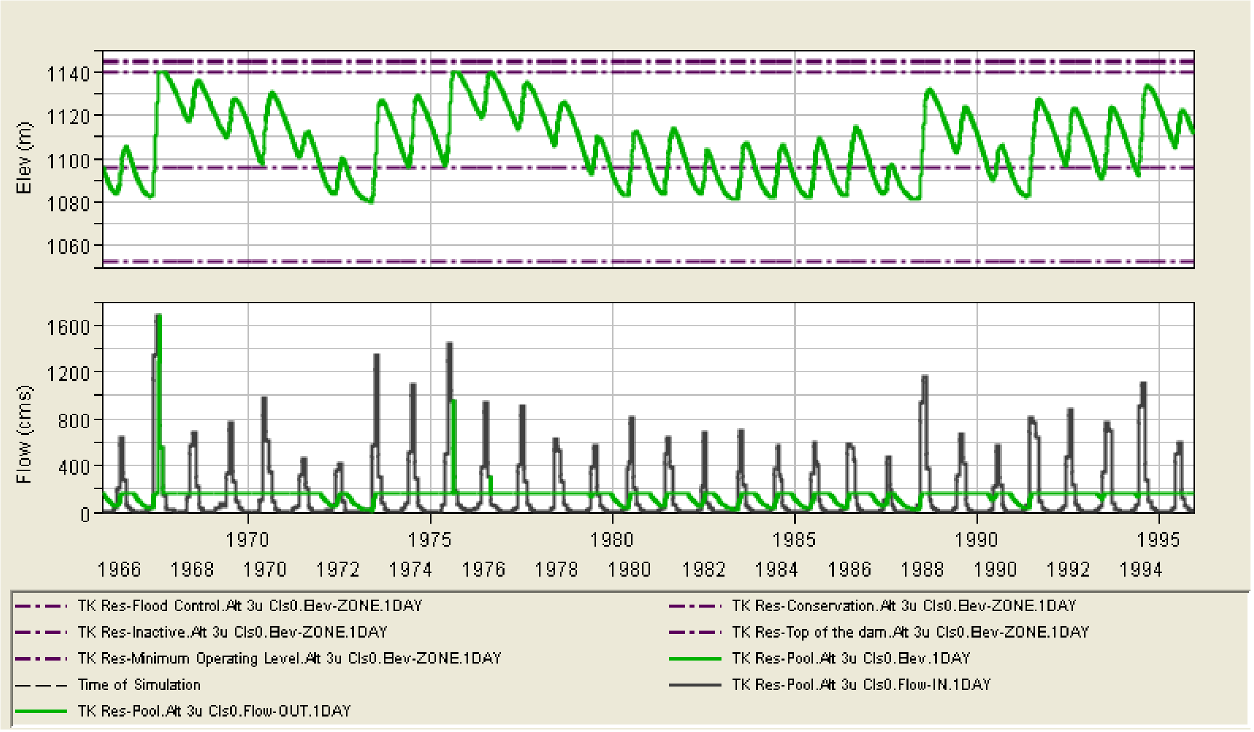


Figure 25: Reservoir operation model output Alternative two of scenario two

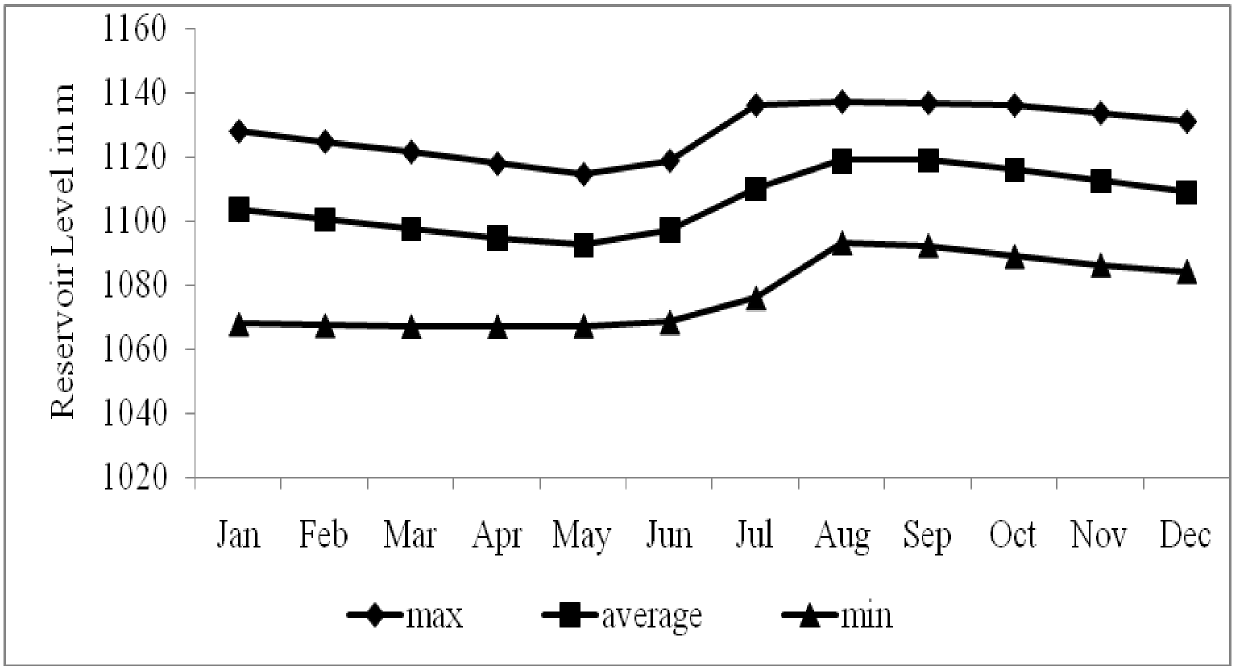


Figure 26: Maximum, average and minimum reservoir level

Fig. 27 shows the total release rule obtained from the model.

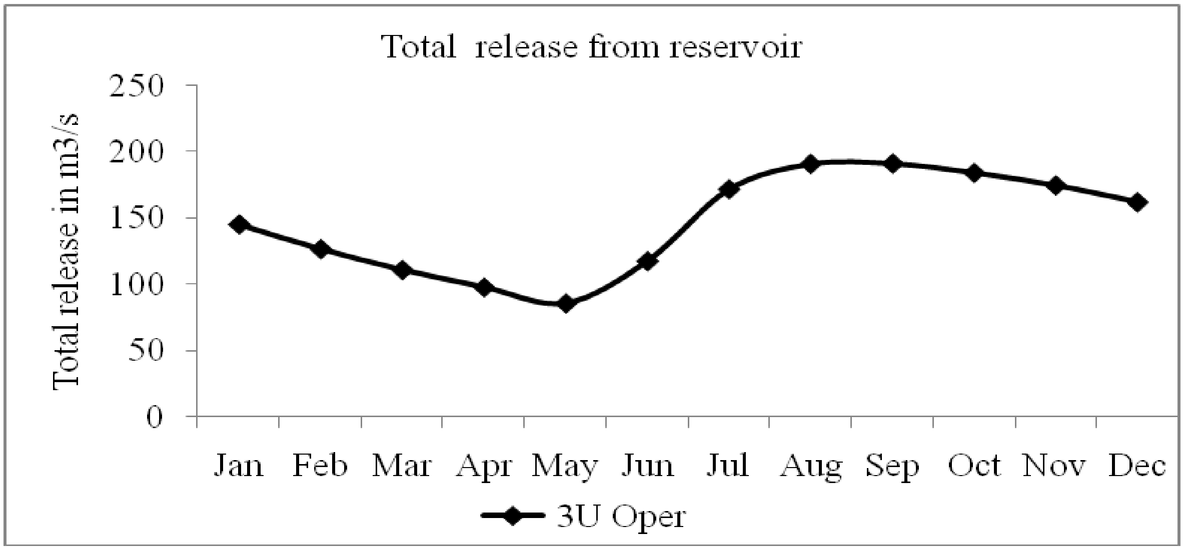


Figure 27: Total release rule model output for scenario two

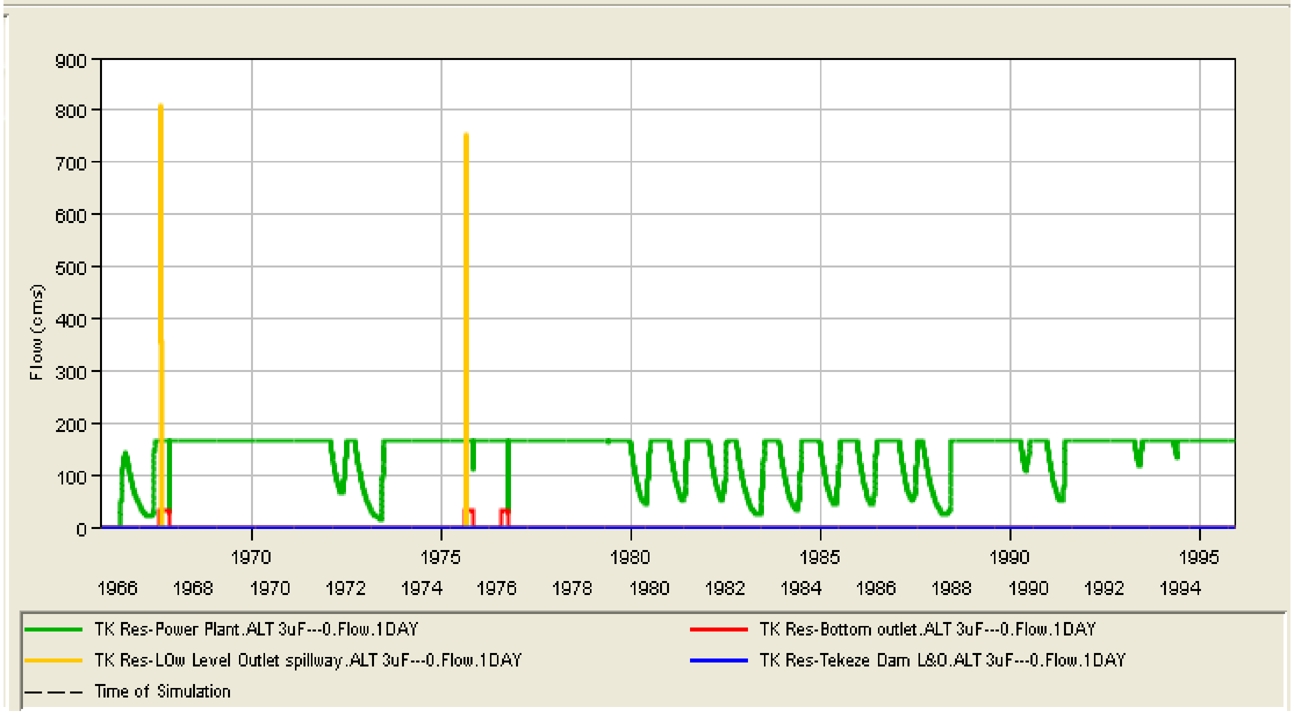


Figure 28: Total release model output Alternative one of Scenario two

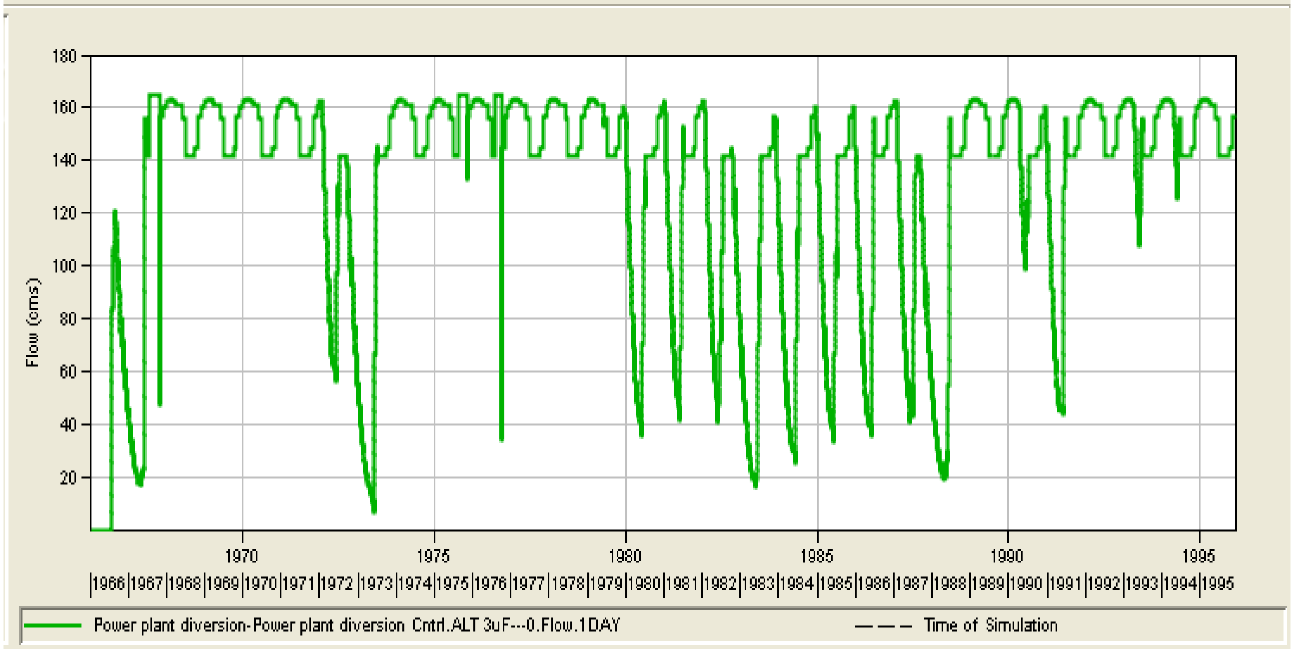


Figure 29: Power plant release model output Alternative one of Scenario two

5.4 Scenario Three

In this case the simulation process was performed in a similar way with that of the first and second scenarios under three alternatives to get the best or optimal power generating alternative. However, only two units are functioning as a result of this the reservoir level increases from the other two scenarios. In general the result of this simulation is shown in table 11:

Table 11: Power summary report from HEC-ResSim model at scenario three

Alternative	Location/Parameter	Output		
		Average	Maximum	Minimum
1	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	154.4	167.9	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3342.1	3709.1	0
	Power Generated (MW)	139.3	154.5	0
	Plant Factor	0.5	0.5	0
	Flow for power generation (cms)	106.4	110	0
2	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	151.4	164.8	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3278.4	3641.2	0
	Power Generated (MW)	136.6	151.7	0
	Plant Factor	0.5	0.5	0
	Flow for power generation (cms)	106.5	110	0
3	Generation Efficiency	0.9	0.9	0.9
	Power Head (m)	151.4	164.8	75.8
	Hydraulic Losses (m)	4.6	4.6	4.6
	Energy Generated per Time Step (MWh)	3278.4	3641.2	0
	Power Generated (MW)	136.6	151.7	0
	Plant Factor	0.5	0.5	0
	Flow for power generation (cms)	106.5	110	0

The above table shows power summery report of this scenario with all alternatives. The best alternative among the three is alternative one. Hence, maximum power is generated in this alternative. So, it is considered as best alternatives and all the results obtained under this scenario are taken from this alternative.

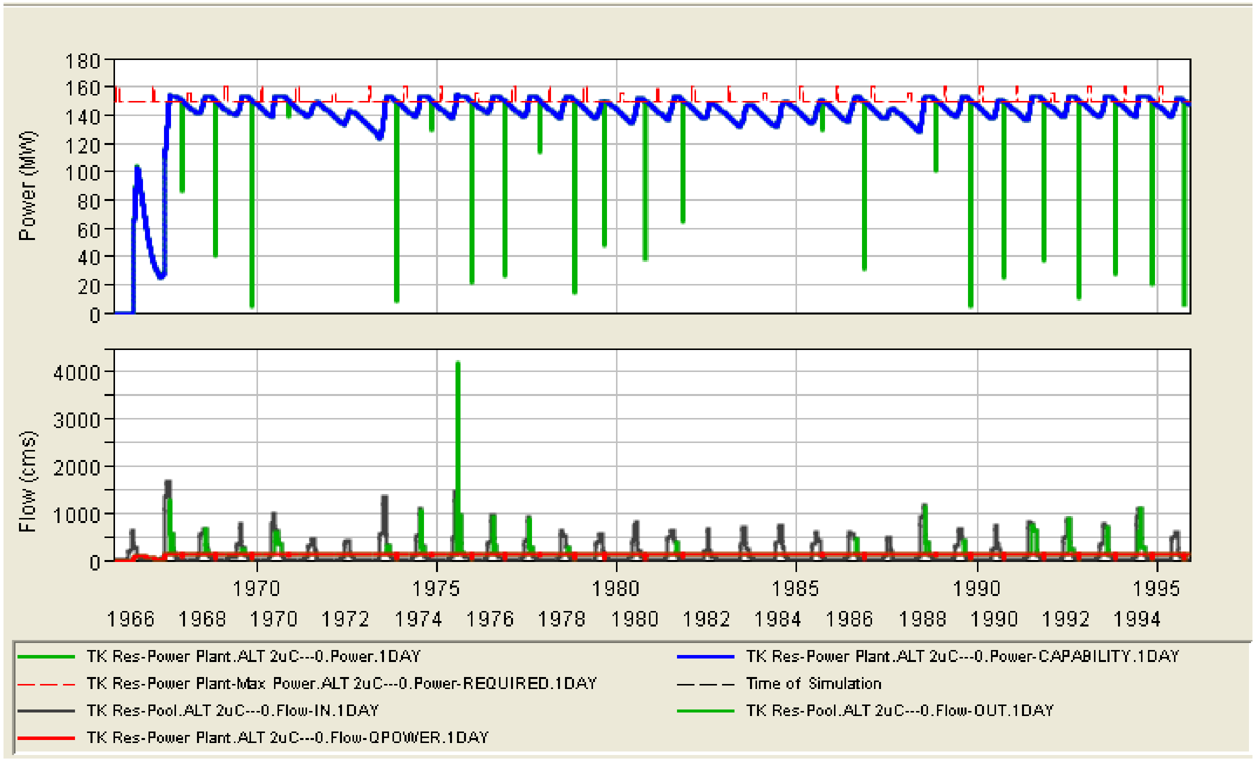


Figure 30: Power generation model output Alternative one of Scenario three

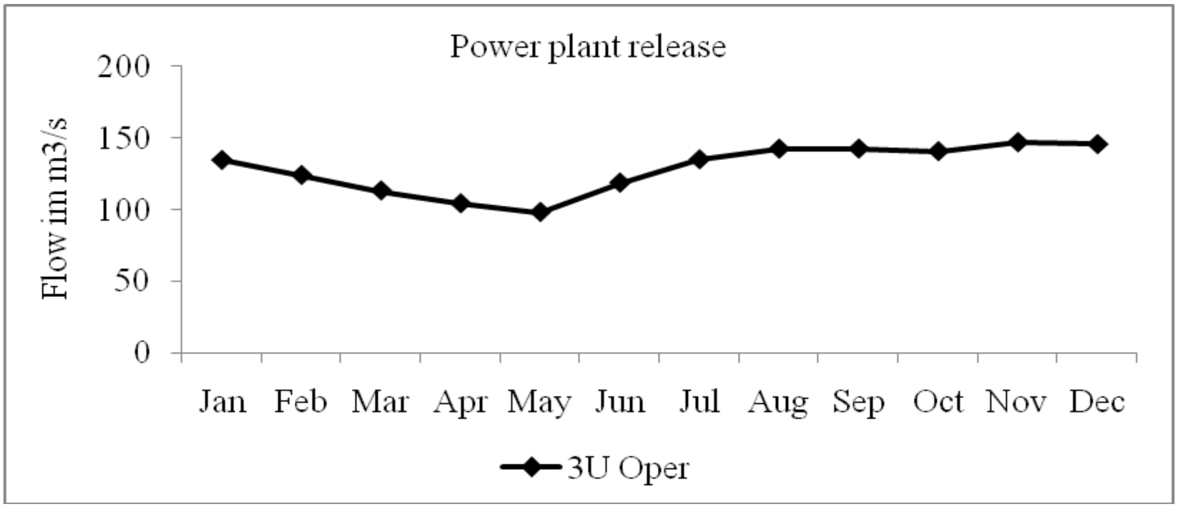


Figure 31: Power guide when two unites are operational

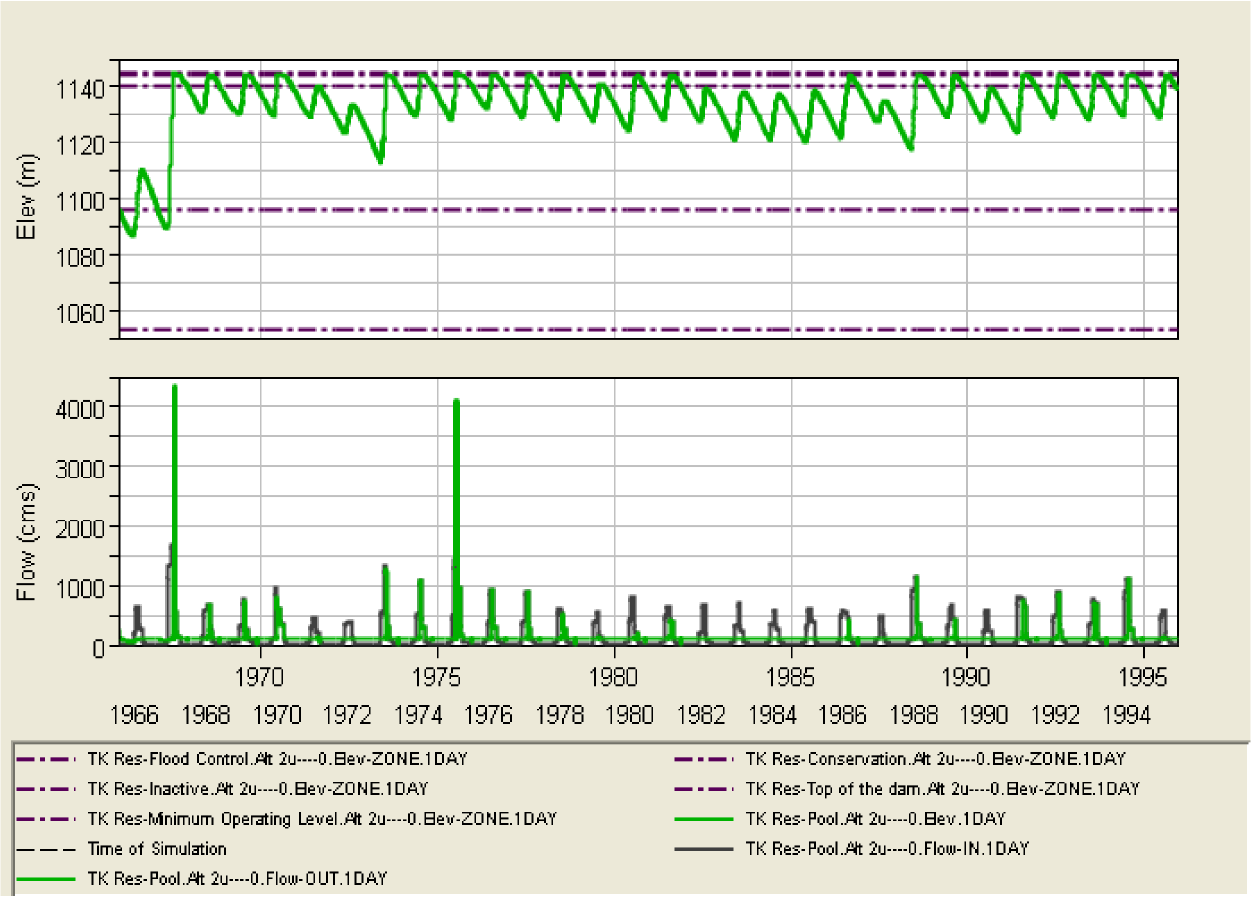


Figure 32: Reservoir operation model output Alternative one of scenario two

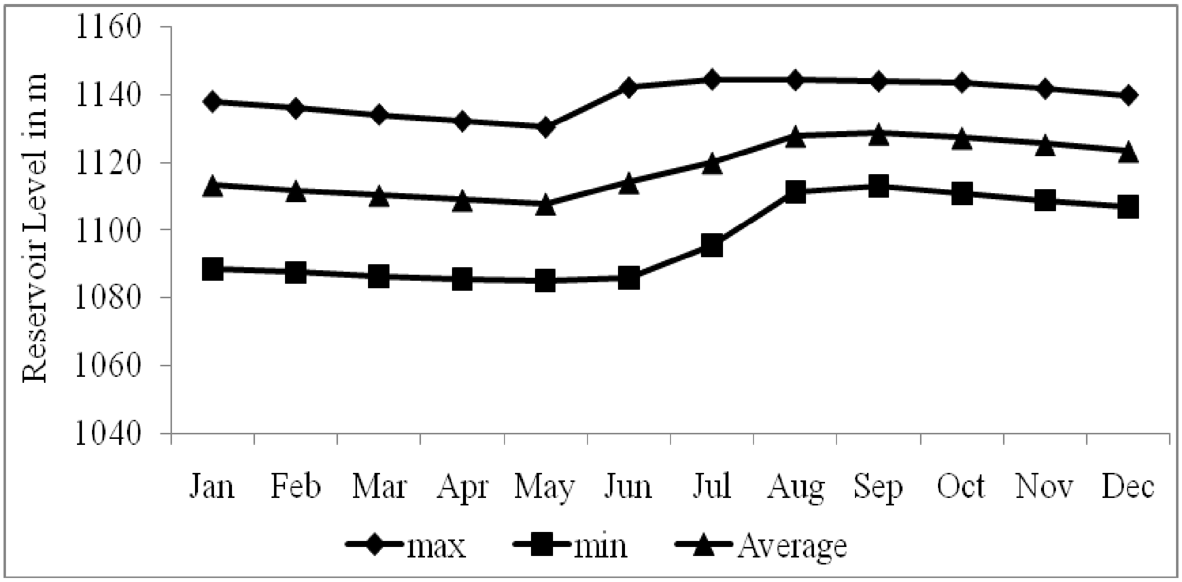


Figure 33: Maximum, average and minimum reservoir level

Reservoir operation alternative two when low level outlets are opened at 1140m.a.s.l

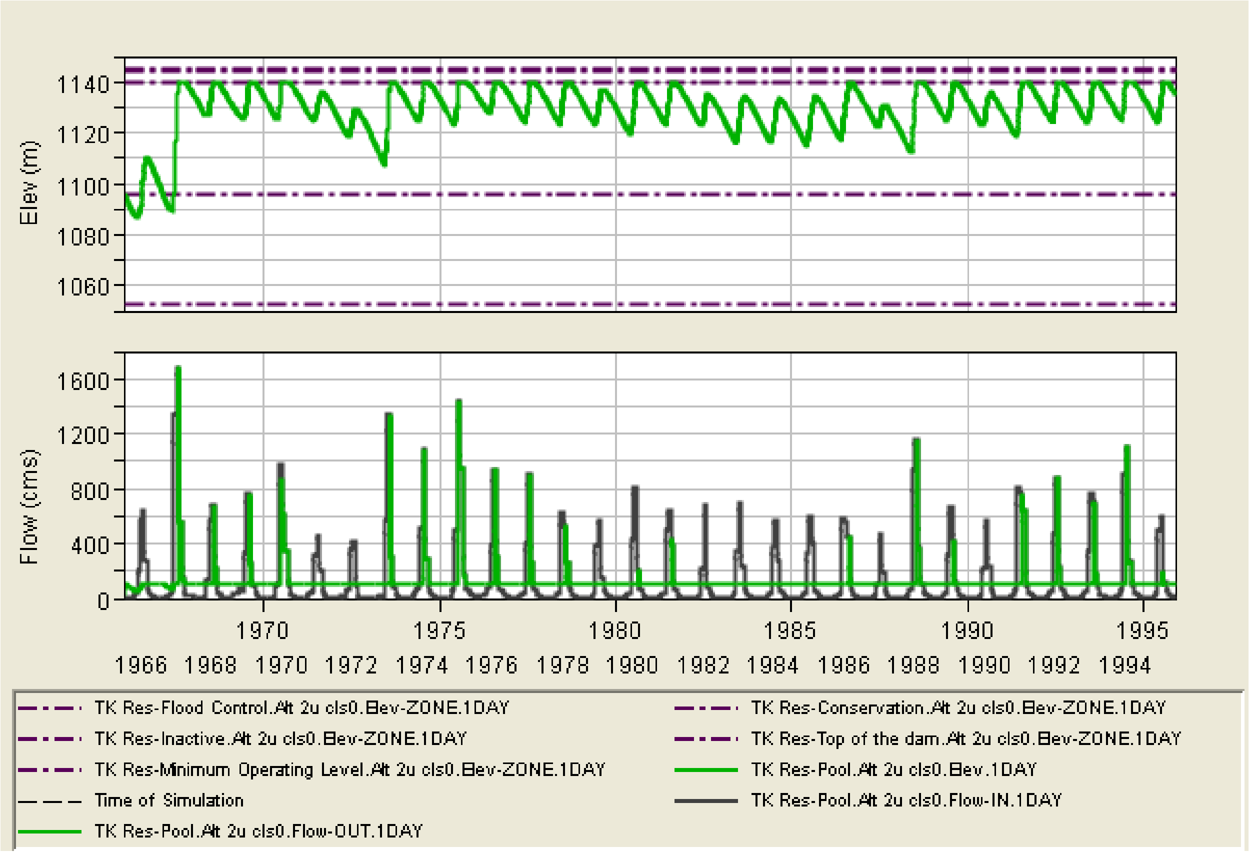


Figure 34: Reservoir operation model output Alternative two of scenario three

Fig. 35 and Fig. 36 shows that the total discharge released from the reservoir at monthly time step, as we observe from fig. 31 there is excess water which is released from the low level outlet almost in every year. However this water is wasting without serving the desired function. As a result of this, scenario three is not economical and is not recommended to operate only two turbines even if the two turbines are working at their maximum capacity. But, in the case of irrigation development, the release from the power plant satisfies the demand. Hence, there is no problem with the irrigation development whether we operate the four, three and two turbines. Figure 35 shows the total release and power plant release of scenario three.

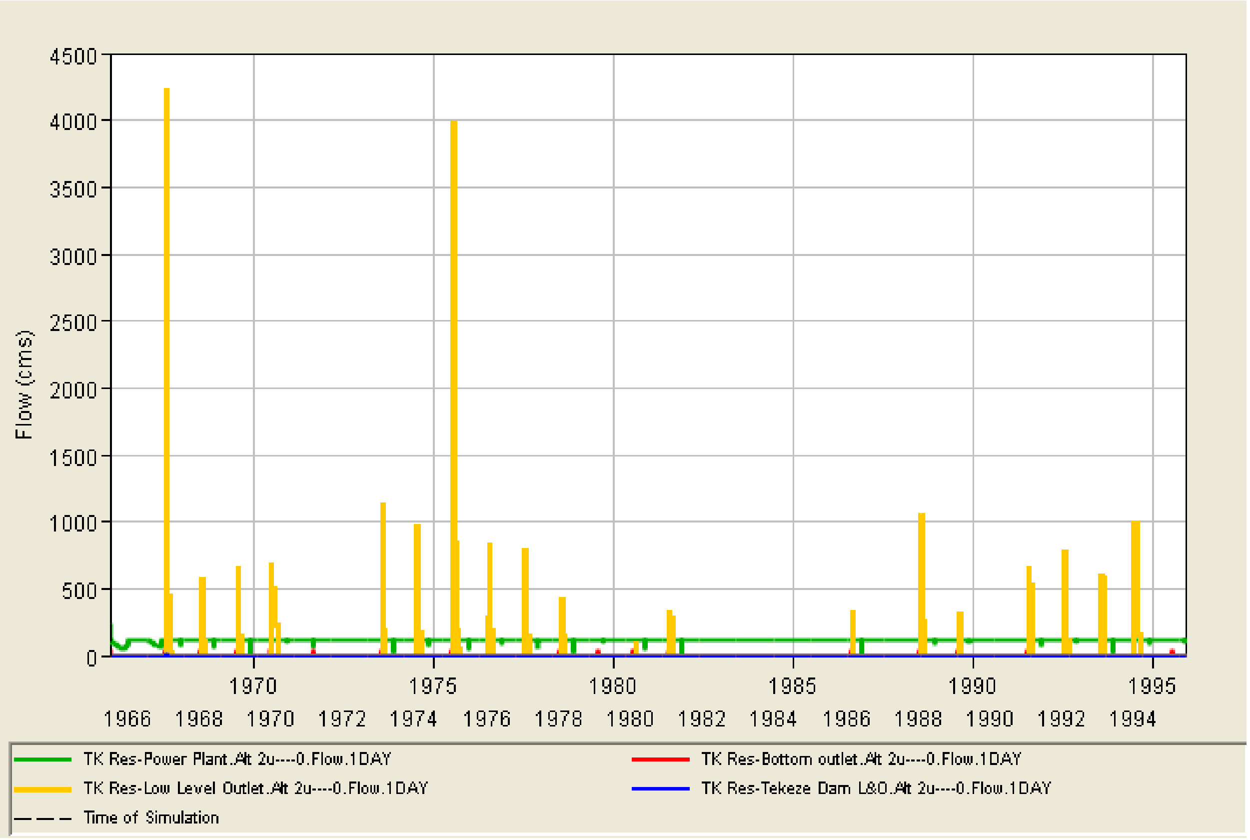


Figure 35: Total reservoir release for Alternative one of Scenario three

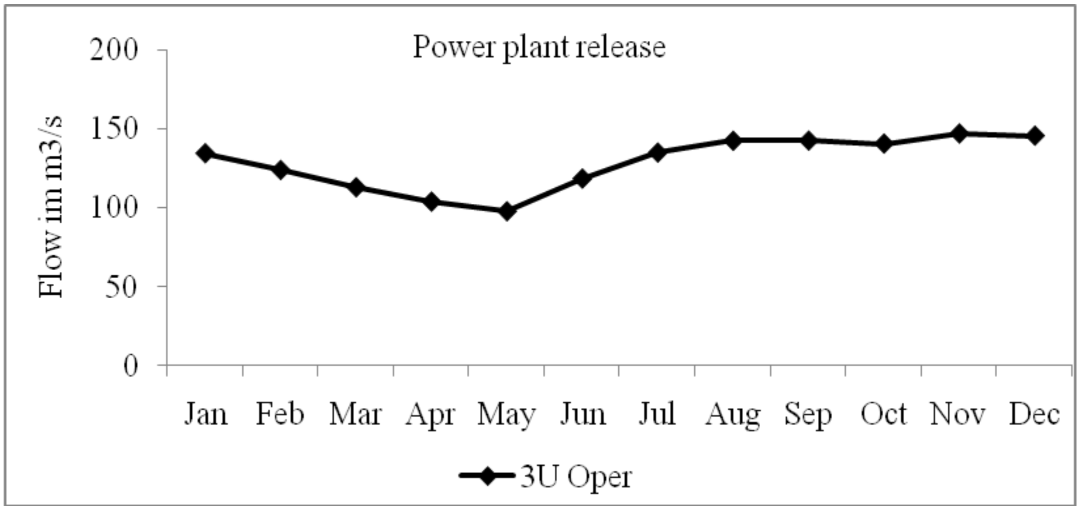


Figure 36: Total releases from reservoir at Scenario three

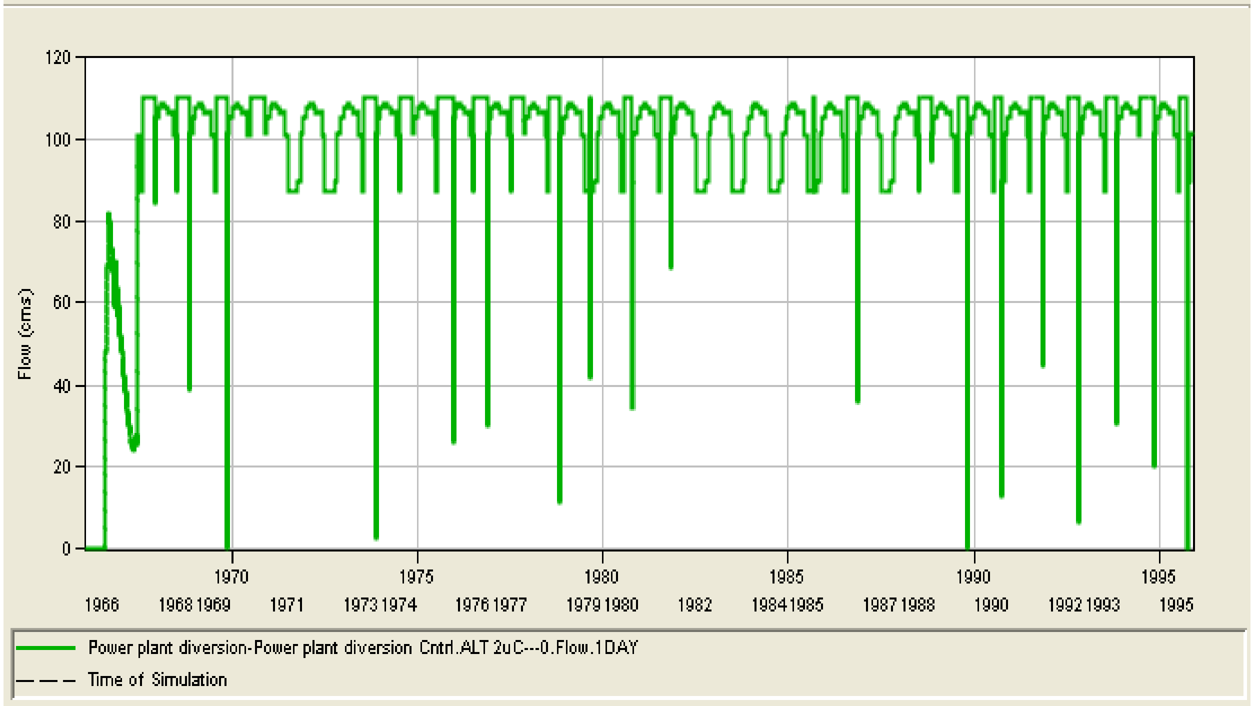


Figure 37: Power plant release of scenario three

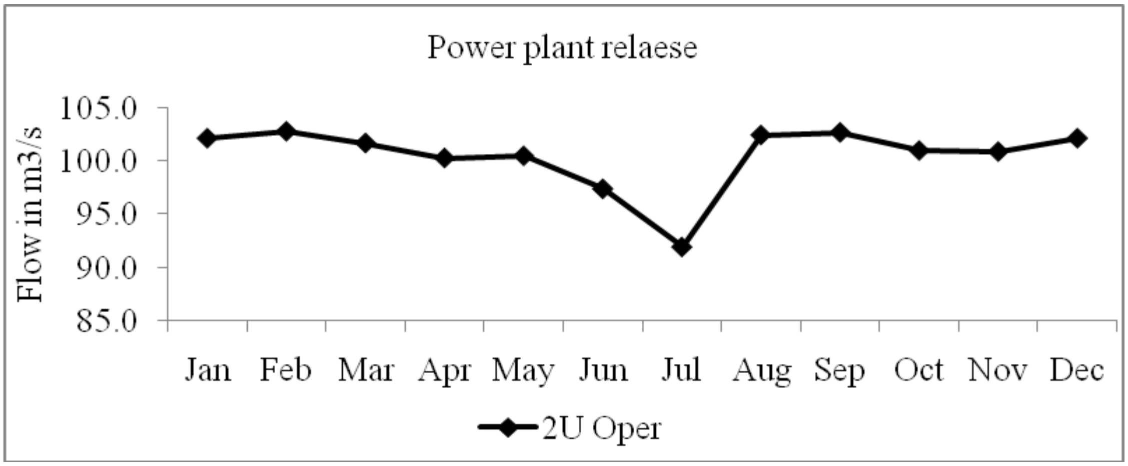


Figure 38: Power plant release rule

Fig. 38 shows the amount of discharge released to the power plant at monthly time step only when the two turbines are operating. The minimum flow is released in June and the maximum in September while the minimum power is generated in May and the maximum in October.

5.5 Power Guide Curve

The following graph indicates the power duration curves for all the three scenarios. The variations were observed the power duration curve drown under the analysis.

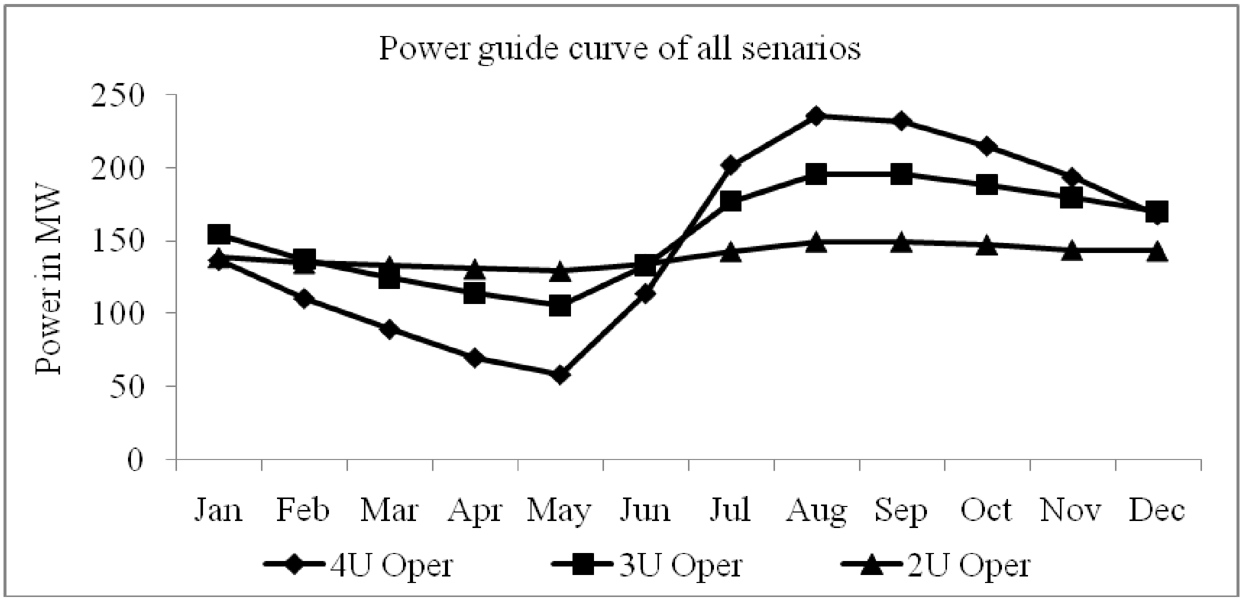


Figure 39: Power guide curve of the three scenarios

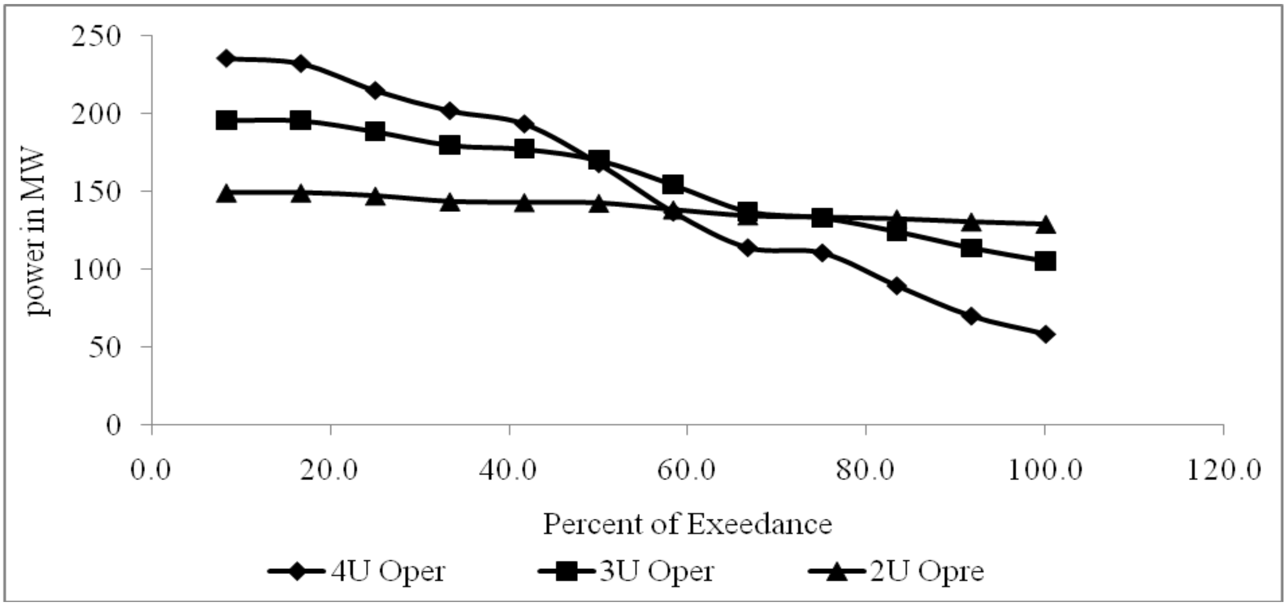


Figure 40: Power duration curves of the three scenarios

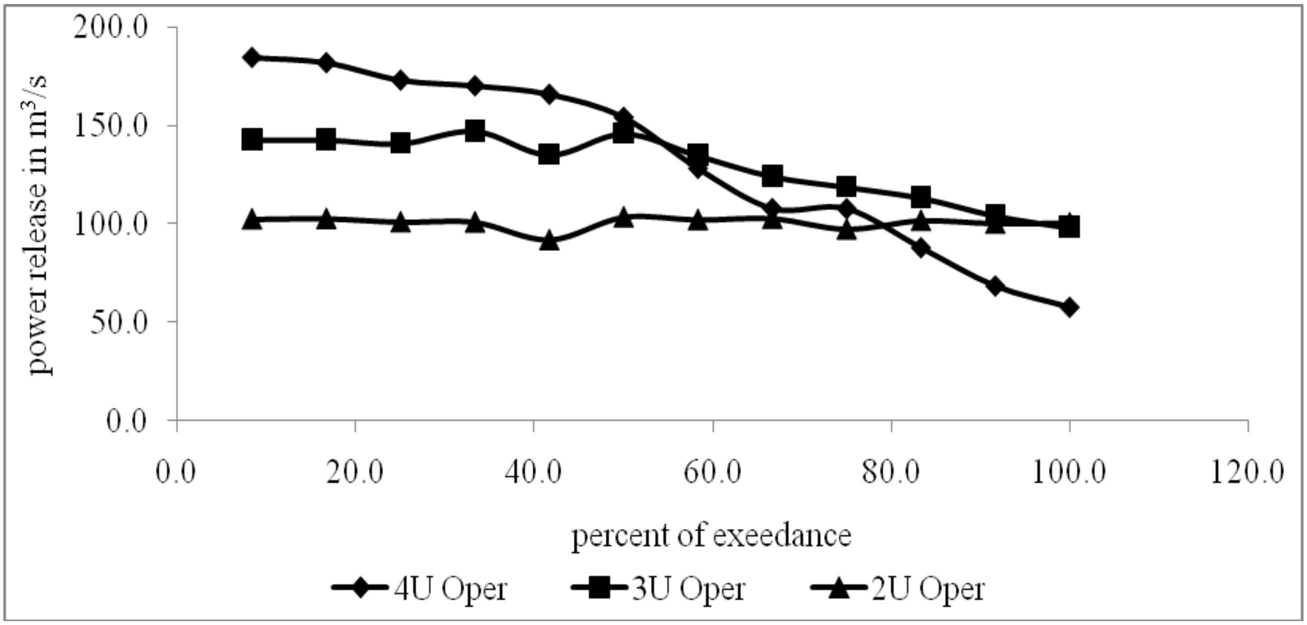


Figure 41: Flow duration curves of the three scenarios

The power which is available for 95% to 97% of the time on the reservoir regulated schemes is usually considered to be the primary or firm power, and the area of the power duration curve under the minimum amount of flow available for 95% to 97% of the time thus gives the total amount of the primary power (P. Novak, 2000). From the graph power generated versus percent of exceeding; 95% of exceeding is assumed to be firm power which is available all the time. According to this analysis; 70.07MW when four power units are operational, 109.6MW when three power units are operational and 129.85MW when two power units are operational firm power is generated.

From the flow duration curve, the minimum downstream releases at different scenarios are observed to be greater than the maximum irrigation requirement. Hence this analysis confirms that the regulated flow (or power release) of Tekeze dam would also increase availability of water for the lower Tekeze basin irrigation projects.

5.6 Water Availability in Lower Tekeze Irrigation Site

Definitely the availability of water in the lower Tekeze basin is increase by the construction of Tekeze dam, since there is a regulated flow throughout the year which was not possible before the construction of the dam. In this study the objective is not only to generate maximum power but also evaluate the development of irrigation in the lower Tekeze basin and check whether or not enough water is available that satisfies the irrigation demand without affecting the total reservoir volume of the reservoir.

Assuming that the agricultural demand per unit area and hydrological conditions will not change in the future and the water demand of the future expansion of irrigation in the lower basin is taken from the integrated master plan study then, the total monthly water demand is compared with average monthly release and the sufficiency is checked easily with graph in Fig 42. The total irrigation demand in the downstream area versus water release from power plant is shown in Fig. 42.

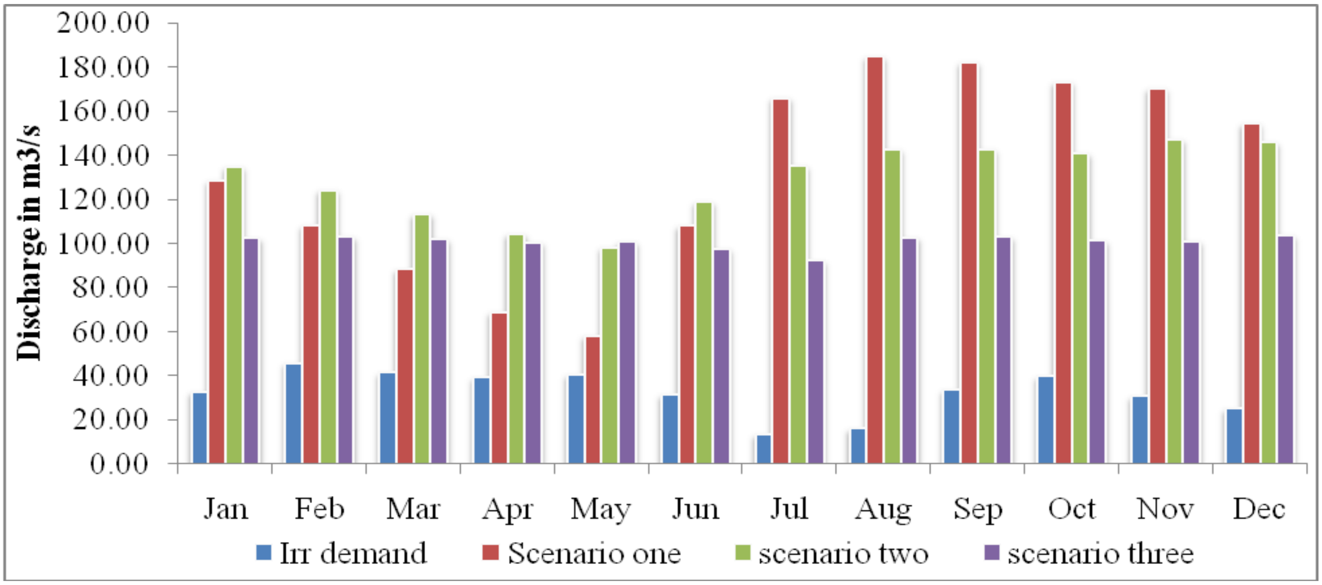


Figure 42: Monthly average power plant release verses monthly irrigation demand

In the simulation period, the minimum downstream releases at different scenarios are observed to be greater than the maximum irrigation requirement. Therefore, this analysis shows that the regulated flow or power release of Tekeze dam would also increase availability of water for the lower Tekeze basin irrigation demand. As a result of this irrigation development should be coupled with the power generation to get more profit from the reservoir.

6 CONCLUSION AND RECOMMENDATION

6.1 Conclusion

This research work attempted to model optimal operation of Tekeze reservoir for better performance of the power plant by HEC-ResSim software. Reservoir operation has been carried out using 30 years average monthly inflow data and the maximum performance of Tekeze hydropower plant is obtained for generation energy and analyzed for the downstream water requirement**.** The main input data; hydro-metrological data, physical data, operational data and spatial data for the model are obtained from their respective sources.

Modeling of the reservoir is carried out using three modules. These are watershed setup, reservoir network and simulation module. In the watershed setup module Arc view-GIS shape file is taken from MoWE as a back ground image and from this image the main River within its tributary are drawn and the reservoir is placed in its appropriate location. In the reservoir net work setup, all the physical and operational data are configured to the model. Here pool and dam components are allocated with their input parameters. The stage-area-volume curve and evaporation loss are set to the pool component while, low level outlet, bottom outlet, power intake and tail water rating curve with their capacities are set to the dam component. In addition to setup of input parameters to the reservoir net work, alternatives are created in this module. Three alternatives are taken to determine the optimal operation of Tekeze reservoir by alternating the gate setting arrangements in the low level outlet. Finally the simulation module is used and simulation carried out for each alternative and a number of iteration should be carried out to determine the best one with optimal operation of the reservoir.

In the three scenarios the optimal operation which can generate maximum average energy and maximum availability of water but uniformly distributed throughout the year in the downstream area is selected. The power and energy generated from HEC-ResSim simulation model is summarized in Table 12. From the table below, Scenario two (operating three power units or turbines) gives relatively maximum average power and energy. The reservoir level will be below the minimum operating level in the dry season and again filled in the rainy season in the first and second scenarios, while it is above the minimum operating level in the third scenario.

Table 12: Average power and energy of all scenarios

	scenario	1	2	3
Power in MW	Minimum	0	0	0
	Average	152.9	157.1	139.3
	Maximum	300	230.5	154.5
Energy in MWh	Minimum	0	0	0
	Average	3669.8	3770.7	3342.1
	Maximum	7200	5532.1	3709.1

Traditionally, reservoir operation is based on trial and error procedures embracing rule curves and subjective judgments by the operator and in addition to that, the load share given from the interconnected systems. Thus, this study has provided general operation strategies for reservoir releases according to the current reservoir level, hydrological conditions and the time of simulation year for the maximum net volume water released and develops a unique yearly average power guide for all the three scenarios in one graph.

In Tekeze reservoir operational modeling with HEC-ResSim some input parameters (Efficiency and plant factor) were modified by the model during simulation for all scenarios. Efficiency is modified from 85.4% to 90% and plant factor from 0.6 to average of 0.5 and maximum of 1.0. This shows the performance of the plant to generate the expected power.

The hydrologic impact of the Tekeze reservoir is simulated and long term effects in the simulation period show that operation of Tekeze power plant would increase water availability in the dry season to the downstream area and decrease flooding in the wet season. The study has determined a smooth release of water from the Tekeze reservoir throughout the year, and irrigation development is possible at the lowland area of Tekeze basin which has net irrigable area of 42965hectars.

The monthly power release is compared with total irrigation demand and found to be more than enough in all the three scenarios. Therefore, irrigation should be developed to contribute to the national economy of the country and recover the cost of the dam in a short period of time.

6.2 Recommendations

For better management of Tekeze hydropower reservoir operation, this thesis recommends the following studies to be carried in Tekeze reservoir operation modeling:

1. This study considers the existing or historical hydrologic data to estimate the power operation pattern and other activities downstream of the reservoir. Because, the gauging stations in the upstream area do not have long term flow data and even generation from metrological data is not possible since the metrological stations have not enough data. However, it is better to use inflow forecasting hydrological models to gate the necessary data such as runoff from the given rainfall amount for simulation.

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

3. To keep the reservoir pool level at the guide curve level it is recommended to release more water and generate more power during the high flow season and minimize release during the low flow season. For low flow season the energy shortage should be compensated from other sources in the power grid.

4. This study proposes to develop irrigation in the downstream area of the reservoir. But, still it needs further study on the conveyance loss, crop water requirement, agronomy and recent hydrological conditions for future development.

5. Sediment deposition problem threatens Tekeze reservoir by decreasing the live storage and it should be studied for further analysis. To minimize the problem, integrated water shade management should be carried out.

6. Water quality and water supply aspect downstream of power plant should be considered for further analysis.

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A APPENDIX

A.1. Hydrology of the reservoir

Table 13: Reservoir inflow

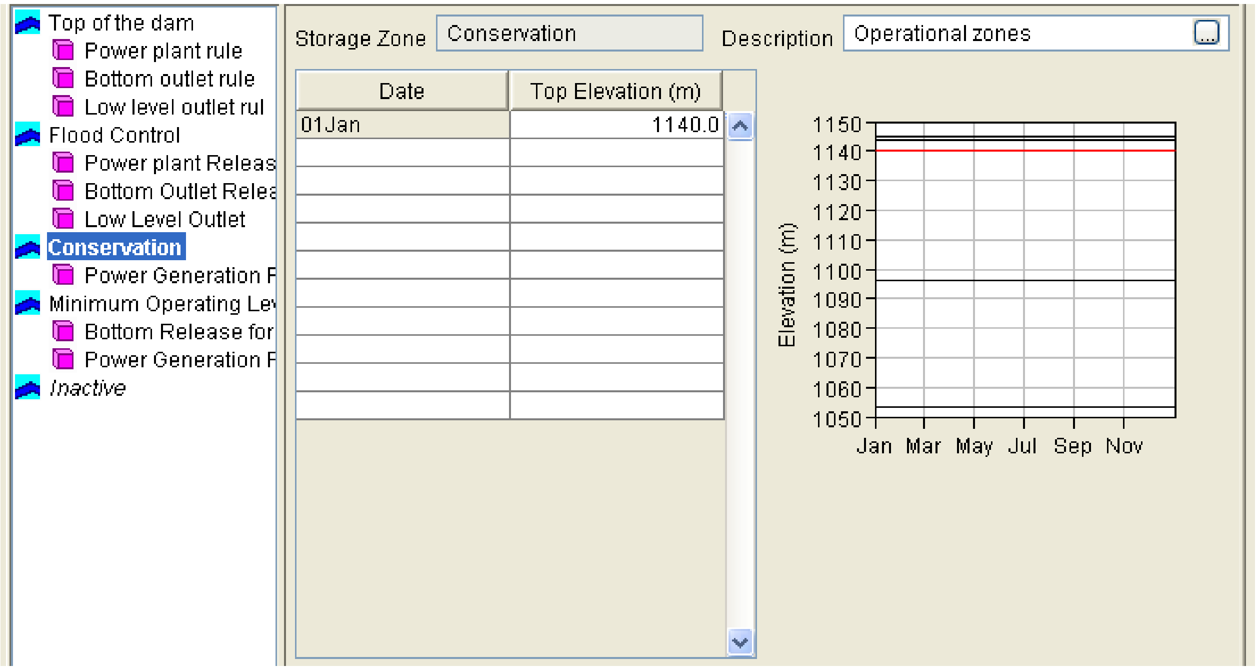
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1966	3.9	2.7	4.4	6.1	10.8	30.6	204.5	641.2	273.0	45.8	15.8	8.9
1967	8.9	6.0	9.4	13.2	23.7	49.9	1342.5	1686.4	556.1	144.4	27.0	23.7
1968	14.8	8.7	6.4	9.7	7.4	130.4	567.2	681.6	221.0	40.4	12.2	8.9
1969	6.9	5.5	33.5	36.2	77.9	46.9	328.7	762.4	255.1	87.7	32.1	9.4
1970	4.9	3.8	3.9	8.1	2.5	102.9	972.8	616.0	347.3	86.2	22.4	12.3
1971	8.9	4.9	5.4	6.6	29.1	51.9	313.4	455.4	197.6	31.5	12.2	7.9
1972	4.4	2.7	3.4	16.8	10.3	63.7	365.2	409.1	98.3	13.8	11.2	3.9
1973	2.5	2.2	2.5	6.1	17.7	3.6	565.8	1340.5	307.6	80.3	20.9	9.9
1974	6.4	3.8	5.4	5.6	31.0	74.4	516.5	1084.2	292.8	46.8	20.9	13.8
1975	7.9	6.9	4.4	11.8	3.4	58.6	501.7	1440.5	955.6	173.0	60.1	41.4
1976	23.7	13.8	18.7	14.3	31.0	70.5	389.8	941.3	307.5	68.5	42.4	20.2
1977	5.9	3.4	5.9	8.4	15.3	41.9	397.2	907.3	264.7	64.6	21.2	12.8
1978	5.4	3.4	5.4	7.4	13.8	37.9	628.4	534.2	266.1	58.6	19.7	11.3
1979	3.9	2.5	4.4	5.9	10.8	29.1	385.9	564.8	148.3	45.3	14.8	8.9
1980	5.4	3.4	5.4	7.4	14.3	38.4	431.7	815.1	205.5	59.6	19.7	11.8
1981	5.9	3.4	5.9	7.9	14.8	40.4	497.3	641.2	390.8	63.1	20.7	12.3
1982	3.4	2.0	3.9	4.9	9.4	25.6	213.4	677.2	70.5	39.4	13.3	7.9
1983	4.9	3.0	4.9	6.4	12.3	33.5	340.5	694.4	232.1	52.2	17.2	10.3
1984	4.4	3.0	4.9	6.4	11.8	32.5	377.0	750.2	271.6	50.3	16.8	9.9
1985	4.9	3.0	4.9	6.9	12.8	35.0	327.2	599.8	396.7	54.7	18.2	10.8
1986	5.9	3.4	5.9	8.4	15.3	41.9	587.9	553.9	443.1	65.1	21.7	12.8
1987	3.0	2.0	3.0	3.9	7.4	20.2	106.5	473.1	184.8	31.5	10.3	6.4
1988	9.4	5.4	9.4	12.8	24.1	65.5	931.0	1158.6	370.1	101.5	33.5	19.7

1989	5.4	3.4	5.4	7.4	13.8	37.5	317.9	666.8	417.9	57.7	19.2	11.3
1990	3.9	2.5	3.9	5.4	9.9	27.1	222.3	753.2	228.7	42.4	13.8	8.4
1991	8.4	4.9	8.4	11.3	21.7	58.6	810.7	761.4	643.6	91.2	30.1	17.7
1992	5.9	3.4	5.9	8.4	15.8	42.4	478.0	885.1	230.2	65.5	21.7	12.8
1993	6.9	3.9	6.9	9.4	17.7	48.3	347.9	773.3	695.4	74.9	24.6	14.8
1994	8.4	5.4	8.9	11.8	22.2	60.6	903.9	1109.9	268.1	94.1	31.0	18.2
1995	4.4	3.0	4.9	6.4	11.8	32.5	503.2	596.8	116.8	50.3	16.8	9.9
Aver	6.6	4.2	6.9	9.4	17.3	47.7	495.9	799.2	321.9	66.0	22.1	12.9

Table 14: Evaporation loss from the reservoir

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Evaporation(mm)	155	162	200	198	201	154	126	116	136	188	146	139

A.2. HEC-ResSim model result

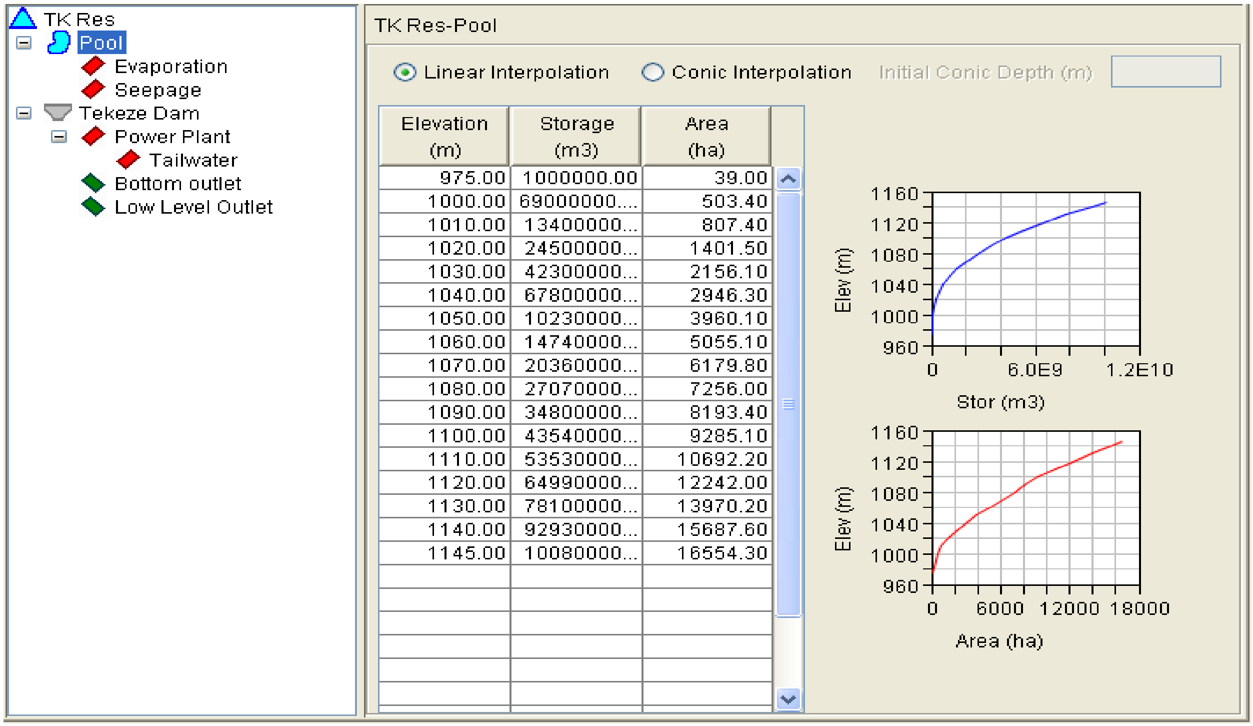


Storage Zone: Conservation

Description: Operational zones

Date	Top Elevation (m)
01Jan	1140.0

Figure 43: Reservoir operation zones

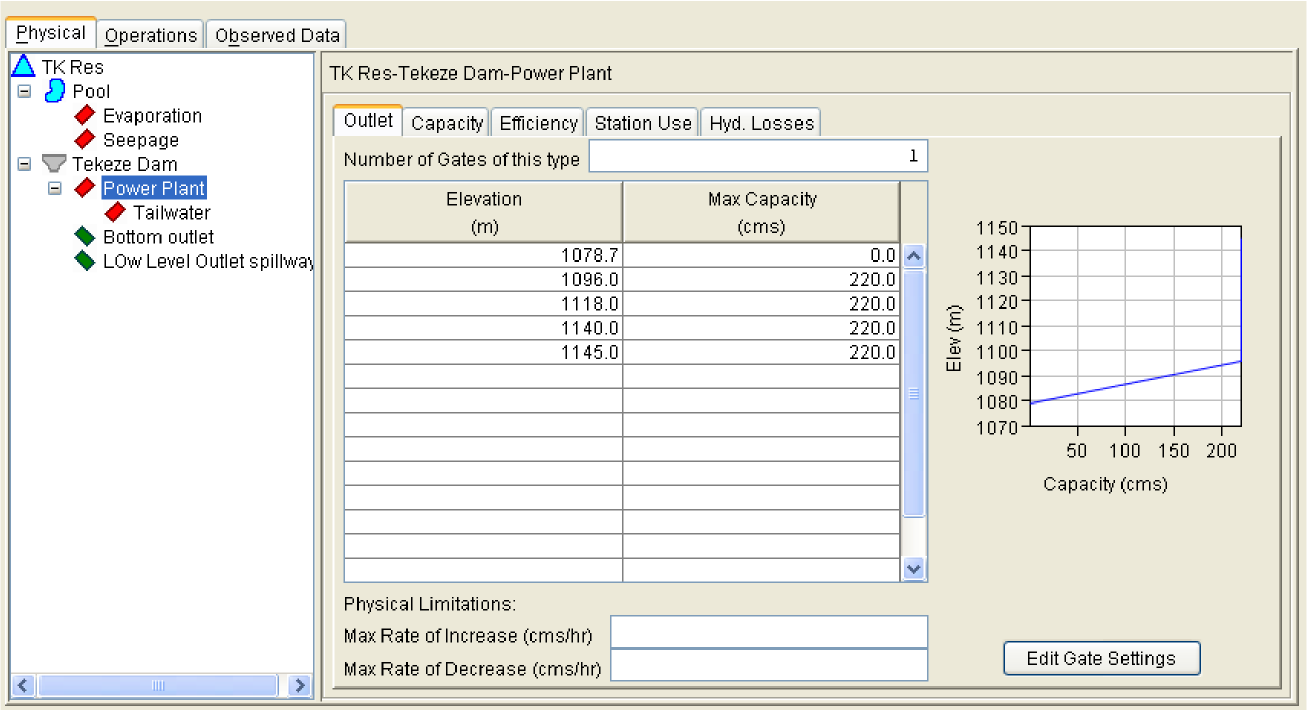


TK Res-Pool

● Linear Interpolation ○ Conic Interpolation

Elevation (m)	Storage (m3)	Area (ha)
975.00	1000000.00	39.00
1000.00	69000000....	503.40
1010.00	13400000...	807.40
1020.00	24500000...	1401.50
1030.00	42300000...	2156.10
1040.00	67800000...	2946.30
1050.00	10230000...	3960.10
1060.00	14740000...	5055.10
1070.00	20360000...	6179.80
1080.00	27070000...	7256.00
1090.00	34800000...	8193.40
1100.00	43540000...	9285.10
1110.00	53530000...	10692.20
1120.00	64990000...	12242.00
1130.00	78100000...	13970.20
1140.00	92930000...	15687.60
1145.00	10080000...	16554.30

Figure 44: Stage – Area – Volume curve



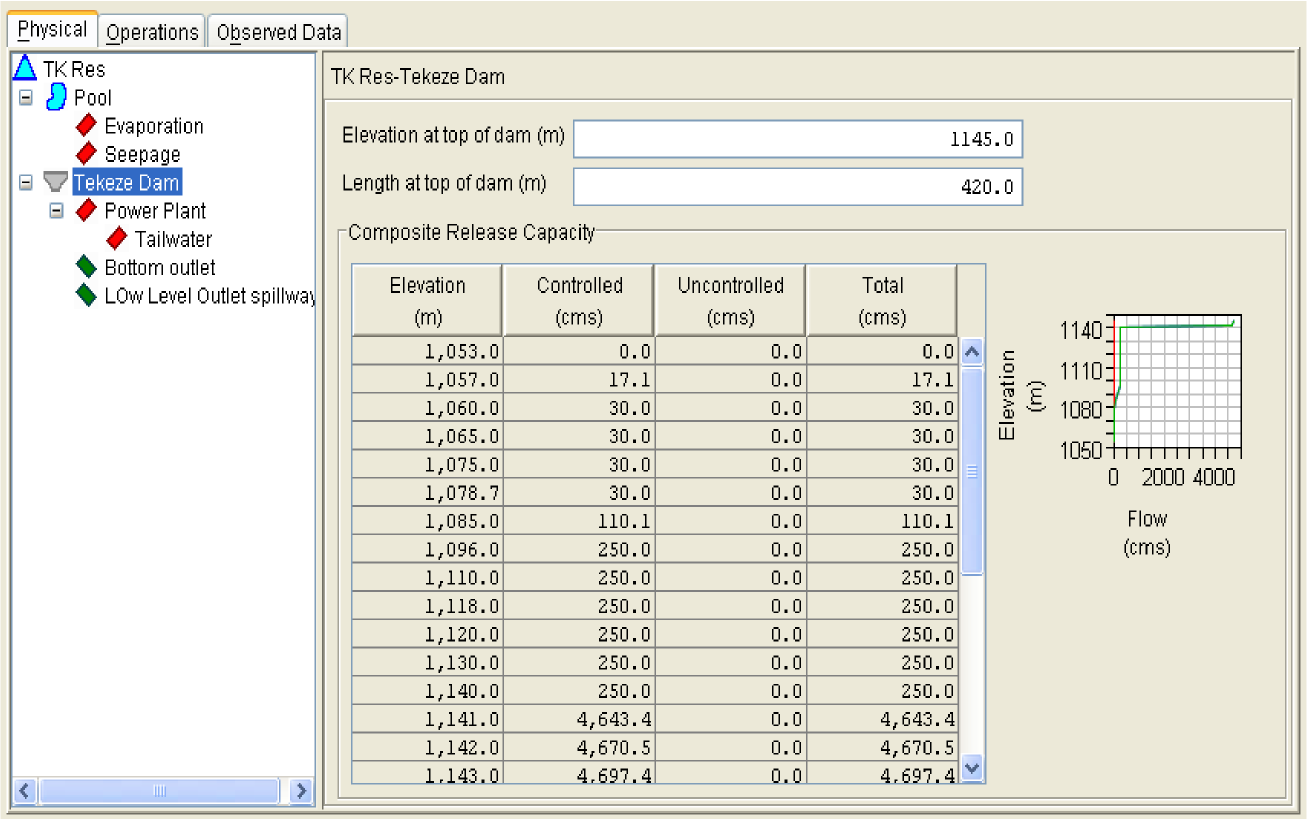
TK Res-Tekeze Dam-Power Plant

Number of Gates of this type: 1

Elevation (m)	Max Capacity (cms)
1078.7	0.0
1096.0	220.0
1118.0	220.0
1140.0	220.0
1145.0	220.0

Physical Limitations:
Max Rate of Increase (cms/hr)
Max Rate of Decrease (cms/hr)

Figure 45; Power plant rating curve



TK Res-Tekeze Dam

Elevation at top of dam (m): 1145.0
Length at top of dam (m): 420.0

Composite Release Capacity

Elevation (m)	Controlled (cms)	Uncontrolled (cms)	Total (cms)
1,053.0	0.0	0.0	0.0
1,057.0	17.1	0.0	17.1
1,060.0	30.0	0.0	30.0
1,065.0	30.0	0.0	30.0
1,075.0	30.0	0.0	30.0
1,078.7	30.0	0.0	30.0
1,085.0	110.1	0.0	110.1
1,096.0	250.0	0.0	250.0
1,110.0	250.0	0.0	250.0
1,118.0	250.0	0.0	250.0
1,120.0	250.0	0.0	250.0
1,130.0	250.0	0.0	250.0
1,140.0	250.0	0.0	250.0
1,141.0	4,643.4	0.0	4,643.4
1,142.0	4,670.5	0.0	4,670.5
1,143.0	4,697.4	0.0	4,697.4

Figure 46: Tekeze dam outlet rating curve

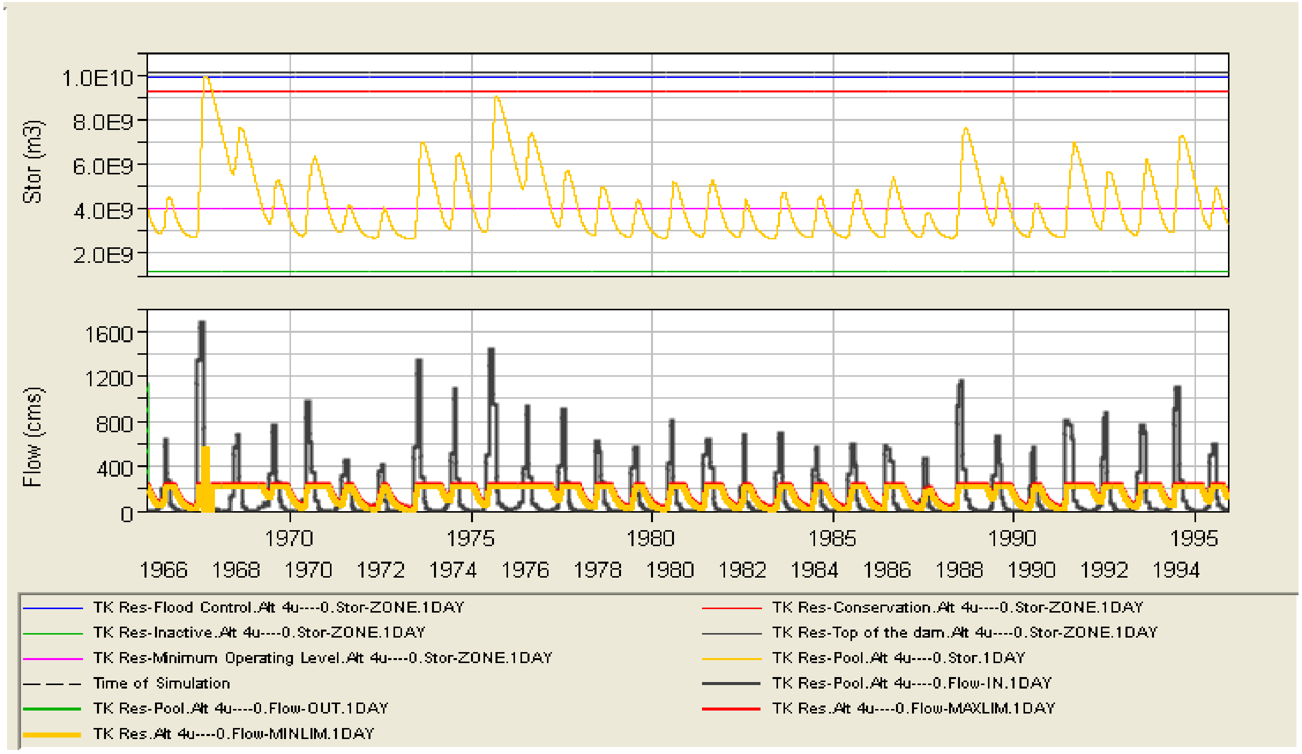


Figure 47: Simulation at scenario one

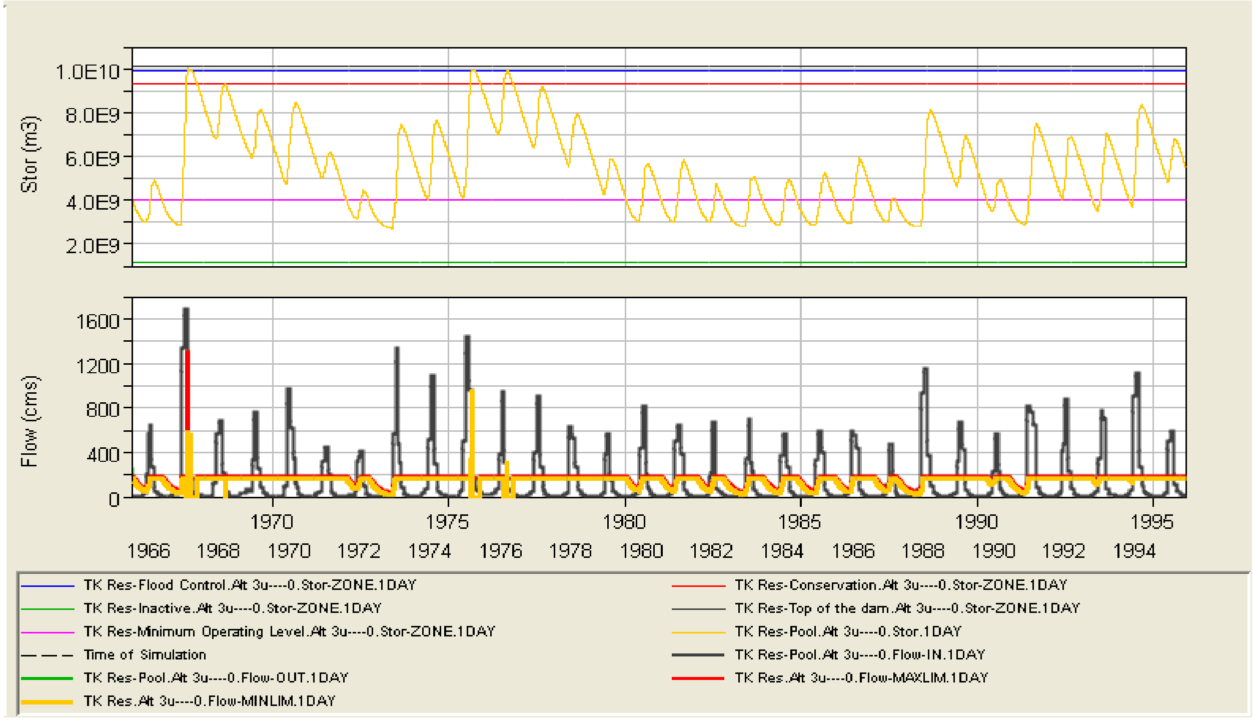


Figure 48: Simulation at scenario two

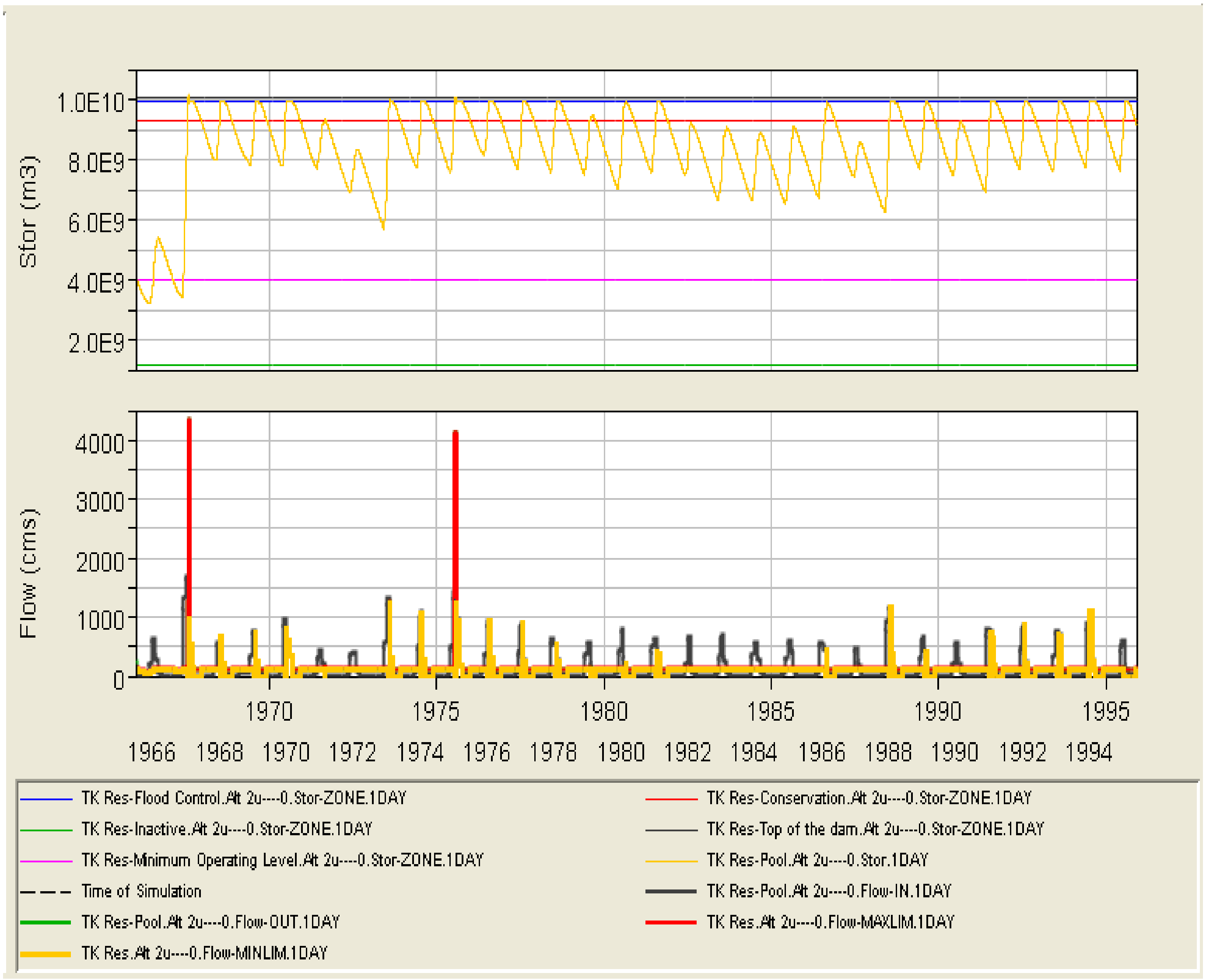


Figure 49: Simulation at scenario three

A.3. HEC- DSS model result

HEC-DssVue is a tool for transferring time series data from Excel HEC-DSS database storage to a working space or it allows to access data stored in HEC-DSS database. A key step in transferring a time series data from the database storage in to the DSS format is the creation of DSS catalog inside the database. DSS catalog is the object class table within the database that contains the information related to the DSS data and its pathname. The DSS pathname consists of six parts in the following format.

A/B/C/D/E/F

Tekeze basin/Dam site/ flow/Jan 1966 – Dec 1995/monthly/Opm

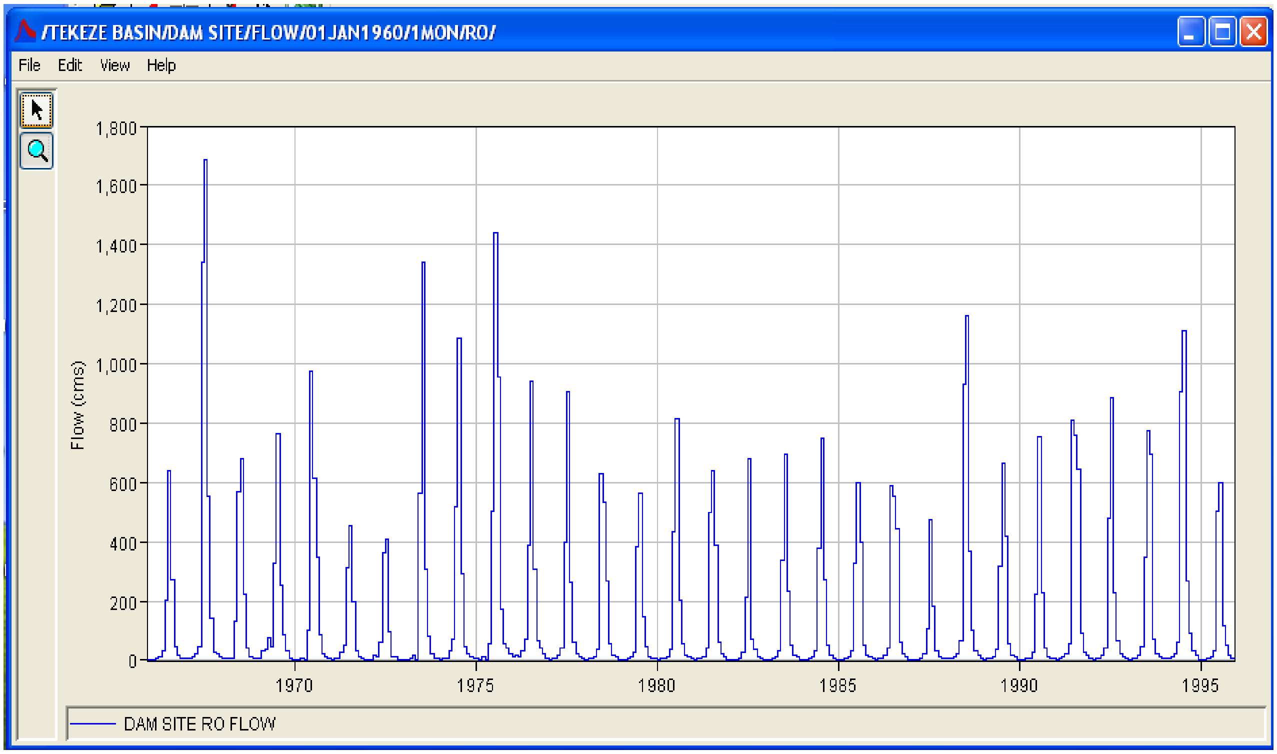
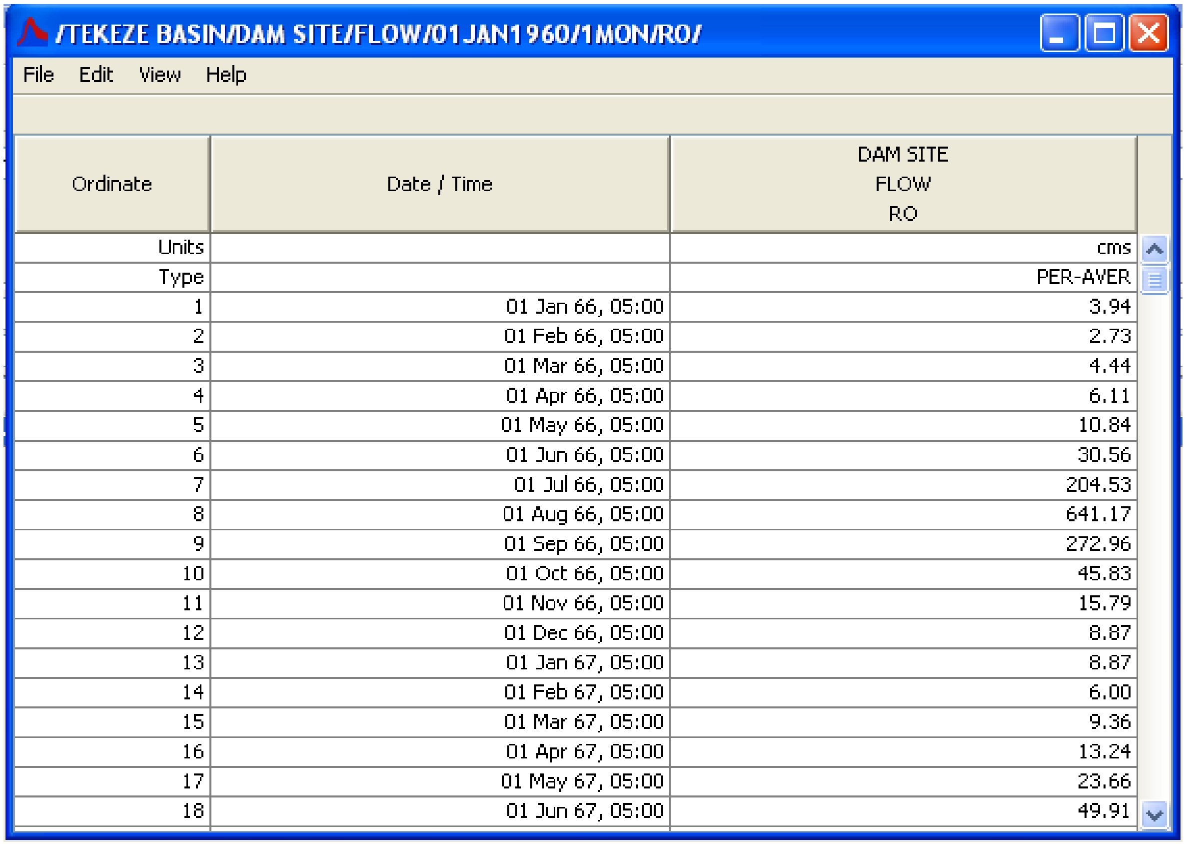


Figure 50: Inflow output in HEC-DssVue



Ordinate	Date / Time	DAM SITE FLOW RO
Units		cms
Type		PER-AVER
1	01 Jan 66, 05:00	3.94
2	01 Feb 66, 05:00	2.73
3	01 Mar 66, 05:00	4.44
4	01 Apr 66, 05:00	6.11
5	01 May 66, 05:00	10.84
6	01 Jun 66, 05:00	30.56
7	01 Jul 66, 05:00	204.53
8	01 Aug 66, 05:00	641.17
9	01 Sep 66, 05:00	272.96
10	01 Oct 66, 05:00	45.83
11	01 Nov 66, 05:00	15.79
12	01 Dec 66, 05:00	8.87
13	01 Jan 67, 05:00	8.87
14	01 Feb 67, 05:00	6.00
15	01 Mar 67, 05:00	9.36
16	01 Apr 67, 05:00	13.24
17	01 May 67, 05:00	23.66
18	01 Jun 67, 05:00	49.91

Figure 51: Inflow parameterization in HEC-DssVue