



Addis Ababa University
School of Graduate Studies
Addis Ababa Institute of Technology

**Establishing optimal reservoir operation of
Fincha`a – Amerty Reservoirs**

**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 Hydraulic Engineering)**

By

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Advisor

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Addis Ababa University

October, 2016

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Approval by Board of Examiners

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Chairman (Department of Graduate Committee)	Signature

ABSTRACT

Hydropower generation is one of the vital components of reservoir operation, especially for a large multi-purpose reservoir. Deriving optimal operational rules for such a large multi-purpose reservoir serving various purposes like irrigation, hydropower and flood control are complex, because of the large dimension of the problem and the complexity is more if the hydropower production is not an incidental. Thus optimizing the operations of a reservoir serving various purposes requires a systematic study. The general objective of this thesis work is to identify the causes of problems of current operational rules and developing alternative operation rules for Fincha`a and Amerty reservoirs. In the present study such a large multi-purpose reservoir, namely, Fincha`a reservoir operations are optimized for maximizing the hydropower production subject to the condition of satisfying the irrigation demands using Excel solver. The hydropower production from the reservoir is analyzed for two different conditions. 1) Considering only fulfilling downstream demand in which yearly average energy production is found to be 678.368GWh and 2) giving priority first for power production, by taking the best alternative, the yearly average energy production is 848.931GWh. The study shows that Fincha`a dam and reservoir is having potential to generate more hydropower than producing the current production.

The study concludes the main problems behind having lower energy production are inappropriate release water and Downstream Wet season water requirement and inappropriate release of water from Amerty reservoir.

Key Words: Amerty Reservoir, Excel Solver, EEPKO, Fincha`a Reservoir, Release rule curve.

DECLARATION

I, the undersigned, certify that I have read and here by recommended for acceptance by the Addis Ababa University a Thesis entitled: **Establishing optimal reservoir operation Of Fincha`a – Amerty Reservoirs** 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 Hydraulic Engineering.

Name: Amayou Belissa

Signature: _____

Date: _____

Place: Addis Ababa Institute of Technology, School of civil and Environmental Engineering,

Addis Ababa University

DEDICATION

This Thesis is dedicated to my Wife

Gadise Mekonen Akuma

And

To my Brother

Tolera Desalegn Enkosa

ACKNOWLEDGEMENT

First and for most I thank my Almighty God, for through Him I had my well-being and passed every hurdle in my study time and in my life.

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I am very grateful to my beloved Wife Gadise Mekonen, my parents and my friends for their consistent encouragement throughout my study.

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List of Acronyms

ETO	Potential Evapotranspiration
FSL	Full supply level
MoWE	Ministry of water resource and energy
MOL	Minimum operating Level
masl	Meter above sea level
Mm ³	Million cubic meters
MW	Mega watt
MWh	Megawatt hour
NMA	National meteorological Agency
Acres	Acres international
MOWIE	Ministry of Water, Irrigation and Energy
PC	Personal computer
EACE	Ethiopian Association of Civil Engineering
GRG	Generalized Reduced Gradient

1. Introduction

1.1. Back ground

Ethiopia is located between 4° and 15° N latitude, 32° and 48° E longitudes. The country has an area of 1112000km^2 . The country is naturally endowed with small to large streams that drain from the high plateau areas to the lowlands. The annual surface runoff potential of the country, excluding ground water, is estimated to be 122 billion m^3 , from the twelve major basins, (MoWR, 2002).

Reservoirs are one of the major storages of surface water and optimally operating single or multi reservoir network forms an integral part in water resources management. By altering the spatial and temporal distribution of runoff, reservoirs serve many purposes, such as flood control, hydropower generation, navigation, recreation, etc. (Chen et al., 2011). 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.

Optimal reservoir operation has been extensively reported in the literature. Yeh (1985) and, more recently, Labadie (2004) provided a state-of-the art review of multi reservoir systems operation. Generally speaking, the problem is to determine a sequence of release decisions that maximize the benefits from system operation over a given planning period while meeting operational and/or institutional constraints. According to Karamouz et al. (2003), optimal hydropower reservoir operation requires a time decomposition approach; optimal decisions are the result of a process consisting of a sequence of models with different time frames. Long-term planning models (e.g., monthly time step and over year planning horizons) provide strategic and tactical policies information. The results of interest (e.g., future marginal water value and storage levels) from this class of models then provide boundary conditions for mid- and short-term optimization tools (e.g., weekly to daily time horizons), to finally feed real-time operation models that focus on load dispatching, unit commitment, and transmission constraints.

Traditionally, reservoir operation is based on heuristic procedures, embracing rule curves and subjective judgments by the operator. This provides general operation strategies for reservoir releases according to the current reservoir level, hydrological conditions, water demands and the

time of the year (Long le Ngo et al., 2006). Established rule curves, however, do not allow a fine tuning (and hence optimization) of the operations in response to changes in the prevailing conditions. Therefore, it would be valuable to establish an analytic and more systematic approach to reservoir operation, based not only on traditional probabilistic/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 the different users.

A reservoir system has been a wide variety of purposes which some of them are not in line with each other. By using mathematical modeling, the behavior of systems can be defined in mathematical terms, and they will be examined under different conditions.

Due to the lack of such advanced reservoir operation system in the country the fluctuation and shortage of power production and improper operation of any one of the reservoir technically inefficient operation that failed to meet the desired objective has been noticed.

Out of the existing few storage schemes of the country, Fincha'a and Amerty Dams and reservoir is the earliest in the Blue Nile basin constructed 1968 and 1984 respectively.. Fincha'a reservoir is a circular shaped reservoir that covers the upstream Fincha'a swamp and a portion of chomen swamp. Its effective capacity is about one billion m^3 . Amerty dam is a diversion dam that diverts the summer Amerty stream flood to the Fincha'a reservoir and it is also storage dam that stores part of the summer flood to augment the Fincha'a system during the dry operation. The shape of Amerty reservoir is U-shape that helps to store a considerable volume of water with relatively small evaporation losses.

The Fincha'a power plant is a unique high head power plant in the country that covers part of the base and the peak loads of the interconnected systems. The installed capacity of the power plant is 134MW and comprises 4-pelton turbines. Each has the generating capacity of 33.3MW. Amerty-Fincha'a reservoirs are the source of water for power plant.

After the continuous power generation, the water from the powerhouse flows back to the natural Fincha'a river course at the lower Fincha'a valley, where it is used by the downstream water resource activities or the lower valley projects. The downstream project comprises irrigation, domestic and factory water supply and effluent dilution requirements. The daily demand of the

downstream projects depends on the daily power production pattern, which itself depends on the load share given from interconnected electricity system.

Currently all the downstream activities level of development is below 50% of their total potential capacities and hence the minimum power release effectively satisfies the daily downstream demands. However, as the downstream irrigation project expands and the corresponding factory production capacity increases, the daily minimum water demand increases and reaches the point where the downstream water requirement affect the daily power generation pattern. At this period, the power production must take in to account the downstream requirement in addition to the interconnected systems load share. The reservoirs have also become multipurpose reservoirs that consider not only just the power requirement, but also the total downstream demands. The reservoir operation, therefore, requires an optimal release rule, which answers the question of water among the conflicting scenarios based on priority and an objective function.

The purpose of this study is to develop a water resource planning model for optimal operation of a multipurpose multi-reservoir system and water allocation for energy production.

1.2. Problem statement

Fincha`a has developed into a small town associated with one of the country`s most important hydroelectric power plants. The dam and power-station were built in the early 1970s.

The Fincha`a River, a tributary of the Blue Nile in western Ethiopia, had great potential for a multi-purpose dam that would provide power generation and water storage for fisheries, irrigation, and recreation. Following these studies, a dam was constructed in 1973. The entire area draining towards this dam is called the Fincha`a watershed.

Hydropower projects on tributaries and the main stream could rapidly modify seasonal flows by means of their storages. Improper operation of any one reservoir especially in the case of series reservoir systems, will lead to technically and economically inefficient operation that fail to meet the desired objective (Genet, 2008).

Most of the reservoirs in our country have a lack of predetermined, up-to-date and real time reservoir operation policy that will benefit all users in the basin. It is not unusual to observe that most of the reservoirs are unable to meet the desired purpose due to lack of optimum operation policies (Daniel, 2011).

Fincha`a and Amerty reservoirs are the sources of water for Fincha`a power plant and the downstream activities. The reservoirs are joined by the diversion tunnel that enables the Amerty reservoir to augment the Fincha`a reservoir. The diversion tunnel is provided with vertical lifted regulating gate. In the existing operation, the tunnel gate is ruled by seasonal gate operation pattern, that is the gate is open mainly from early June to end of September or early October and closed otherwise. Due to this seasonal operation it has been difficult to know the exact period of starting or ending of the tunnel releases. Hence it is very common to observe the problem of high evaporation and spillage losses from the two reservoirs due to early or to late releases, respectively. To make the tunnel gate operation more realistic and advantageous in terms of the minimum total loses, the operation has to consider the level of the two reservoirs.

Due to the expansion of Fincha`a sugar factory at the downstream and the level of the development of the people the current existing release may not satisfy the total downstream requirements. This requires an optimal release operation.

In spite of the huge amount of untapped regulatable water resources available in the reservoir, the reservoir level has fallen close to its minimum operating level.

Therefore, this study analysis the optimal reservoir operation by Excel model and downscale the effect for the coming years. This research will show how to use proper water release system in the Fincha`a and Amerty reservoirs.

1.3. The objective of the study

1.3.1. General Objectives

The general objective of this thesis work includes identifying the causes of problems of current operational rules and developing alternative operation rules for Fincha`a and Amerty reservoirs.

1.3.2. Specific Objectives

Some of the specific objectives adopted to meet the main objective include:

- To identify the challenges and problems of current reservoir operation for Fincha`a and Amerty Reservoirs.
- To establish water release rules for different scenarios of the simulation
- To determine the optimum reservoir operation system to maximize the energy generation and crop production.

1.4. Scope of the study

Information is available on the capacity of existing; committed Fincha`a hydropower plant as well as that of both Fincha`a and Amerty reservoirs under study. This research involves determining the capacity of reservoirs and water release rules especially for Fincha`a reservoir for maximization of energy and fulfillments of downstream demand. Efforts were made to include efficiently the available water from Amerty reservoir to Fincha`a reservoir to attain maximum head from Fincha`a reservoir and gain additional water to use for hydropower and downstream release. The scope of the research has been limited to determine reservoir release rule and maximization of Energy Attained from Fincha`a hydropower.

1.5. Outline of the study

This study presents the optimal reservoir operation of Fincha`a – Amerty reservoir systems for the maximum system performance. The study considers a number of interrelated activities including the downstream demands.

This study is divided in to eight sections. Section one contain the introduction part for optimal reservoir; in section two the general description of the project area including the geological and climatic conditions and some important unique features in the upper Fincha`a –Amerty watershed. In Section three literature reviews is presented and some previous related studies in the project area are available. Section four the reservoirs, existing dam operation and the downstream activities area discussed in detail. In section five methods and material used are presented. In section Six, data collection and analysis from different sources are presented and analyzed. In section seven, the result of the optimal reservoir operation and brief summery are presented. Section eight contains brief conclusion and recommendation.

2. Study area

2.1. Location

The Fincha`a River sub-basin is located in the south central portion of the Blue Nile River basin. It is bounded on the south by the Great Gibe River basin, on the north by the Abbay (Blue Nile) River, on the west by the Diddessa sub-basin, and on the east by the Guder drainage area.

The Fincha`a watershed is located between 9°10'30" to 9°46'45" north latitude and between 37°03'00" to 37°28'30" east longitude. In administrative terms, it is situated in the Wollaga, Oromiya region in western Ethiopia (figure 1). It covers an area of about 1,318 km².

The Fincha`a hydropower dam has 340 m crest length and reaches 20 m above the lowest foundation level (HARZA, 1975).

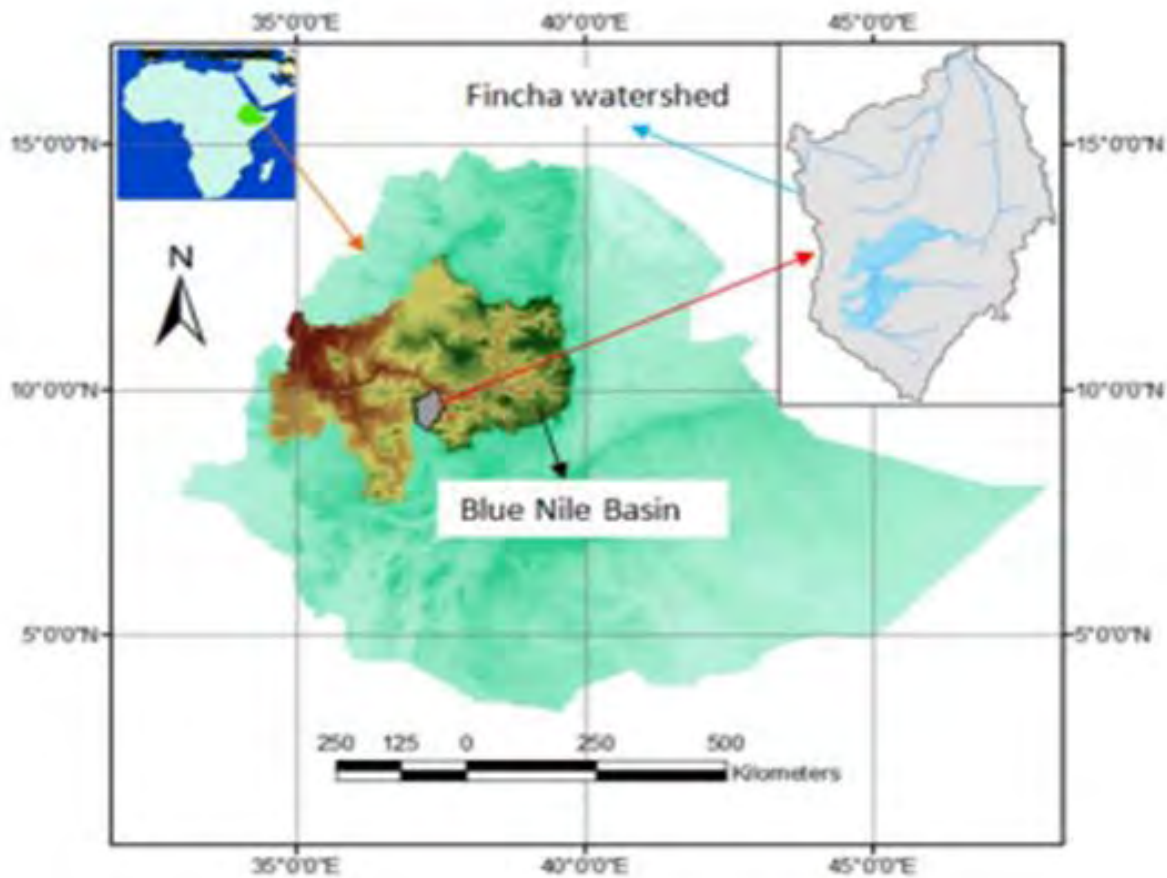


Figure 2.1 Location of Fincha`a Watershed in Blue Nile basin, Ethiopia

2.2. Climate and Rainfall

Weather data were available from a station at Shambu town, which is situated in the middle part of the watershed (09°34' N latitude and 37°06' E longitude and elevation 2430 m). The average annual rainfall over the period of 1970–2003 was 1823 mm. About 80% of the annual rain falls between May and September.

The climate of the area upstream from the escarpment is typical of the high plateau area of Ethiopia. Temperatures are moderate as a result of the high elevation.

Climatological records for the project area were obtained at the climatological station located near the outlet of Fincha`a swamp. These records were kept for a very short period. However, the variation in climatological factors from one year to another is quite moderate, so that even a short record provides a reasonable determination of average conditions.

2.3. Temperatures

The temperature in the area will be seen that daytime temperatures are moderate and night temperatures cool. Temperature variations from month to month are small, there being a range of only 3.6°C between the warmest and the coolest average monthly temperatures. Day-to Day variations also are small, as indicated by the small differences between daily maximum and average monthly maximum values. The monthly mean temperature varies from 14.9°C to 17.5°C. The average annual Reference Evapotranspiration (based on Penman-Monteith) is 1320 mm, with low monthly variations.

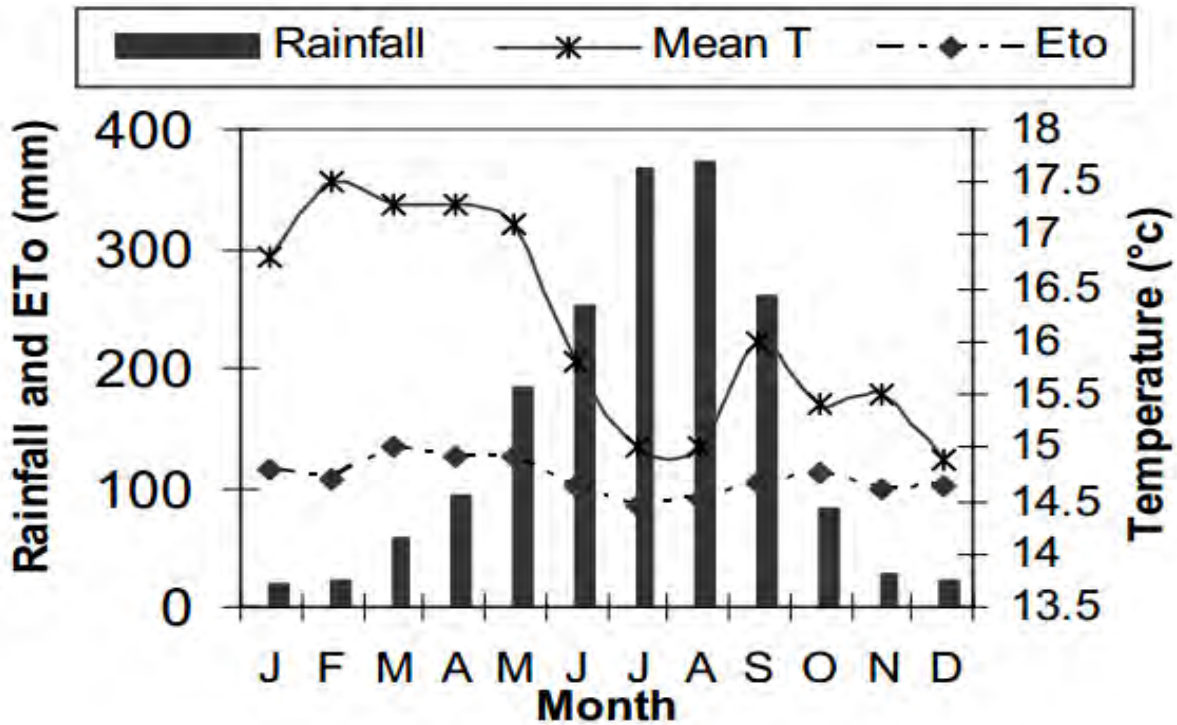


Figure 2.2 climatic condition of Fincha`a reservoir area

2.4. Topography

Elevation in the watershed ranges from between 2,200 m at the dam site to 3,100 m at the highest level. Most of the area (80%), which can be described as a wide rolling plateau, is within the altitude range of 2,200 m-2,400 m (figure 3). About 51% of the watershed is at (0-3% gradient) and this land is mainly under water reservoir and swamp. Gently sloping (3-8% slope) to sloping (8-15% slope) areas cover about 34% of the territory,

While steep (15-30% slope) to very steep (>30% slope) areas cover about 15% of the watershed. The higher areas near the boundary of the watershed, plus the elevated parts in the middle of the water-shed, which are isolated outcrops, consist of Quaternary volcanic rock. The dominant soils in the watershed have textures ranging from clay to clay-loam and loam.

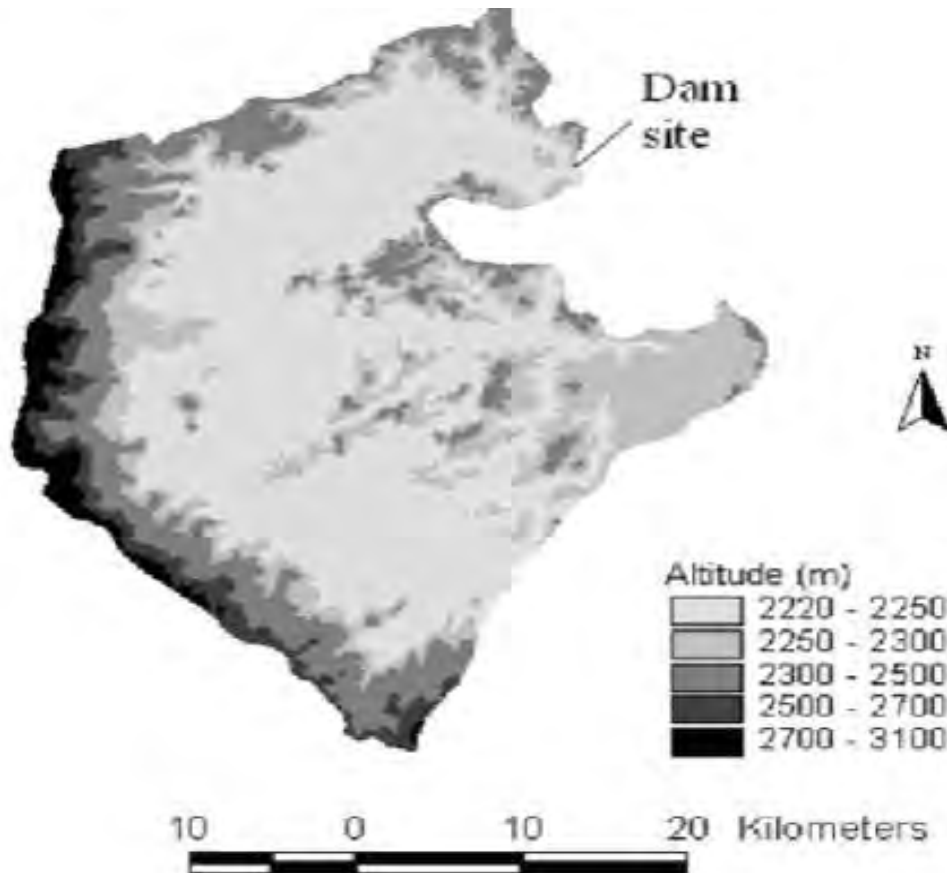


Figure 2.3 Topographic map of Fincha'a watershed

2.5. Reservoir Geology

The Fincha'a reservoir would be in the chomen swamp, the basin of which is covered with black clay of unknown depth. It may be as much as 10 meters in depth and is believed to be underlain by volcanic rock. The soil cover forms an excellent impermeable blanket and seepage is not considered to be a serious factor. The reservoir at a normal water surface elevation would impound 464 million cubic meters of water at initial storage, covering an area of 188 square kilometers.

Amerty basin is covered with clay, forming an excellent impervious blanket. Seepage is not considered a serious problem. The wide, flat bottomed, grassland valleys are underlain by a thin flow of younger basaltic lava which has prevented rapid downward erosion. The reservoir at normal water surface elevation would impound 847 million cubic meters of water covering an area of 53 square kilometers.

2.6. Main rivers and swamps in the Fincha`a- Amerty Watershed

Fincha`a river

The Fincha`a river is a medium sized left bank tributary of the Blue Nile river originating in the high plateau block of Ethiopia. It drains an area of about 2500km² in Oromia-east Wollega zone.

At the upper sub-basins, above the fall, the river drains about 1275km², of which the chomen and Fincha`a water shade covers 860km² and 415km² respectively. Amerty and Neshe are the major perennial rivers that join to Fincha`a river in the lower valleys before the river joins the Blue Nile. The average annual flow of Fincha`a river is about 405Mm³ or 12.7 m³/s, (Salzgitter, 1986).

Amerty River

Amerty River emerges from the elongated Amerty swamp. The river has 245km² drainage area and about 4.3m³/s annual mean flow. The River joins to Fincha`a river at the lower valley before Fincha`a join to the Blue Nile. The flow of Amerty River is diverted to Fincha`a reservoir.

Fincha`a and Chomen swamps

The upper Fincha`a watershed is highly dominated by swam complex. The swamp complex includes chomen, Fincha`a and Amerty swamps, which are the major sources of Fincha`a and Amerty Rivers. The chomen and the Fincha`a swamp are the main sources of Fincha`a River. The two swamps cover about 265km² and 145km² of land, which is about 32% of the total upper Fincha`a watershed, 1275km².

The chomen swamp is located in the southern upstream of Fincha`a swamp. The swamp drains towards Fincha`a reservoir through the adjoining saddle point. The adjoining saddle bottom is 1200m wide and 2212m above sea level. The very common features of all the upper watershed swamps, specifically Chomen, Fincha`a and Amerty swamps is the existence of the floating islands over the surface of the water (HARZA, 1975)

Floating islands

The floating islands, also called phreatophytes are the large mass of vegetation lands float on the surface of the reservoirs and move along the direction of flowing water or the direction of blowing wind. The floating islands covering the reservoir surface affects the volume lost and gained by evaporation and rainfall, due to the interception of the floating island vegetation cover. The two independent studies over the reservoirs and the swamps reveals that the evapotranspiration losses from floating islands plant is 1.2 to 1.35 times more than free water surface losses from the reservoirs,(Acres I.L, 1981).

In actual condition, the floating island causes the operation problems in the Amerty diversion and Fincha`a power intake. The huge mass of floating island is driven along with the blowing wind or the flowing water towards the diversion intake gate or power intake. Hence, it causes a problem of full flow of water .In Both Fincha`a and Amerty reservoirs chain-belt has been kept at the upstream of the reservoir and head reach canal to protect blocking of the in power take and diversion tunnel respectively.

2.7. Evaporation

The process by which water is changed from the liquid or solid state into the gaseous state through the transfer of heat energy is known as evaporation.

In the hydrological cycle evaporation is an important process, so much so that on a continental basis, approximately 70 to 75 per cent of the total annual precipitation is returned to the atmosphere by evaporation and transpiration. In hot climates, the loss of water by evaporation from rivers, canals and open-water storage equipment is a vital matter as evaporation takes a significant proportion of all water supplies. It is significant in the sense that most of the water withdrawn for beneficial uses ultimately returns to streams and aquifers and becomes available for reuse, while the loss of water due to evaporation is entirely lost from the usable supply. Even in humid areas, evaporation loss is significant although the cumulative precipitation tends to mask it so that it is ordinarily not recognized except during rainless periods. Storage reservoirs expose wide surfaces to evaporation and thus are a major source of water loss even though they may lessen natural evaporation by confining floods in deep storages instead of spreading over wide flood plains. The factors controlling evaporation have been known for a long time, but evaluating them is difficult because of their interdependent effects. However, in general,

evaporation is affected by temperature, wind, atmospheric pressure, humidity, water quality, water depth, soil type and nature, and shape of surface.

2.7.1. Measurement of evaporation

Estimation of evaporation from water surface is of a great importance in hydrological studies and is useful in determining the operation procedure for reservoir system. Direct measurement of evaporation from large water bodies is not possible at present. However, several indirect methods have been developed that give acceptable result. Some of the common measuring methods are:

- A. Measurement using evaporimeters (i.e., pan evaporimeters and atmometers).
- B. Empirical equations.
- C. Water balance method.
- D. Energy budget method.
- E. Mass transfer method.

Out of all the above methods measurement using an evaporimeters are the most reliable. Evaporation records of pans are frequently used to estimate evaporation from lakes and reservoirs. Many different types of evaporation pans are in use. Among various type the US class A was recommended by WMO. Its performance has been studied under a range of climatic condition within wide limit of latitude and elevation, (WMO, 1994).

The other common evaporation measuring instrument is the piche atmometer. The piche atmometer has, as an evaporating element, a 32mm diameter disk of filter paper attached to the underside of an inverted graduated cylinder tube graduated from zero to 300mm closed at one end, which supplies water to the disk. Successive measurement of the volume of water remaining in the graduated tube will give the amount lost by evaporation in any given time. Water replacement occurred whenever the water level was above 200mm.

The evaporimeters still have some inconveniency due to heat diffusion in small pan cross section compare to large water bodies, due to insertion of water droplets at the time of rainfall, due to dust accumulation on the filter paper etc. Therefore, the value obtained cannot be used without adjustment to arrive at reliable estimate of lake or reservoir evaporation. To relate the daily piche and the pan records, and pan and the reservoir surface evaporation,

different experimenters and regression analysis were made. The most applicable and widely used coefficient is that pan Evaporation rate is 0.752 times the piche records and pan Evaporation rate is 0.7 times lake or reservoir evaporation, (WMO, 1994; Web 22, 23 and 24).

2.8. Dam and Reservoirs

2.8.1. Fincha`a and Amerty Dams

Fincha`a dam is an earth and rock fill embankment structure with a length of 340m and 22.2m high. The dam crest is at 2225masl and located 900m upstream of the Fincha`a fall. In cross section, it consists of impervious clay core inside with stabilizing rock shells on the outside upstream and downstream sloping faces. This cross section and dam type was selected as the most economical to make the most use of large quantity of natural earth material available in the immediate vicinity of the dam. The dam contains the power intake, uncontrolled spill way and irrigation outlets. The crest of the dam is 10m wide and is used as an access road to the Fincha`a to Addis Ababa main road.



Figure 2.4 Fincha`a rock fill Dam

The physical structure of Amerty dam is similar to Fincha'a Dam. The dam crest is 740m long and 15.3m high. It was constructed to augment the Fincha'a reservoir. The uncontrolled spill way is 10m long and is set at 2234masl respectively. The dam crest also used as an access road to the newly constructed Neshe hydropower project.

2.8.2. Fincha'a and Amerty Reservoirs

The Fincha'a Dam creates a reservoir that floods the Fincha'a and a portion of the chomen swamp. The maximum capacity of the reservoir is about 2394.83Mm³ without including the chomen swamp. The minimum water level of the reservoir is at 2212.5masl and the maximum normal operation level is at 2219masl. The reservoir volume between these two level is 1120.48Mm³. The maximum reservoir level reaches during the occurrence of the probable maximum flood is at 2221.9masl. Chomen in the south and southeast, the high plateau in the southwest and agricultural farm lands in the east bound the Fincha'a reservoir.





Figure 2.5 Fincha`a Reservoir

Amerty reservoir is a narrow and elongated U-shaped reservoir located at upper Amerty water shed. The reservoir acts as additional storage for Fincha`a reservoir due to its small surface area and hence lower evaporation losses. The reservoir has 40.1Mm³ effective capacity. The two reservoirs are joined by a 1.57 km long tunnel.

2.9. Hydropower and downstream activities

2.9.1. Fincha`a Hydropower

The Fincha`a hydropower plant is a high head plant with installed capacity of 134MW and the maximum generating capacity of 128MW. The power plant was completed in 1973 and comprises of four Pelton turbines each 33.3MW generating capacity. The power plant uses the net head of 555m and the total discharge of 29.68Mm³ of discharge.

2.9.2. Irrigation Potential in Fincha`a Water shed

The gross command area of the project that is favorable for sugar cane plantation is greater than 20,145ha. The project currently cultivates 8145ha at the west bank and 12000 ha at the east bank by sprinkler and small amount with drip irrigation system. The irrigation consists of river diversion structure, lined and unlined canal network, culverts, pumping stations and inverted siphon. Luvisol and vertisol soil types dominate the command area. The luvisol soil has high infiltration rate and covers about 75% of the total irrigable area.



Figure 2.6 Fincha`a irrigation Area

2.9.3. Fincha`a Sugar factory and main camp township water supply

The Fincha`a sugar factory is located almost at the center of the command area. The sugar factory produces white sugar and ethanol. The factory water supply system is divided in to the main camp and the small village water supply system. The small village`s water demand was added to the main canal capacity. The main camp water supply and factory demand at this stage is $2.5\text{m}^3/\text{s}$.

2.9.4. Environmental flows

Environmental flows are defined as the stream flow necessary to sustain habitats (including channel morphology and substrate), encourage spawning and the migration of fauna species to previously unpopulated habitats enable the processes upon which succession and biodiversity depend, and maintain the desired nutrient structure within lakes, streams, wetlands and riparian areas. Environmental flows may comprise elements from the full range of flow conditions which describe long term average flows, variability of flows including low flows and irregular flooding events.

Depending on the condition of a stream and the environmental values specified for that stream, the planning and management issues in respect to environmental flows might be:

- to manage stream flow diversion and discharges so as to maintain the current status of the aquatic ecosystems; or
- to manage stream flow diversion and discharges so as to restore aquatic ecosystems to a standard to meet the community's environmental values.

2.10. Diversion potential of Fincha`a reservoir

The upper Fincha`a watershed is rich in its water potential. The numbers of poorly drained swampy areas located adjacent to the Fincha`a reservoir are some of the good potential sites. The Fincha`a project still uses the First potential site, joining of Amerty and Fincha`a reservoirs by tunnel. There are also a number of similar alternatives by which diverting one or more rivers to the existing system could increase the annual flow by a significant amount, (Acres, 1981).

Table 2.1 Diversion potential to Fincha`a reservoir

Identification	Basins	Drainage area (km ²)	Mean annual flow (m ³ /s)
1	Fincha`a	415	4.48
2	Chomen	860	9.12
3	Amerty	245	4.3
4	Neshe	309	5.4
5	Fekere	135	2.36
6	Degaga	32	0.56
7	Dancho	62	1.09
8	Boye	55	0.96

3. Literature review

3.1. The Hydropower Potential of Ethiopia

Ethiopia has a vast hydropower potential, which is estimated to be about 15,000 - 30,000 MW. So far very little percentage (less than 2%) of the vast potential has been harnessed. In order to develop this vast potential of power several projects have been initiated to generate more and more hydroelectric power. Some 300 hydropower plant sites in the whole river basins of the country with a total technical power potential of 159,300 Gwh/year have been identified. Out of these potential sites, more than 100 are large scale (more than 60 MW) and the rest are small (less than 40 MW) and medium scale (40-60 MW) hydropower plant sites.

Table 3.1 Ethiopian hydropower potential sites

Name of River Basin	Number of Potential Sites				Technical Hydropower Potential (GWH/year)	Percentage Share of the Total %
	Small Scale 40 MW	Medium Scale 40-60 MW	Large Scale > 60 MW	Total		
Abbay	74	11	44	129	78800	48.9
Rift valley lakes	7	-	1	8	800	0.5
Awash	33	2	-	35	4500	2.8
Omo-Gibe	4	-	16	20	35000	22.7
Ganale - Dawa	18	4	9	31	9300	5.8
Wabi-shebelle	9	4	3	16	5400	3.4
Baro Akobo	17	3	21	41	18900	11.7
Tekeze-angereb	11	1	8	20	6000	4.2
Total	173	25	100	300	159300	

Source (EACE bulletin vol1, no1, 1998-by Solomon Seyoum Hailu)

3.2. Overview of Hydropower stations 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 3.2 Major Hydropower dams in Ethiopia

(Source: MoWR)

Name	Installed Capacity	Commissioning	Basin	contractor	Financing	cost
Fincha'a	134 MW	1973	Fincha'a (Blue Nile)	HARZA engineering company Chicago 6, Illinois		Eth\$86,127,000
Gilgel Gibe I	180 MW	2004	Gilgel Gibe River	Salini(bid)	World bank	\$331M
Tekeze	300MW	2009	Tekeze(Atbara)	Sino-hydro Corporation (bid)	Chinese government	\$365M
Beles	460MW	2010	Lake Tana (Blue Nile)	Salini (No bid)	Ethiopian Government	
Gilgel Gibe II	420MW	2010	Omo River (no Dam, fed by GGI)	Salini (no bid)	Italy and EIB	Euro 370M
Gilgel Gibe III	1870MW	2012-13	Omo River	Salini (no bid)	Italy	Euro 1.55 billion
Fincha'a-Amertyneshe (FAN)	100MW	2011	Fincha'a (Blue Nile)	China Gezhouba group co.	Exim Bank of China	\$276M
Halele Worabesa	440MW	2014	Omo River	Sino-Hydro Corporation	Fair-Fund	Euro 470M

Gilgel Gibe IV	2000MW	2014	Tributary of the Omo River	Sino- Hydro Corporation	Chinese	\$1.9 Billion
Chemoga - Yeda	278MW	2013	Tributary of the Blue Nile, near Debre Markos	Sino- Hydro Corporation	Chinese	\$555M
Ganale Dawa III	256MW	awarded in 2009	Between Oroma and Somali state	Chinese CGGC	Chinese	\$408M
Millennium Dam	6000MW	2014	Blue Nile River	Salini	Ethiopian Government	Euro4.8 Billoion

3.3. Hydrology

3.3.1. General

Hydrology is the science that treats the water of the earth, their occurrence, circulation and distribution and their reaction with the environment. It deals with precipitation, evaporation, infiltration, ground water flow, runoff stream flow and the transport of substances in the flowing water (Mays, 2002). A clear understanding of the hydro metrological conditions of the area is one of the basic requirements of any water management studies. In this study, basic statistical approaches were used to analyze the variability of the watershed hydro metrological variables such as rainfall, stream flow and evaporation.

3.3.2. Rain fall

The major analytic approaches carried out on the rainfall records are the following:

3.3.3 Estimation of missing rainfall records

Failure of any rain gauge or absence of observations from a station causes a short break in the record of rainfall at the station. These gaps can be filled using data from the surrounding gauging stations located within the basin on the assumption that the group of stations has a metrological similarity (Patra, 2002) .

There are different methods that used to fill the missing records. Some of the widely used statistical methods are the arithmetic mean, the Normal ratio method, the regression method and the inverse distance methods. This study considers the first two methods.

3.3.3.1. Arithmetic mean method

This method is used when the normal annual rainfall of the missing station is within 10% of the normal annual rainfall of the surrounding stations. The surrounding index stations are necessarily required to be evenly spaced around the missing station and ideally as close as possible. The method yields a good estimate in flat area if the gauges are uniformly distributed and the individual gauges catch does not vary widely from the mean. (patra, 2002 : Garg 1989).

The mean arithmetic mean is given by:

$$\bar{P} = \frac{P_1 + P_2 + P_3 + \dots + P_n}{n} = \frac{1}{n} \sum_{i=1}^n P_i \quad \text{-----3.1}$$

Where;

\bar{P} = the station with missing record, mm/d

P_i = index station, mm/ d

n = number of index stations

3.3.3.2. Normal ratio method

The method is used when the normal annual precipitation of the index station differs by more than 10% of the missing station. The rainfall of the surrounding index station are weighted by the ratio of the normal annual rainfall by using the following relation, (patra, 2002: Garg, 1989).

$$P_x = \frac{N_x}{n} \left[\frac{P_1}{N_1} + \frac{P_2}{N_2} + \dots + \frac{P_n}{N_n} \right] \quad \text{-----3.2}$$

Where;

P_1, P_2, P_n = rainfall data of index stations, mm/d

N_1, N_2, N_3 = Normal annual rainfall of index stations, mm

P_x, N_x = the corresponding values of the missing station X

n = number of stations surrounding the station X

3.3.4. Rainfall data consistency

Rainfall data reported from a station may not always be consistent. Over the period of observation of rainfall record, there could be unreported shifting of the gauge site by as much as 10km spatially and 30m in elevation, change in the observation procedure incorporated from a certain period or significant construction work, heavy forest fire, earthquake and land slide might have taken place in that area. Such changes at any station are likely to affect the consistency of the data, (Patra, 2002).

The double mass curve uses to check and correct the consistency of the record. The method is based on the graphical representation. The graph is plotted taking the cumulative rainfall of the group of station as abscissa and cumulative rainfall of the affected station as ordinate. The deviation of the curve from the straight lines shows inconsistency of the record. The slope of the line of the group of the station is used to correct the record, (patra, 2002: Garg, 1989).

3.3.5. Determination of Aerial rainfall

A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. The average depth of precipitation over the area under consideration is one of the most important parameters in the hydrological analysis, (Patra, 2002). There are many ways of determining the aerial rainfall over the catchments from the point rain gauge measurement.

These most common are:

- A. Arithmetic mean method
- B. Isohyetal method
- C. Thiessen polygon method

3.3.5.1. Arithmetic mean method

It is the simplest objective method of calculating the average rainfall over the area. the method is suitable for a basin where the gauges are uniformly distributed and the individual gauges catches do not vary much from the mean. The method assumes that all gauges are weighing equally and is given by:

$$P_{avg} = \frac{1}{n} \sum_{i=1}^n P_i \text{ -----3.3}$$

Where:

P_{avg} = aerial rainfall, mm/d

P_i = rainfall record by n number of metrological gauging stations located within the Basins, mm/d

Arithmetic mean does not account for the orographic effects and for use of this method, no gauge station located outside the boundary of the water shed should be considered, (Patra, 2002).

3.3.5.2. Isohyetal methods

This method is the best and most reliable method. It takes account of both the orographic and storm characteristics of the catchments. The main limitation of this method is that it is a subjective approach and needs an experienced analyst to draw contours of equal rainfall depth over the basin (Patra, 2002).

This relation is given by the formula:

$$P_{avg} = \frac{A_1 * [\frac{P_1 + P_2}{2}] + A_2 * [\frac{P_1 + P_2}{2}] + \dots + A_{n-1} * [\frac{P_{n-1} + P_n}{2}]}{A_1 + A_2 + \dots + A_n} \text{ -----3.4}$$

Where:

P_{ave} = Aerial rainfall, mm/d

P_1, P_2 = Isohyetes, mm/d

A_1, A_2 = Area between the isohyetes, km²

Even though this method is reportedly better than the other, it is very difficult to apply the method accurately in the inaccessible and very limited data source.

3.3.5.3. Thiessen polygon method

In this method, a weight is assigned to each station in proportion to its respective area defined by a polygon. These polygons are formed as follows:

1. The stations are plotted on a map of the area drawn to a scale.
2. The adjoining stations are connected by lines.
3. Perpendicular bisectors are constructed on each of these lines.
4. These bisectors form polygons around each station. Each polygon represents the effective area for the station within the polygon. For stations close to the boundary, the boundary lines form the closing limit of the polygons.
5. The area of each polygon is determined and then multiplied by the rainfall value for the station within the polygon. This is done by using a planimeter or drawing the figure to a scale on the graph paper and counting the division squares covered by the polygon, duly multiplied by the map scale.
6. The sum of item 5 divided by the total drainage area provides the weighted average precipitation.

$$P = \sum_{i=1}^n W_i P_i \quad \text{but} \quad W_i = \frac{A_i}{\sum_{i=1}^n A_i} \quad \text{-----} \quad 3.5$$

P [mm] = areal precipitation

W_i = weight of station i

P_i [mm] = height of precipitation at station / element i

A_i [km²] = area associated with station / element i provides areal precipitation

3.4. Hydropower Generation

3.4.1. Head loss calculation

In any real moving fluid, energy is dissipated due to friction; turbulence dissipates even more energy for high Reynolds number flows. This dissipation, called head loss, is divided in to two main categories, “major losses” associated with energy loss per length of pipe, and “ minor losses” associated with bends, fittings, valves etc. the most common equation used to calculate major head losses is the Darcy-weisbach equation. Older, more empirical approaches are Hazen-williams equation and the Prony equation.

3.4.2. Efficiency of Pelton turbine calculation

The type of turbine used in Fincha`a hydropower plant is Vertical pelton turbine. Many variations of impulse turbines existed prior to Pelton's design, but they were less efficient than Pelton's design. Thus the design extracted almost all of the water's impulse energy which allowed for a very efficient turbine.

3.4.3. Design rules

The specific speed η_s of a turbine dictates the turbine's shape in a way that is not related to its size. This allows a new turbine design to be scaled from an existing design of known performance. The specific speed is also the main criterion for matching a specific hydro-electric site with the correct turbine type.

$$N_s = \frac{N\sqrt{P}}{H^{1.25}} \text{-----} 3.6$$

The formula implies that the Pelton turbine is most suitable for applications with relatively high hydraulic head H , due to the 5/4 exponent being greater than unity, and given the characteristically low specific speed of the Pelton.

3.5. Reservoir operation

Since the 1960s water resources management policy and practice have shifted to a greater reliance on improving water use efficiency. Water research teams in many countries have conclusively demonstrated the value of adopting the modern tool of operations research or systems analysis for assisting in the development, operation, planning and management of the water resources project. However, these tools can only assist; they cannot replace the water resource decision making process. Furthermore, some studies indicate a gap between theories of water resources models and the application of these models in the real world. There are many analysis techniques and computer models available in the real world for developing quantitative information for use in evaluating storage capacities, water allocation, and release policies. Yeh (1985), Wurbs (1996) and McKinney (1999), in their state-of-the-art review, discuss different optimization techniques that are used in water resources system analysis at the basin level and reservoir operation.

The operation of a system of reservoirs involves a complex set of human decisions. Depending on hydrologic in the supply network involving watersheds, lakes and rivers, outflow are adjusted in an attempt to provide an optimal response to consumer demand. Many of the parameters involved in establishing system operating policies are random function of time [karamouz and Vasiliadis (1994)].

3.6. Reservoir Operations Optimization

To find efficient operational releases that consider multiple objectives the reservoir hydrologic-demand system can be described mathematically with a prescriptive optimization model which relies on mathematical programming for solution (Wurbs, 1993). Loucks et al. (1981) describe the classic reservoir system optimization problem in which mathematical programming is used to find the optimal set of releases given a description of inflows to a single reservoir. Mathematical programming has been used to improve the efficiency and reliability of reservoir operations since the 1940s (Masse, 1946; Little, 1955; Yakowitz, 1982; Yeh, 1985; Kirshen and Ginnetti, 1985; Labadie, 2001; McCartney, 2007)

Several different optimization models have been proposed for operation of reservoirs. Houck and Cohon [1976, a, b], corely [1978], Major and Lenthon [1979], Yeh et al. [1979], Loucks et al.[1981], Goodman [1984]m, Yeh[1985], and others have viewed each of the models in the

detail. Most of the models reviewed had the form of linear or dynamic programming. Dynamic programming (DP) is particularly suited to situations involving multistage decision problems such as reservoir operation. Yakowitz [1982], has discussed DP applications in water resources planning and management.

The decision variables of the reservoir operations optimization problem are the reservoir releases and network diversions made in each time step of a prescribed time horizon. The characteristics of the system and the scale of the decision process determine the length of the model horizon and the discretization of the time steps (Loucks et al., 1981).

The reservoir operations objective function aims to maximize both the present and future benefits of releases and storage. Alternatively the objective function can be formulated in a minimization mode in which deficits incurred to user demands are penalized. For allocations between multiple users or objectives, each benefit or penalty is converted into a scalar value which is factored by the weight associated with the objective (Labadie, 2004).

The constraint set includes equations that describe the reservoir network dynamics, conservation of mass within each reservoir, the maximum storage capacity, the release capacity, the demand targets, and the reservoir inflows (Yeh, 1985). The parameters of the equations, which define the constraint set, are determined from the physical system.

3.7. Reservoir operation model

3.7.1. Solver

Solver is part of a suite of commands sometimes called what-if analysis tools. With Solver, you can find an optimal (maximum or minimum) value for a formula in one cell called the objective cell subject to constraints, or limits, on the values of other formula cells on a worksheet. Solver works with a group of cells, called decision variables or simply variable cells that participate in computing the formulae in the objective and constraint cells. Solver adjusts the values in the decision variable cells to satisfy the limits on constraint cells and produce the result you want for the objective cell.

3.8. The contribution of energy sector to the national economy

Energy is one of the major inputs and facilitator of socio-economic development. It helps in improving productivity and performance efficiency of production of goods and services. Access to modern energy is also one aspect of civilization and modernization of the standard of living. Ethiopia is known to have a large and untapped potential energy resource including hydropower, geothermal, wind and solar energy. Compared to the potential, however, the current level of energy production is minimal; and the country is among the lowest per capita modern energy consuming society.

Following the recent pace of the socio-economic development, a growing demand for energy for household, industrial and service sectors use in Ethiopia is a real phenomenon. This fact has won an appreciation by the government which has recently undertaken significant energy sector planning and investments to meet the ever increasing demands.

Ethiopia has registered impressive GDP growth in recent years, ranging between 6% and 12% per year depending on the data source. The World Bank and IMF forecast average growth of 7% over the next three years. In addition to boasting strong economic performance, Ethiopia ranks as Sub-Sahara Africa's second-most populous country, with over 90 million people. Investments in renewable energy resources and hydropower in particular have been key drivers of economic growth in recent years. Ethiopia's existing generation capacity totals 2,145 MWs; up more than 200% since 2008. Projections suggest the total demand for power will grow by 30% per year. In 2012/13, hydropower comprised 90% of the electricity supplied in Ethiopia.

In the energy sector, the Ethiopian government's main stated objective is to use a carbon-neutral growth pathway to improve the living conditions of its population. The GTP includes an aggressive energy policy framework designed to expand installed electricity capacity from approximately 2,000MWs to 8,000MWs, build 132,000 kms of new distribution lines, and increase the number of customers from two million to four million by 2015. Renewable energy capacity, primarily hydro, and energy efficiency will play major roles in this growth by 2015.

The Ministry of Water, Irrigation and Energy (MOWIE) is actively seeking additional investments in Ethiopia's energy sector to meet rapidly growing domestic need and to fulfill ambitious plans to export electricity to neighboring countries.

3.9. The Water Balance

The study of water balances is the application in the hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that for any arbitrary volume and during any period of time, the difference between total input and output will be balanced by the change of water storage within the volume. In general, therefore use of water balance technique implies measurements of both storage and fluxes (rate of flow of water, through by appropriate selection of the volume and the period of time for which the balance will be applied, some measurements may be eliminated. For example, if the balance is computed for a year over a number of years, the change in storage in any component of the hydrological cycle will usually be smaller than errors in measurement input and outputs.

A common use of water balance equation is to infer one term from measurement of the others, as when the evaporation from the earth's surface is determined from measurement of changes in soil moisture. But if all relevant terms are measured their balance, or lack of it, can be used to check the accuracy of measurements and the understanding of principles.

The world water balance project is mainly concerned with the measurement of all relevant terms on the global scale. It is a central problem of the hydrology, involving the entire hydrological cycle. Thus the world water balance constitutes the general framework for the study of water balance in various areas (River basins, continents etc.) and for different periods of time. The water balance equation can be usually employed on its own in studies of the land components of the hydrological cycle. When atmospheric water is to be considered, difficulties of measuring fluxes and phase changes of water vapor usually lead to the use of techniques for indirect measurement or estimation, based on the principle of conservation of energy. Consideration of water balances involving phase changes, therefore, normally requires study of heat balances; that is, the measurement of all, or all but one, of the terms in the energy-balance equation. (R. Maidment, 1993)

3.9.1. Water Balance Equation

In quantitative terms the hydrologic cycle can be represented by a closed equation which represents the principle of the conservation of mass, often referred to in hydraulics as a continuity equation. Many forms of this expression, called the water balance equation, are possible by subdividing, consolidating, or eliminating some of the terms, depending on the purpose of computation.

The Water balance can be expressed (1) for a short interval or for a long duration; (2) for a natural drainage basin or an artificially separated boundary or the phase above the ground surface, that below the surface, or the entire phase.

Three applications of the water balance equation are common: (1). a water balance equations for large basin areas, (2). a water balance equations for water bodies, and (3). a water balance equation for the direct runoff.

Large reservoirs

The water balance of a large reservoir, RL, was calculated on a daily basis according to

$$V_t = V_{t-1} + Q_c + Q_{in} - Q_{out} - U_{RL} + (P - E) \cdot A_{RL}$$

where

V_t is the reservoir storage volume (m^3) at day t , Q_c is the daily inflow from the sub-basin area adjacent to the reservoir after the passage of the cascade of small and medium-sized reservoirs in this sub-basin, Q_{in} is the inflow from all other upstream sub-basins via the river network, delayed by a simple stream flow routing scheme (Bronstert et al., 1999), Q_{out} is the outflow from the large reservoir, U_{RL} is water withdrawal (all variables in m^3), P and $E(m)$ are precipitation to and evaporation from the reservoir water surface, $A_{RL}(m^2)$.(Güntner, A. & Bronstert, A. (2004)

3.10. Water Resources Management

Water resources management is a multi-objective optimization problem. It is a difficult task to estimate reservoir operating policies that maximize all the benefits provided by these reservoirs and also minimize their adverse impacts. It is a complex decision making process which will involve a number of variables, risks, uncertainties and also conflicting objectives. Reservoirs serve many purposes. They are used to drive turbines to generate electricity. They are used to supply water for irrigation, city and industrial uses and also for flood protection. Reservoirs may be built to satisfy a single purpose or multipurpose. Some of the purposes are conflicting in nature. For example for power generation, the reservoir should be as full as possible to increase the head, whereas for flood protection, it should be empty to provide for maximum storage of flood waters if flood occurs.(J.A. Adeyemo , 2011).

3.11. Previous studies in the study area

Acres International Limited

The objective of the study was to determine whether Fincha`a reservoir can be operated to satisfy downstream irrigation requirement and if so, what constraint or penalty was imposed on the operation of Fincha`a power plant and in turn to EEPCO system.

The study was conducted when the installed capacity of the plant was 100MW and after the Amerty diversion and rising of the Fincha`a spillway crest (I.e., from 2217m to 2219masl) were practical (Acres,1981).

The study was based on the basic two assumptions of the downstream irrigation demand and the firm power production. The assumptions were:

- The Given monthly irrigation demands were constant and that they must be met continuously (i.e., no re-regulation capability was available downstream)
- Due to diversion of Amerty and the raised spillway crest, 613GWh of energy would be available as a firm energy and hence it was assumed that this energy would be utilized each month with no seasonal variation. The energy is corresponds to a continuous firm power of 70MW.

The simulation result of the study indicated that the flow required to generate the firm energy was $15\text{m}^3/\text{s}$ which was greater than the maximum monthly irrigation requirement of the study

period. (i.e., 10.6 m³/s). This shows that no economical penalty would be incurred when the Fincha`a power plant was operated to meet the given irrigation requirement, but EEPCO lose some flexibility in selecting its pattern. The study also proposed a simple and inexpensive sluice gate b incorporated in the modified spillway weir, which provides security of irrigation supplies in the event of an unscheduled outage of the tunnel or the powerhouse at a time no water is spilling and used to supplement power flows and thus allow flexibility in the pattern of power and irrigation released.

Salzgitter Consult GMBH

The study was based on the review and assessment of the firm power production of the Fincha`a/Amerty system with special consideration of the revised database. The revised data set were the characteristic curve of the Fincha`a reservoir surface which is covered by floating islands (Salzgitter, 1986).

The study point out that there was a significant difference in the reservoir area, evapotranspiration losses in comparison to the estimates presented in the previous studies due to the less accurate topographic information. The simulation run was carried out by RESOP and HEC-3 over several alternatives as firm power requirement. The simulation result confirmed that the most favorable firm power and energy production was 70MW and 613GWh.

The study also showed the advantage of the gate installation at Fincha`a/Amerty diversion tunnel intake. Through the gate operation, the evaporation losses can be reduced and an additional of 0.4MW of firm power production was maintained, thus seasonal gate operation was proposed.

Getachew Daniel

This research work attempted to determine the reservoir operation that maximizes the system performance of the Fincha`a hydropower plant. The main source of water for the power plant and the downstream activities are the Fincha`a and the Amerty reservoirs which are joined by diversion tunnel. The reservoir simulation software HEC-ResSim was used to analyze the diversion tunnel and the main power intake gate operation. (Getachew 1, 2007)

A tandem operation rule of HEC-ResSim was applied to simulate the two reservoirs as a system reservoir on the same stream. The Amerty reservoir is operated based on the reservoir water level of the Fincha`a reservoir. The final output of the tandem operation results in an operation rule based on water levels of the two reservoirs that maximizes the net volume of diverted water. The optimal release analysis considered the existing power release pattern and alternative downstream release patterns for downstream irrigation. The advantage and disadvantage of the release patterns were evaluated. After a number of simulation trials and comparisons of alternative release patterns, the simulation/ optimization indicates that careful consideration needs to be given to the downstream demands.

4. Reservoirs, existing dam operation and the downstream activities

4.1. General

Reservoirs are large water bodies artificially created by the construction of Dams across the river and used to store large volume of water during the rainy seasons where the stream flood flows is maximum. They protect the large flood damage in the downstream areas and use to maintain the constant flows throughout the year at the period of low flow. The stored water is used for different water related activities such as water supply, irrigation, power generation etc. Amerty and Fincha`a reservoirs are also used for same purposes.

4.2. Amerty Reservoir

Amerty reservoir is a narrow and elongated U-shaped reservoir located in the upper Amerty watershed. The reservoir extends from the main Amerty Swamp to the tip of Fincha`a valley. It is created to the construction of Amerty rock fill dam across the Amerty River. The active storage of the reservoir is about 40.1Mm³. The shape and the location of the reservoir are favorable to store a significant volume of water with relatively small surface area and hence reduce evaporation losses. Table below shows some of the salient features of the dam or the reservoir (HARZA, 1975).

Table 4.1 salient features of Amerty dam and Reservoir

No	Descriptions	Amerty reservoir
1	Dam crest length	740.0m
2	Dam height	15.3m
3	Dam crest width	10.0m
4	Crest level	2237.8masl
5	Maximum storage level	2236.0masl
6	Full supply level	2234.0masl
7	Dead storage level	2232.0masl
8	Live storage	40.1Mm ³

4.2.1. Amerty reservoir characteristic curve

The volume-elevation curve and area elevation curve of the Amerty reservoir has been revised by EEPKO in 1984. The revision was made based on 1:10,000 scale topographic maps and was used by various studies in the project area. This analysis also used the revised curve with constant effective volume of the reservoir due to the absence of the sediment data of the river.

Table 4.2 Amerty reservoir characteristic curve data

Volume Mm ³	0	0.2	1.5	4.7	9.6	16.5	25.5	36.4	49.7	65.7	84.5	105.9	130.1	157.1
Area km ²	0	0.4	2.1	4.2	5.6	8.1	9.9	11.9	14.7	17.4	20	22.8	25.6	28.4
Elev	2223	2224	2225	2226	2227	2228	2229	2230	2231	2232	2233	2234	2235	2236

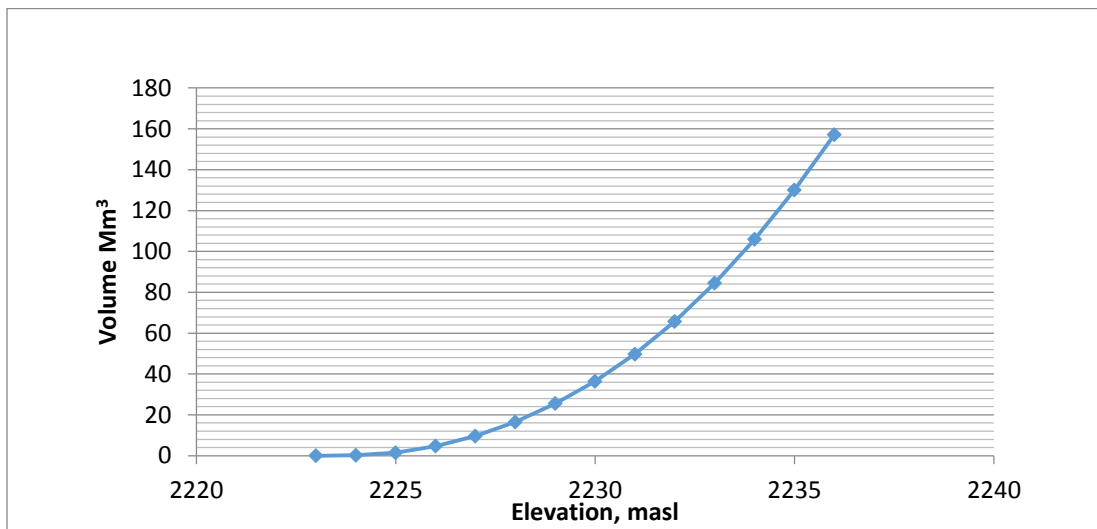


Figure 4.1 Volume - elevation curve of Amerty reservoir.

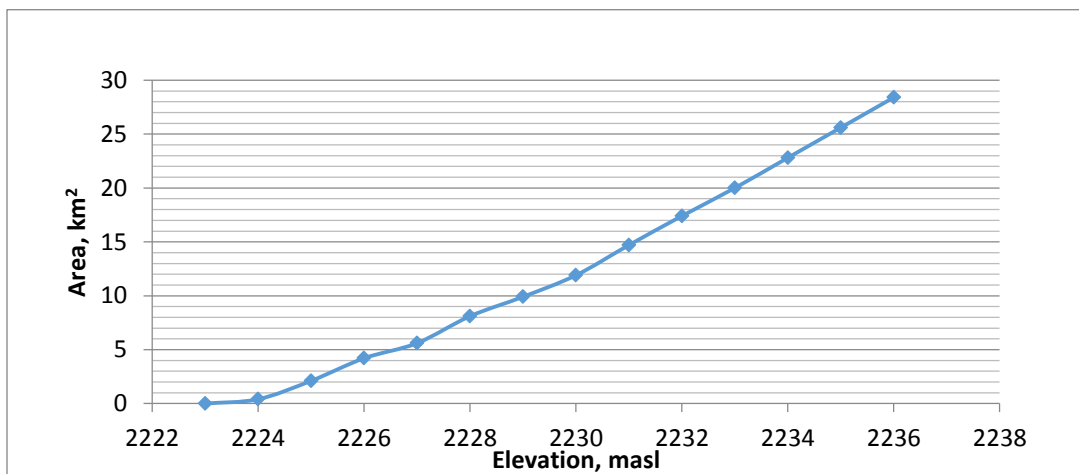


Figure 4.2 Area – elevation Curve of Amerty reservoir

4.2.2. Amerty Diversion and Existing Tunnel Operation

Amerty reservoir is designed to augment the Fincha`a system through 1.57km long diversion tunnel made between the two reservoirs. The diversion tunnel consists of upstream and downstream lined canal and vertically lifted regulating gate. The maximum capacity of the tunnel intake is $28.7\text{m}^3/\text{s}$.

Table 4.3 Important data`s of Amerty diversion tunnel

No	Descriptions	Diversion tunnel
1	Approaching channel - shape	trapezoidal
2	Tunnel shape	Circular
3	Tunnel diameter	3.0m
4	Tunnel length	1.57km
5	Tunnel intake elevation	2232.0masl
6	Tunnel outlet elevation	2226.30masl

The existing Amerty tunnel gate operation was controlled by seasonal gate operation pattern. The main objective of the gate is maximization of the volume of water diverted to Fincha`a system subjected to evaporation losses and the capacity of the tunnel.

4.3. Fincha`a Reservoir

The reservoir is created due to the construction of Fincha`a rock fill dam across the Fincha`a river. The site of the dam and the reservoir is suitable for the creation of a large storage reservoir with a dam of low height. According to the revised area – elevation curve the surface area of the reservoir at FSL is 345km^2 and the storage corresponding to this elevation is about 1120.48Mm^3 .

Table 4.4 Salient feature of Fincha`a reservoir

	Descriptions		No		
1	Dam crest length	340.0m	6	Full Supply level	2219.0masl
2	Dam height	20.0m	7	Dead storage level	2214.0masl
3	Dam crest Width	10.0m	8	Live storage	1050.48Mm^3
4	Crest level	2223.0masl	9	Normal operation level	2216.0masl
5	Maximum storage level	2221.9masl			

4.3.1. Fincha`a reservoir characteristic curve

Fincha`a reservoir has two applicable characteristic curves developed by HARZA Engineering limited company before the construction of the dam and revised by EEPKO after the construction of the dam. The revised characteristic curve is developed based on the topographic map scale 1:10,000 and including the portion of chomen swamp. For this study the revised curve was used.

Table 4.5 Fincha`a reservoir characteristic curve data

Elevation(m)	2212	2214	2215	2216	2217	2218	2219	2220	2221	2222
Volume(Mm3)	0	70	160	332.7	536.4	801.9	1120.5	1492.2	1916.9	2394.8
Area (sq.km)	0	60	150	206	238	266	345	425	455	470

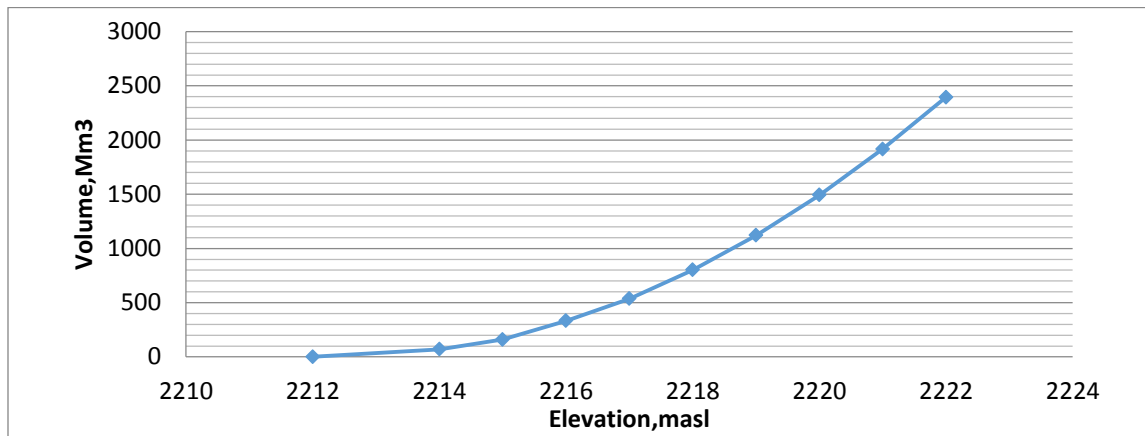


Figure 4.3 Volume – Elevation curve of Fincha`a reservoir

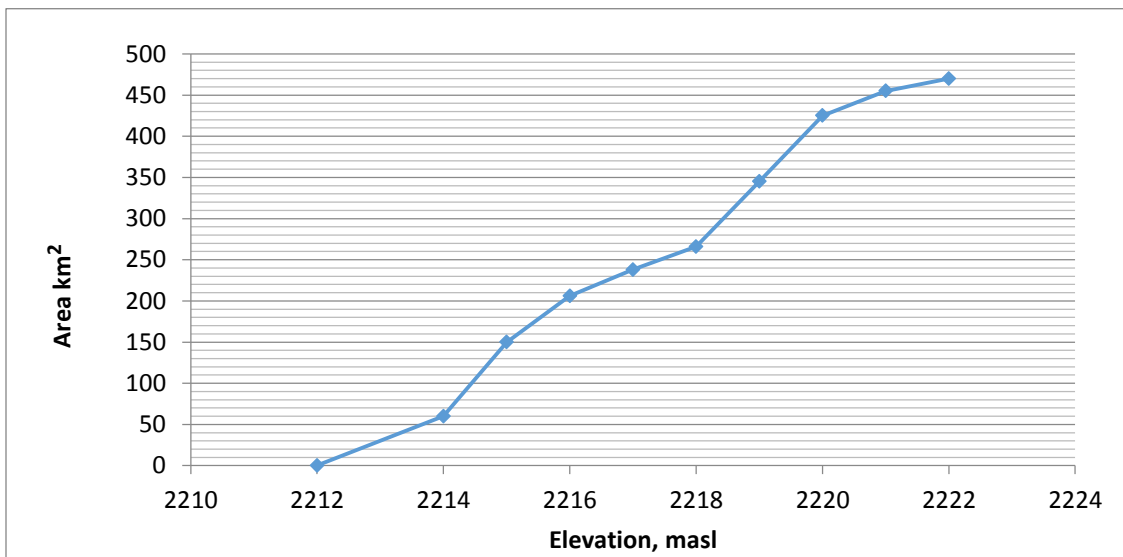


Figure 4.4 Area – Elevation curve of Fincha`a reservoir

4.4. The Effect of sediment in the Fincha`a Reservoir

The effective Volume of the reservoir is the volume between the dead storage level to the full supply level, which is very important for reservoir planning, operation and management studies. The reduction of this space is the major problem in the reservoir operation. The cause for the reduction comes mainly from the sediment load from the river and from the adjacent farming lands. The former was not yet the big problem in the project area since the swamps have an advantage of reducing the velocity and the sediment load of the incoming flood in the main stream and from the highlands.

However, the sediment comes from agricultural lands of the upper watershed where people largely depend on sustainable farming has been a big problem. According to the soil and water conservation studies held at Fincha`a reservoir, the dramatic increase of the reservoir area is likely to be caused by sediment from these agricultural lands, (Tsfaye Y., 2005). From the Fincha`a dam design report the total volume for sediment storage or the dead storage capacity of Fincha`a reservoir is 70Mm^3 (HARZA, 1965).

4.5. Fincha`a power and irrigation intakes

The Fincha`a reservoir consists of the power intake and irrigation outlet. The power intake is located near to the dam spillway. It consists of two rectangular openings each 3.0m high and 2.0m width separated by concrete piers. The centerline of the water passage is at 2208.5masl or 4m below the minimum head elevation. Immediately downstream from the intake, the water passage merges in to the circular section of 3.0m diameter high-level tunnel, (table 4.6)

The irrigation outlet is rectangular shaped 2 X 2.5m size outlet located in the body of the spillway. The crest level of irrigation outlet is at 2214masl and is used to release the downstream requirement during unscheduled outage of the power system maintenance and to supplement the power flow when it is not equal to the downstream requirement. The uncontrolled ogee over flow spillway of Fincha`a reservoir is 10m wide and is at a crest level of 2219masl.

Table 4.6 silent features of Fincha`a hydropower plant

No	Description	Length, m	Diameter, m
1	High level tunnel	3900	3.0
2	Inclined shaft	300	2.1
3	Intermediate level tunnel	300	2.1
4	Surface penstock	1450	2.1
5	Maximum gross head	594m	
6	Rated head	555m	
7	Average net head	575m	
8	Minimum head	555m	
9	Inlet to the turbine	1625masl	
10	Maximum tail water level	1623.4masl	
11	Minimum tail water elevation	1620.3masl	

4.6. Existing monthly and weekly operation rule

The existing Fincha`a reservoir operation considers only the power generation pattern that is depend upon the load share given from the national power grid (i.e. from the interconnected systems). In nine dry months the power plant monthly operation pattern was based on equally sharing of the amount of water stored at the end of reservoir filling period. The dry month contains October to June and wet month contains July to September. The wet month contains July to September. The power plant monthly operations in wet month were minimum because of small amount of water used or needed in the downstream and much water was used in the dry months. Hence in wet months the reservoir must be filled and back to its full supply level. The wet months are also called the reservoir filling periods. Thus, the monthly operation policy was based on controlling of each month of the year not to utilize much more water than the allocated amount. Weekly water allocation was based on dividing of the monthly load in to four equal parts, among each week.

Table 4.7 Current Fincha`a Reservoir Operation (Source EEU, power generation department)

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Discharge	16.716	16.682	17.177	16.065	17.028	17.233	9.363	5.625	6.753	8.198	15.612	16.086

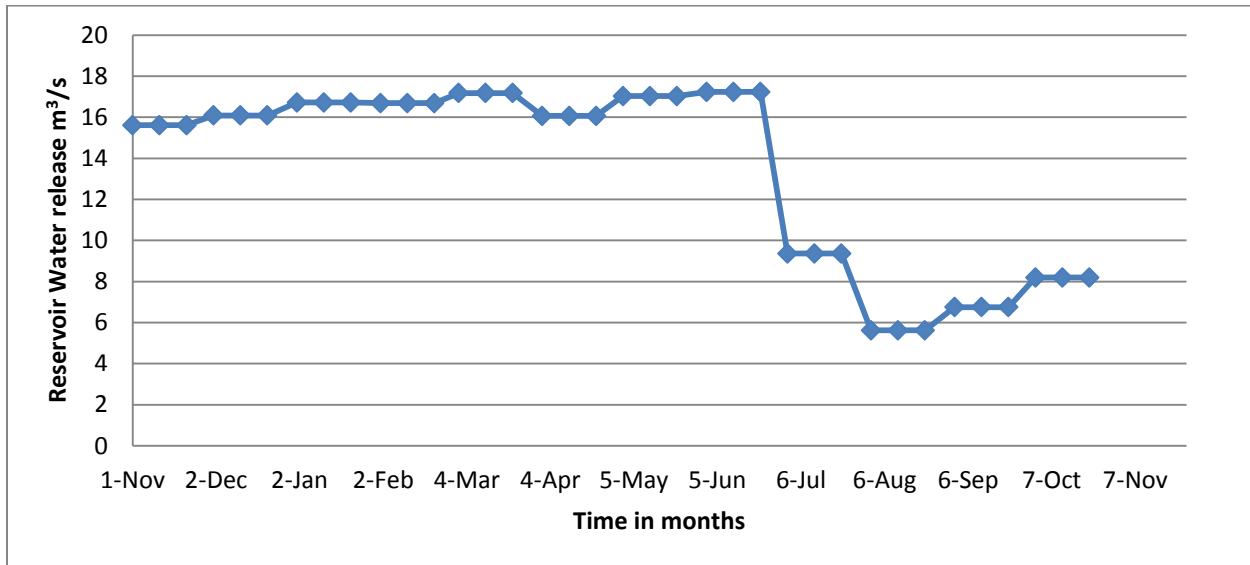


Figure 4.5 Current Fincha`a reservoir operation curve

4.7. Downstream Water related activities

Downstream of the power plant, there are two major water related activities. The activities consist of irrigation and water supply for domestic and factory use. The activities situated such that the irrigation diversion comes first then the water supply and the factory pump site. Each activity depends upon the water plant release and the activities upstream. For special condition when the power release was not sufficient for downstream requirement, the irrigation outlet allows direct flow of water to the river course without passing through the turbines. However, the irrigation outlet kept close for normal operation.

4.7.1. Fincha`a irrigation project

Fincha`a irrigation project consists more than 20,000ha irrigable land below the power house. The command area is situated both in the east and in the west side of the river course. The west command area contains cultivated 8145ha and the east bank contains 12000ha potential site. The irrigation project uses intensive pressurized sprinkler and very few furrow irrigation system. From the pressurized system, gravity off take covers 66% and the pumping station covers 34% of command area. The source of water for the irrigation project is the fincha`a river. The river diversion structure is constructed over the Fincha`a river few kilometers downstream of the confluence of the main river course and the tailrace canal from the power station, (Table 4.8)

Table 4.8 salient feature of Fincha`a diversion and conveyance structure

no	Diversion weir		Main canal	
	Description		Description	
1	Length	52.5m (5 span & 10.5 each)	West canal length	41.5km lined 2.5km unlined
2	Shape	Ogee with bucket energy dissipater	East canal length	48km
3	Weir crest level	1602.65masl	Intake canal bed level	1600masl
4	Sluice gate	Radial gate	Canal shape	Trapezoidal
5	Canal regulator	Radial gate	Max. canal depth	1.735m
6	Canal capacity	6.2m ³ /s	Min. canal depth	0.90m

Irrigation operation

The existing irrigation operation was based on monthly constant release at the diversion intake gate. The release reaches the maximum level in April and the minimum value in December.

In the case of wet season, no irrigation diversion was required except small discharge for the small villages in the command area. The level of irrigation requirement consists of the 20145ha of the land. The system requires 20.67m³/s of water during the peak month April.

Table 4.9 Fincha`a Monthly irrigation requirement (m³/s)

month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Irrigation requirements(m ³ /s)	14.51	17.87	19.13	20.67	17.97	17.41	1.6	1.6	15.07	15.33	13.62	13.31

5. Methodology

5.1. Reservoir operation models

Complex constrained multi-objective optimization problems are solved by Excel solver. This ability makes Excel solver a good choice for solving reservoir operation problems which present multiple conflicting objectives and constraints. The objective functions are always non-linear, con-convex and multi-modal functions. It is characterized with many decision variables, multiple conflicting objectives.

Formulation of Objective function and constraints

When a reservoir is a multipurpose reservoir, the multiple objectives set in. In this case, the reservoir may be required to maximize hydropower generation, maximize the irrigation water releases and minimize the flood risk. The constraints may be to satisfy the minimum downstream water requirement, the minimum height required for hydropower generation and the height should be less than the maximum height to prevent spilling.

Reservoir Water Balance Simulation

In order to understand the basic hydrological process, water balance computation of the reservoir is made using excel spread model. This model approach stems on solving the reservoir water balance equations.

The study of the water balance is the application in hydrology of the principle of conservation of mass, often referred to as the continuity equation. This states that, for any arbitrary volume and during any period of time, the difference between total input and output will be balanced by the change of water storage with in the volume.

$$V_t = V_{t-1} + Q_c + Q_{in} - Q_{out} - U_{RL} + (P - E) * A_{RL} \dots\dots\dots 5.1$$

Where

V_t is the reservoir storage volume (m^3)

Q_c is the daily inflow from the sub-basin area

Q_{in} is the inflow from all other upstream sub-basins via the river network

Q_{out} is the outflow from the large reservoir

U_{RL} is water withdrawal (all variables in m^3)

P and E (m) are precipitation to and evaporation from the reservoir water surface

A_{RL} is area of the reservoir (m^2)

Water Balance Recursive Formula

Equation 5.1 is the general water balance equation formulated for the Reservoir. Using equation 5.1 and knowing the initial storage (at some reference time) and the recursive continuity equation is formulated as:

1. For Amerty Reservoir

$$V_t = V_{t-1} + (Q_{IN} - Q_{out}) * \Delta t + (R_t - E_t) * A_{RE} - S_e_t \dots \dots \dots 5.2$$

Where

V_t = total Volume of Amerty reservoir at time t

V_{t-1} = initial full reservoir volume at time t

$Q_{in,t}$ is the inflow to the reservoir in time t,

$Q_{out,t}$ is the total volume of water released to Fincha`a reservoir in time t

R_t = aerial rainfall on the reservoir in time t (mm)

E_t = Evaporation from the reservoir in time t (mm)

A_{RE} = Area of the reservoir in time t (m^2)

S_t is the Losses by seepage within time Δt

For this research Losses by seepage were not accounted for, because no information on their magnitude was available, which is compatible with the original/designed assumption.

Reservoir can be operated to maximize hydropower generation while satisfying other uses like irrigation, downstream water requirement and flood control. The objective function can be formulated for 12 months period as follows:

For Fincha`a Reservoir

Objective Function

$$\text{Maximize } \sum_{i=1}^{12} (\eta Q_{out} H_t) \Delta t$$

The constraints are as follows

$$V_t = V_{t-1} + (Q_{in,t} + Q_{run} - Q_{out,t}) * \Delta t - S_t + (R_t - E_t) * A_{re} \dots \dots \dots 5.3$$

Dead storage $\leq V_t \leq$ Reservoir capacity

$$70\text{Mm}^3 \leq V_t \leq 1120.5 \text{ Mm}^3$$

$$60\text{Mm}^3 \leq A_{re} \leq 345\text{km}^2$$

$$2214\text{m} \leq H \leq 2219\text{m}$$

$$7.26 \text{ m}^3/\text{s} \leq Q_{out} \leq 22.26\text{m}^3/\text{s}$$

$$S_t, A_{re}, Q_{out}, H \geq 0$$

Where,

H_t is the net height of water above the turbine at the end of month t

η is the efficiency of the turbines,

$Q_{out,t}$ is the total volume of water released to the turbine in time t , which includes downstream irrigation requirement, water supply and Environmental flow.

$Q_{in,t}$ is the inflow to the reservoir in time t ,

Q_{tun} = the inflow coming through the tunnel from Amerty reservoir

Δt is the time of consideration

S_t is the Losses by seepage within time Δt

For this research Losses by seepage were not accounted for, because no information on their magnitude was available, which is compatible with the original/designed assumption.

5.2. Head loss calculation

For relatively short pipe systems, with a relatively large number of bends and fittings, minor losses can easily exceed major losses. In design, minor losses are usually estimated from tables using coefficients or a simpler and less accurate reduction of minor losses to equivalent length of a pipe. For Fincha`a hydropower the total loss which includes both major losses and minor losses calculated by Darcy-Weisbach equation are given by the following formula:

$$H_l = 0.1095Q^2 \left[\frac{16.05}{\left[\ln \left(2.7 \cdot 10^{-4} + \frac{5.74}{(4.244 \cdot 10^5 Q)^{0.9}} \right) \right]^2} + 2 \cdot \frac{7.346}{\left[\ln \left(1.93 \cdot 10^{-5} + \frac{5.74}{(6.062 \cdot 10^5 Q)^{0.9}} \right) \right]^2} \right] + \frac{35.5}{\left[\ln \left(1.93 \cdot 10^{-5} + \frac{5.74}{(6.062 \cdot 10^5 Q)^{0.9}} \right) \right]^2} + 4.291 \cdot 10^{-3} Q^2 \quad \text{Eq. 5.4}$$

5.3. Efficiency of Pelton turbine calculation

Table 5.1 discharge versus Efficiency for Pelton turbine (SOURCE: Mosonyi, 1965)

Discharge	6	8	30	50	75	100
efficiency	0	0	60	80	90	84

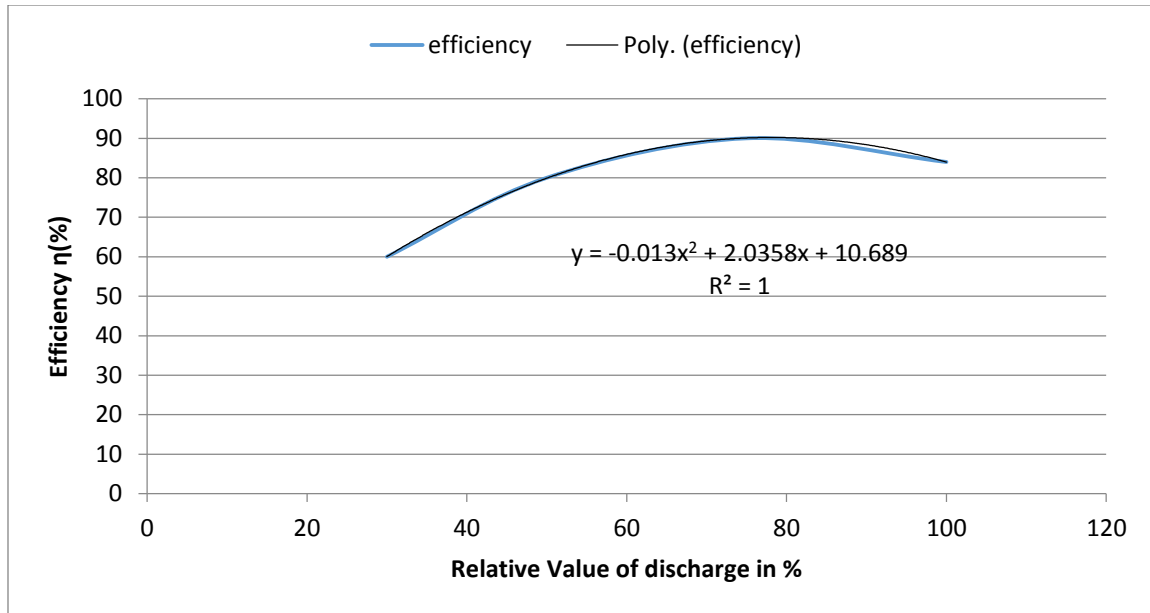


Figure 5.1 Efficiency versus relative discharge

$$\eta = [-0.013Q_{11}^2 + 2.0358 Q_{11} + 10.689]/100$$

Where: η - is efficiency of a turbine and

$$Q_{11}:- \text{ is relative discharge in } m^3/s \text{ given by } Q_{11} = \frac{Q}{D^2 H^{0.5}}$$

5.4. General equation for Power calculation

The power generated in Fincha`a hydropower plant is given by general power formula below

$$P = \eta \gamma Q H$$

By substituting for efficiency and simplifying the general formula for Fincha`a Pelton wheel is given by

$$P = \frac{[-0.013(\frac{Q}{D^2 H^{0.5}})^2 + 2.0358(\frac{Q}{D^2 H^{0.5}}) + 10.689]}{100} * \gamma * Q * H * \quad \text{Eq. 5.5}$$

Where: H - is the net head present from reservoir elevation to the center of the turbine nozzle

η - is the efficiency of the turbine and

Q - is Discharge m^3/s .

Hl - is head loss

5.5. Power generation data analysis by fulfilling downstream activities

The Power generation data includes the generated power and the released water. The power generated and the amount of water used to generate the given power was directly obtained from the three old turbines. The unit four, the new turbine, was only shown the amount of the generated power. Hence, the total discharge passed through the system was analyzed by the power formula.

5.6. The Simulation Process

The water balance recursive formula as presented in section 5.1 equation 5.2 & 5.3 is used to run the simulation. Simulation is made using EXCEL. The above mentioned recursive formula has been adjusted to simulate reservoir volumes on ten day basis and the full table is given in the annex part.

Reservoir simulation done in the table

Q _{in} (m ³)	Q _{out} (m ³)	volume (m ³)	Elevation (m)	Area (km ²)	Net loss Evapo(m ³)	Rainfall(m ³)	Net Evap(m ³)	Seep(m ³)	New Vol (m ³)	Spilled water	Q from tunnel	New Vol (m ³)	New Elev(m)

$Q_{out,t}$ is the total volume of water released to the turbine in time t, which includes downstream irrigation requirement, water supply and Environmental flow.

$Q_{in,t}$ is the inflow to the reservoir in time t,

Net loss = Rainfall – Evaporation

$$\text{Rainfall (m}^3\text{)} = \text{Rainfall (mm/km}^2\text{)} * \text{Area (km}^2\text{)}$$

$$\text{Evaporation (m}^3\text{)} = \text{Evaporation (mm/km}^2\text{)} * \text{Area (km}^2\text{)}$$

$$\text{Change in reservoir storage } (\delta V) = \text{initial volume} + (Q_{in} - Q_{out} + \text{net loss} - \text{seepage})$$

$$\text{Spilled water} = Q_{in} + \delta V + \text{Net loss} - \text{seepage} - \text{initial reservoir volume}$$

Q_{tunnel} = is inflow throw the tunnel

Hence, the final change in volume is

$$\text{Change in reservoir storage } (\delta V) = \text{initial volume} + (Q_{in} - Q_{out} + Q_{\text{tunnel}} + \text{net loss} - \text{seepage})$$

Power production process

The power production formula is presented in section 5.4 equation 5.5 is used to run the simulation of hydropower. Similar to reservoir simulation, the simulation is done using Excel. The above mentioned recursive formula has been used to simulate Power production on ten day basis and the full table is given in the annex part.

To attain the optimal power production in the simulation process, the variable (the constraint) which is varied is the amount of Discharge passing through the turbine. Hence, as the amount of discharge is varied the amount of power production is also varied. So by varying the amount of discharge passing through the turbine of the tunnel, the optimum power production is attained or produced.

6. Hydro metrological Data Analysis

6.1. Data Analysis

This section describes the methods applied and the results obtained to estimate the major ten days and mean hydrological variables that served as an input to the Fincha`a-Amerty reservoir operation model. The study considered ten days of rainfall; stream flow and power plant release and mean ten days of evaporation data and the downstream requirements data analysis.

6.1.1. Rainfall data analysis

The daily time step data was collected from metrological gauging stations were analyzed for missing records, data quality and consistency as follows.

6.1.2. Estimation of the daily missing rainfall record

The Normal ratio method was used to make the data series continuous. That means, to fill the gaps of the rainfall record. In addition to this method, for a period of well-defined dry season or months visual judgment was also one of the gaps filling techniques.

In the data analysis, equation 3.2, of normal ratio method was used. From the previous study the monthly normal rainfall at the metrological gauging stations were collected and the missed daily rainfall record of the given index station was determined. Table 6.1 shows an example of the computation.

Table 6.1 Determination of the missed daily rainfall data by Normal ratio method

Determination of missing rain fall data								Shambu estimated value
Shambu		Respective daily data at						
Missed daily rainfall data	Monthly normal rainfall mm	Fincha`a		Neshe		Homi		Normal ratio
		Daily, mm/d	Annual normal rainfall mm	Daily, mm/d	Annual normal rainfall mm	Daily, mm/d	Annual normal rainfall mm	
17/11/1998	4.9	0	14.1	0	3.2	0	1	0
7/10/2000	151.1	0	190	12.4	227	0	168.9	2.75

6.1.3. Rainfall data Consistency

Rainfall data of the gauging stations were not consistent enough for the period of records. Thus, to check the consistency of these data double mass curve analysis were applied and a significant correction was made on some records. Table 6.2 shows the double mass analysis made at shambu metrological stations. The cumulative mean annual rainfall of the four gauging stations, which means all stations except the shambu station, and the cumulative annual rainfall of the shambu station were evaluated. The deviation of the curve from the straight line was considered as an error and the proper adjustment was made. The annual correction factor was distributed to all daily records by the ratio of the previous to the adjusted values.

Table 6.2 Double mass curve analysis of Shambu metrological station

	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004
cum	130.53	293.45	439.72	549.29	675.48	825.37	955.60	1093.00	1274.91	1436.21	1563.31	1697.22
shambu	108.28	245.10	373.72	469.48	585.47	703.94	827.22	965.91	1103.96	1234.53	1353.15	1477.26

2003	2002	2001	2000	1999	1998	1997	1996	1995	1994	1993	1992	1991	1990	1989
1822.08	1931.54	2043.46	2193.35	2373.49	2537.97	2678.85	2809.87	2930.03	3065.07	3220.19	3377.07	3518.97	3668.11	3806.38
1587.62	1728.15	1840.72	1962.92	2093.09	2214.77	2361.38	2492.54	2604.06	2708.71	2864.19	3007.84	3134.21	3281.90	3421.14

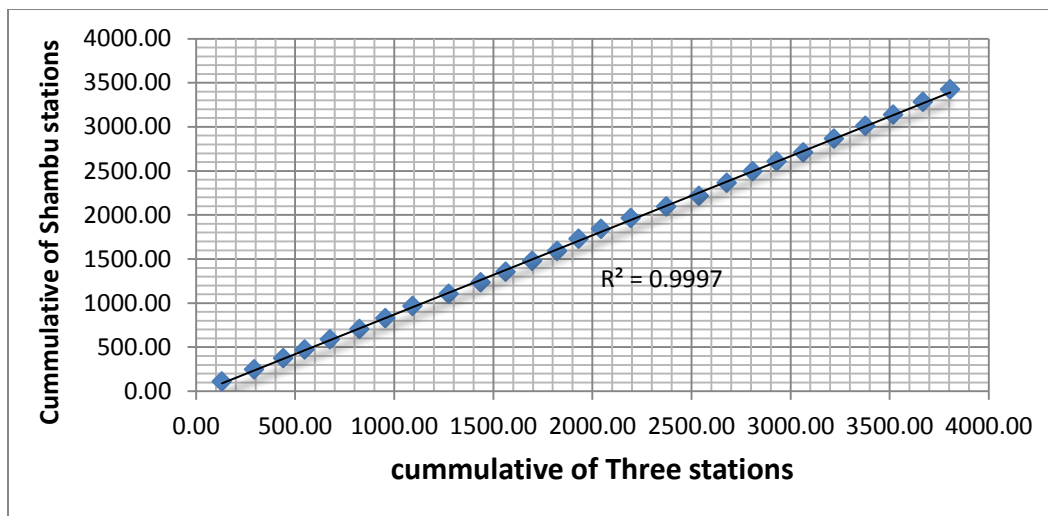


Figure 6.1 Shambu annual rainfall record (double mass curve)

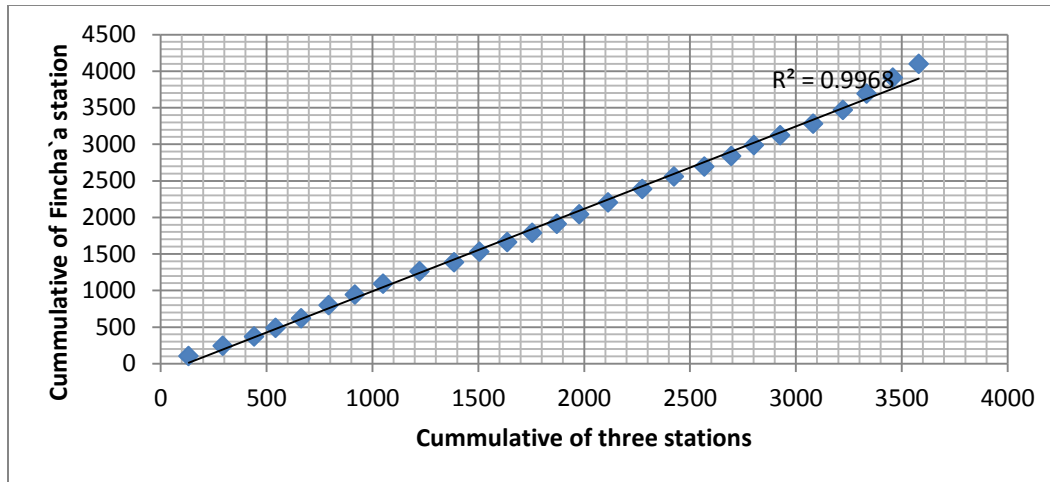


Figure 6.2. Fincha`a annual rainfall record (double mass curve)

6.1.4. Determination of Aerial rainfall

A rain gauge records the rainfall at a single point. This point rainfall record has to be converted to aerial rainfall. The average depth of precipitation over the area under consideration is one of the most important parameters in hydrological analysis.

The Fincha`a-Amerty water shed is analyzed using Thiessen-Polygon method. For Fincha`a water shed; Fincha`a and Shambu gauging stations were considered to determine their corresponding aerial rainfall. The Thiessen coefficient of each gauging stations for specific water shed was determined at table 6.3.

The detail of the Fincha`a and Amerty Watershed aerial rainfall daily time series data is analyzed. But for the illustration purpose the mean monthly data is given in table 6.3.

Table 6.3 Double mass curve analysis of Shambu metrological station

Metrological station	Fincha`a Watershed		
	Area km ²	Thiessen coefficient	Total Area km ²
Shambu	246.5	0.594	415
Fincha`a	168.5	0.406	
total	415	1	

Table 6.4 The mean Decadal Fincha`a aerial rainfall

RAINFALL OF FINCHA`A RESERVOIR (mm/10day/KM2)																		
Jan			Feb			Mar			Apr			May			Jun			
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	
10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10	
(mm)	2.96811	2.96811	3.264921	4.132202	4.132202	3.305761	15.64297	15.64297	17.20726	24.30054	24.30054	24.30054	54.42847	54.42847	59.87132	91.20934	91.20934	91.20934
(m)	0.002968	0.002968	0.003265	0.004132	0.004132	0.003306	0.015643	0.015643	0.017207	0.024301	0.024301	0.024301	0.054428	0.054428	0.059871	0.091209	0.091209	0.091209

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
115.7309	115.7309	127.304	106.1189	106.1189	116.7308	80.1636	80.1636	80.1636	29.68375	29.68375	32.65213	8.324572	8.324572	8.324572	4.196642	4.196642	4.616306
0.115731	0.115731	0.127304	0.106119	0.106119	0.116731	0.080164	0.080164	0.080164	0.029684	0.029684	0.032652	0.008325	0.008325	0.008325	0.004197	0.004197	0.004616

Table 6.5 the mean Amerty aerial rainfall

RAINFALL OF AMERTY RESERVOIR (mm/10day/KM2)																		
Jan			Feb			Mar			Apr			May			Jun			
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	
10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10	
(mm)	6.15	6.15	6.765	3.78	3.78	3.024	16.98	16.98	18.678	25.06	25.06	25.06	62.23	62.23	68.453	101.82	101.82	101.82
(m)	0.00615	0.00615	0.006765	0.00378	0.00378	0.003024	0.01698	0.01698	0.018678	0.02506	0.02506	0.02506	0.06223	0.06223	0.068453	0.10182	0.10182	0.10182

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
115.07	115.07	126.577	105.68	105.68	116.248	82.66	82.66	82.66	43.71	43.71	48.081	9.71	9.71	9.71	6.48	6.48	7.128
0.11507	0.11507	0.126577	0.10568	0.10568	0.116248	0.08266	0.08266	0.08266	0.04371	0.04371	0.048081	0.00971	0.00971	0.00971	0.00648	0.00648	0.007128

6.2. Stream flow Data Analysis

The main streams of the study are Fincha`a and Amerty rivers that start from their respective upstream swamps. Fincha`a and Amerty stations were abundant after the start of Fincha`a and Amerty dam constructions in 1968 and 1983, respectively. The streams flow data was collected from the ministry of Water Resources Hydrology department.

The former Fincha`a River gauging station was established in February 1959, 5km upstream of Fincha`a fall, where the Fincha`a River emerges from the Chomen swamp. Starting from Feb 1963, the station was relocated 3km downstream of the previous station. The new gauging station was almost 1km upstream of the existing rock fill dam.

Amerty river gauging station was established in January 1964 upstream of the Amerty Falls. The river emerges from the elongated Amerty swamp and flows towards the lower Fincha`a valley.

Table 6.6 the mean stream inflow volume to Fincha`a reservoir

	VOLUME OF FINCHAA STREAM FLOW M ³																	
	Jan			Feb			Mar			Apr			May			Jun		
	10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days
year	10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10
1995	2669760	2669760	2936736	665280	665280	532224	1486080	1486080	1634688	2151360	2151360	2151360	1131840	1131840	1245024	1676160	1676160	1676160
1996	2972160	2972160	3269376	1261440	1261440	1009152	1235520	1235520	1359072	2151360	2151360	2151360	967680	967680	1064448	1831680	1831680	1831680
1997	2799360	2799360	3079296	1278720	1278720	1022976	1382400	1382400	1520640	1892160	1892160	1892160	1313280	1313280	1444608	2255040	2255040	2255040
1998	3101760	3101760	3411936	1261440	1261440	1009152	1313280	1313280	1444608	2393280	2393280	2393280	1313280	1313280	1444608	1736640	1736640	1736640
1999	3576960	3576960	3934656	1347840	1347840	1078272	1209600	1209600	1330560	2427840	2427840	2427840	1166400	1166400	1283040	2125440	2125440	2125440
2000	3352320	3352320	3687552	976320	976320	781056	1365120	1365120	1501632	1874880	1874880	1874880	1278720	1278720	1406592	1719360	1719360	1719360
2001	3438720	3438720	3782592	1486080	1486080	1188864	1442880	1442880	1587168	2013120	2013120	2013120	1382400	1382400	1520640	1814400	1814400	1814400
2002	2877120	2877120	3164832	328320	328320	262656	1347840	1347840	1482624	1537920	1537920	1537920	1512000	1512000	1663200	1745280	1745280	1745280
2003	2384640	2384640	2623104	1080000	1080000	864000	1296000	1296000	1425600	2583360	2583360	2583360	1615680	1615680	1777248	1728000	1728000	1728000
2004	2151360	2151360	2366496	1209600	1209600	967680	933120	933120	1026432	2626560	2626560	2626560	1598400	1598400	1758240	1900800	1900800	1900800
Average	2932416	2932416	3225658	1089504	1089504	871603.2	1301184	1301184	1431302	2165184	2165184	2165184	1327968	1327968	1460765	1853280	1853280	1853280

	Jul			Aug			Sep			OCT			Nov			Dec		
	10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days
	10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
4268160	4268160	4694976	19673280	19673280	21640608	36210240	36210240	36210240	17245440	17245440	18969984	17945280	17945280	17945280	5633280	5633280	6196608	
10195200	10195200	11214720	23664960	23664960	26031456	32149440	32149440	32149440	21669120	21669120	23836032	18256320	18256320	18256320	6229440	6229440	6852384	
13841280	13841280	15225408	39553920	39553920	43509312	25392960	25392960	25392960	23077440	23077440	25385184	19077120	19077120	19077120	6791040	6791040	7470144	
6972480	6972480	7669728	23094720	23094720	25404192	28416960	28416960	28416960	44789760	44789760	49268736	19586880	19586880	19586880	6825600	6825600	7508160	
11966400	11966400	13163040	46137600	46137600	50751360	48954240	48954240	48954240	41368320	41368320	45505152	18999360	18999360	18999360	6868800	6868800	7555680	
5348160	5348160	5882976	13495680	13495680	14845248	28650240	28650240	28650240	35657280	35657280	39223008	19517760	19517760	19517760	7603200	7603200	8363520	
7344000	7344000	8078400	39208320	39208320	43129152	27578880	27578880	27578880	21418560	21418560	23560416	18135360	18135360	18135360	5806080	5806080	6386688	
8242560	8242560	9066816	33238080	33238080	36561888	31363200	31363200	31363200	14895360	14895360	16384896	17832960	17832960	17832960	5538240	5538240	6092064	
5244480	5244480	5768928	36106560	36106560	39717216	41947200	41947200	41947200	21245760	21245760	23370336	17910720	17910720	17910720	5512320	5512320	6063552	
12657600	12657600	13923360	28805760	28805760	31686336	27743040	27743040	27743040	31147200	31147200	34261920	18385920	18385920	18385920	5780160	5780160	6358176	
8608032	8608032	9468835	30297888	30297888	33327672	32840640	32840640	32840640	27251424	27251424	29976566	18564768	18564768	18564768	6258816	6258816	6884698	

Table 6.7 The mean stream inflow volume to Amerty reservoir

	VOLUME OF AMERTY STREAM FLOW M ³																	
	Jan			Feb			Mar			Apr			May			Jun		
	10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days
year	10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10
1995	319680	319680	351648	233280	233280	186624	216000	216000	237600	146880	146880	146880	371520	371520	408672	527040	527040	527040
1996	336960	336960	370656	216000	216000	172800	112320	112320	123552	190080	190080	190080	483840	483840	532224	1114560	1114560	1114560
1997	328320	328320	361152	224640	224640	179712	190080	190080	209088	190080	190080	190080	259200	259200	285120	3049920	3049920	3049920
1998	345600	345600	380160	216000	216000	172800	181440	181440	199584	103680	103680	103680	250560	250560	275616	777600	777600	777600
1999	388800	388800	427680	224640	224640	179712	138240	138240	152064	103680	103680	103680	362880	362880	399168	2445120	2445120	2445120
2000	371520	371520	408672	241920	241920	193536	181440	181440	199584	190080	190080	190080	276480	276480	304128	725760	725760	725760
2001	380160	380160	418176	233280	233280	186624	164160	164160	180576	77760	77760	77760	34560	34560	38016	820800	820800	820800
2002	328320	328320	361152	216000	216000	172800	181440	181440	199584	241920	241920	241920	120960	120960	133056	803520	803520	803520
2003	293760	293760	323136	172800	172800	138240	164160	164160	180576	77760	77760	77760	34560	34560	38016	820800	820800	820800
2004	276480	276480	304128	155520	155520	124416	51840	51840	57024	69120	69120	69120	51840	51840	57024	1460160	1460160	1460160
Average	336960	336960	370656	213408	213408	170726.4	158112	158112	173923.2	139104	139104	139104	224640	224640	247104	1254528	1254528	1254528

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
4898880	4898880	5388768	15474240	15474240	17021664	7499520	7499520	7499520	4052160	4052160	4457376	864000	864000	864000	432000	432000	475200
12355200	12355200	13590720	17729280	17729280	19502208	11093760	11093760	11093760	5235840	5235840	5759424	1200960	1200960	1200960	518400	518400	570240
16848000	16848000	18532800	26334720	26334720	28968192	14679360	14679360	14679360	5624640	5624640	6187104	2056320	2056320	2056320	604800	604800	665280
8510400	8510400	9361440	17297280	17297280	19027008	14765760	14765760	14765760	11301120	11301120	12431232	2661120	2661120	2661120	604800	604800	665280
14765760	14765760	16242336	30032640	30032640	33035904	30913920	30913920	30913920	20822400	20822400	22904640	1874880	1874880	1874880	613440	613440	674784
6212160	6212160	6833376	12320640	12320640	13552704	14420160	14420160	14420160	8968320	8968320	9865152	2453760	2453760	2453760	734400	734400	807840
6419520	6419520	7061472	26006400	26006400	28607040	29954880	29954880	29954880	27941760	27941760	30735936	838080	838080	838080	406080	406080	446688
10463040	10463040	11509344	22610880	22610880	24871968	11568960	11568960	11568960	3481920	3481920	3830112	751680	751680	751680	414720	414720	456192
6419520	6419520	7061472	26006400	26006400	28607040	29738880	29738880	29738880	8588160	8588160	9446976	838080	838080	838080	406080	406080	446688
15750720	15750720	17325792	20062080	20062080	22068288	15336000	15336000	15336000	7732800	7732800	8506080	1321920	1321920	1321920	449280	449280	494208
10264320	10264320	11290752	21387456	21387456	23526202	17997120	17997120	17997120	10374912	10374912	11412403	1486080	1486080	1486080	518400	518400	570240

6.3. Evaporation Data Analysis

The study considered a mean monthly evaporation for further analysis. The piche evaporation records were obtained from the metrological gauging station. Assuming the common and widely acceptable evaporation rate from larger water bodies such as lakes and reservoirs to pan evaporation rate be 0.7 to relate the piche reading to lake evaporation the following coefficient was used (WMO,1994)

- Pan evaporation rate = Piche evaporation rate * 0.752
- Reservoir evaporation rate = Pan evaporation rate * 0.7
- Alternatively, Reservoir evaporation rate = Piche evaporation rate * 0.53

Hence, the study was considered this conversion factor to relate the daily base metrological stations record to the actual reservoir records. The mean monthly evaporation data used to determine the pool loose in the model is in table 6.8.

Table 6.8 Mean evaporation rate mm/ Decade of Fincha`a Reservoir

EVAPORATION OF FINCHA`A RESERVOIR (mm/10day/KM2)																		
Jan			Feb			Mar			Apr			May			Jun			
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	
10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10	
(mm)	31.3	31.3	34.43	34.8	34.8	27.84	29.9	29.9	32.89	33.4	33.4	33.4	38.7	38.7	42.57	12.8	12.8	12.8
(m)	0.0313	0.0313	0.03443	0.0348	0.0348	0.02784	0.0299	0.0299	0.03289	0.0334	0.0334	0.0334	0.0387	0.0387	0.04257	0.0128	0.0128	0.0128

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
8.5	8.5	9.35	8.3	8.3	9.13	9.5	9.5	9.5	15.8	15.8	17.38	21.1	21.1	21.1	24.8	24.8	27.28
0.0085	0.0085	0.00935	0.0083	0.0083	0.00913	0.0095	0.0095	0.0095	0.0158	0.0158	0.01738	0.0211	0.0211	0.0211	0.0248	0.0248	0.02728

Table 6.9 Mean evaporation rate mm/ Decade of Amerty Reservoir

EVAPORATION OF AMERTY RESERVOIR (mm/10day/KM2)																		
Jan			Feb			Mar			Apr			May			Jun			
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	
10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10	
(mm)	26.2	26.2	28.82	27.1	27.1	21.68	21.1	21.1	23.21	21.3	21.3	21.3	25	25	27.5	6.5	6.5	6.5
(m)	0.0262	0.0262	0.02882	0.0271	0.0271	0.02168	0.0211	0.0211	0.02321	0.0213	0.0213	0.0213	0.025	0.025	0.0275	0.0065	0.0065	0.0065

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
4.4	4.4	4.84	4.2	4.2	4.62	6.3	6.3	6.3	9.6	9.6	10.56	12.6	12.6	12.6	21.5	21.5	23.65
0.0044	0.0044	0.00484	0.0042	0.0042	0.00462	0.0063	0.0063	0.0063	0.0096	0.0096	0.01056	0.0126	0.0126	0.0126	0.0215	0.0215	0.02365

6.4. Fincha`a irrigation project data analysis

From the Acres international water requirement studies, the peak monthly average irrigation requirement of Fincha`a valley irrigation project occurred in April while the minimum in December. No irrigation is required in July and August. However small discharge in order of one meter cube is allowed for small villages (Acres, 1981).

The existing command area of the project was taken about 8145ha in the west bank of the river and 12000ha in the east bank of the river and the gross or total potential is about 21,450ha. The concrete lined main canal maximum design capacity is 1.03 l/s/ha. The monthly diversion requirements were given in table 6.10.

Table 6.10 Monthly gross diversion requirement (m³/s) to Fincha`a valley irrigation project

Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
6.01	7.4	7.92	8.56	7.44	7.21	1.0	1.0	6.24	6.35	5.64	5.51

Table 6.11 Diversion water requirement for irrigation Development

OUT FLOW OF FINCHA`A RESERVOIR (mm/10day/KM2)																		
Jan			Feb			Mar			Apr			May			Jun			
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	
10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10	
Vol(m3)	16024608	16024608	17627069	18927648	18927648	15142118	20016288	20016288	22017917	21346848	21346848	21346848	19014048	19014048	20915453	18530208	18530208	18530208

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
3682368	3682368	4050605	3682368	3682368	4050605	16670880	16670880	16670880	17619552	17619552	19381507	15255648	15255648	15255648	14987808	14987808	16486589

6.5. Sugar factory water supply

Table 6.12 The existing main camp and factory water supply total demand

Monthly minimum water requirement m ³ /s					
Jan	Feb	March	April	May	June
2.5	2.5	2.5	2.5	2.5	2.5
Monthly minimum water requirement m ³ /s					
July	August	September	October	November	December
1.125	1.125	2.5	2.5	2.5	2.5

6.6. Total Fincha`a reservoir outflow

The total out flow to the downstream through the turbine include the downstream irrigation requirement, water supply for sugar factory domestic use and factory use and Environmental flow for downstream aquatic life is given in table below.

Table 6.13 Total Downstream flow (m³/s)

Month	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
For irrigation(m ³ /s)	14.51	17.87	19.13	20.67	17.97	17.41	1.6	1.6	15.07	15.33	13.62	13.31
For water supply(m ³ /s)	2.5	2.5	2.5	2.5	2.5	2.5	1.125	1.125	1.125	2.5	2.5	2.5
Environmental flow(m ³ /s)	1.537	1.537	1.537	1.537	1.537	1.537	1.537	1.537	3.1	2.563	1.537	1.537
Total(m ³ /s)	18.547	21.907	23.167	24.707	22.007	21.447	4.262	4.262	19.295	20.393	17.657	17.347

7. Result and discussion

7.1. Fincha'a reservoir optimal operation result

The optimal operation analysis carried out results an optimal solution after successive trials. The modeling run is undertaken for the two main conflicting alternatives, power production and only the total downstream requirements.

7.1.1. Summary of optimal release and output power for only downstream demand

After considering only irrigation requirement, sugar factory water supply and for environmental flow optimal release for each ten days associated with each discrete value of the initial storage volume has been obtained. The power output is given in the analysis below. The maximum output power is 115.303MW and the minimum is 7.520MW at the first ten days of February and at the first ten days of July respectively. This is because of dry season and wet season irrigation requirement found in the downstream.

The only downstream alternative main objective is primarily to satisfy the downstream demand and to maximize the system released based on the downstream release pattern.

The optimum release curve of this alternative shows in fig. 7.1.

- Maximum release for a dry period operation i.e. even more than the power priority release pattern.
- Very minimum release is for July and August. Since the irrigation and the sugar factory demand for summer season is almost zero.

Table 7.1 Summary of optimal release (m³/s)

OUT FLOW OF FINCHA'A RESERVOIR (m ³ /s)																		
Jan			Feb				Mar			Apr			May			Jun		
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days
10	10	11	10	10	8	10	10	11	10	10	10	10	10	10	11	10	10	10
Total(m ³ /s)	18.547	18.547	18.547	21.907	21.907	21.907	23.167	23.167	23.167	24.707	24.707	24.707	22.007	22.007	22.007	21.447	21.447	21.447

Jul			Aug			Sep			OCT			Nov			Dec			
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	10 days	11 days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	10	11
4.262	4.262	4.262	4.262	4.262	4.262	19.295	19.295	19.295	20.393	20.393	20.393	17.657	17.657	17.657	17.347	17.347	17.347	17.347

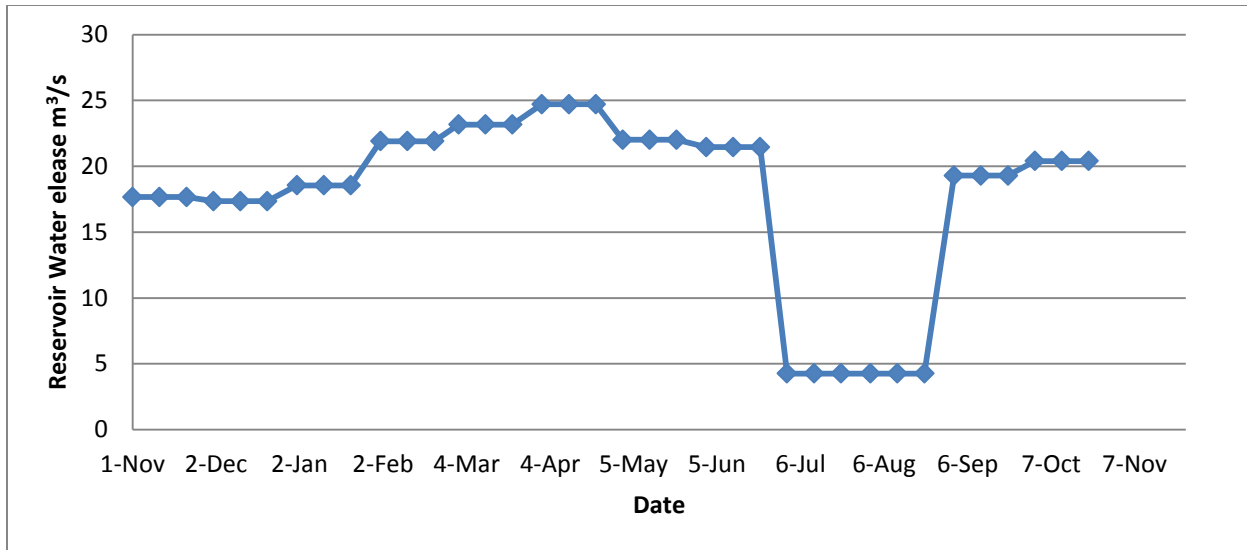


Figure 7.1 release rule curve for Fincha'a reservoir

Table 7.2 Summary of output Power (MW)

OUT FLOW OF FINCHA'A RESERVOIR (m3/s)																		
Jan			Feb			Mar			Apr			May			Jun			
10 days	10 days	11 days	10 days	10 days	8 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	
10	10	11	10	10	8	10	10	11	10	10	10	10	10	11	10	10	10	
power (M)	73.893	73.898	73.898	72.002	72.002	72.000	79.337	79.330	79.322	99.589	99.577	99.567	106.841	106.830	106.817	115.303	115.291	115.278

Jul			Aug			Sep			OCT			Nov			Dec		
10 days	10 days	11 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days	10 days	10 days	10 days	10 days	10 days	11 days
10	10	11	10	10	11	10	10	10	10	10	11	10	10	10	10	10	11
100.087	100.081	100.073	96.777	96.780	96.783	7.520	7.521	7.523	7.525	7.527	7.528	83.923	83.923	83.923	90.597	90.597	90.597

Ten days Energy out put

The ten day energy output of the Microsoft Excel 10 model is given the table below. The yearly average energy production for the mean ten days flow is found to be 678.368GWh.

The plot for ten days variability for the optimum energy output is shown in the figure below. The variability is very high. The maximum energy output found is 28.199GWh during the last eleven days of May whereas the smallest energy output is found to be 1.804GWh during the first ten days of July. This is because of the Wet season effect, that is, there is high amount inflow during the months of July and August as compared to very low amount of inflow during the other months of the year.

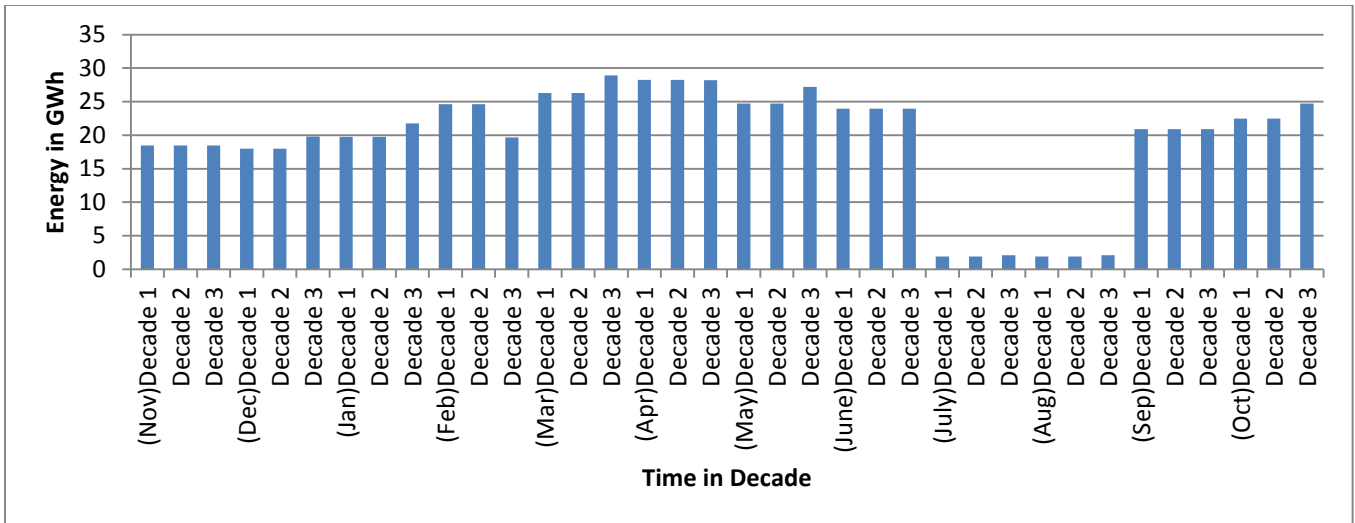


Figure 7.2 plot of Decadal energy output for Fincha`a hydropower

7.1.1.1 Reservoir operation Guide Curve by considering only downstream requirement

A reservoir operation guide curve is a guide line which proposes the status of the reservoir as a function of time for a period of one year. From the water levels for each month from the table below the guide curve has been developed as shown in figure below. This curve can be interpreted as the most effective operation guide curve for those years of hydro-metrological condition. This information will help to give an idea on how the reservoir should have been operated.

The normal pool level of Fincha`a reservoir is at 2219masl. Whereas the optimum guide curve developed using Microsoft Excel 10 falls always above the dead storage level for considering only irrigation, factory water supply and environmental flow requirement which imply that there will always be a spilled outflow without generating power.

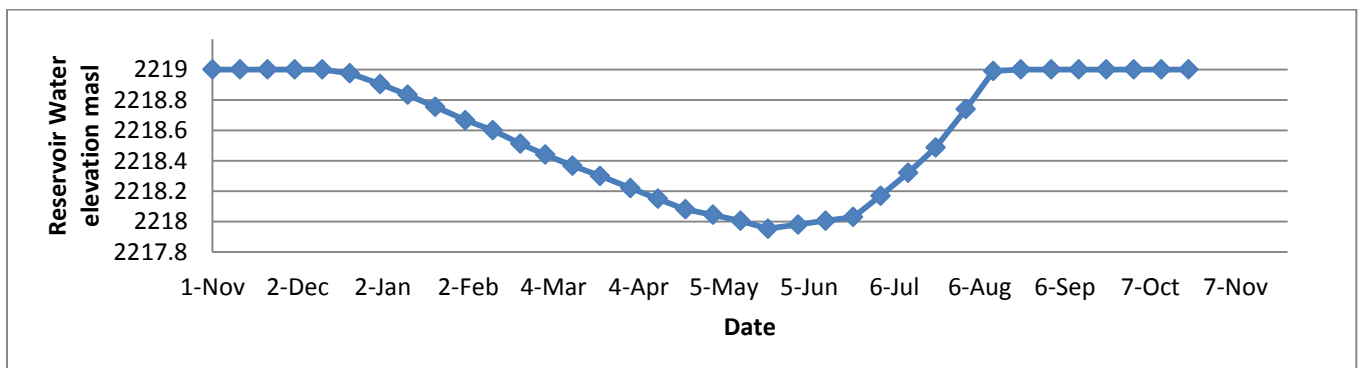


Figure 7.3 optimal reservoir operation for Fincha`a reservoir

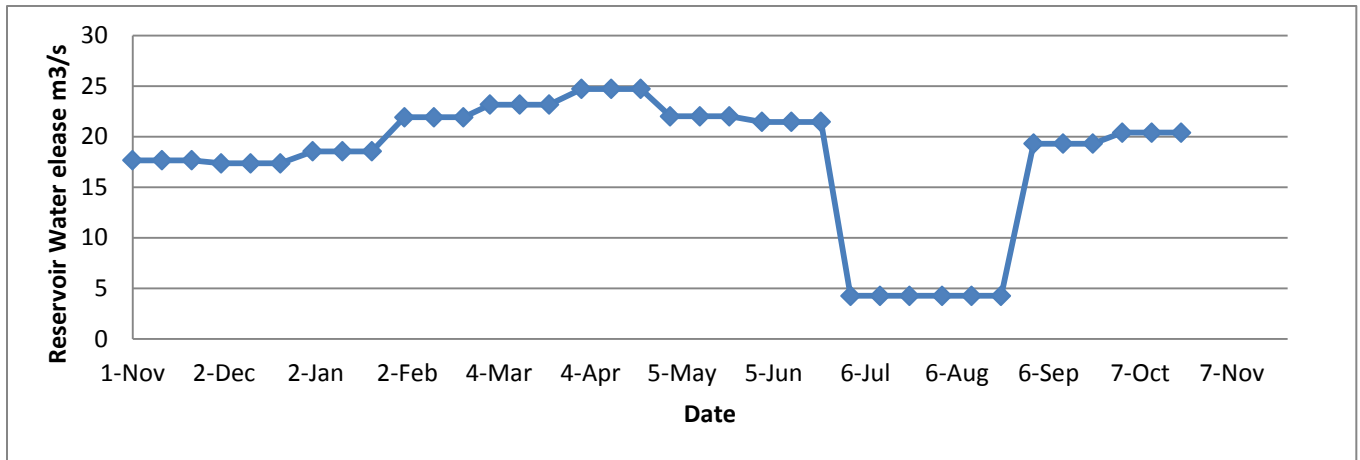


Figure 7.4 Guide curve developed for Fincha`a reservoir

This result concluded that for the downstream development (i.e. for 20,145ha) the only downstream release pattern underestimates the Wet release and results in high power stress in the country.

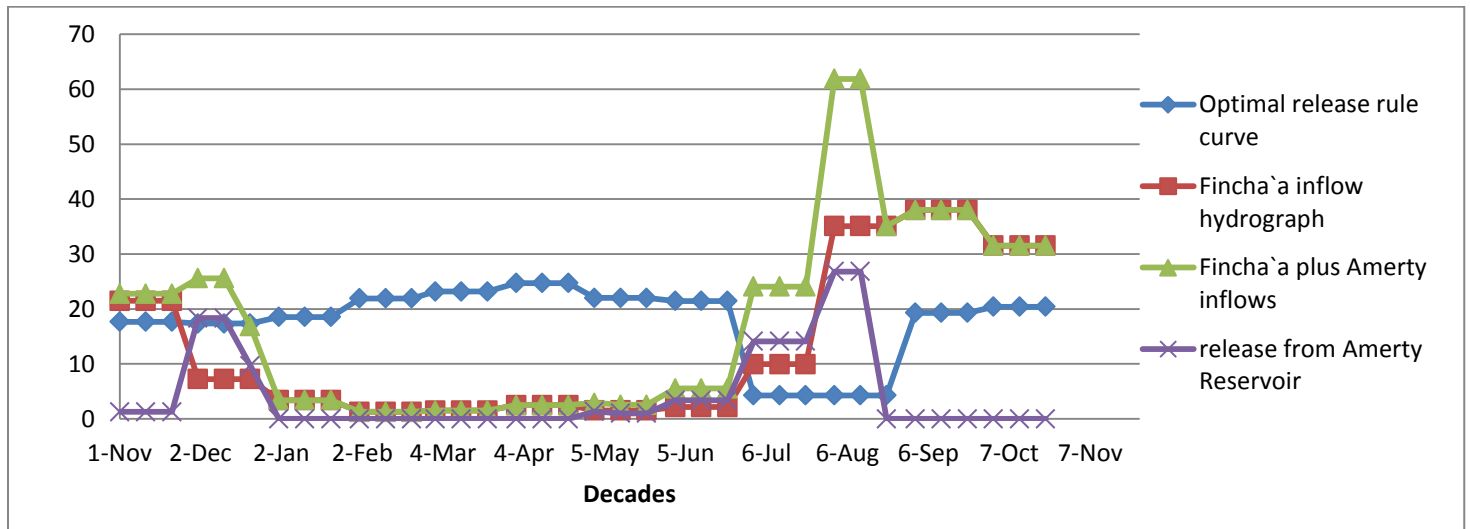


Figure 7.5 Relation between release rule curve and inflows

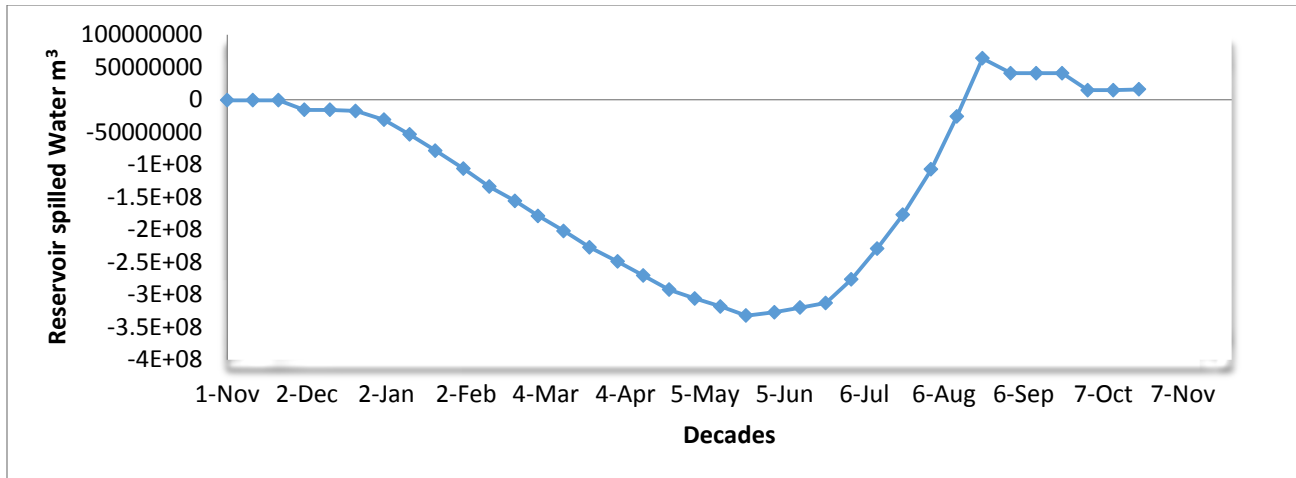


Figure 7.6 spilled water through spill way

7.1.2. Optimal release operation and Optimal output power and Energy if power generation has first priority

The existing phase power prioritized alternative simulation is taken primarily to maximize the power generation from the system. The simulation analysis, after a number of simulation trials result the optimal release rule for the given resource constraints and reservoir water levels.

The results of the optimal release rules are the following:

- ❖ Maximum releases dominated the dry period operation (i.e. from March to the end of June) since during this period both the power and the downstream demand are maximized.
- ❖ From July to the end of October, the power release is minimum, The Fincha`a high head power plant experiences a lower head share from the national Grid because most of the power load of the National Grid system is given to the low head (high discharge) plants of the country to minimize excess flows over the spillways.
- ❖ The Water release does not effectively satisfy the total downstream demand for some months.

In this study all the three power units are considered to generate power and one unit is always considered as standby 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.

Power and energy production in the model are generated from the power data input to the reservoir. Excel Solver and Microsoft Excel model 10 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, and power head in meter. To find the optimal power generation different iteration steps should be taken by changing the flow coming from Amerty reservoir through the tunnel, and the initial level of the reservoir. Finally the output of the iteration is given below.

Table 7.3 Power summary report from Excel and solver output

parameters	Out put		
	Maximum	average	minimum
Generation Efficiency	0.826	0.826	0.825
Power Head (m)	558.128	557.524	556.8163
Peak Power Generated (MW)	96.918	96.91	96.903
Peak Flow for power generation (cms)	21.475	21.459	21.445
Total Energy generated in a year (GWh)	848.931		

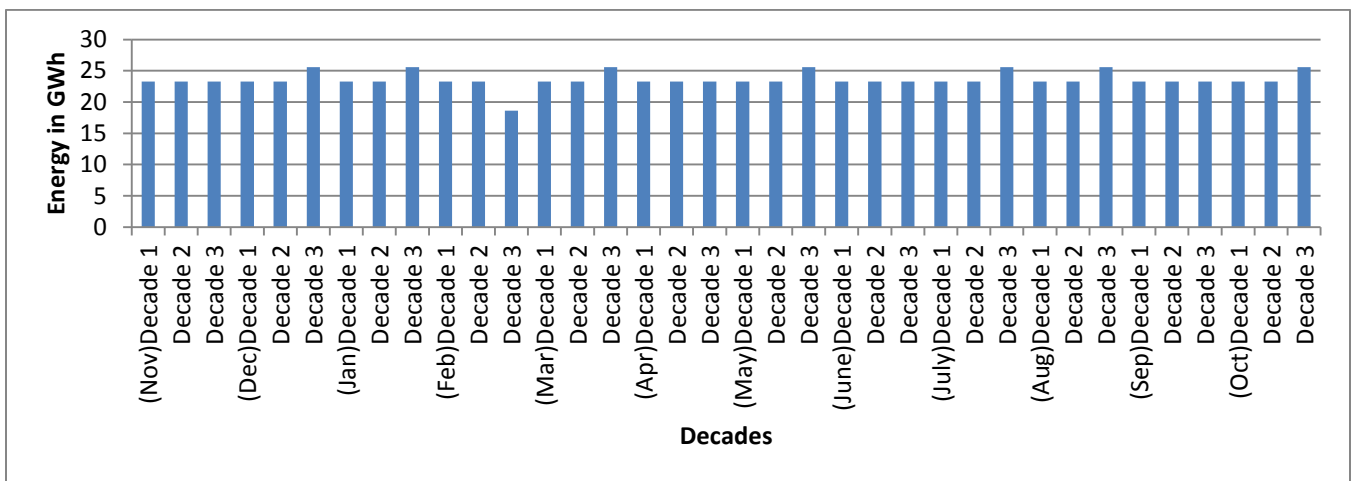


Figure 7.7 Decadal Energy output

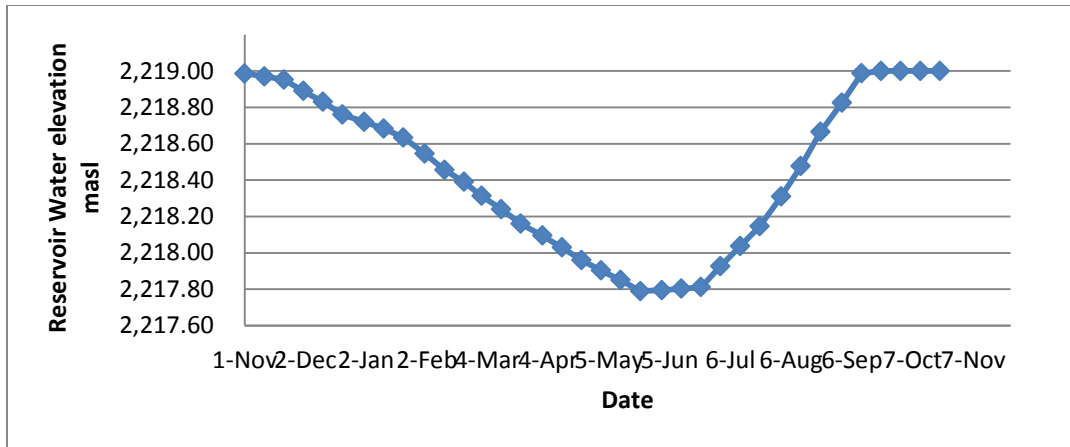


Figure 7.8 Reservoir operations Guide Curve

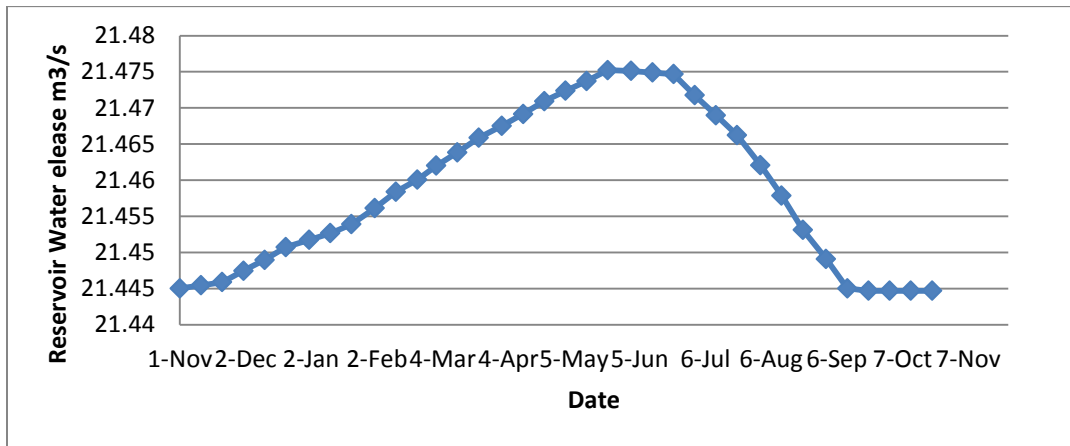


Figure 7.9 Optimal release rule curve

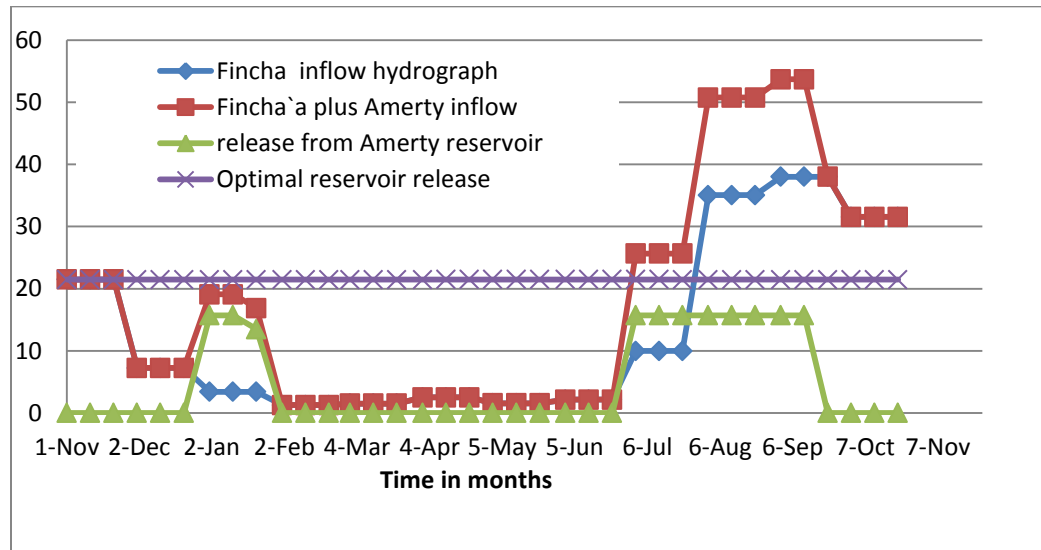


Figure 7.10 Relation between release rule curve and inflows

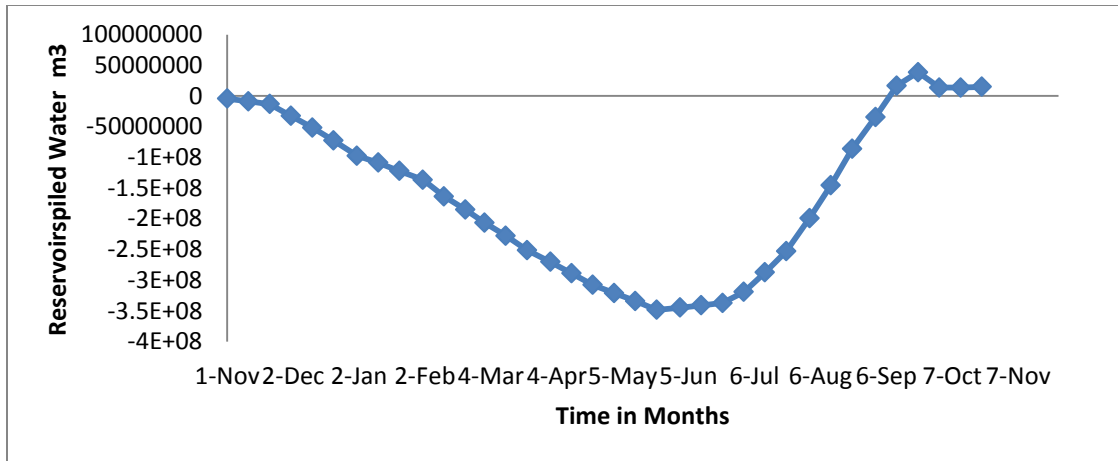


Figure 7.11 spilled water through spill way

The best alternative among different iteration including iteration given in the annex part, is the one which gives maximum energy generation. Hence, Maximum power generating option among the different iterations which is given above. So, it is considered as best alternatives and all the results obtained under this scenario and alternative is discussed below.

As shown in table 7.3 the following general reports are obtained for alternative one.

Maximum Energy generated (MWh)/year = 848.931

Maximum power generated per 10 days = 96.918MW

Average power generated per 10 days = 96.91MW

Average Generation efficiency per 10 days = 0.826 and Maximum = 0.826

Average Power head per 10 days = 557.524m and Maximum head per 10 days = 558.128m

Average flow per 10 days = 21.459m³/s and Maximum = 21.475m³/s are obtained.

7.2. Summary

The Fincha`a power plant and the downstream water requirement were investigated for different alternatives. The alternatives were made based on the reservoir levels, Amerty release through tunnel and the different priorities given to the power and only downstream scenarios.

Since the downstream development is at high level, there is a significant downstream water demand stress and if the existing downstream irrigation and water supply and environmental flow level show a certain change, the existing feature is also changed and a considerable demand conflicts will appear. Some of the conflicts are strong enough to affect the existing power release pattern and the load share given to the Fincha`a power plant from the national Grid.

- ❖ The only downstream alternative generally results in greater power generation during dry period operation and has a considerable advantage due to utilization of the reservoir water against losses due to evaporation but highly underestimate the summer power production and may cause stress in the country.
- ❖ The summer minimum release of the downstream alternative results increased losses via the Fincha`a spillway and also affects the operation of Amerty tunnel and results large spill at Amerty spillway.
- ❖ When hydropower production is given the first priority downstream releases has a significant advantage over power release operation that results in maximum utilization of the reservoir water against evaporation and spillage loss for both summer and the dry period condition.

8. Conclusion and Recommendation

8.1. Conclusion

This research work attempted to determine the reservoir operation that maximize the system performance of the Fincha`a hydropower plant. The system consists of the two reservoirs (i.e. Amerty and Fincha`a reservoirs). Amerty and Fincha`a reservoirs are different reservoirs in adjacent watersheds. The reservoirs are joined by a diversion tunnel. The main objective of the Amerty reservoir is to divert the summer Amerty flood flows to the Fincha`a system and also to store a volume of water for dry period operation.

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 average power guide. In this study, it was assumed that the two reservoirs were system reservoirs on the same stream whereby the upper reservoir (i.e. the Amerty reservoir) is used to support or augment the lower reservoir (i.e. Fincha`a reservoir) based on the specific desired storage.

The main concern of the optimal reservoir operation study was to determine the optimal release rule that maximize the system performance as stated in the objective of the study. The existing power plant release is mainly based on the load share given from the interconnected system. As the downstream activities increase in the daily production capabilities and the command area, the total water requirement also increase and the existing power release pattern cannot satisfy the downstream requirements. To analyze the effect, this study used the Microsoft excel 10 model and solver tool to this reservoir operation. In the analysis, power prioritized release pattern and only downstream release pattern were examined. After a number of simulation/ optimization steps, the optimal release rule for the given initial reservoir water level and release pattern was obtained. Based on the analysis, this study concluded that for the downstream development (i.e. for 20,145ha) the only downstream release pattern underestimates the Wet release and results in high power stress in the country. However, the alternative result shows the best release pattern.

In spite of this for all power operation system, the power release pattern has to consider the downstream requirements in addition to national grid load share.

8.2. Recommendation

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

1. Ethiopia needs more energy than agriculture for future. Because of this downstream irrigation schedule must be corrected according to the release rule curve attained.
2. In the actual condition, Fincha`a and Amerty reservoirs are highly affected by floating islands, which significantly change the evaporation values and the water balance of the reservoir. This study recommends that a detailed study of the characteristics of the floating island vegetation, the percentage of the coverage at the reservoirs and the rate of the evapotranspiration from the islands should be conducted to accurately estimate the reservoir loss due to evaporation and interception.
3. 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.
4. 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.
5. The main source of sediment problem of the reservoir is from the adjacent farmlands. Hence, this study recommends that the intensive soil and water conservation works or watershed management works is important to minimize the reservoir sedimentation problems from the agricultural and bare lands.
6. Downstream of the plant, water quality should be considered for further analysis. This study recommends that proper environmental studies and water quality investigations should be performed in the area because the downstream zone is highly affected by factory waste and surface drainage from the irrigation fields.
7. It is usually the case that a lot of water is spilled during wet seasons. Structural measures such as raising the height of Fincha`a dam to enable additional water storage, and/or means to reduce the sediment inflow need to be pursued.

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Appendix

Appendix 1 Different iterations for hydropower maximization

Alternative 1

Table A.1 Power summary report from Excel output for Alternative 1

parameters	Out put		
	Maximum	average	minimum
Generation Efficiency	0.826	0.8255	0.825
Power Head (m)	558.128	557.609	556.9334
Peak Power Generated (MW)	96.916	96.909	96.903
Peak Flow for power generation (cms)	21.473	21.456	21.444
Total Energy generated in a year (GWh)	848.923		

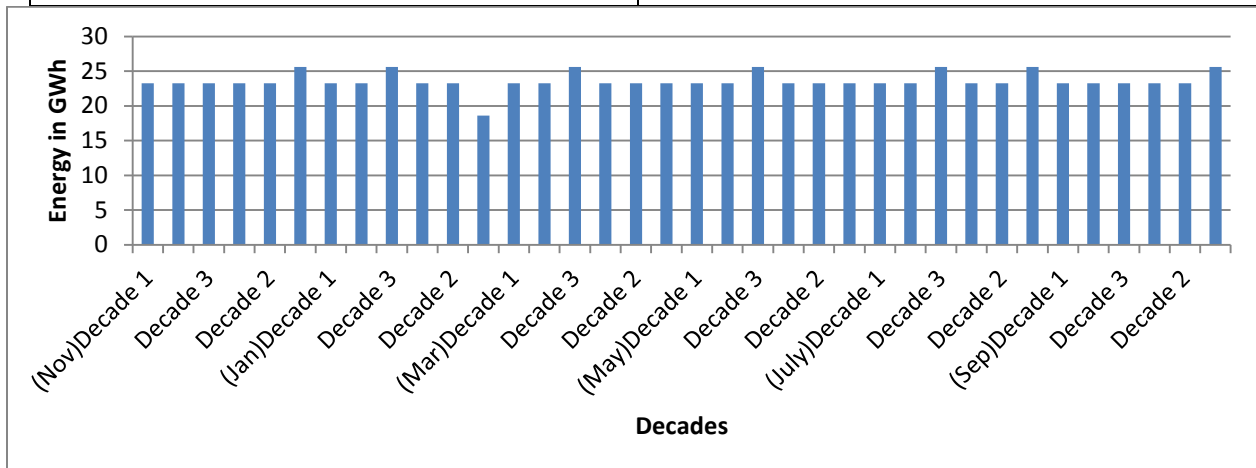


Fig A.1 Decadal Energy output of Alternative 1

Reservoir operation Guide Curve

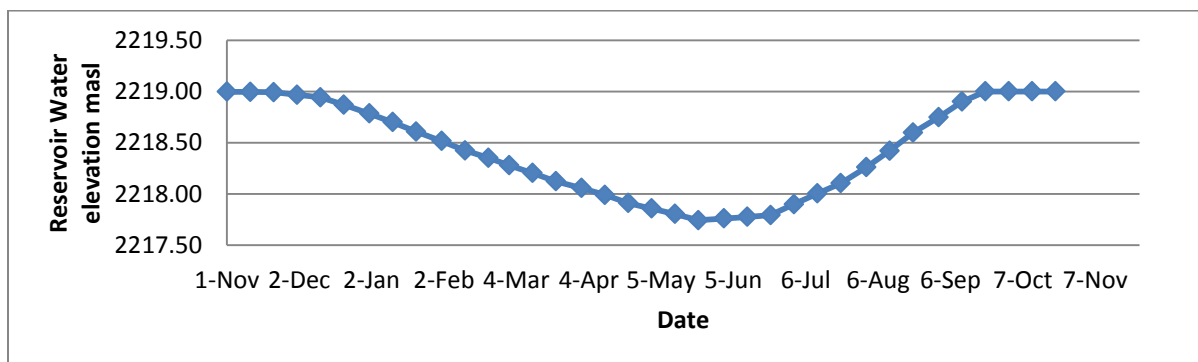


Fig A.2 Optimal reservoir operation of Alternative 1

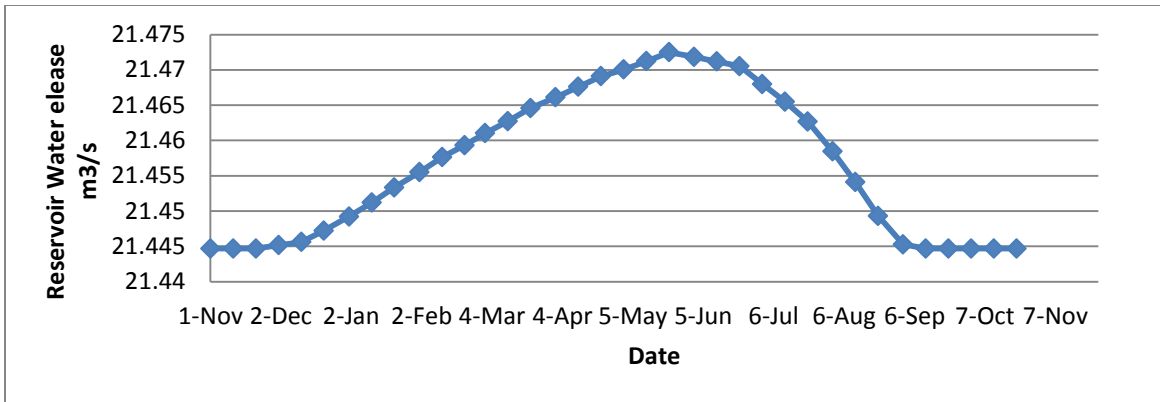


Fig A.3 Optimal release rule curve of Alternative 1

Alternative 2

Table 6.4 Power summary report from Excel output for Alternative 2

parameters	Out put		
	Maximum	average	minimum
Generation Efficiency	0.826	0.8255	0.825
Power Head (m)	558.128	557.605	556.929
Peak Power Generated (MW)	96.917	96.909	96.903
Peak Flow for power generation (cms)	21.473	21.457	21.445
Total Energy generated in a year (GWh)	848.923		

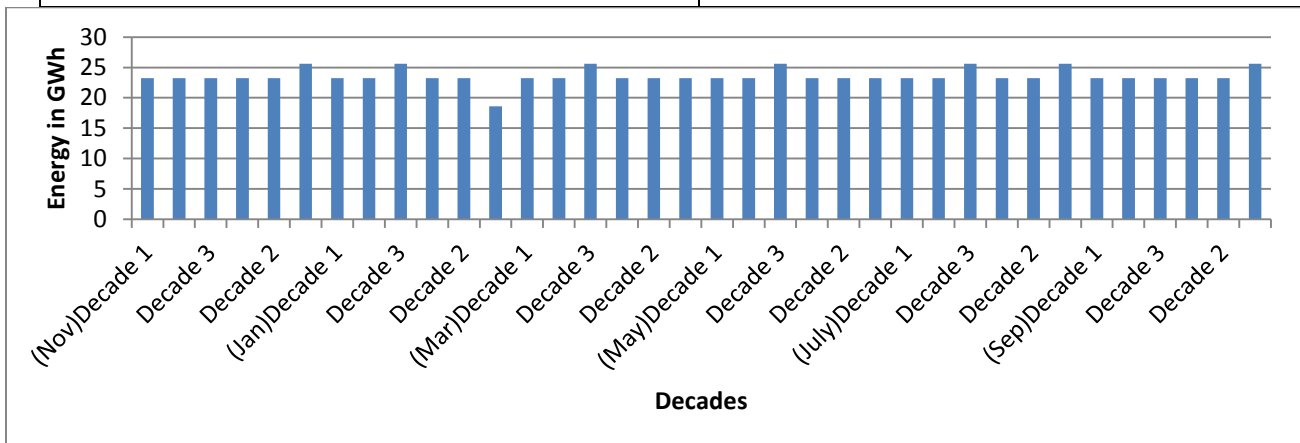


Fig 6.8 Decadal energy output

Reservoir operation Guide Curve

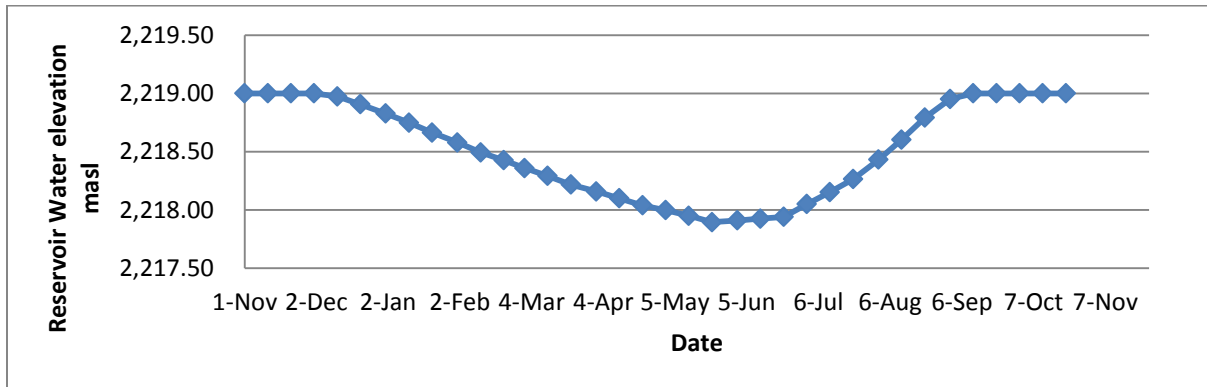


Fig 6.9 Optimal reservoir operation of Alternative 2

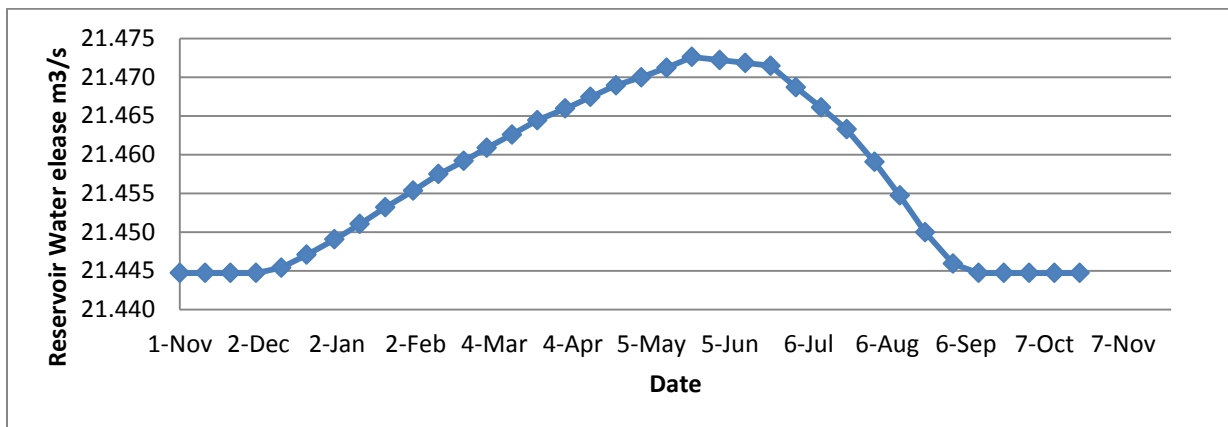


Fig 6.10 Optimal release rule curve of Alternative 2

Alternative 3

Table 6.6 Power summary report from Excel output for Alternative 3

parameters	Out put		
	Maximum	average	minimum
Generation Efficiency	0.826	0.826	0.825
Power Head (m)	558.128	557.584	556.899
Peak Power Generated (MW)	96.917	96.909	96.903
Peak Flow for power generation (cms)	21.473	21.457	21.445
Total Energy generated in a year (GWh)	848.925		

Appendix 2 Amerty uncontrolled spillway capacity curve

Table 4.4 Amerty uncontrolled spillway capacity, m³/s

Elevation	2234	2234.4	2234.8	2235.2	2235.6	2236	2236.4	2236.8	2237.2	2237.6	2238
Discharge	0	4.7	13.2	24.2	37.2	52	68.4	86.2	105.3	125.7	147.2

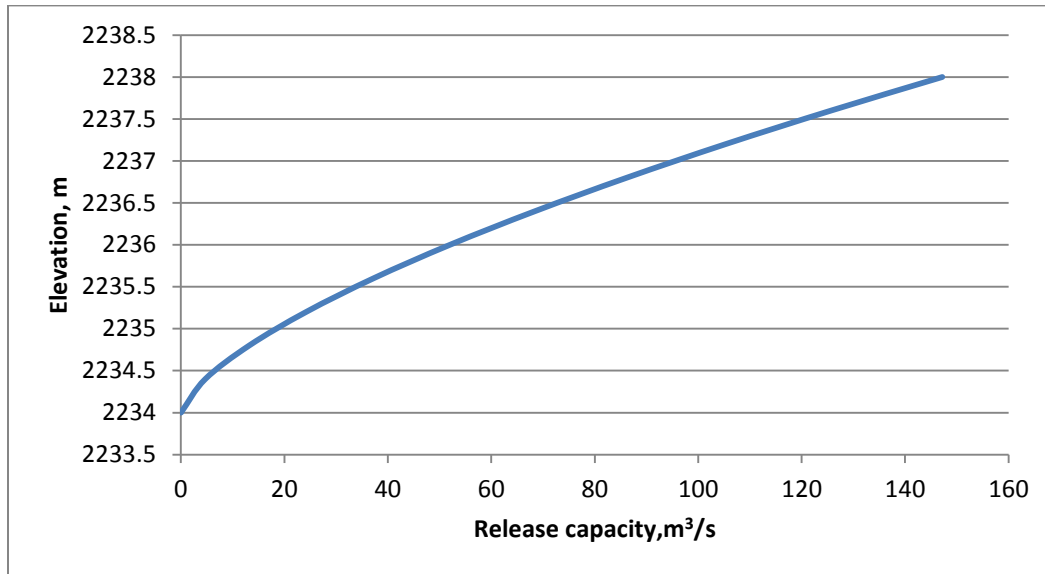


Figure 4.3 release capacity of Amerty reservoir

Appendix 3 Fincha`a uncontrolled spillway capacity curve

Table 4.6 Fincha`a uncontrolled spillway capacity m³/s

Elevation	2219	2219.4	2220	2220.5	2221	2221.3	2221.6	2221.8	2222.1	2222.3	2222.6	2222.8
Discharge	0	5.1	14.3	26.3	40.5	56.6	74.4	93.7	114.5	137	160	181

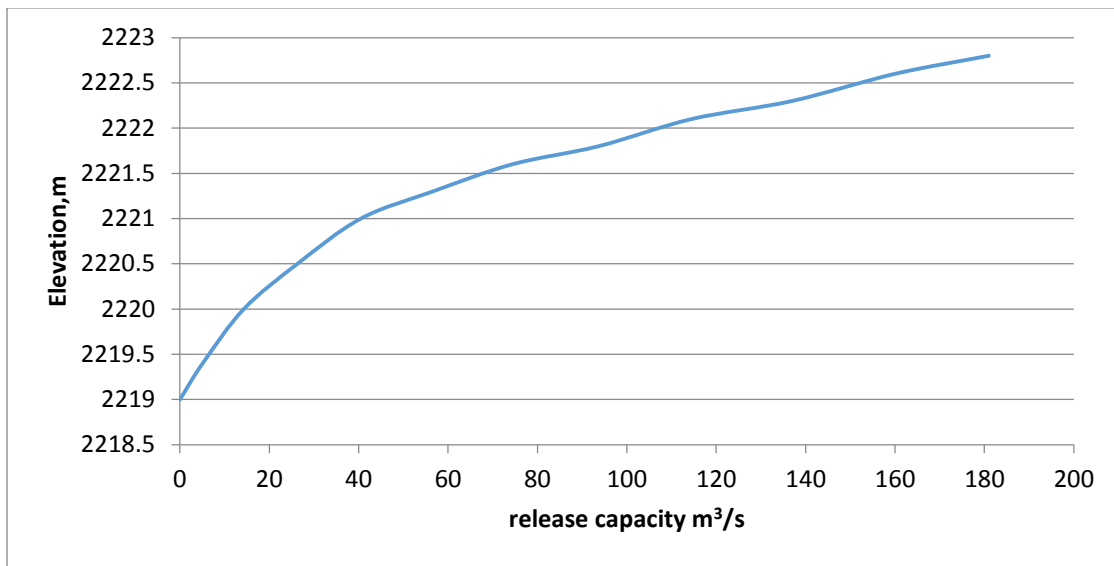


Figure 4.5 Fincha`a uncontrolled spillway capacity curve

Appendix 4 Amerty Diversion Tunnel capacity (m³/s)

		Amerty Diversion Tunnel Capacity (m ³ /s)									
Elevation	2232	2232.6	2233	2233.8	2234.4	2235	2235.6	2236.2	2237	2237.6	2238
Discharge	0	2.9	6.7	13.3	20.5	28.7	37.7	47.1	58	69.3	81.1

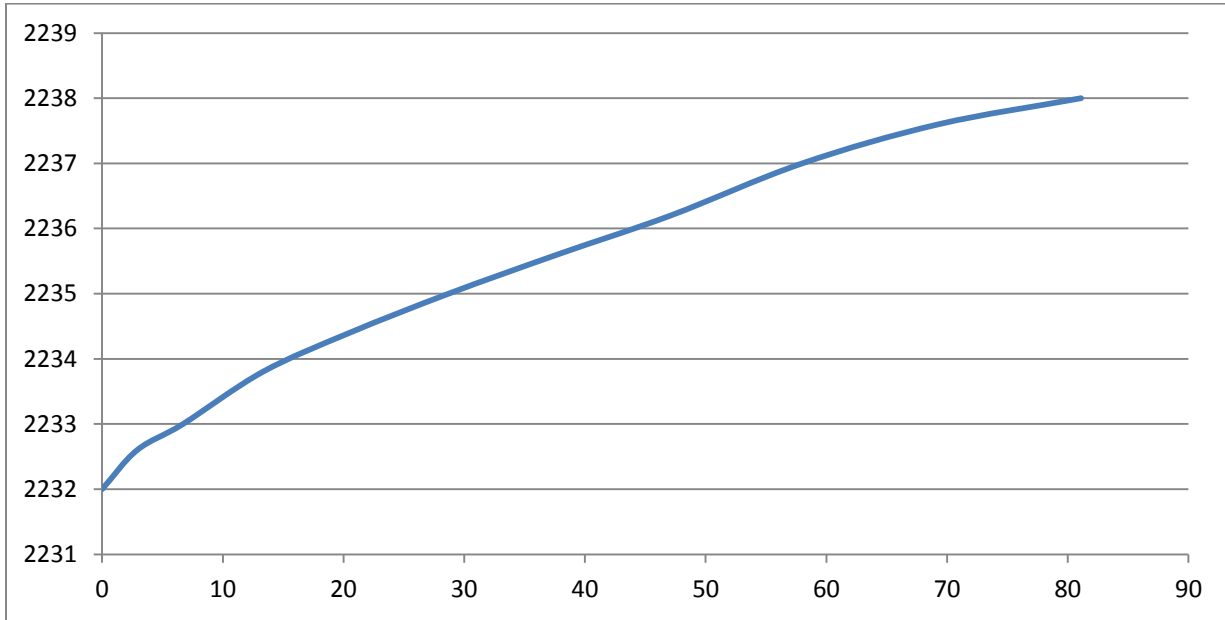


Figure 4.6 Amerty Diversion Tunnel capacity curve

Appendix 5 Reservoir Simulation table for Amerty Reservoir

	month	Q in	volume	Elevation	Area	Net loss			Vol I =vol	i-1 + (Q in - Q out)*Δt				
		(m3)	(m3)	(m)	(km2)	Evapo	rainfall	et Evap(m	Seep(m3)	New Vol (m3)	Spilled water	Qtunnel	new vol	ew Elev(m
10 days	Nov (30)	1486080	105900000	2234	22.8	287280	221388	-65892	0	105900000	1420188	0	105,900,000.00	2234
10 days		1486080	105900000	2234	22.8	287280	221388	-65892	0	105900000	1420188	0	105,900,000.00	2234
10 days		1486080	105900000	2234	22.8	287280	221388	-65892	0	105900000	1420188	0	105,900,000.00	2234
10 days	Dec (31)	518400	105900000	2234	22.8	490200	147744	-342456	0	105900000	175944	0	105,900,000.00	2234
10days		518400	105900000	2234	22.8	490200	147744	-342456	0	105900000	175944	0	105,900,000.00	2234
11 days		570240	105900000	2234	22.8	539220	162518.4	-376702	0	105900000	193538.4	0	105,900,000.00	2234
10 days	Jan (31)	336960	105900000	2234	22.8	597360	140220	-457140	0	105779820	-120180	13564800	92,215,020.00	2233.36
10 days		336960	92215020	2233.36	21.008	550409.6	129199.2	-421210	0	92130769.6	-13769230.4	13564800	78,565,969.60	2232.69
11 days		370656	78565970	2232.69	19.2	553344	129888	-423456	0	78513169.6	-27386830.4	12813170	65,700,000.00	2232
10 days	Feb (28)	213408	65700000	2232	17.4	471540	65772	-405768	0	65507640	-40392360	0	65,507,640.00	2231.988
10 days		213408	65507640	2231.988	17.37	470727	65658.6	-405068	0	65315979.6	-40584020.4	0	65,315,979.60	2231.976
8 days		170726.4	65315980	2231.976	17.335	375822.8	52421.04	-323402	0	65163304.2	-40736695.76	0	65,163,304.24	2231.97
10 days	Mar (31)	158112	65163304	2231.97	17.319	365430.9	294076.6	-71354.3	0	65250062	-40649938.04	0	65,250,061.96	2231.972
10 days		158112	65250062	2231.972	17.3244	365544.8	294168.3	-71376.5	0	65336797.4	-40563202.57	0	65,336,797.43	2231.977
11 days		173923.2	65336797	2231.977	17.338	402415	323839.2	-78575.8	0	65432144.8	-40467855.18	0	65,432,144.82	2231.983
10 days	Apr (30)	139104	65432145	2231.983	17.354	369640.2	434891.2	65251.04	0	65636499.9	-40263500.14	0	65,636,499.86	2231.996
10 days		139104	65636500	2231.996	17.39	370407	435793.4	65386.4	0	65840990.3	-40059009.74	0	65,840,990.26	2232.01
10 days		139104	65840990	2232.01	17.426	371173.8	436695.6	65521.76	0	66045616	-39854383.98	0	66,045,616.02	2232.018
10 days	May (31)	224640	66045616	2232.018	17.45	436250	1085914	649663.5	0	66919919.5	-38980080.48	0	66,919,919.52	2232.065
10 days		224640	66919920	2232.065	17.57	439250	1093381	654131.1	0	67798690.6	-38101309.38	0	67,798,690.62	2232.112
11 days		247104	67798691	2232.112	17.69	486475	1210934	724458.6	0	68770253.2	-37129746.81	0	68,770,253.19	2232.163
10 days	Jun (30)	1254528	68770253	2232.163	17.834	115921	1815858	1699937	0	71724718.1	-34175281.93	0	71,724,718.07	2232.32
10 days		1254528	71724718	2232.32	18.232	118508	1856382	1737874	0	74717120.3	-31182879.69	0	74,717,120.31	2232.48
10 days		1254528	74717120	2232.48	18.648	121212	1898739	1777527	0	77749175.7	-28150824.33	0	77,749,175.67	2232.641
10 days	July (31)	10264320	77749176	2232.641	19.07	83908	2194385	2110477	0	90123972.6	-15776027.43	13564800	76,559,172.57	2232.58
10 days		10264320	76559173	2232.58	18.908	83195.2	2175744	2092548	0	88916040.9	-16983959.07	13564800	75,351,240.93	2232.513
11 days		11290752	75351241	2232.513	18.73	90653.2	2370787	2280134	0	88922126.9	-16977873.06	14921280	74,000,846.94	2232.44
10 days	Aug (31)	21387456	74000847	2232.44	18.544	77884.8	1959730	1881845	0	97270148.1	-8629851.944	13564800	83,705,348.06	2232.96
10 days		21387456	83705348	2232.96	19.896	83563.2	2102609	2019046	0	105900000	1211850.136	13564800	93,547,050.14	2233.423
11 days		23526202	93547050	2233.423	21.844	100919.3	2539321	2438402	0	105900000	13611653.77	14921280	104,590,373.77	2233.94
10 days	Sep (30)	17997120	104590374	2233.94	22.632	142581.6	1870761	1728180	0	105900000	18415673.29	13564800	105,900,000.00	2234
10 days		17997120	105900000	2234	22.8	143640	1884648	1741008	0	105900000	19738128	13564800	105,900,000.00	2234
10 days		17997120	105900000	2234	22.8	143640	1884648	1741008	0	105900000	19738128	0	105,900,000.00	2234
10 days	Oct (31)	10374912	105900000	2234	22.8	218880	996588	777708	0	105900000	11152620	0	105,900,000.00	2234
10 days		10374912	105900000	2234	22.8	218880	996588	777708	0	105900000	11152620	0	105,900,000.00	2234
11 days		11412403	105900000	2234	22.8	240768	1096247	855478.8	0	105900000	12267882	0	105,900,000.00	2234
10 days	Nov (30)	1486080	105900000	2234	22.8	287280	221388	-65892	0	105900000	1420188	0	105,900,000.00	2234
10 days		1486080	105900000	2234	22.8	287280	221388	-65892	0	105900000	1420188	0	105,900,000.00	2234
10 days		1486080	105900000	2234	22.8	287280	221388	-65892	0	105900000	1420188	0	105,900,000.00	2234

Reservoir simulation Table for Fincha`a Reservoir

		Q in (m3)	Q out (m3)	volume (m3)	Elevation (m)	Area (km2)	Net loss Evapo(m3)	Rainfall(m3)	Vol I =vol i-1 + (Qin - Q out)*Δt et Evap(m3)	Seep(m3)	New Vol (m3)	Spilled wat	Q from tunne	New Vol (m3)	New Elev(m)
10		18564768	18528513	1120500000	2219	345	7279500	2871977.36	-4407523	0	1116128733	-4371267.3	0	1,116,128,732.74	2,218.99
10	Nov (30)	18564768	18528866	1116128733	2,218.99	343.9161	7256630	2862954.36	-4393675	0	1111770959	-8729041	0	1,111,770,958.97	2,218.97
10		18564768	18529258	1111770959	2,218.97	342.63	7229493	2852248.12	-4377245	0	1107429225	-13070775	0	1,107,429,224.51	2,218.95
10		6258816	18530605	1107429225	2,218.95	341.208	8461958	1431927.74	-7030031	0	1088127404	-32372596	0	1,088,127,404.50	2,218.89
10	Dec (31)	6258816	18531910	1088127404	2,218.89	336.31	8340488	1411372.59	-6929115	0	1068925195	-51574805	0	1,068,925,194.97	2,218.83
11		6884698	20386776	1068925195	2,218.83	331.57	9045230	1530628.56	-7514601	0	1047908515	-72591485	0	1,047,908,515.30	2,218.76
10		2932416	18534303	1047908515	2,218.76	326.04	10205052	967722.726	-9237329	0	1023069299	-97430701	13564800	1,036,634,098.63	2218.72
10	Jan (31)	2932416	18535109	1036634099	2,218.72	322.88	10106144	958343.497	-9147801	0	1011883605	-108616395	13564800	1,025,448,405.35	2218.683
11		3225658	20389793	1025448405	2,218.68	319.957	11016120	1044634.48	-9971485	0	998312785	-122187215	12813169.6	1,011,125,954.35	2218.634
10		1089504	18538114	1011125954	2,218.63	316.086	10999793	1306131.15	-9693662	0	983983683	-136516317	0	983,983,682.54	2218.545
10	Feb (28)	1089504	18540054	983983683	2,218.55	309.055	10755114	1277077.63	-9478036	0	957055096	-163444904	0	957,055,096.45	2218.456
8		871603.2	14833194	957055096	2,218.46	302.024	8408348	998419.299	-7409929	0	935683577	-184816423	0	935,683,576.61	2218.39
10		1301184	18543172	935683577	2,218.39	296.81	8874619	4642988.91	-4231630	0	914209958	-206290042	0	914,209,958.23	2218.313
10	Mar (31)	1301184	18544765	914209958	2,218.31	290.727	8692737	4547832.74	-4144905	0	892821472	-227678528	0	892,821,472.36	2218.24
11		1431302	20401163	892821472	2,218.24	284.96	9372334	4903381.73	-4468953	0	869382659	-251117341	0	869,382,659.01	2218.16
10		2165184	18547932	869382659	2,218.16	278.64	9306576	6771102.65	-2535473	0	850464438	-270035562	0	850,464,438.05	2218.095
10	Apr (30)	2165184	18549352	850464438	2,218.10	273.505	9135067	6646319.38	-2488748	0	831591523	-288908477	0	831,591,522.55	2218.03
10		2165184	18550882	831591523	2,218.03	268.37	8963558	6521536.1	-2442022	0	812763803	-307736197	0	812,763,802.62	2217.96
10		1327968	18552128	812763803	2,217.96	264.88	10250856	14417012.9	4166157	0	799705799	-320794201	0	799,705,799.04	2217.903
10	May (31)	1327968	18553288	799705799	2,217.90	263.284	10189091	14330145.1	4141054	0	786621533	-333878467	0	786,621,533.46	2217.85
11		1460765	20410061	786621533	2,217.85	261.8	11144826	15674310.5	4529485	0	772201722	-348298278	0	772,201,721.94	2217.79
10		1853280	18554502	772201722	2,217.79	260.12	3329536	23725374.8	20395839	0	775896338	-344603662	0	775,896,338.47	2217.7945
10	Jun (30)	1853280	18554316	775896338	2,217.79	260.246	3331149	23736867.2	20405718	0	779601021	-340898979	0	779,601,020.59	2217.803
10		1853280	18554119	779601021	2,217.80	260.484	3334195	23758575	20424380	0	783324561	-337175439	0	783,324,561.09	2217.812
10		8608032	18551604	783324561	2,217.81	260.736	2216256	30175217.6	27958962	0	801339951	-319160049	13564800	814,904,751.09	2217.927
10	July (31)	8608032	18549199	814904751	2,217.93	263.956	2243626	30547871.2	28304245	0	833267829	-287232171	13564800	846,832,629.37	2218.037
11		9468835	20401499	846832629	2,218.04	268.923	2514430	34234977.3	31720547	0	867620512	-252879488	14921280	882,541,792.46	2218.146
10		30297888	18543238	882541792	2,218.15	277.534	2303532	29451613.7	27148082	0	921444524	-199055476	13564800	935,009,324.25	2218.31
10	Aug (31)	30297888	18539596	935009324	2,218.31	290.49	2411067	30826490.7	28415424	0	975183040	-145316960	13564800	988,747,839.98	2218.477
11		33327677	20389051	988747840	2,218.48	303.683	2772626	35449169.7	32676544	0	1034363010	-86136990	14921280	1,049,284,289.96	2218.665
10		32840640	18532019	1049284290	2,218.67	318.535	3026083	25534910.8	22508828	0	1086101739	-34398261	13564800	1,099,666,539.43	2218.825
10	Sep (30)	32840640	18528497	1099666539	2,218.83	331.175	3146162	26548178.7	23402016	0	1120500000	16880699	13564800	1,120,500,000.00	2218.987
10		32840640	18528214	1120500000	2,218.99	343.973	3267743	27574112.4	24306369	0	1120500000	38618794	0	1,120,500,000.00	2219
10		27251424	18528214	1120500000	2,219.00	345	5451000	10240895.1	4789895	0	1120500000	13513105	0	1,120,500,000.00	2219
10	Oct (31)	27251424	18528214	1120500000	2,219.00	345	5451000	10240895.1	4789895	0	1120500000	13513105	0	1,120,500,000.00	2219
11		29976566	20381036	1120500000	2,219.00	345	5996100	11264984.7	5268885	0	1120500000	14864415	0	1,120,500,000.00	2219
10		18564768	18528513	1120500000	2,219.00	345	7279500	2871977.36	-4407523	0	1116128733	-4371267.3	0	1,116,128,732.74	2,218.98
10	Nov (30)	18564768	18528866	1116128733	2,218.98	343.736	7252830	2861455.1	-4391375	0	1111773260	-8726740.2	0	1,111,773,259.84	2,218.97
10		18564768	18529258	1111773260	2,218.97	342.63	7229493	2852248.12	-4377245	0	1107431525	-13068475	0	1,107,431,525.38	2,218.95

Appendix 6 Optimal Power production table of Fincha'a reservoir

10 days		21.44504	9810	1833125	3.13E-06	-8.20556	67.33118	0.238374	2526670	2.2718E-06	-10.74412527	115.4362	0.063636868	0.127274	2526670	2.27E-06	-10.7441	115.4362	0.307529	0.67317679	33.89978	1.973386	35.87317	593.98628	558.1131	0.537129	53.712949	-37.506052	109.348822	82.53177002	0.8253177	96903443
10 days	Nov (30)	21.44545	9810	1833156	3.13E-06	-8.20556	67.33119	0.238374	2526713	2.2717E-06	-10.74412708	115.4363	0.063636847	0.127274	2526713	2.27E-06	-10.7441	115.4363	0.307529	0.67317663	33.90107	1.973462	35.87453	593.97	558.0955	0.537148	53.7148235	-37.508669	109.352638	82.53296828	0.825329683	96903637
10 days		21.4459	9810	1833191	3.13E-06	-8.20556	67.33119	0.238374	2526761	2.2717E-06	-10.74412908	115.4363	0.063636823	0.127274	2526761	2.27E-06	-10.7441	115.4363	0.307529	0.67317646	33.90249	1.973545	35.87603	593.952	558.076	0.537169	53.7168963	-37.511564	109.356858	82.53429319	0.825342932	96903852
10 days		21.44746	9810	1833311	3.13E-06	-8.20556	67.3312	0.238374	2526927	2.2715E-06	-10.74413597	115.4365	0.063636741	0.127273	2526927	2.27E-06	-10.7441	115.4365	0.307528	0.67317586	33.90739	1.973832	35.88122	593.89	558.0088	0.53724	53.7240377	-37.521539	109.371396	82.53885699	0.82538857	96904591
10 days	Dec (31)	21.44897	9810	1833427	3.13E-06	-8.20556	67.33121	0.238374	2527087	2.2714E-06	-10.74414265	115.4366	0.063636662	0.127273	2527087	2.27E-06	-10.7441	115.4366	0.307528	0.67317528	33.91214	1.97411	35.88625	593.83	557.9438	0.53731	53.7309511	-37.531196	109.38547	82.5432739	0.825432739	96905306
11 days		21.45073	9810	1833563	3.13E-06	-8.20556	67.33123	0.238374	2527274	2.2712E-06	-10.74415043	115.4368	0.06363657	0.127273	2527274	2.27E-06	-10.7442	115.4368	0.307528	0.6731746	33.91768	1.974435	35.89211	593.76	557.8679	0.53739	53.7390199	-37.542469	109.401897	82.54842736	0.825484274	96906142
10 days		21.45174	9810	1833640	3.13E-06	-8.20556	67.33124	0.238374	2527380	2.2711E-06	-10.74415488	115.4369	0.063636517	0.127273	2527380	2.27E-06	-10.7442	115.4369	0.307527	0.67317421	33.92084	1.97462	35.89546	593.72	557.8245	0.537436	53.7436322	-37.548914	109.411286	82.55137229	0.825513724	96906620
10 days	Jan (31)	21.45267	9810	1833712	3.13E-06	-8.20556	67.33124	0.238374	2527479	2.271E-06	-10.744159	115.437	0.063636468	0.127273	2527479	2.27E-06	-10.7442	115.437	0.307527	0.67317385	33.92377	1.974792	35.89856	593.683	557.7844	0.537479	53.7478995	-37.554877	109.419974	82.55409668	0.825540967	96907062
11 days		21.45391	9810	1833807	3.13E-06	-8.20556	67.33125	0.238374	2527610	2.2709E-06	-10.74416446	115.4371	0.063636404	0.127273	2527610	2.27E-06	-10.7442	115.4371	0.307527	0.67317337	33.92765	1.975019	35.90267	593.634	557.7313	0.537536	53.7535522	-37.562777	109.431482	82.5577047	0.825577047	96907647
10 days		21.45615	9810	1833979	3.13E-06	-8.20556	67.33127	0.238374	2527848	2.2707E-06	-10.74417436	115.4373	0.063636287	0.127273	2527848	2.27E-06	-10.7442	115.4373	0.307526	0.67317251	33.93471	1.975432	35.91014	593.545	557.6349	0.537638	53.7638236	-37.577133	109.452392	82.56425859	0.825642586	96908711
10 days	Feb (28)	21.4584	9810	1834152	3.13E-06	-8.20556	67.33129	0.238374	2528086	2.2705E-06	-10.74418427	115.4375	0.063636169	0.127272	2528086	2.27E-06	-10.7442	115.4375	0.307526	0.67317164	33.94177	1.975846	35.91761	593.456	557.5384	0.537741	53.7741003	-37.5915	109.473313	82.57081319	0.825708132	96909776
8 days		21.46006	9810	1834280	3.13E-06	-8.20557	67.3313	0.238374	2528263	2.2703E-06	-10.74419163	115.4377	0.063636082	0.127272	2528263	2.27E-06	-10.7442	115.4377	0.307525	0.67317121	33.947	1.976152	35.92315	593.39	557.4668	0.537817	53.7817248	-37.602161	109.488835	82.57567432	0.825756744	96910567
10 days		21.462	9810	1834430	3.13E-06	-8.20557	67.33132	0.238373	2528469	2.2701E-06	-10.74420021	115.4378	0.06363598	0.127272	2528469	2.27E-06	-10.7442	115.4378	0.307525	0.67317075	33.95311	1.97651	35.92962	593.313	557.3834	0.537906	53.7906238	-37.626411	109.506952	82.58134622	0.825813462	96911489
10 days	Mar (31)	21.46385	9810	1834572	3.13E-06	-8.20557	67.33133	0.238373	2528664	2.27E-06	-10.74420834	115.438	0.063635884	0.127272	2528664	2.27E-06	-10.7442	115.438	0.307524	0.67316954	33.95891	1.97685	35.93576	593.24	557.3042	0.537991	53.7990643	-37.626411	109.524135	82.58672392	0.825867239	96912365
11 days		21.46587	9810	1834727	3.13E-06	-8.20557	67.33135	0.238373	2528879	2.2698E-06	-10.74421726	115.4382	0.063635778	0.127272	2528879	2.27E-06	-10.7442	115.4382	0.307524	0.67316876	33.96527	1.977222	35.94249	593.16	557.2175	0.538083	53.8083183	-37.639356	109.542974	82.59261783	0.825926178	96913325
10 days		21.46751	9810	1834854	3.13E-06	-8.20557	67.33136	0.238373	2529053	2.2696E-06	-10.74422451	115.4384	0.063635692	0.127271	2529053	2.27E-06	-10.7442	115.4384	0.307523	0.67316813	33.97044	1.977525	35.94796	593.095	557.147	0.538158	53.8158404	-37.649881	109.558288	82.59740706	0.825974071	96914105
10 days	Apr (30)	21.46916	9810	1834980	3.13E-06	-8.20557	67.33137	0.238373	2529227	2.2695E-06	-10.74423176	115.4385	0.063635607	0.127271	2529227	2.27E-06	-10.7442	115.4385	0.307523	0.6731675	33.97561	1.977828	35.95344	593.03	557.0766	0.538234	53.8233654	-37.660411	109.573607	82.60219665	0.826021967	96914886
10 days		21.47093	9810	1835116	3.13E-06	-8.20557	67.33139	0.238373	2529415	2.2693E-06	-10.74423957	115.4387	0.063635514	0.127271	2529415	2.27E-06	-10.7442	115.4387	0.307523	0.67316682	33.98118	1.978154	35.95933	592.96	557.0007	0.538315	53.8314725	-37.671757	109.590112	82.6073551	0.826073551	96915727
10 days		21.47237	9810	1835227	3.13E-06	-8.20557	67.3314	0.238373	2529568	2.2692E-06	-10.74424594	115.4388	0.063635439	0.127271	2529568	2.27E-06	-10.7442	115.4388	0.307522	0.67316626	33.98572	1.97842	35.96414	592.903	556.9389	0.538381	53.8380765	-37.681	109.603556	82.61155587	0.826115559	96916413
10 days	May (31)	21.47371	9810	1835330	3.13E-06	-8.20557	67.33141	0.238373	2529710	2.269E-06	-10.74425185	115.4389	0.063635369	0.127271	2529710	2.27E-06	-10.7443	115.4389	0.307522	0.67316575	33.98994	1.978667	35.96861	592.85	556.8814	0.538442	53.844219	-37.689599	109.616061	82.61546211	0.826154621	96917051
11 days		21.47523	9810	1835447	3.13E-06	-8.20557	67.33142	0.238373	2529871	2.2689E-06	-10.74425855	115.4391	0.063635289	0.127271	2529871	2.27E-06	-10.7443	115.4391	0.307521	0.67316516	33.99472	1.978947	35.97367	592.79	556.8163	0.538512	53.8511752	-37.699338	109.630222	82.61988456	0.826198846	96917773
10 days		21.47512	9810	1835439	3.13E-06	-8.20557	67.33142	0.238373	2529859	2.2689E-06	-10.74425805	115.4391	0.063635295	0.127271	2529859	2.27E-06	-10.7443	115.4391	0.307522	0.67316521	33.99436	1.978926	35.97329	592.7945	556.8212	0.538507	53.8506534	-37.698607	109.62916	82.61955286	0.826195529	96917719
10 days	Jun (30)	21.4749	9810	1835422	3.13E-06	-8.20557	67.33142	0.238373	2529836	2.2689E-06	-10.7442571	115.4391	0.063635306	0.127271	2529836	2.27E-06	-10.7443	115.4391	0.307522	0.67316529	33.99369	1.978887	35.97257	592.803	556.8304	0.538497	53.8496678	-37.697227	109.627154	82.61892633	0.826189263	96917617
10 days		21.47468	9810	1835404	3.13E-06	-8.20557	67.33142	0.238373	2529812	2.2689E-06	-10.7442561	115.439	0.063635318	0.127271	2529812	2.27E-06	-10.7443	115.439	0.307522	0.67316538	33.99297	1.978745	35.97181	592.812	556.8402	0.538486	53.8486243	-37.695766	109.625029	82.61826296	0.82618263	96917508
10 days		21.47176	9810	1835180	3.13E-06	-8.20557	67.33139	0.238373	2529503	2.2692E-06	-10.74424326	115.4388	0.06363547	0.127271	2529503	2.27E-06	-10.7442	115.4388	0.307522	0.6731665	33.98381	1.978308	35.96212	592.927	556.9649	0.538353	53.8352956	-37.677108	109.597895	82.60978711	0.826097871	96916124
10 days	July (31)	21.46898	9810	1834966	3.13E-06	-8.20557	67.33137	0.238373	2529208	2.2695E-06	-10.74423098	115.4385	0.063635616	0.127271	2529208	2.27E-06	-10.7442	115.4385	0.307523	0.67316757	33.97505	1.977795	35.95285	593.037	557.0842	0.538226	53.822549	-37.659276	109.571957	82.60168083	0.826016808	96914802
11 days		21.46622	9810	1834754	3.13E-06	-8.20557	67.33135	0.238373	2528916	2.2697E-06	-10.74421882	115.																				