OPERATION ANALYSIS OF KARADOBI RESERVOIR IN BLUE NILE RIVER BASIN AND IT'S IMPACT ON DOWNSTREAM WATER USES

BY

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CERTIFICATION

I, the undersigned, certify that I read and hereby recommend for the acceptance by the Arbaminch university a dissertation entitled: ''**Operation Analysis Of Karadobi Reservoir In Blue Nile River Basin And It's Impact On down Stream Water Uses**'' in partial fulfillment of a degree of Masters of Science in Hydraulic and Hydropower Engineering.

____

Dr. Semi Ayalew
Supervisor

Date ________________________________

DECLARATION AND COPYRIGHT

I the undersigned, declare that this dissertation is my own original work and that it has not been copied and will not presented by me to any other University for similar or any other degree award.

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DEDICATION

TO

My beloved family

ABSTRACT

This study is carried out using the HEC-ResSim model to simulate the operation of Karadobi reservoir and analyze the modifications in the flow pattern, power generation and sediment transportation that may occur on the down stream areas due to regulation of Blue Nile at Karadobi in Ethiopia. Thirty-one years (1972-2002) of extended inflow records to Karadobi reservoir (dam site) were used to simulate the model.The main input data to the model were the reservoir physical characteristics (Elevation-Capacity-Area curve), net monthly evaporation from the reservoirs (mm), daily inflow (m^3/s) and Elevation maximum capacity relation of dam appurtenant structures such as spillway and penstocks. The outputs from the model were the inflow to the down stream reservoir, out flow and power generated at Karadobi and at the immediate downstream reservoir (Roseires in Sudan), storage and level pool of reservoirs. After running the model the changes in flow magnitude and power generation for the existing down stream water uses(pre regulation at Karadobi) and the regulated condition (down stream water uses with Karadobi) has been analyzed.

From the result of the analysis, it is observed that the mean monthly inflow to Roseires reservoir has increased by about $397m^3/sec(1.12Mm^3/day)$ during dry period from December to June and the inflow to Roseires has decreased on average, by about 938 m^3/sec during the flood season (July to October). Because of regulating Abbay at Karadobi with FSL of 1164m a.m.s.l and MOL of 1088m a.m.s.l the gain in discharge at Roseires will improve the power generated at Roseires by about 68.75% during dry season on monthly basis with only 2.0% reduction during flood seasons than the existing condition with out any additional investment on the existing down stream reservoir. The sediment inflow rate to Karadobi reservoir was estimated to be $104.1Mm^3/year$ with an out flow of only $6.3Mm^3/year$. Thus, the sediment contribution of Karadobi watershed to the down stream areas will be reduced from 104.1 to $6.3Mm^3/year$. More over, the operational analysis result shows that the regulation of Abbay at Karadobi will reduce the mean reservoir level at Roseires by about 1m; as a result, regulation of Blue Nile at Karadobi will help to save the water lost through high rate evaporation at the downstream low elevation areas.

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ABBREVIATION

A.M.S.L	Above mean sea Level
ATP	Applied training Project
AVG	Average
BMC	Billion metric cube
CMS	Cubic meter per second
COM	Commission
CONC	Concentration
CUM	Cumulative
DSS	Data storage system
EFF	Efficiency
EVAP	Evaporation
FIG	Figure
FSL	Full supply level
GIS	Geographic information system
GMT	Greenwich Mean Time
GT	Geothermal
GWH/Y	Giga Watt Hours per year
HEC	Hydrologic Engineering Center
HP	Hydropower
ICS	Inter Connected Systems
IDEN	Integrated Development of Eastern Nile
ITCZ	Inter tropical convergent Zone
KD	Karadobi
KM	Kilo meter
KVAC	Kilo Volt Alternate Current
KW	Kilo Watt
lat	Latitude
long	Longitude
MAX	Maximum

MIN	Minimum
MMC	Million metric cubes
mm	millimeter
MOL	Minimum operating Level
MoWR	Ministry of water resources
MWH	Mega Watt Hours
MW	Mega Watt
M.Wakena	Melka Wakena
NBI	Nile Basin Initiative
NMA	National meteorological Agency
RCC	Roller Compacted concrete
UNREG	Unregulated
REP	Replace
RES	Reservoir
ResSim	Reservoir Simulation model
ROS	Roseires
RPM	Revolution per Minute
SCS	Self Contained Systems
SED	Sediment
TEMP	Temperature
TMAX	Maximum temperature
TMEAN	Mean temperature
TMIN	Minimum Temperature
USBR	United States Bureau Of Reclamation
USC	United states cents
VOL	Volume
WAPCOS	Water and Power Consultancy Service
WH	Watt Hours

CHAPTER ONE

INTRODUCTION

1.1 General

Ethiopia is rich in its water resource potential, but the development yet achieved is insignificant, as a result it is yet impossible to meet the energy demand and self sufficiency in food as well. More over the unevenness of distribution and occurrence of rainfall imposes a recurrent drought during dry season and flooding during wet season. Such variation of flow in both extremes has created an adverse effect in power production, food security , flood warning and protection.

In the past ten years a frequent interruption of power and hence rationing has occurred during dry periods, while flood passing the reservoirs has caused several damages in the down stream settlement and river banks during wet seasons[15]. Even though the main cause of such an event is supposed to be the erratic nature of the rainfall, it is impossible to deny that the aggravating factors of the events are poor water resource management and inefficient operation of the reservoirs.

1.2 Problem statement

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. Most reservoirs in our country have a lack of pre determined, up-to-dated and real time reservoir operation policy that will benefit all users in a basin. In most case it is not unusual to observe reservoirs suffering to meet the desired purpose because of lack of optimum operation Policies. More over, detailed analysis for optimal operation of the Karadobi reservoir and its impact on the existing down stream water uses is not yet conducted on research basis.

1.3 Objective and scope of the study

1.3.1 Objectives

The main objectives of this study are:

To assess the modification that may occur on the flow pattern, power generation and sediment transport of down stream areas because of regulation of Abbay at Karadobi.

To obtain the optimum operational strategy (rules or Guide curve), which enables to maximize power generation at Karadobi, and helps in the optimum usage of the stored water by minimizing spill and adverse impacts on the existing down stream water uses.

The specific objectives of the study are:

I) To under take reservoir operation simulation, that helps in evaluating the best way to utilize the reservoir storage so that maximum power production, minimum spill and power deficits are assured.

II) To quantify the changes in high flow, low flows power and sediment transport.

1.3.2 Scope of the study

The scope of this study comprises of the following main activities:

- Hydro-meteorological data processing and analysis, which includes
    - Data collection
    - Filling missed data
    - Checking consistency of data
    - Data record extension
    - Reservoir evaporation calculation
    - Hydro-meteorological data base preparation
- Description of the base scenario(existing downstream water use with out Karadobi)
- Developing reservoir operation guide curve(rule curve) for Karadobi reservoir

- module set up for HEC-ResSim software
    - ✓ watershed set up module
    - ✓ Reservoir network module
    - ✓ Simulation module
- Simulation run
    - ✓ Analysis of the changes on the existing condition in terms of flow (during wet and dry periods), power generation and sediment transport after the development of Karadobi

1.3.3 Description of the study area

Blue Nile known as Abay in Ethiopia is the largest of the twelve major river basins in the country. The source of Blue Nile is a small spring at height of 2900 m a.m.s.l and at about 100 KM South of Lake Tana. From this spring, the Little Abay (Gilgel Abay) flows down to Lake Tana (1785 m a.m.s.l). There are numerous influents of Lake Tana, of which the Gilgel Abay is usually regarded as the most important [3].

The Blue Nile basin, up to the confluence with the main Nile, has an area of 324,530 KM^2 (Table 1). This area is located between 40^0 E long. and between 9^0 and 12^{0}N lat. Figure 1 show the map of the basin within Ethiopia boundary, which has an area of 199,812 KM^2. The basin area up to the Ethiopian border contributes two third of the total water of Nile at Khartoum. While in the flood season between July and October its share rises as high as 78 % [1, 3]

Table 1: Main drainage basins of the Abbay Basin(Blue Nile Basin) [6]

S.No	Sub basin Name	Drainage Area(KM^2)
1	Lake Tana	15054
2	North Gojam	14389
3	Beshilo	13242
4	Weleka	6415
5	Jema	15782
6	South Gojam	16762
7	Muger	8108
8	Guder	7011
9	Fincha	4089
10	Didesa	19630
11	Anger	7901
12	Wombera	12957
13	Dabuse	21032
14	Beless	14200
15	Dinder	14891
16	Rahad	8269
Total		324530 KM^2

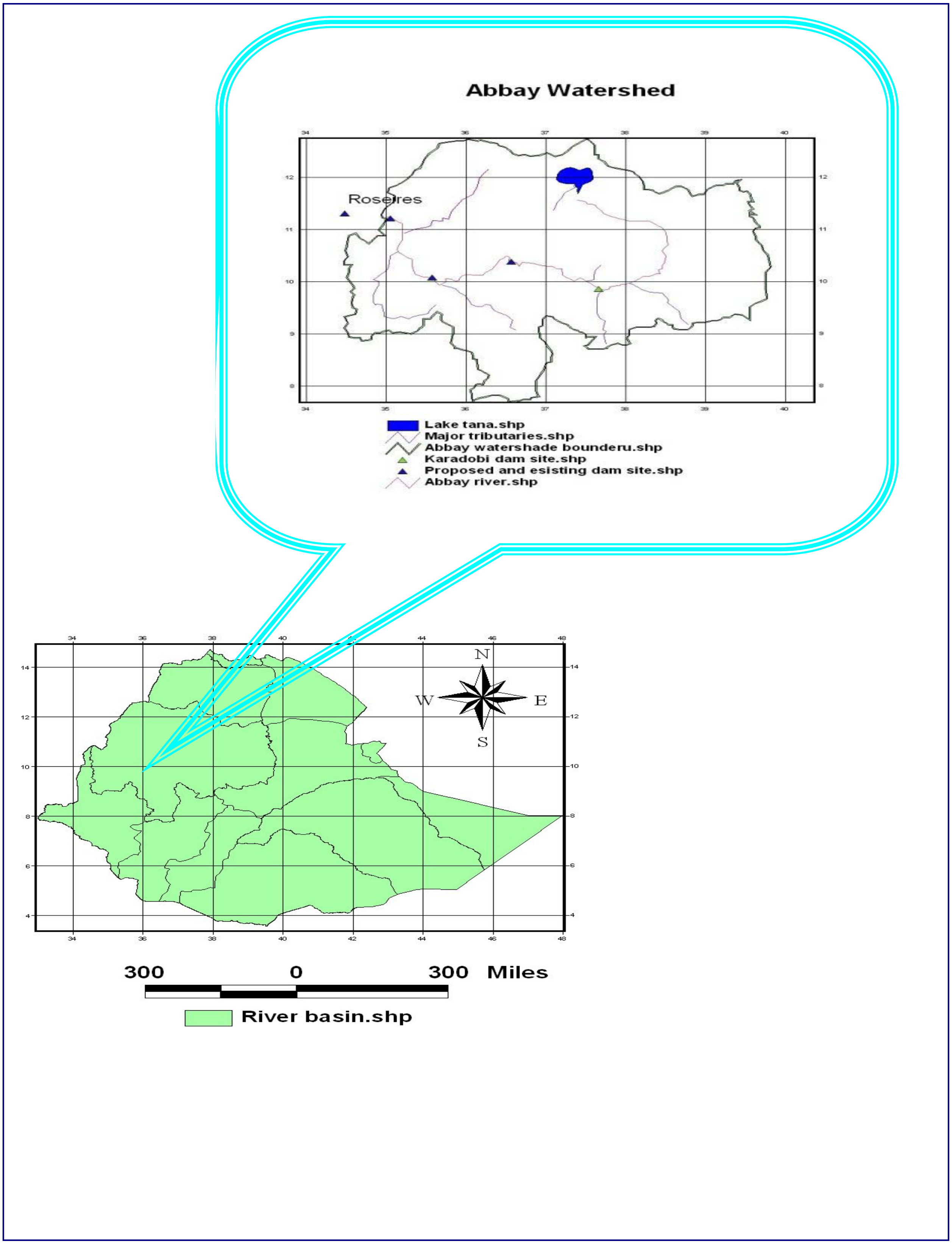

Figure 1 Description of the Study area

Detailed descriptions of Karadobi and Roseires projects are given in the literature review part (Chapter 2).

1.5. Thesis structure

Chapter One: Introduction.

This chapter introduces the objective of this study and why it was carried out. Moreover description of the study area and the detail to which the study is to be conducted is stated.

Chapter Two: Literature review

This chapter takes a glance at the study area from different angles (Climatic, Hydrological, topography water resource and hydropower potential and status) and salient features of the proposed and existing reservoirs and other studies carried out using HEC-ResSim model are stated.

Chapter Three: **Hydro meteorological data processing and analysis**

In this chapter the hydro meteorological data processing such as method of filling data missing, data record extension and consistency checks were conducted

Chapter Four: Data configuration and HEC-ResSim model set up

Here the main input data of the simulation model HEC-ResSim and the watershed and reservoir network set up for the study area will be described.

Chapter Five: simulation, result and discussion

In this chapter the method of simulation and the out puts of the analysis are stated, the results of the different alternatives are compared.

Chapter Six: Conclusions, Recommendation and Limitations

Conclusion and Possible recommendations are forwarded based on the result of the analysis and limitations encountered during the study (if any) will be stated

CHAPTER TWO

LITERATURE REVIEW

2.1 Hydropower development, potential and status in Ethiopia

2.1.1 Hydropower Development

Even though there is no recorded history, the use of water power in Ethiopia in its none electrical form is estimated to exist since long period of time. It has been used in water mills and such practice is still exist in some rural area of the country. The use of water for power generation, came to existent since 1930’s, when Aba-Samuel hydropower scheme is commissioned in1932 [2]. In Ethiopia, by 2005 the number of electrified towns under the Ethiopian electric power corporation were 641 of which 567 are with in the inter connected system(ICS) and the remaining 74 with in the self contained system(SCS) [16]. Currently It is estimated that about 17% of the total population of the country has access to electricity.

2.1.2 Potential and status

Ethiopia has substantial hydropower potential from which less than 2% has been utilized so far, and the government has started to utilize this environmental friendly source through the construction of Gilgel Gibe, Tekez and Beless Hydropower schemes and other sources like coal and gas to satisfy the increasing demand of energy in different development sectors. The hydropower potential of different river basins of the country is shown in table 2.

Estimated energy potential of the country is about 160,000GWH/y (WAPCOS, 1995). As seen in table 2, Abbay contributes about 50% of the countries potential but the development of the sector so far in the basin is 218.4MW(1004GWH/y) from Tis-Isat and Fincha plants which is less than 1% of the potential.

There are two electric supply systems in Ethiopia. The inter connected systems (ICS) and self contained systems (SCS). The ICS, (Table3) system consists primarily of large hydropower generating facilities supplying the National grid, while the SCS (Table4) consists of several small isolated distribution systems located far from the ICS. The ICS consists of 9 hydropower, 13 diesels, and one geothermal power plant with a total installed capacity of 1112.6MW, 112.52MW and 7.3MW respectively i.e. over 98% of the total energy generation in the country came from the ICS. The Geo thermal station at Aluto-Langano is not functional[1]. Currently the Government of Ethiopia has a wide plan of exporting power to the neighboring countries and satisfying the domestic consumption as well through the implementation of Beless, Tekeze, Gilgel Gibe-III and other sources of energy through its electrification programs and goals of the millennium

Table 2 : Estimated hydropower potential of Ethiopian river basins (WAPCOS, 1995)

River basin	Estimated potential GWH/y	Share of the total %	No of potential sites
Abay	78,880	48.90	129
Awash	4,500	2.80	35
Baro Akobo	18,900	11.70	41
Genale Dawa	9,300	5.80	31
Tekez Angereb	6,000	4.20	20
Wabe Shebell	5,400	3.40	16
Omo Gibe	35,000	22.70	20
Rift valley Lakes	800	0.50	8
TOTAL	158,780	100	171

Table 3: Existing ICS power plants in Ethiopia, capacity (MW)[16]

Plant Name	Type			total	Com.year
	HP	Diesel	GT		
Koka	43.20			43.20	1960
Awash II	32.00			32.00	1966
Awash III	32.00			32.00	1971
Fincha	134.00			134.00	1973/03
M.Wakena	153.00			153.00	1988
Tis Abbay I	11.40			11.40	1964
Tis Abbay II	73.00			73.00	2001
Gilgel Gibe I	184.00			184.00	2004
Gilgel Gibe II	450.00			450.00	2006
Aluto Langano*	-		7.30	7.30	1999
Sub total	**1112.60**		**7.30**	**1119.90**	
Alemeya	-	2.30		2.30	1958
Dire Dawa	-	45.50		45.50	1965
Adigrat	-	2.50		2.50	1992,93,95
Axum	-	3.20		3.20	1975,92
Adwa	-	3.00		3.00	1998
Mekele	-	5.70		5.70	1984,91,95
Shire	-	0.80		0.80	1975,91,95
Nekemte	-	1.10		1.10	1984
Ghimbi	-	1.10		1.10	1962,84
Awash Arba	-	35.00		35.00	2004
Kaliti	-	14.00		14.00	2004
Jimma	-	1.00		1.00	2004
Sub total	**1112.60**	**114.20**		**114.20**	
Grand Total	**1126.60**	**114.20**	**7.30**	**1234.00**	

*** Not functional**

Table 4 : Existing SCS Generation installed capacity (MW) [16]

Plant Name	Type			total	Com.year
	Hydro	Diesel	GT		
Yadot	0.35			0.35	1991
Sor	5.00			5.00	1992
Dembi	0.80			0.80	1994
Sub total	**6.15**			**6.15**	
Semera	-	2.13		2.13	
Setit Humera	-	1.59		1.59	
Asosa	-	1.83		1.83	1991,94,95,98
Asayita	-	1.43		1.43	1970,71,88,95
Tepi	-	0.98		0.98	
Gode	**-**	0.94		0.94	
Alem Ketema		0.88		0.88	
Others		14.11		14.11	1962-2004
Subtotal		**23.89**		**23.89**	
Grand total	**6.15**	**23.89**		**30.04**	

Table 5: Planned and on going hydropower and other sources of power in Ethiopia [6]

plant	Ins.capacity MW	Firm energy GWH/YEAR	Status
Gilgel Gibe III	1,900	-	Under construction
Gojeb	153	364	-On bid
Omo	1,780	-	Under construction
Tekez	300	981	Under construction
Awash IV	34	-	-
Neshe	40	-	-
Aleltu	400	780	Pre-feasibility
Halele	374	2,376	Pre-feasibility
Upper belles	195	1,100	Pre-feasibility
Chemoga yeda I	118	2,526	-
Chemoga yeda II	90	-	-
Guder	300	361	-
Geba I&II	154+100	857+776	Pre-feasibility
Baro I&II	194+475	647+2,094	Pre-feasibility
Genale I&ii	174+164	567+1,215	Pre-feasibility
Kalub gas	200	-	plan
Dilboye(cool)	50	-	plan
Tendaho(Geothermal)	3	-	plan
Karadobi	1,600	9,308	Pre feasibility
Mabel	1,400	-	identified
Mendeya	1,700	-	identified
border	1,780	-	identified
total	**12,685**	**-**	**-**

2.2 Abbay River Basin

2.2.1 Water Resource

The Abbay basin is by most criteria the most important river basin in Ethiopia (6). It accounts for about 17.5% of Ethiopian land use, 50% of its total annual runoff and 25% of its population. The river has a mean annual run off of about 50BMC. The basin contributes on average about 62% of the average Nile total at Aswan. Together with the contribution of Baro Akobo and Tekeze basins originating from Ethiopia, the country accounts for more than 80% of the run-off at Aswan. [6]

The basin accounts for the major share of the countries irrigation and hydropower generation, current utilization is, however, very low. Estimated energy potential of the basin is about 98,831GWH/y (WAPCOS, 1995), but the development of the sector in the basin is 218.4MW (1004GWH/y) from Tis-Abbay and Fincha plants which is less than 1% of the potential.

2.2.1 Climate

Traditional classification based on altitude and temperature shows the presence of the following three zones in the river basin [1]

I) Kola (tropical hot and arid type): altitude below 1500 m a.m.s.l with mean temperature range of 20-28^{o}c

II) Woina-Dega (subtropical warm): altitude varies between 1500-2500 m a.m.s.l with mean temperature range of 16-20^{o}c

III) Dega (temperate): altitude above 2500 m a.m.s.l with mean temperature in the range of 6-16 ^{o}c

A detailed description of the seasonal migration of the inter tropical convergence zone and other climatic inter actions at different latitude zone within Ethiopia, is given in the work of Daniel Gemechu [5]. Seasonal variation in climate is associated with the oscillation of the inter tropical convergence zone (ITCZ). Essentially the ITCZ exerts its influence through its Northerly migration commencing in the month of

March, which is accompanied by a short wet-season in the South of the country. Around June, the ITCZ moves further North and produce the main wet season in most of the central and Northern areas of the country, which is most part of the basin. The wet season in the basin lasts till October, until the influence of the ITCZ diminishes as it moves Southwards towards the equator. As a result dry condition dominates between November and March in most area of the basin.

2.2.2 Topography

Most of the basin area in Ethiopia is hilly and it has relatively flat areas near borders and in Sudan. The high land areas of the country are cut up by deep ravines or canyons in which the rivers flow, the largest of which is that of the Blue Nile (Fig.2). In some place, the river flows in a channel that is about 1200 m a.m.s.l below the level of the country on either side [3].

The drop of the plateau to the Sudan plain is, in most places, steep. However, there are many outlying hills some of which are as high as the plateau itself [3].

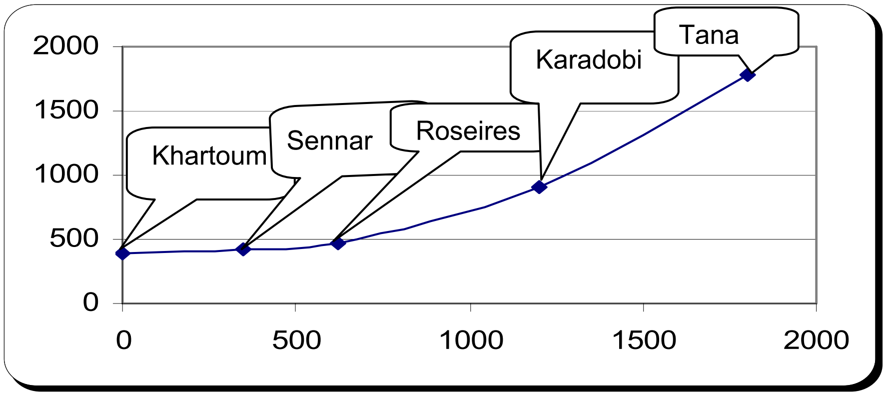

Figure 1: Longitudinal profile of Blue Nile river basin from Tana to Khartoum

2.3 Karadobi hydropower project

2.3.1 Back ground

The Karadobi dam and multi purpose project forms one element of the sub projects under the integrated development of the eastern Nile project (IDEN), which is again a project under the Nile basin initiative (NBI) [1].

The project is under study at pre feasibility level and expected to be implemented in the near future. The dam is located on Abay River in Ethiopia, approximately 55 KM South of Debre Markos, 65KM down Stream of Kessie Bridge and 1.7KM down stream of confluence of the Abay and Guder River. Its geographical location is 9^0 51' N.lat and37^0 40'E.long. The dam site has a catchment area of 82,730 KM^2, average elevation of 910m a.m.s.l [1]. Annual rain fall over the catchment is 1,300mm[1]. The mean inflow at the site is $649m^3/s$[1]. The proposed dam has a height of 250m and capable of producing 1,600MW of power.

2.3.2 Salient features

- Hydrological data

Catchment area	$82,730KM^2$
Arial rain fall	1,300mm
Mean river flow at site	$649m^3/s$
Design flood Q_{1000}	$2,0710m^3/s$

- Reservoir

Full supply level	1,146m a.m.s.l
Minimum operation level	1,100m a.m.s.l
Total volume at FSL	$40,200Mm^3$

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[1] These figures are taken from [1] for comparison purpose and in this paper its value might be changed based on result of data analysis

Active reservoir volume	17,000 Mm^3
Surface area at FSL	445 KM^2
Extension of reservoir towards u/s	150 KM

- Dam

Type of dam	(RCC)
Dam crest elevation	1,150 m a.m.s.l
Max. Height of dam above foundation	260m
Crest length of dam	684m
Dam volume	6.5Mm^3

- [1]Spillway

Type	Gated overflow spillway
Crest Elevation	1,130 m a.m.s.l
Number of gated bays	10
W*H of radial gets	12*16.5m
Spillway design capacity at FSL	15,560 m^3/s
Spillway capacity at dam crest level	21,450 m^3/s

- Power and energy

Total rated output from 8 units	1,600 MW
Mean annual energy generation	9,708G WH/y
Plant factor	0.67
Design discharge total for 8 units	800 m^3/s
Max. Gross head	236 m
Minimum gross head	185 m

Voltage and type of transition line to Roseires	500 KVAC
Unit cost of Energy supplied at Roseires	3.75 USC/KWH

- Power intake

Elevation of intake sill	1,065 m a.m.s.l
Number of intake opening	8
Trash rake dimensions	8*24 m

- Headrace tunnel

Number of concrete lined headrace tunnel	4
Tunnel diameter	9
Number of headrace roller gets	8
Headrace roller get dimensions (w*h)	3.2*7.5

- Steel lined shaft penstocks

Number of steel conduits	4
Diameter of penstocks	6.5m
Length of each penstock	30m

- Power house

Type	Under ground power house
Power house cavern (L*W*H)	240*25*50 m
Elevation of machine hall floor	914.45 m a.m.s.l
Cross section of access tunnel	50 m^2
Length of access tunnel	830 m
Elevation of turbine center	900.8 m a.m.s.l

- Tailrace tunnel

Number of concrete lined tunnels	4
Tunnel diameter	9 m
Tunnel length from draft tube out let to river out let	350-460 m
Dimensions of draft tube gets, W*H	9*3 m
Elevation of tailrace out late	901.7 m a.m.s.l

- Turbines

Type of turbines (8 units)	Vertical Francis
Rated discharge per unit	100 m^3/s
Installed capacity (8 units)	1,600 MW
Synchronous speed	272.73 rpm

2.4 Roseires and Sennar dams

2.4.1 Background

The Roseires and Sennar dams located 624 and 350KM upstream of the confluence of the Blue Nile with White Nile respectively. It supports the largest irrigated area(Ghezera scheme) in Sudan and provides a great share of the electricity in the country [2, 1].

Roseires is situated at 120KM from Ethiopian border at 11^0 51' N.lat and 34^0 23' E.long. It has a catchment area of 185,000KM^2, with mean elevation of 470m a.m.s.l and the mean inflow at the site is 1,530m^3/sec. As the altitude of the basin is very low it is characterized by high temperature and Evaporation.

2.4.2 Salient features of downstream reservoir

The salient features of Roseires[1,3].

- Hydrological data

Catchment area	185,000 KM^2
Mean annual Rain fall	784 mm

Mean annual inflow	1,530 m^3/sec

- Reservoir

Full supply level (FSL)	480 m a.m.s.l
Minimum operating level	467m a.m.s.l
Reservoir area at FSL	300KM^2
Total storage	3,200Mm^3
Live storage	2,700Mm^3
Dead Storage	500 Mm^3
Silted volume	1,200 Mm^3
Rate of sedimentation	50Mm^3 /year
Mean net head for power generation	27.8 m
Evaporation and seepage	370 Mm^3/year

- Dam

Type of dam	Earth dam
Total length of dam	16 KM
Length of concrete section	1 KM
Length of earth embankment	15 KM

- Sluices

Five low level Sluices, Seven high level Spillways and the intakes for Seven turbines

- Power and Turbines

Installed Capacity	275 MW
Type of turbines	Vertical Kaplan

2.5 Reservoir operation and operation policies

2.5.1 General

Reservoir operation is a complex task involving numerous hydrologic, technical, economical, environmental and political considerations. It involves allocating storage capacity between multiple uses and users, minimizing the risks and consequences of water shortage and flooding, maximizing the beneficial uses of water and minimizing adverse environmental impacts.

A reservoir operating policy is a sequence of release decision in operational periods (such as months), specified as a function of the state of the system. The state of the system in a period is generally defined by the reservoir storage at the beginning of period and the inflow to the reservoir during the same period [7].

2.5.2 Downstream Reservoirs Operation [1]

Both Sennar and Roseires reservoirs operate in conjunction with the aim to maximize the generation of hydropower and the storage and supply of irrigation water, while at the same time minimizing the sediment intake in the reservoirs. This is done by drawing down the reservoirs during the flood season and allowing the heavily silted water to pass through the dam’s bottom outlet. The storage starts during the falling stage of the flood, when silt content is decreasing; making sure that the two dams will reach their maximum storage by the end of October. This procedure, while minimizing the silt accumulation in the reservoirs, leads to large flow modifications, which results in a lower hydropower generation during this period.

After the construction of the Roseires dam the operation of the two dams in conjunction meant that Roseires was to be used mainly for storage of water, which was passed down to Sennar whenever required for the irrigation of the Gezira-Managil scheme and the pump schemes along the riverbank downstream from Sennar. In addition to this storage function, Roseires is used to maximize hydropower generation. The following principles have been adopted for the operation of the

Roseires reservoir, based on the regulation rules of the Ministry of Irrigation and Water Resources [1]:

- The minimum release downstream of Sennar is taken to be 8 million m^3/day.
- The minimum release from Roseires reservoir is to supply the minimum release downstream of Sennar.
- By the time that Sennar reservoir reaches its minimum operating level, Roseires is to supply all the downstream requirements.
- By the time that Roseires reaches its minimum operating level, any unsatisfied irrigation requirements will be considered as irrigation deficit. Irrigation water deficits currently occur towards the height of the low flow season in January and February. On average deficits range on the order of slight in normal years to high (200 Mm^3) in dry years.

2.5.3 Karadobi reservoir operation

Karadobi is a proposed dam in Ethiopia on Abbay River, as it is on pre feasibility level a detailed research based operational analysis is yet not conducted, except the study in the pre feasibility report. In the pre feasibility report a reservoir operation analysis was conducted on monthly bases and it is found that a dam height of 250m will offer high degree of flow regulation (low flow augmentation and attenuation of high flow) in the respective season. Moreover a firm power of 1600MW can be guarantied over seasons and years.

Monthly analysis of reservoir operation is very approximate. In the current study, it is planned to undertake further analysis on this reservoir’s operation on daily basis.

2.6 Reservoir operation simulation

2.6.1 General

Simulation is by far the most widely used method for evaluating alternative water resource systems and plans. It is defined as the solution of management model by trial and error. It is extensively used in the analysis of complex water resource systems [7, 12].

A reservoir operation can be simulated in time with a given inflow, out flow(release), available storage and reservoir physical data. A reservoir operation simulation is mainly computed for discrete time intervals applying the well known continuity equation(equation of state)

$$S_{t+1} = S_t + Q_i - Q_o - L_t \quad \text{---}2.1$$

Where:

S_{t+1} = storage at the end of time step, m^3

S_t = Storage at the start of time step, m^3

Q_t = Out flow(release) from the system during the time step, m^3

L_t = loss from the system during the same period, m^3

A number of reservoir simulation algorithms have been developed for reservoir operation simulation. One possible method is the application of the HEC-ResSim simulation model (detail description of the model is given in section 2.6.3). The main purpose of operation simulation of the Karadobi reservoir is to quantify the modification on power production flow modification and sediment transport pattern in the system before and after implementation of Karadobi.

2.6.2 Reservoir operation simulation models

A Simulation model provides a rapid means for evaluating the anticipated performance of any water resource system, such models do not identify the optimal design and operation policy, but they are an excellent means of evaluating the expected performance resulting from any design and operation policy set by the modeler. Hence they are often used to assist water resource planners in evaluating those designs and operating polices defined by simpler optimization models [7, 11]. HEC-ResSim is among those models used to simulate reservoir system operation.

2.6.3 The reservoir operation simulation model (HEC-ResSim)

HEC-ResSim has been designed and developed by the Hydrologic Engineering Center(HEC) of the U.S. Army Corps of Engineers to perform Reservoir System Simulation(ResSim). It is intended to meet the needs of real-time reservoir regulators for a decision support tool, as well as the needs of modelers doing reservoir projects studies. It is comprised of a graphical user interface (GUI), a computational program to simulate reservoir operation, data storage and management capabilities, and graphics and reporting facilities. The Data Storage System (DSS), HEC-DSS, is used for storage and retrieval of input and output time-series data [8].

ResSim offers three separate sets of functions called Modules that provide access to specific types of data with in a watershed. These modules are Watershed Setup module, Reservoir Network module, and Simulation modules. Each module has a unique purpose and an associated set of functions accessible through menus, toolbars, and schematic elements. Figure 3, illustrates the basic modeling features available in each module [8].

2.6.3.1 Watershed Setup Module

The purpose of the Watershed Setup module is to provide a common framework for watershed creation and definition among different Modeling applications. A watershed is associated with a geographic region for which multiple models and area coverage can be configured. A watershed may include all of the streams, projects, gage locations, impact areas, and hydrologic and hydraulic data for a specific area. All of these details together, once configured, form a watershed framework.

2.6.3.2 Reservoir Network Module

The purpose of the Reservoir Network module is to isolate the development of the reservoir model from the output analysis. Reservoir Network module, enables building up of river schematic, describe the physical and operational elements of reservoirs, and develop the alternatives that we want to analyze. Using Configurations that are created in the Watershed Setup module as a template, it is possible to create the basis of a reservoir network, add routing reaches and possibly other network elements (alternatives and operation sets) to complete the connectivity of the network schematic [8].

2.6.3.3 Simulation Module

The purpose of the Simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the Simulation module is used to configure the simulation. The computations are performed and results are viewed within the Simulation module. The model were used to simulate and rout flow through the river reach connected by junctions. Operation rules, reservoir and dam physical data, hydrological, evaporation and turbine efficiency were set and edited from simulation module editor box and the model has been run and the same procedure was repeated several times till the desired parameter and constraints were fulfilled .

2.6.4 Similar work done Using HEC-ResSim

There is one masters thesis done using HEC-ResSim model in this University in the 2005/06 Academic year. The thesis is entitled" Operational Analysis of the Cascaded Wadecha-Belbela Reservoir System". In the paper it was tried to estimate the supply and demand of the Wedecha-Belbela irrigation project in the Adea-Liben Woreda of Oromia regional state. Moreover the operation rule curve of both reservoirs were estimated using the HEC-ResSim model.

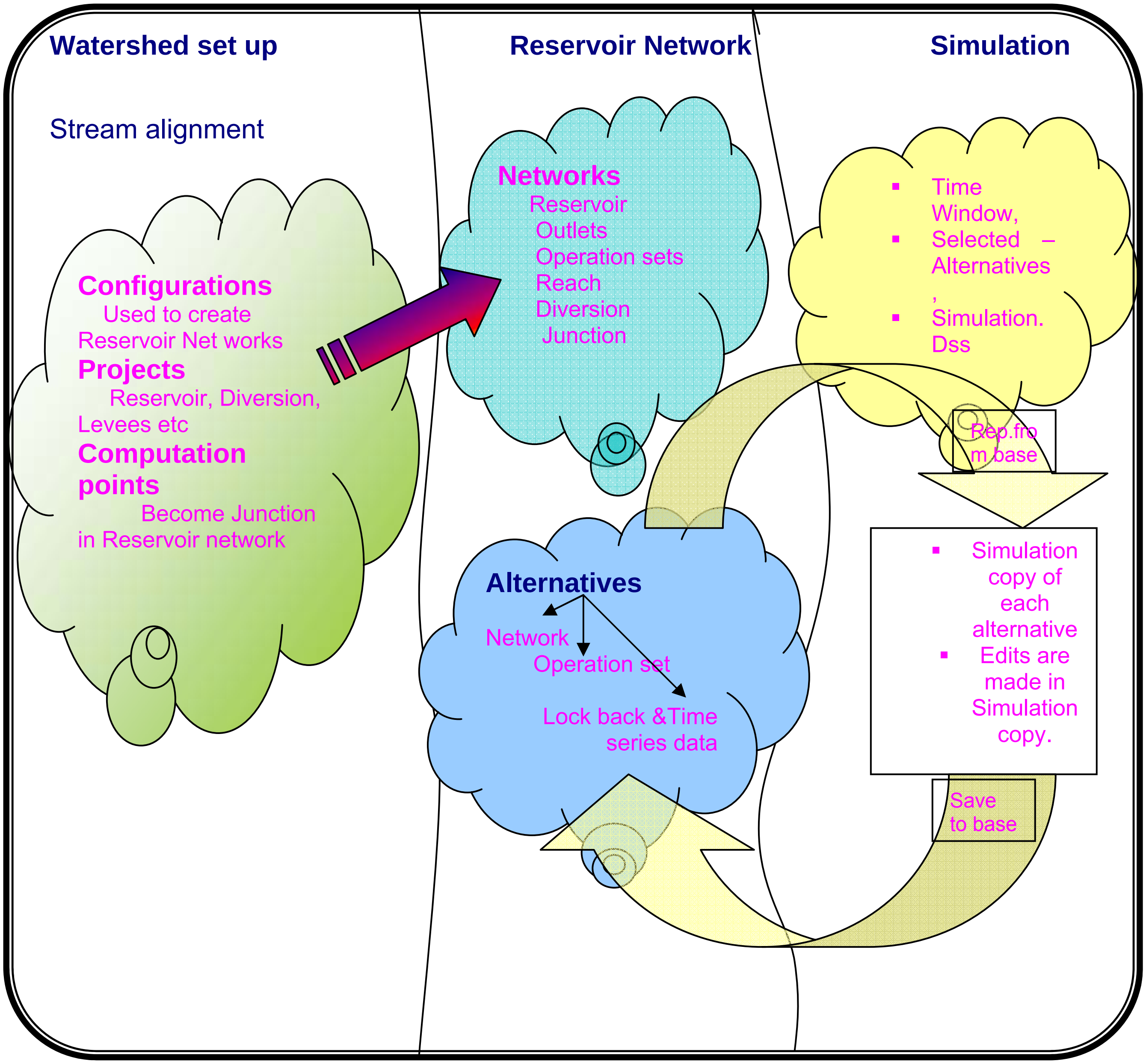


Figure 2 ResSim Module Concepts

CHAPTER THREE

HYDRO-METEOROLOGICAL DATA PROCESSING AND ANALYSIS

3.1 Introduction

Organization and analysis of hydro - meteorological data are fundamental parts of development planning, and the associated tasks of project design and operation [9]. Before commencing any hydrological data analysis and simulation it is important to make sure that data are homogenous, correct, sufficient and complete with no missing data. Erroneous data resulting from lack of appropriate recording ,shifting of station location and processing are serious because they lead to inconsistency and ambiguous results that may contradict to the actual situation.

A number of methods are available for adjusting inconsistency, infilling missed data and extension of short records encountered in the actual data processing activity. A detailed description of such methods have been given in the subsequent discussions. Fort this particular study area hydrological and hydro-meteorological data have been collected from Ethiopian Ministry of water resources (MoWR) and National meteorological Authority (NMA) respectively.

3.2 Hydro meteorological data

3.2.1 Rainfall data and its availability

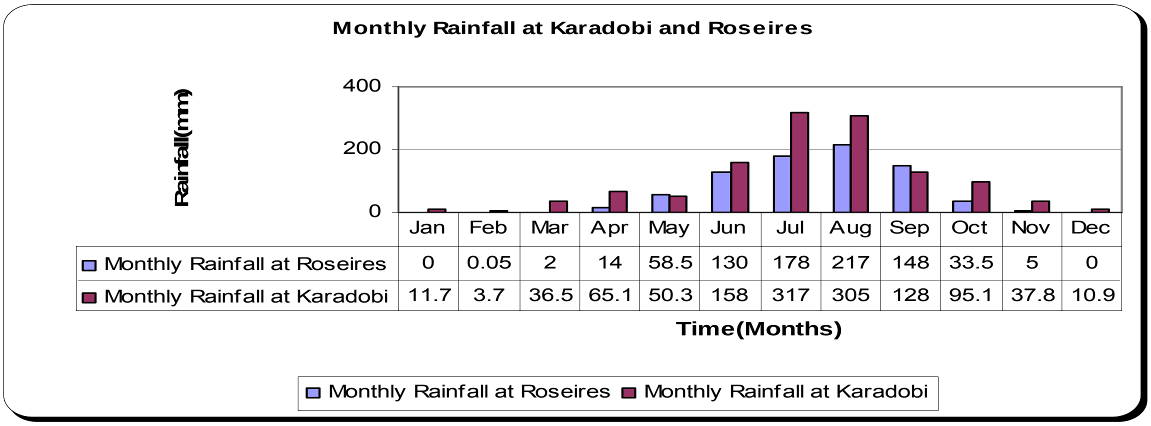
It is imperative to have reliable precipitation estimates as they represent the upper bound on available water resource. A particular feature of precipitation is its extremely wide variation in time and space, and for this reason, it always is a significant component of any hydrological data collection and analysis system.

For this particular study daily rainfall data have been collected from twelve stations (see Table 6) five of them being located down stream of Karadobi area and the remaining are located up stream of Karadobi dam site (With in Karadobi watershed) The data collected covers recent period of 10 years (from 1996-2005). As is common in most meteorological stations except for Debre Markos and Bahir Dar stations most of the data are incomplete and short. The monthly Rainfall pattern at Karadobi and Roseires is shown in (Fig.4) below and the monthly rainfall plot of each station are attached in Appendix-B(fig.B-16)

Table 6 **:** Rainfall stations and their main features

station	Location		Elevation (a.m.s.l)	Mean annual Rainfall(mm/y)
	Latitude(N)	Longitude(E)		
Ambo	8^{0} 58’	37^{0} 52’	2,130	975
Bahir Dar	11^{0} 36’	37^{0} 25’	1,770	1,331
Chagni*	10^{0} 57’	36^{0} 30’	1,620	1,269
Debre Markos*	10^{0} 20’	37^{0} 40’	2,515	1,335
Dedesa*	9^{0} 23’	36^{0} 06’	1,200	1,444
Fetera	10^{0} 00’	38^{0} 56’	2,150	971
Filikliki	10^{0} 03’	38^{0} 10’	1,850	1,220
Fincha	9^{0}34’	37^{0}22’	2,320	1,751
Guder	8^{0} 57’	37^{0} 47’	2,002	1,336
Muketuri	9^{0} 33’	38^{0} 52’	1,979	998
Tokierenso	8^{0} 58’	37^{0} 37’	1,983	1,314
Nedjo*	9^{0}20’	35^{0}25’	1,800	1,391
Damazine*	11^{0}51'	34^{0}23’	467	784

*Station located out of Karadobi water shade



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Rainfall at Roseires	0	0.05	2	14	58.5	130	178	217	148	33.5	5	0
Monthly Rainfall at Karadobi	11.7	3.7	36.5	65.1	50.3	158	317	305	128	95.1	37.8	10.9

Figure 3 Monthly Rainfall pattern at Karadobi and Roseires

3.2.2 Checking Homogeneity and consistency of the data

In order to check the homogeneity of the selected gauging stations in the Karadobi watershed monthly rainfall records were non–dimensionalised and plotted to compare the stations with each other (Fig.6).

The non-dimensionalizing of the monthly values were carried out as

$$Pi = \frac{\overline{pi}}{\overline{P}} * 100 \text{ --- } 3.1$$

Where Pi= non-dimensional value of precipitation for the month i

$\overline{pi}$ =Over years averaged monthly precipitation for the station i

$\overline{p}$ =The over years averaged yearly precipitation of the station

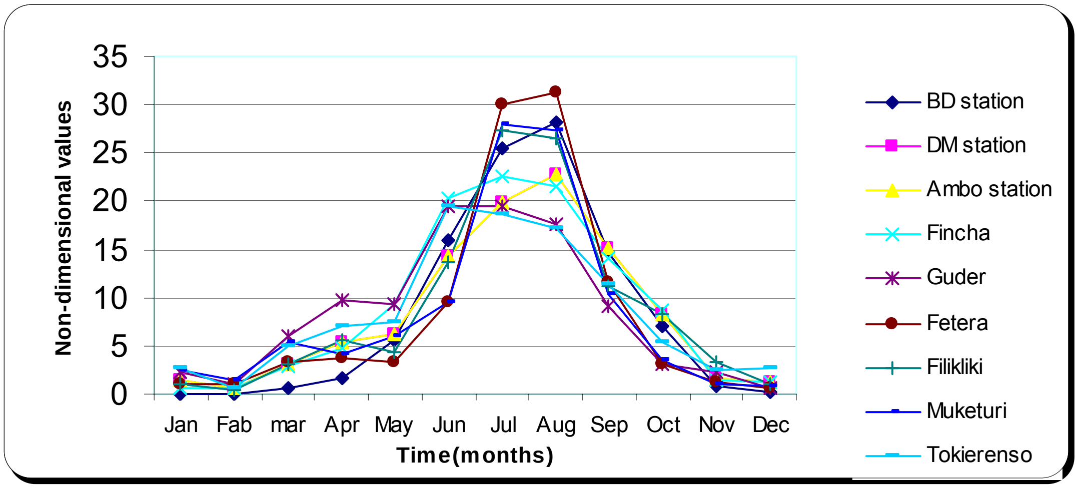


Figure 4 Non-dimensionalised plot of selected stations around Karadobi dam site

From the above figure, except Guder station all of them have a Uni-modal rainfall pattern. Moreover, the region can be categorized in to two groups that is Bahir Dar, Fetera, Muketuri and Filikliki in one and Debre Markos, Ambo, Fincha Guder and Tokierenso in to the other. Stations in similar group were used to fill missed records.

Shifting of gauge location, observational and instrumental errors are the common causes for inconsistency of rainfall record. A change due to meteorological causes would not cause inconsistency (change in slope of double mass plot), as all base stations would be similarly affected [10].

The checking for in consistency of rainfall records in Karadobi watershed is done by the method of Double mass curve analysis(Fig.5). This technique is based on the principle that when each recorded data comes from the same parent population, they are consistent. Double mass curve analysis is a graphical method for identifying and adjusting inconsistency in a station record by comparing its time trend with those of adjacent stations. For the basin in question a double mass analysis has been done for each of the stations listed above all the stations shows good consistency except Ambo which shows a little deviation and this record were not used in infilling missed data of other stations. Filikliki is the only station available in the lower valley and very close to the dam site. As a result, the Filikliki station records were used directly for computation of net evaporation from Karadobi reservoir. The double mass analysis shows that the record of the station was consistent enough for farther use in the analysis. The double mass plots of the remaining stations are attached in Appendix-B (Fig.B-22)

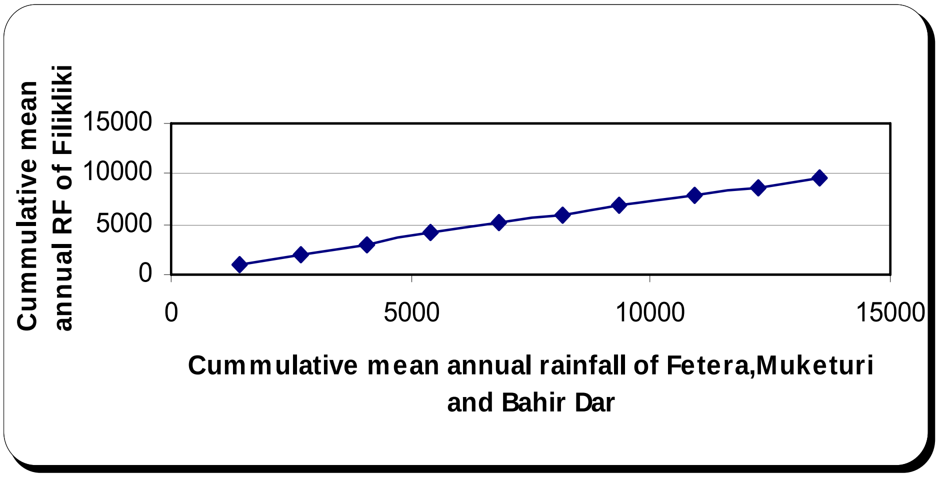


Figure 5 Double mass plot of Filikliki Station

3.2.3. Estimating missing precipitation data

Most of the rainfall stations in the study area have short breaks in their records and it is necessary to estimate the missing records to keep the continuation of the data. In this paper missed rainfall records have been estimated from observations at three stations as close to and as evenly spaced around the station with the missing record as possible. There are different methods for infilling missed rainfall records, the most common methods are the simple arithmetic mean method and the normal ratio method. The simple arithmetic mean method is used where the mean annual rainfall of all the index stations is with in 10% of the station under question.

$$P_X=\frac{1}{N}\left[p_1+p_2+p_3+.....+P_N\right]\text{---}3.2$$

Where, P_X is the precipitation for the station with missed record; p_1, p_2, and p3 are corresponding rainfall record at the surrounding stations.

The normal ratio method is used where the mean annual rainfall of one or more of the adjacent (index) stations differs from that at the station in question by more than 10%.

$$P_X=\frac{1}{N}\left(\frac{N_x}{N_A}P_A+\frac{N_x}{N_B}P_B+\frac{N_x}{N_C}P_C+......+\frac{N_x}{N_N}P_N\right)\text{-------------------------}\quad 3.3$$

Where, P_X is the precipitation for the station with missed record, P_A, P_B and P_C are the corresponding precipitation at the index stations and N_A, N_B, N_C and N_X are the long term mean annual precipitation at the index stations and at the station in question respectively. In this study the normal ratio method have been applied as the mean annual rainfall of all the selected stations varies by more than 10% with the station considered.

3.3 Climatological data

The climatological data at Filkliki is incomplete i.e. the rain fall, maximum temperature and minimum temperature data are available but , relative humidity, sun shine hours and wind speed data are unavailable as a result these data from other near by station, Debre Markos, were used for computation of reservoir evaporation by method of pen man. Table 7 exhibits the monthly summary of hydro meteorological data of Filikliki station.

Table 7: Monthly summary of rainfall and temperature records of Filikliki Station

Month	Rain Fall(mm)	Max.temp (0^{c})	Min.temp (0^{c})	Mean temperature
Jan	11.72	29.69	16.30	22.99
Feb	3.70	32.09	17.68	24.88
Mar	36.48	32.68	16.96	24.82
Apr	65.12	32.22	16.81	24.51
May	50.27	32.97	17.18	25.07
Jun	158.27	29.44	15.73	22.58
Jul	316.77	24.62	13.85	19.23
Aug	305.31	24.78	14.75	19.86
Sept	128.32	26.44	15.90	21.17
Oct	95.06	26.81	16.22	21.51
Nov	37.80	27.03	15.10	21.07
Dec	10.94	28.52	15.51	22.02
Mean	101.60	28.90	16.00	22.50

3.4 River flow data

3.4.1 Data availability

Daily River flow data of selected stations were collected from MoWR and from study reports compiled by different individuals and master plan of the basin. It includes data on the Main stream at Kessie (1960-2002), Bahir Dar (1973-2003), Shegole (1960-1992),Border (1961-2002) and on Tributaries up stream and down stream of Karadobi dam site Such as Muger (1973-2002), Guder (1974-2002), Chemoga (1973-2002), Didesa(1960-2004), Dabus(1963-1979), Beless(1962-2002), and Dabana(1962-1980) and monthly flow of Abbay at Roseires(1954-2002) were taken from[1]. Locations of the stations and their main characteristics are shown in (fig.7) and (table 8) respectively.

Table 8 : Hydrometric station and their characteristics

Station name	Drainage Area(KM2)	Location		Mean annual discharge (m^3/s)
		Latitude	Longitude	
Abbay at Bahir Dar	15,321	$11^{0}35'$	$37^{0}25'$	123
Abbay at Kessie	65,784	$10^{0}04'$	38011’	516.80
Abbay at Shegole	156,458	$11^{0}14'$	$34^{0}59'$	1,399
Abbay at Border	172,254	$11^{0}14'$	$34^{0}59'$	1,564
Abbay at Roseires	185,000	$11^{0}51'$	$31^{0}23'$	1,530
Beless	3,431	$11^{0}30'$	$37^{0}20'$	143
Chemoga	364	$10^{0}18'$	$37^{0}44'$	5.61
Dabus	10,139	$09^{0}52'$	$34^{0}54'$	215
Dabena	3,281	$09^{0}02'$	$36^{0}03'$	60.50
Didesa	9,981	$08^{0}04'$	$36^{0}03'$	38
Guder	524	$08^{0}57'$	$37^{0}45'$	12.70
Muger	489	$09^{0}18'$	$38^{0}44'$	31.80

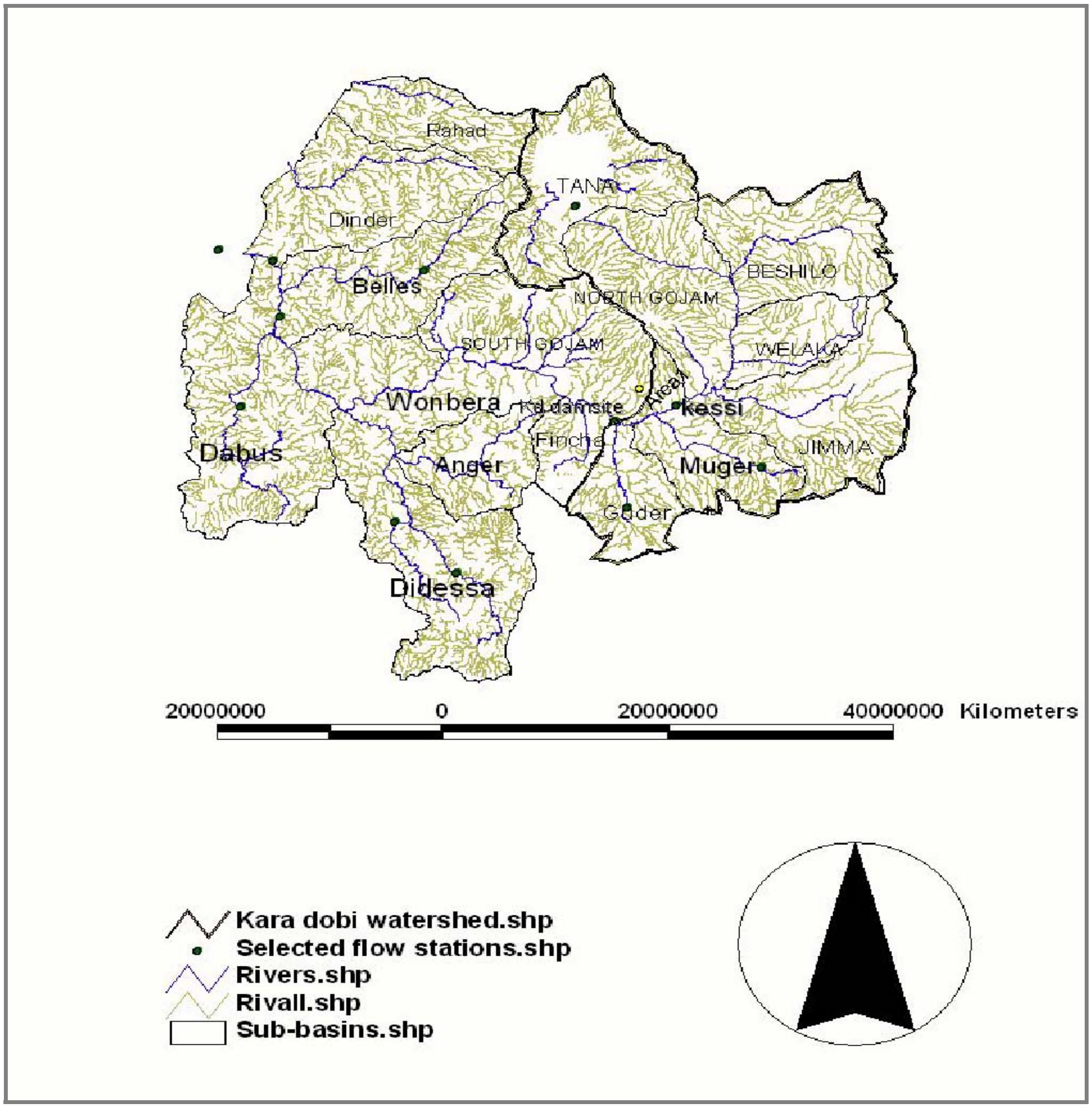


Figure 6 Abbay sub Basin and selected flow stations

3.4.2 Infilling missed data and data record extension

There are some periods with missed and short gauge records, and efforts were made to infill the missed records and extend the short one before using the data for further analysis. In this report, infilling and extension of missed records were carried out by developing correlation between the station with missed data and any of the near by stations, whichever gives good correlation for common data period. Correlation using mean daily flow among different station was summarized in table 9.

Table 9 Inter-station correlation coefficients

stations	Equation	Type of function	Correlation coefficient(r^2)	Length of record
Kessie(D)				
Muga	Y=87.44x-7.07	Linear	0.837	1973-2002
Sud. border	$Y=0.385x^{1.0001}$	Power	0.856	1960-2002
Beless	$Y=39.42x^{0.728}$	power	0.84	1962-2002
Guder	Y=44.389x+7.69	Linear	0.8999	1974-2001
Muger	Y=20.04x-111.5	Linear	0.984	1973-2002
	$Y=4.141x^{1.35}$	power	0.94	
Chemoga	Y=79.04x+12.81	Linear	0.971	1980-2002
Bahir Dar	Y=2.33x+196.63	Linear	0.138	1973-2002
Roseires	$Y=0.42x^{0.963}$	power	0.955	1960-2002
Shegole	$Y=0.172x^{1.041}$	power	0.957	1960-1992
Muger(D)				
Guder	$Y=10.44x^{0.498}$	Power	0.833	1973-2001
	Y=2.247x+5.56	Linear	0.942	
Didesa(D)				
Dabus	Y=0.844x+4.14	Linear	0.721	1963-1979
Dabena	Y=2.413x-6.737	Linear	0.957	1962-1980
	$Y=1.0934x^{1.159}$	power	0.976	
Beless	Y=0.407x+3.717	Linear	0.955	1984-2002
Roseires(D)				
Border	Y=0.987x-105.4	Linear	0.998	1961-2002
Shegole	$Y=1.054x^{0.983}$	power	0.965	1962-2002

D: *Dependant station*

3.5 Generation of in flow to Kardobi dam site

It would be ideal if there exist a gauge with a long record of measured stream flows at each desired reservoir site in a basin [12]. For the area under study, there is no gage at the dam site. As it is seen in the above (fig 7). The nearest gauge station on the main stream is Kessie as a result the inflow to Karadobi dam site can be found using any one of the following two methods

- Transferring the Kessie flow directly to the dam site
- Summing flow of Kessie and contribution of Guder, Muger and adjoining un gauged drainage area(Area 1 in fig.7)

The two South tributaries, Guder and Muger are not gauged at the confluence with Abbay as result it is required to transfer the data from the gauge location to the confluence.

In regions where watersheds are generally homogeneous throughout the basin, the spatial distribution of monthly or season rainfall does not significantly vary from one part of the basin to another [12]. In such situation estimated flow Q_s at any site can be based on the drainage area above the site, A_s, and the stream flow at the gauged site, Q_g, and the drainage area above the gauge sit, A_g.

$$Qs = Qg\left(\frac{As}{Ag}\right)^n \text{--} \mathbf{3.4}$$

n=value between 0.6-1.20

If A_S is with in 20% of A_g ($0.8 \leq A_S/A_g \leq 1.2$) then n=1 to be used.

A_S/A_g=13.4 for Guder

A_S/A_g=16.6 for Muger

A_S/A_g=1.25 for Kessie

In this case A_s is Karadobi watershed area 82,730KM^2 and

Ag is Kessie Watershed area 65,784KM^2

For this work the first method have been used , as it is difficult to estimate accurately the run off contribution of the un gauged adjoining drainage area from South Gojam sub basin. The maximum value of n (taken as 1.2) was used for transferring the flow of Abbay at Kessie to Karadobi dam site. The mean daily flow at Karadobi dam site and Kessie were estimated to be 645m^3/s and 451.5 m^3/sec respectively.

The catchment area of Abbay at Sudan border and Karadobi dam site is about 199,812KM^2 and 82,730KM^2 respectively .That means Karadobi watershed is about 41.4% of the border .This shows the contribution of the Karadobi watershed to border is quite significant. The same is true for the discharge of Abbay at border and at Karadobi which shows the mean monthly flow of Abbay at border and Karadobi is about 1469m^3/s and 585m^3/s respectively which is about 40%, as a result the regulation of Abbay at Karadobi is expected to offer higher flood protection in the downstream areas. Figure 8 shows the mean monthly variation of flow at the two sites.

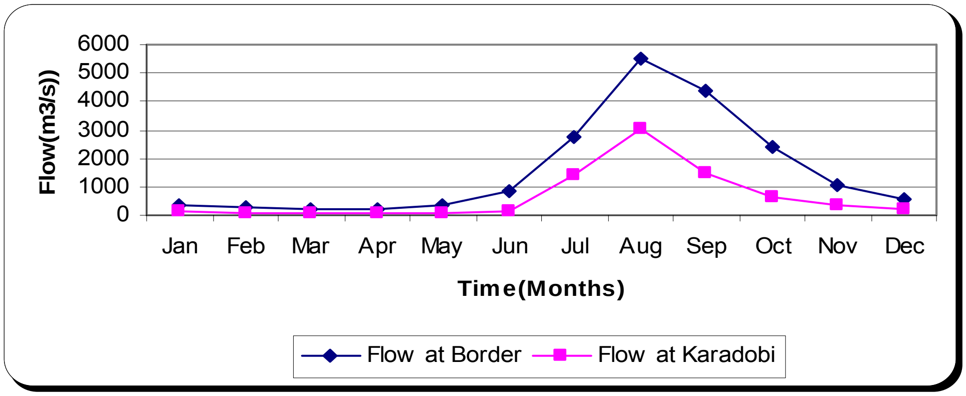


Figure 7 Mean monthly flow of Abbay at Border and Karadobi

3.6 Reservoir Evaporation

3.6.1 General

This portion describes the estimation of evaporation from the reservoir to be created behind the proposed dam on Abbay River at Karadobi. The determination of evaporation is essential as it is among the major inputs for reservoir operation simulation using HEC-ResSim model.

There are several methods for evaporation determination: Water balance, Energy balance, Aerodynamic, Penman and pan evaporation methods being the most common [19].

In this study, the most commonly used method, the Penman and 1985 Hargreave's method, have been applied and were explained in the following section. The remaining methods need some data which is difficult to estimate accurately such as the ground water inflow, ground water out flow in water balance method and sensible heat term in the energy balance method.

3.6.2 Penman method

Penman's equation is based on sound theoretical reasoning and is obtained by combination of the energy -balance and mass- transfer approaches [11]. Penman's equation incorporating modifications suggested by other investigators is

$$E_o = \frac{\Delta R_n + \gamma E_a}{\Delta + \gamma} \qquad \text{[Mm/day]} \qquad \text{----------------3.5}$$

Where:

EO = daily evaporation in mm/day

Δ = slope of the saturation vapour pressure versus temperature curve at the mean air temperature, in KP/ ^{o}c

R_n = Net radiation in mm/day

g =psychometric constant, KP/ ^{o}c

E_a = parameter including wind velocity and saturation deficit, mm/day

- The Gradient of the saturation vapour pressure, Δ, is defined as:

$$\Delta = \frac{4098 e_s}{(T + 237.3)^2} \qquad [\text{kp}/^o\text{c}] \qquad \text{-----------------------3.6}$$

Where:

T= air temperature, ^{o}c

e_s= saturated vapour pressure at ambient air temperature given as:

$$e_s = Exp\left(\frac{16.78T - 116.9}{T + 237.3}\right) \qquad \text{[KP]} \qquad \text{--------------------3.7}$$

- The psychometric constant is given by:

$g= 0.0016286\frac{p}{\lambda}$ [kp/^{o}c] -------------------3.8

Where:

l=the latent heat of vaporization computed from

L= 2.501-0.002361T [MJ/kg] ---------------3.9

P=mean atmospheric air pressure and can be estimated from ideal gas low equation as:

$P=101.3\left(\frac{288-0.0065Z}{288}\right)^{5.259}$ [KP] --------------3.10

Z= altitude of the place (a.m.s.l)

- The net radiation, Rn, is the net input of radiation at the surface, which is the difference between the incoming and reflected short wave radiation (R_{ns}), plus the difference between the incoming and out going long wave radiation(R_{nl}) and it is given as:

  $R_n=R_{ns}+R_{nl}$ [mm/day] --------------3.11

- The net short wave radiation, R_{ns}, is given by:

  $R_{ns}= R_t\,(1-r)$ [mm/day] ------------------3.12

  Where, r is reflection coefficient or albedo and it has a value of 0.23 for land surface and 0.08 for water surface and R_t is in coming short wave radiation give as:

  $R_t = R_a\,(0.25+0.5n/N)$ [mm/day] -----------------3.13

  Where, R_a is extraterrestrial radiation (mm/day), n is actual daily sunshine hours, and N is maximum possible daily sunshine hours. Both R_a and N are found in standard tables (Table A-29) as a function of latitude of the place and month of the year [13].

- The net long-wave radiation, R_{nl} can be found from the relation:

$$R_{nl} = -\tau(T+273.2)^4\left(0.1+0.9\frac{n}{N}\right)\left(\frac{0.34-0.14\sqrt{e_d}}{\lambda}\right)$$ [Mm/day] ---3.14

In which

s = Stefen Boltzmann constant and is equal to $4.903*10^{-9}$MJ/m2/^{o}k/day

e_d is vapour pressure at dew point and computed from:

$e_d = \frac{e_s RH}{100}$ [KP] -----------------------3.15

Where e_s is the saturation vapour pressure and RH is relative humidity in %

➪ The parameter E_a in the original equation can be defined by:

Ea= $6.43(a+0.536u_2)D_{vp}$ [mm/day] ---------------------3.16

Where *a* is a constant and assumed to be 0.5 for open water and 1.0 for land surface and u_2 is wind speed in m/s at 2.0m height .

D_{vp} is vapour pressure deficit estimated from the relation:

$D_{vp} = \left(\frac{e_{s(T\max)}+e_{s(T\min)})}{2}\right)\left(1-\frac{RH}{100}\right)$ [KP] -----------------3.17

In which, $e_{s\ (Tmax)}$ and $e_{s\ (Tmin)}$ are computed from equation 3.6 for $T=T_{max}$ and $T=T_{min}$ respectively

For the present study the evaporation computed using the above method and spreadsheet application and the result is summarized in (table10) below.

Table 10 Summary of monthly net loss from Karadobi reservoir (penman method)

Month	E_o at Debre-Markos	E_o at Kara-dobi	Rainfall(mm) Filikliki	Net loss[2]
Jan	170.2	191.7	11.7	180.0
Feb	190.7	217.7	3.7	214.0
Mar	196.7	222.6	36.5	186.1
Apr	192.3	217.2	65.1	152.0
May	182.3	207.3	50.3	157.0
Jun	124.5	135.7	158.3	-22.6
Jul	105.7	110.0	316.8	-206.7
Aug	107.9	112.5	305.3	-192.8
Sep	129.2	136.2	128.3	7.9
Oct	155.6	169.3	95.1	74.2
Nov	158.5	173.2	37.8	135.4
Dec	163.9	182.4	10.9	171.4
Total	1877.5	2075.8	1219.8	856.0

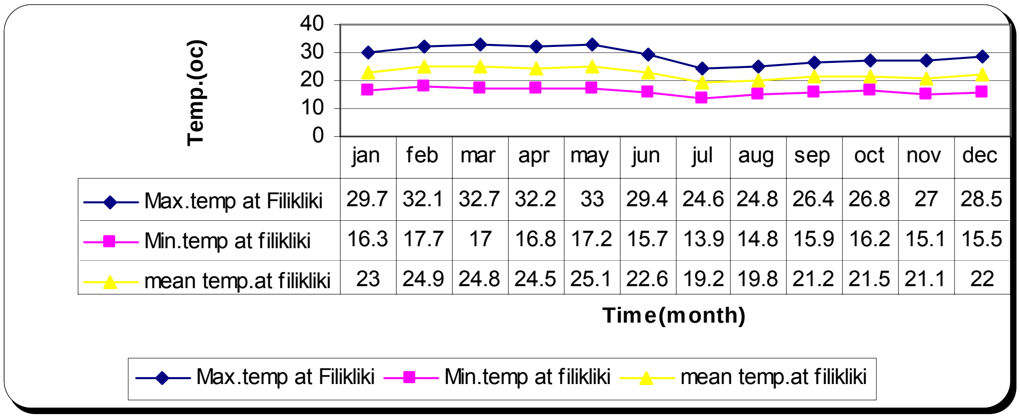
[2] ***Net loss= Evaporation - rainfall over reservoir***

3.6.3 1985 Hargreave's method

The Hargreave's equation (Hargreave's and Samani, 1982, 1985) is suggested as means for estimating evaporation in situations where data banks are limited and only maximum and minimum air temperature data are available [14]. This method was adopted for Filikliki and Damazine stations, the nearest station to Karadobi and Roseires dam sites, where the only available climatological data were maximum and minimum temperature(see fig.9 and fig.10) .The equation of Hargreav's is given by:

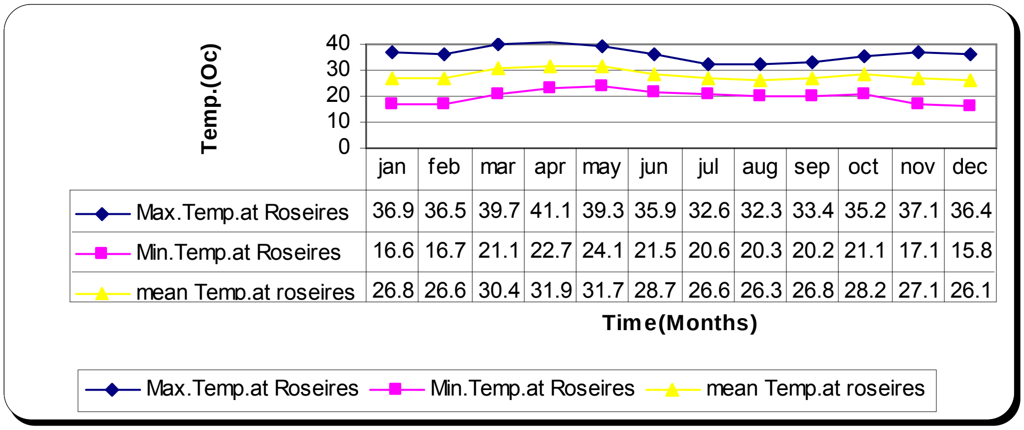
$$ET_O = 0.0023\,(T_{max} - T_{min})^{0.5}(T_{mean}+17.8)\,R_a \text{ ---------------------- } 3.18$$

In which T_{max} and T_{min} are the maximum and minimum daily air temperature in ^{0}c respectively, T_{mean} is mean air temperature and R_a is average daily extraterrestrial radiation in mm/day. The value of Ra in mm/day is taken from standard table given as a function of latitude of the place and months (see Table A-29).



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Max.temp at Filikliki	29.7	32.1	32.7	32.2	33	29.4	24.6	24.8	26.4	26.8	27	28.5
Min.temp at filikliki	16.3	17.7	17	16.8	17.2	15.7	13.9	14.8	15.9	16.2	15.1	15.5
mean temp.at filikliki	23	24.9	24.8	24.5	25.1	22.6	19.2	19.8	21.2	21.5	21.1	22

Figure 8 Temperature pattern at Filikliki



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Max.Temp.at Roseires	36.9	36.5	39.7	41.1	39.3	35.9	32.6	32.3	33.4	35.2	37.1	36.4
Min.Temp.at Roseires	16.6	16.7	21.1	22.7	24.1	21.5	20.6	20.3	20.2	21.1	17.1	15.8
mean Temp.at roseires	26.8	26.6	30.4	31.9	31.7	28.7	26.6	26.3	26.8	28.2	27.1	26.1

Figure 9 Temperature pattern at Roseires

Evaporation(**Y**) computed at different location around the dam site was correlated with Elevation(**X**) of stations on monthly basis; the correlation so obtained shows a good correlation with R^2 that varies from 0.92 for the month of April to 0.355 for June. As shown in table 11 below monthly evaporation of Karadobi and the correlation of Evaporation and Elevation for each month.

Table 11 Estimate of monthly net loss from Karadobi (Hargreave's method**)**

Month	Equation	R^2	Evaporation (mm/month)	Rain fall (mm/month)	Net Loss(mm)
Jan	$Y=7007.9x^{-0.5133}$	0.76	140.5	11.7	128.8
Feb	$Y=8202.5x^{-0.530}$	0.85	148	3.7	144.3
Mar	$Y=13053x^{-0.5712}$	0.88	184	36.5	147.5
Apr	$Y=15538x^{-0.598}$	0.92	180	65.1	115
May	$2164.9x^{-0.3425}$	0.52	188.3	50.3	138
Jun	$2377.8x^{-0.3841}$	0.36	157.9	158.3	0.0
Jul	$Y=-0.0282x+175.3$	0.71	132.6	316.8	0.0
Aug	$Y=-0.0292x+180.87$	0.7	131.5	305.3	0.0
Sep	$Y=-0.0233x+180.26$	0.57	138	128.3	9.7
Oct	$Y=184.08e^{-0.0002X}$	0.47	134	95.1	38.9
Nov	$Y=194.36e^{-0.0002X}$	0.70	126	37.8	88.2
Dec	$Y=214e^{-0.0002x}$	0.79	132	10.9	121.1
Total			**1793.3**	**1219.8**	**932.0**

Moreover, evaporation computed by Penman method was plotted against evaporation computed by method of Hargreave's (fig.11) and it exhibits that the solution obtained by both methods are very close to each other with out significant difference. A sample plot for Debre Markos, Nedjo and Chagni are shown below.

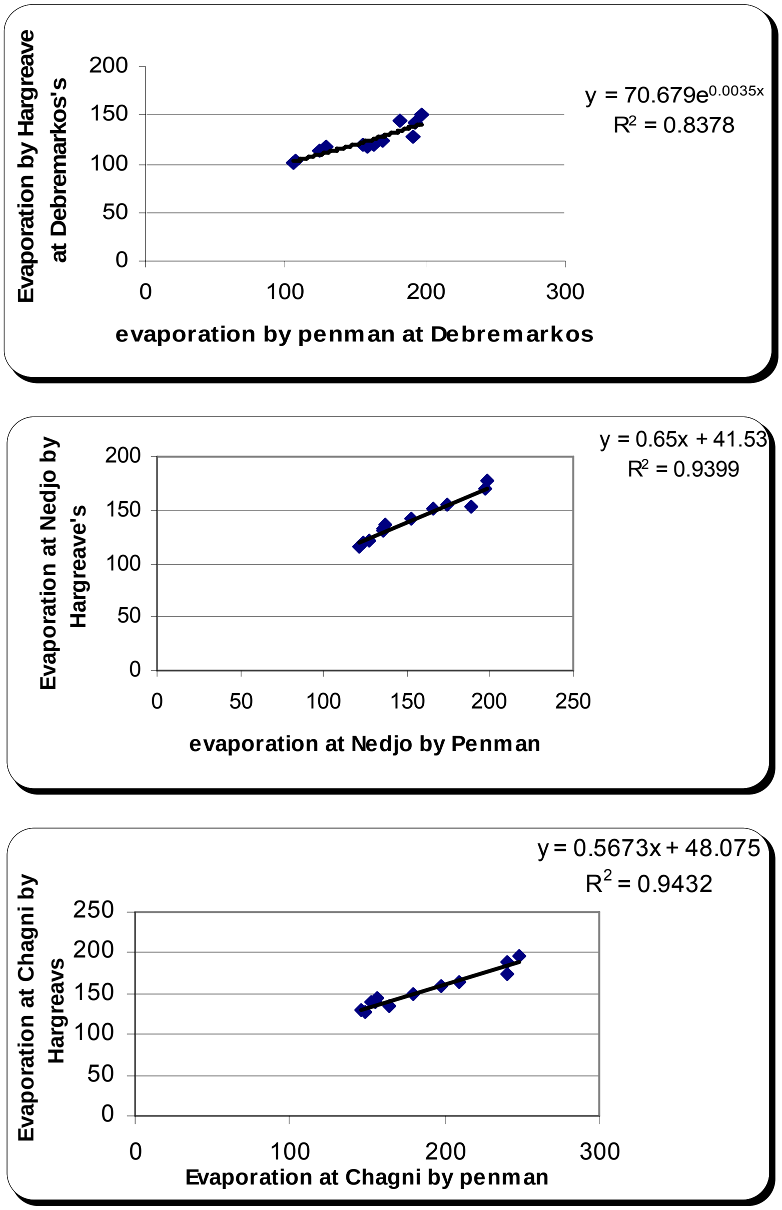
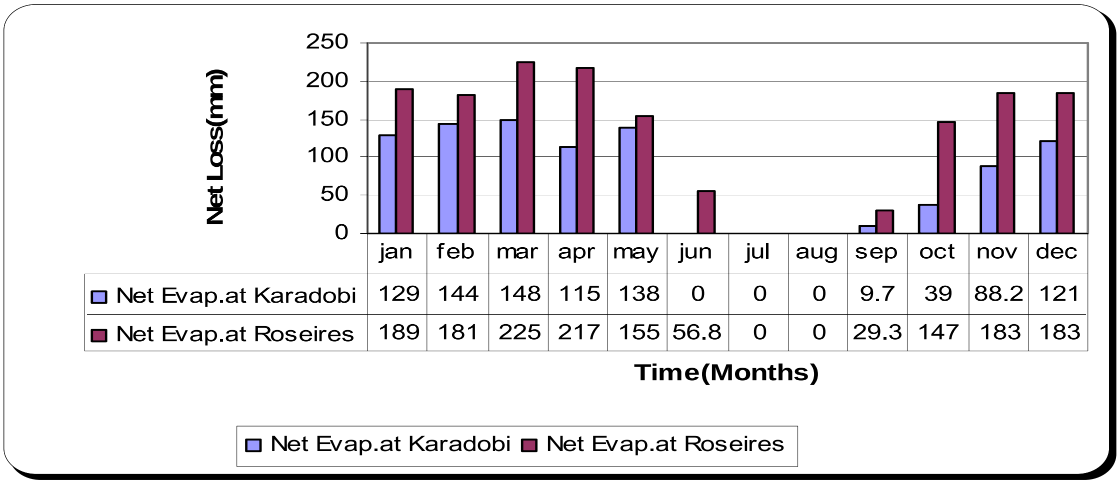


Figure 10 Plot of Evaporation by method of penman against Hargreave's

The mean monthly Maximum and minimum temperature data of Roseires station was collected from the eastern Nile technical regional office (See table 12) and the same method (Hargreave's) was applied for Roseires reservoir. It has been found that the mean annual evaporation at Roseires is 61.8% more than that of Karadobi.

Table 12 Summary of monthly evaporation loss from Roseires reservoir (Damazine station)

Month	**Evaporation (mm/month)**	**Rain fall (mm/month)**	**Let loss(mm)**
Jan	188.9	0	188.9
Feb	180.7	0.05	180.7
Mar	226.8	2.0	224.8
Apr	230.9	14	216.9
May	213.3	58.5	154.8
Jun	186.3	129.5	56.8
Jul	167.8	178	0.0
Aug	168.8	216.5	0.0
Sep	176.8	147.5	29.3
Oct	180.8	33.5	147.3
Nov	188.4	5	183.4
Dec	183.3	0	183.3
Total	**2292.8**	**784.6**	**1508.3**



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
🟦 Net Evap.at Karadobi	129	144	148	115	138	0	0	0	9.7	39	88.2	121
🟥 Net Evap.at Roseires	189	181	225	217	155	56.8	0	0	29.3	147	183	183

Figure 11 Monthly net loss at Karadobi and Roseires

3.7 Sediment load

Suspended sediment load on the main stream at Bahir Dar, Kessie and Bure (no record at all) were collected from MoWR. The data was available for some days with in a month and for only some month with in a year. Actually, the sampling time was scheduled to incorporate a wider range of values representative of both low and high flow rates. The data also includes the corresponding flow and depth of the river at each gauge locations. Sediment rating curve developed for the station at Kessie is as shown in fig.13. The developed rating curves at Kessie were used to estimate sediment inflow to Karadobi reservoir.

3.7.1 Reservoir Sedimentation computation methods

Concentration graph – hydrograph method

This is the most accurate method of computing suspended-sediment load, but it s also the most laborious and requires the most complete and detailed discharge and sediment data. It is especially appropriate for computing the sediment discharge during individual storms where there has been extensive sampling over the entire hydrograph. It is difficult or impossible to use this method if sediment data on the stream are sparse [17]. Accordingly as the data available for this study is sparse this method is not applicable for this work.

Flow Duration curve – sediment rating curve method

This is a speedier but less accurate method for estimating sediment discharge on a stream. It is particularly useful where we have only scattered water and sediment data, i.e., where we have irregular or discontinuous sampling. The technique can be used to calculate suspended-sediment, bed load, or dissolved-solids discharges. The flow- duration curve (or simply duration curve) at a measurement site is a plot of the percent of time any given mean daily discharge is equaled or exceeded there. A suspended-sediment rating curve is a plot of instantaneous suspended-sediment discharge Qs verses instantaneous water discharge Q_w for a measurement site (see fig 13). The computation has been done on a spreadsheet and the results are summarized as in Table.13

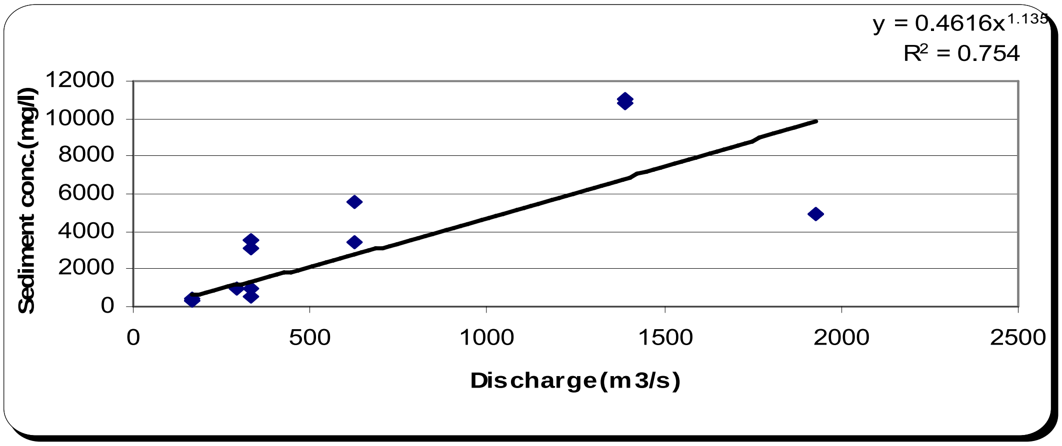


Figure 12 Sediment rating curve at Kessie stations

Procedure for sediment inflow rate computation at Karadobi reservoir

- The Plot of flow-duration curve for the daily stream flow at Kessie was prepared using spreadsheet application
- A sediment rating curve for the site was prepared using the available sediment data for the site
- Column 1: the flow-duration curve was divided into about 20 intervals.
- Column 2: duration of increment (. % of time)
- Column 3: median time % of increment
- Column 4: From the flow duration curve, the water discharge (Q_w) corresponding to each median time % was determined
- Column 5: From the sediment rating curve the instantaneous sediment discharge (Qs) corresponding to each water discharge (Q_w) was determined
- Column 6: unit conversion from mg/l to ton/day
- Column 7: the contribution of each time increment to the mean daily sediment discharge by Multiplying each Qs (column 6) by the % time in the corresponding increment (column 2) and dividing by 100
- The mean daily suspended-sediment discharge (in tons/day) was determined by summing column 7.
- The total suspended-sediment discharge in tons per year was computed by multiplying the daily discharge by 365

Table 13 Sediment inflow rate computation to Karadobi

Low bound of % inc	Change In inc. (%)	Median of inc.	Q_w (m3/s)	Q_s .(mg/l)	Q_s (t/day)	Mean Q_s for Time increment (t/day)
1	2	3	4	5	6=0.864*col4*col5	7=col.5*col.2
0.02	0.02	0.01	17899	30997	47936137.4	9587.2
0.1	0.08	0.06	12953	21473	24031691.9	19225.4
0.2	0.1	0.15	10841.9	17547	16437041.0	16437.0
0.5	0.3	0.35	8083.5	12574	8782100.9	26346.3
1	0.5	0.75	6262.1	9411	5091793.9	25458.9
2	1	1.5	4932.6	7177.9	3059078.8	30590.8
3	1	2.5	4091.6	5805.8	2052416.7	20524.2
5	2	4	3384.1	4680	1368468.6	27369.4
9	4	7	2491.1	3305.7	711489.9	28459.6
15	6	12	1552.7	1933.0	259325.7	15559.5
25	10	20	855.9	983.2	72710.4	7271.0
35	10	30	465.5	492.5	19809.9	1980.9
45	10	40	305.6	305.5	8066.3	806.6
66	10	50	199	187.7	3227.9	322.8
65	10	60	124.1	109.8	1177.8	117.8
75	10	70	76.5	63.4	419.3	41.9
85	10	80	46.8	36.3	146.8	14.7
95	10	90	25.5	18.2	40.2	4.0
99.9	4.9	97.4	6.5	3.8	2.2	0.1
Total						**230118.3ton/day**

Note: Q_s –sediment discharge, Q_W water discharge

Specific sediment yield at Kessie =1292.2ton/KM^2/year

At Karadobi=1615ton/KM^2/year

3.7.2 Reservoir sediment distribution

The rate with which reservoir gets silted is varying from time to time through the life of the reservoir. The capacity inflow ratio verses trap efficiency curve (Given by Brune, 1953 see fig.B-21) shows that, if the capacity of a reservoir reduces with constant inflow, the trap efficiency of reservoir reduces which means new reservoirs traps more sediment than old reservoir in other words the trap efficiency of reservoir reduces as it get older. In this study it has been tried to estimate the average trap efficiency and the corresponding sediment distribution in the reservoir for different life period of the reservoir. The input data for the computation were the gross reservoir volume at full supply level (48Bm^3) the average annual sediment in flow rate at the dam site (105Mm^3) and the average annual inflow volume of water (21.57Bm^3). The computation has been done by dividing the over all storage zone of the reservoir in to five parts (20% each). Table14 shows the computation stapes and the sediment distribution at Karadobi

Table 14 Sediment Distribution

Capacity (%)	Capacity (Bm^3)	$\frac{Capacity}{Inflow}$	Trap eff.	Avg.trap eff.	Sed.traped/y (Mm^3)	Years to fill 20%
1	2	3	4	5	6=col.5*105Mm^3	7
100	48.00	2.23	95.00			
				95.00	99.75	96.20
80	38.40	1.78	95.00			
				4.75	99.49	96.50
60	28.80	1.34	94.50			
				94.50	99.23	96.70
40	19.20	0.89	94.50			
				91.75	96.34	99.60
20	9.60	0.45	89.00			
					Mean=98.70Mm^3	Total=389years

Referring the Elevation-volume relation of Kardobi reservoir the year at which different levels of the reservoir will get silted up is computed as given in table 15

$$Numberofyears = \frac{\mathrm{Re}\,servoirVolume}{AverageAnnualRateofSe\,\mathrm{dim}\,entation}$$

Table 15 Long-term reservoir sedimentation

Reservoir Level(m)	Volume(m^3)	Number of years to fill
960	4.66E8	5.0
980	1.38E9	14.0
1000	3.12E9	31.6
1020	5.61E9	59.0
1040	8.7E9	88.0
1060	1.25E10	127.0
1080	1.7189E10	174.0

CHAPTER FOUR

DATA CONFIGURATION AND HEC-RESSIM MODEL SET UP FOR THE STUDY AREA

4.1 System Watershed setup

The purpose of this Watershed Setup module is to provide a common framework for watershed creation and definition among different modeling applications. The background image that describes the geo-referenced area of the watershed was imported from Arc View GIS (fig.14). The unit to be used in the system and the international time zone of the area was set to be SI unit and GMT+3 respectively. Items that describe the watershed's physical arrangement such as Streams, gauge locations, computation points and junction points were drawn using their respective mouse tools provided in the watershed set up module of the software.

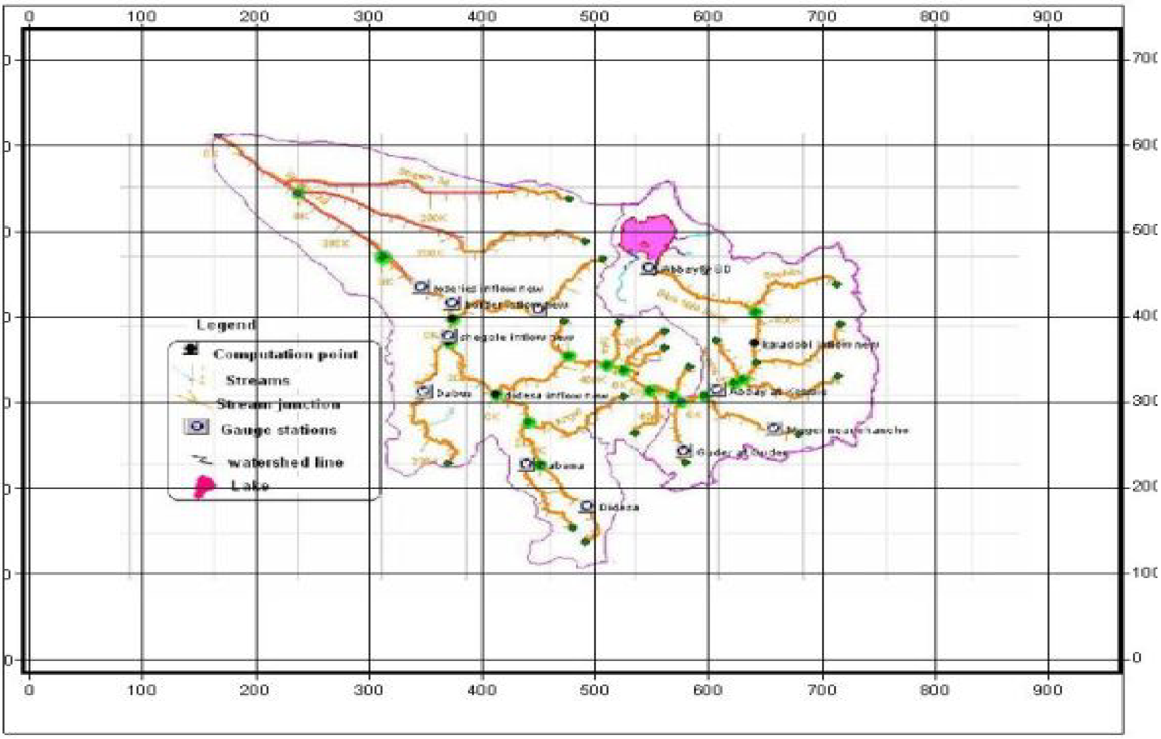


Figure 13 Blue Nile watershed set up

4.2 System Reservoir network setup

The primary task of developing the reservoir network was to connect the junctions (computation points) with routing reaches between junctions. A reservoir network represents a collection of watershed elements connected by routing reaches. Elements created in the Watershed Setup Module were connected with each other through routing reach, moreover reservoirs pool, dam and diverted out lets have been created making use of this module for both reservoirs (Fig.15).

The Reservoir Network module was also used for editing and entering elemental data and placing additional elements onto the stream alignment. The most important elemental data that has been entered in to the reservoir network module were reservoir volume-elevation-area curves, reservoir evaporation, spillway, penstock and bottom out let capacity curves.

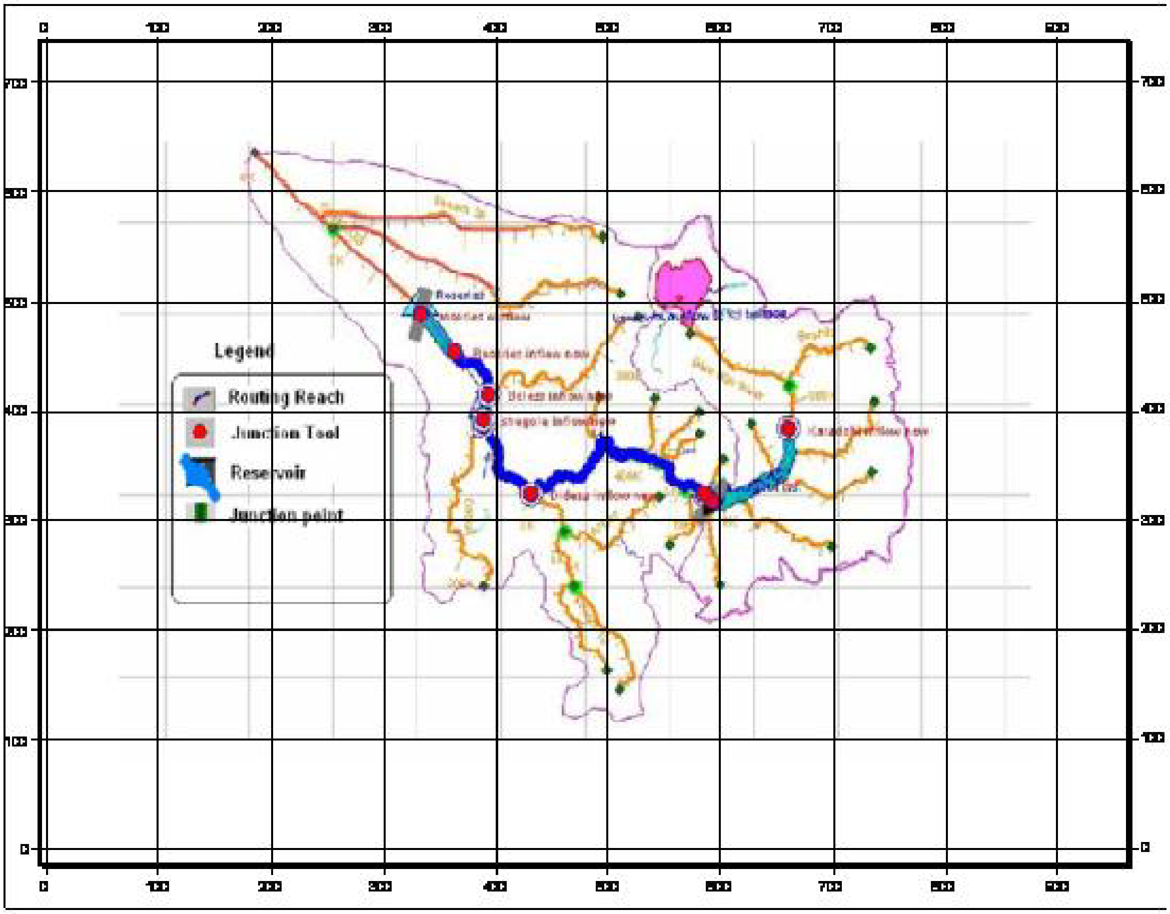


Figure 14 Blue Nile reservoir system setup

4.3 Input data set up

4.3.1 Reservoir Storage-Elevation-Area Curves

The reservoir physical data incorporates the pool storage-elevation-area relation (Table 16 and fig.16) and this data was directly taken from the pre-feasibility report of Karadobi and that of Roseires is not available as a result it was interpolated by the software between minimum and maximum operating levels (Fig.17). The reservoir surface area is required for computation of evaporation loss from the reservoir area and the storages are used to compute storage at any time based on the basic storage (continuity) equation (Equation 2.1).

Table 16 Karadobi capacity-Elevation-Area relation

Elevation (a.m.s.l)	**Area(KM^2)**	**Volume(Mm^3)**
900	0.0	0.0
920	0.65	4
840	10.2	93
960	28.6	466
980	65.7	1383
1000	110	3117
1020	140	5605
1040	170	8703
1060	212	12520
1080	256	17189
1100	306	22799
1120	363	29479
1140	424	37338
1160	495	46524

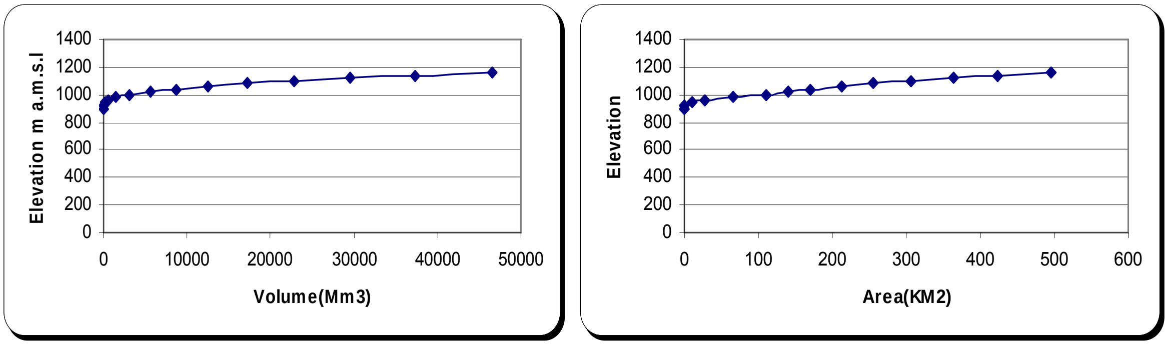
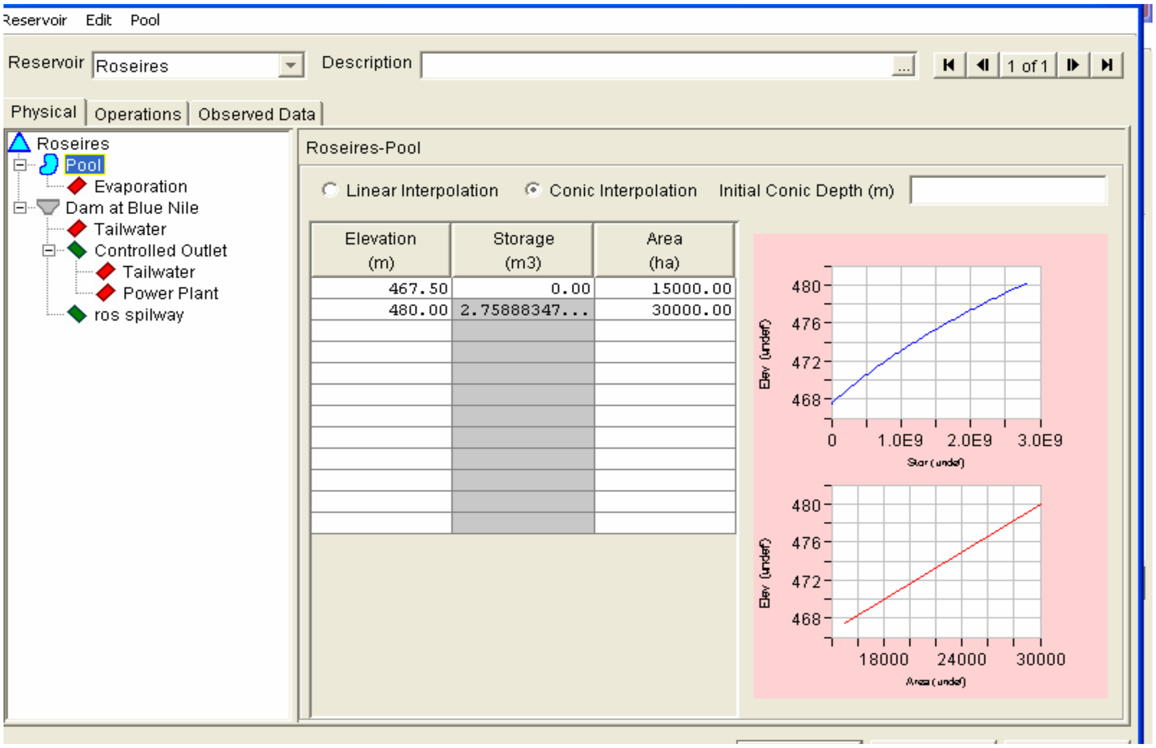


Figure 15 Area-Elevation-Volume Curve for Karadobi Reservoir



Reservoir: Roseires

Roseires-Pool

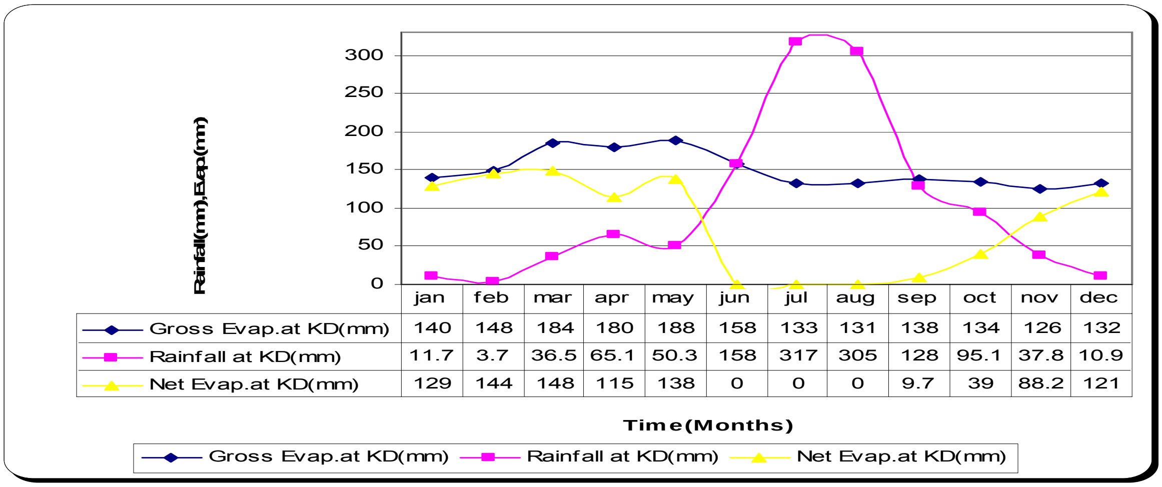
○ Linear Interpolation ● Conic Interpolation Initial Conic Depth (m)

Elevation (m)	Storage (m3)	Area (ha)
467.50	0.00	15000.00
480.00	2.75888347...	30000.00

Figure 16 Area-Elevation-Volume Curve for Roseires

4.3.2 Karadobi reservoirs Evaporation and Rainfall

As the dams are located at low elevation, reservoir evaporation contributes a great share of the total loss from the reservoir. The evaporation data series has been determined using both Penman and Hargreave's formulas on long-term mean monthly basis for Debre Markos and Filikliki station respectively. For this study, the result obtained by Hargreave's method for Filikliki station was adopted directly for Karadobi reservoir (Fig.18), as it is the only station located at lower valley of the basin near the River stream and the dam site as well. The net loss (Gross evaporation minus rainfall) from the reservoir as shown in fig. below has been used as input to the model.

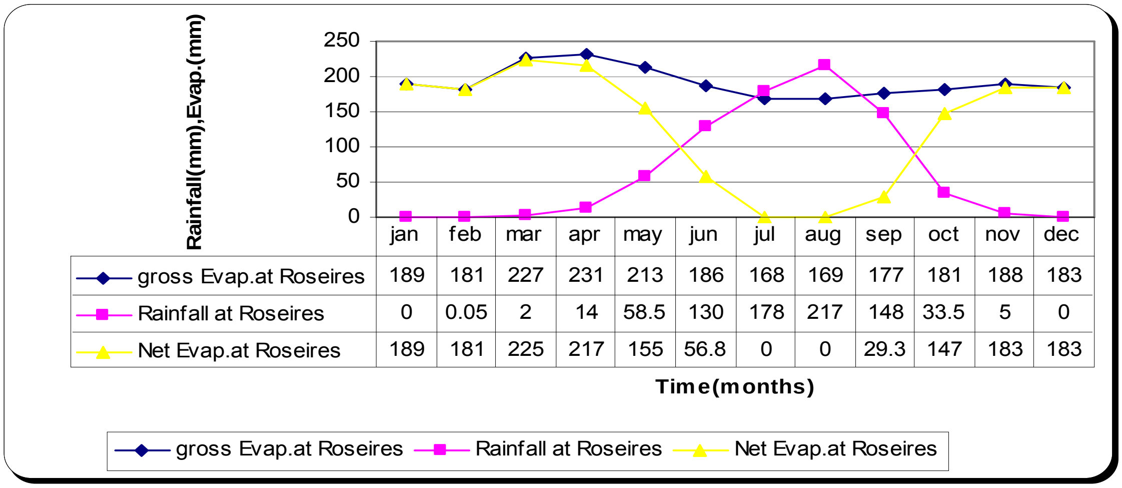


	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Gross Evap.at KD(mm)	140	148	184	180	188	158	133	131	138	134	126	132
Rainfall at KD(mm)	11.7	3.7	36.5	65.1	50.3	158	317	305	128	95.1	37.8	10.9
Net Evap.at KD(mm)	129	144	148	115	138	0	0	0	9.7	39	88.2	121

Figure 17 Karadobi Reservoir Rainfall gross and net evaporation

4.3.3 Roseires Reservoir Evaporation and Rainfall

The evaporation for Roseires reservoir as computed and tabulated in section 3.6.3 has been used as input to Roseires Reservoir in the reservoir editor of the model in the same way as that of Karadobi. The rain fall pattern at Roseires is uni –modal from june to September. Figure19, below shows monthly distribution of rainfall and net evaporation at Roseires.



	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
gross Evap.at Roseires	189	181	227	231	213	186	168	169	177	181	188	183
Rainfall at Roseires	0	0.05	2	14	58.5	130	178	217	148	33.5	5	0
Net Evap.at Roseires	189	181	225	217	155	56.8	0	0	29.3	147	183	183

Figure 18 Roseires Reservoir Rainfall gross and net evaporation

4.3.4 Karadobi Reservoir Inflow

The daily inflow record collected from MoWR for the Kessie was extended to the Karadobi dam site as described in section3.5. These data have been used as input to the reservoir in the model. The mean annual flow of this time series date was 645m^3/sec (20.34Bm^3/year) which is about 41% of the total annual at border. Figure 20, below shows the monthly inflow hydrograph of Karadobi.

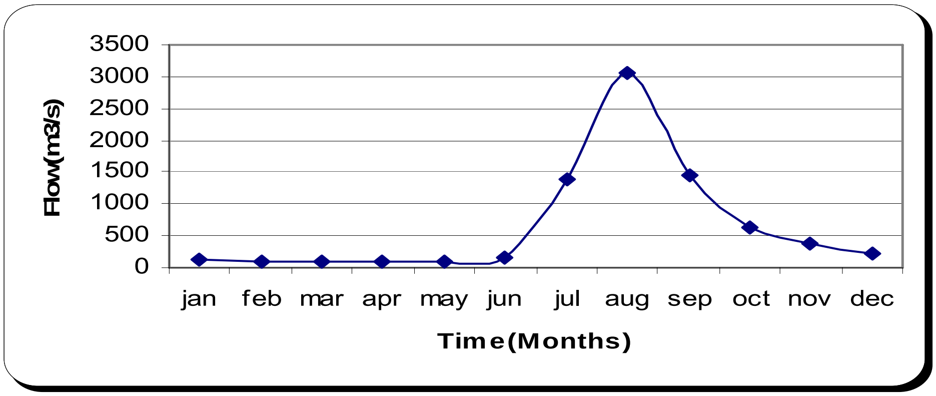


Figure 19 Karadobi reservoir inflow Hydrograph

4.3.5 Down stream flow condition

There are so many streams and Rivers that contribute to the main River down stream of Karadobi dam site, out of which Didesa, Dabuse and Beless are the major ones. The daily flow recorded for these stations have been transferred to their respective confluence with Abbay using the same method that has been used for Karadobi(see section 3.5). And the transferred records (Table17) were used as in put to their respective computation points that are shown in section 4.2, Fig.15. and the monthly hydrographs of the stations are as shown in fig.20

Table 17 of Monthly flows at down stream locations.

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Annual
Border	355	271	214	223	331	823	2757	5473	4357	2365	1046	553	1564
Didesa	11	8.6	7.1	6.9	11	33	72.2	104	96	64.3	27	15.3	38.1
Dabuse	87	67.3	57	58	92	191	356	506.1	467	352.8	208	132	215
Beless	16	10.2	7.3	5.8	13	80	280	599.8	379	227	64.8	26.3	142
Shegole	302	193	141	135	223	636	2421	4858	3805	2301	1169	504	1399
Roseires	264	170	133	135	251	698	2564	5356	4116	2177	925	460	1437

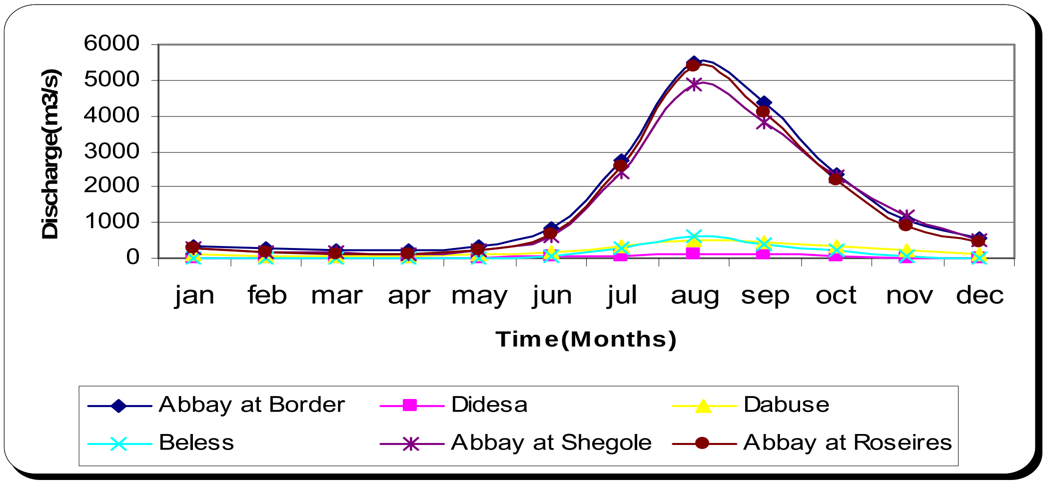


Figure 20 Monthly Hydrograph of down stream locations

As can be seen from the above (table 17) and chart above the mean annual inflow to Roseires is about 92% of that of Border, which might be an indication for a considerable loss between border and Roseires.

4.3.6 Channel reaches inputs

In this report, a lumped flow routing was assumed since there is no method for distributed flow routing in the model. The Muskingum method has been applied for each river reach. Here the attenuation coefficient (x=0.5) is considered which means Direct translation of the hydrograph to the down stream points and the value of K (travel time of the flood wave) was approximated using the Kirpich's formula since the usual trial and error method of Determining K gives a negative value for the inflow and out flow hydrographs at Karadobi and all other points.

$T_c = 0.001947 L^{0.77} S^{-0.385}$ --4.1

Where:

T_c = travel time for a drop of water to travel from the remotest point to the outlet (Minutes), Length between the reaches(m), and S is the slope of the reach. The computed T_c, x and number of sub reach have entered as main inputs to the reach editor of the model.

4.3.7 Spillway and Penstock data inputs

Elevation versus maximum capacity relation for the spillway of Karadobi was computed for the varies elevations above the spillway crest from the well known broad crested weir formula

$$Q = CL_e H^{3/2} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.2$$

Where:

Q= discharge over the spillway in m^3/sec

C=discharge coefficient which is usually taken as 2.2 for high spillways

L_e=effective length of the spillway in m

$= L - 2[n * Kp + Ka]He$

In which L=the net clear length of the spillway crest, m

K_P =pier contraction coefficient determined based on pier nose shape

K_a = abutment contraction coefficient

N =number of piers=9

H_e =total design head including velocity head, m

The computed head verses-maximum capacity for both spillways has been used as input to the model (see fig B-8 and figB-12a)

The same was done for penstock, but in this case, as the flow is pressurized the orifice formula was applied to compute the head verses maximum capacity relations.

$$Q = CA\sqrt{2gH} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 4.3$$

Where A and g are cross sectional area of conduits and acceleration due to gravity and C is contraction coefficient usually taken as 1 for bell mouth entry and the remaining terms are as explained in the above formula.

The top elevation of the dams and its length at the crest were also incorporated along with tail water elevation. Moreover, the installed capacity, efficiency of the system, station use and hydraulic losses are incorporated in this section.

The head loss in the hydraulic system includes losses due to friction, transition and bends. Generally, head loss is a function of the square of the discharge and head loss coefficient, i.e.

$$H_L = KQ^2 \qquad [\mathrm{m}] \qquad \text{---}4.4$$

In this particular report the minor losses were neglected and the major loss due to friction has been computed using coefficient of friction (K_F) as determined by the Manning's equation

$$K_f = \frac{L}{A^2 M^2 R^{4/3}} \qquad [\mathrm{s}^2/\mathrm{m}^3] \qquad \text{---------------------------------}4.5$$

Where L is length of headrace tunnel (m), A is cross sectional area (m^2), M is Manning's roughness coefficient, and R is the hydraulic radius (m).

The head loss computed by the above relation using standard values for the Manning's coefficient and design dimensions for the penstock and head race tunnel taken from the pre feasibility report were used as input to the simulation model.

As the design dimensions of penstock of Roseires are not known an estimate has been done using the known operating head and installed capacity.

$$P = ghQH \qquad [\mathrm{w}] \qquad \text{--}4.6$$

In which P, g， h， Q and H are power in Watt, unit weight of water in N/m^3, efficiency, Discharge in m^3/sec and Net head (27.8m) in m respectively. Here if the system is to generates the installed capacity (275MW) at the mean net head of 27.8m assuming the efficiency for the installed Kaplan turbine be 90%, the discharge (Q) was determined from equation 4.7 as:

$$Q = VA = A*0.125\sqrt{2gH} = \pi\frac{D^2}{4}0.125\sqrt{2gH} \qquad [\mathrm{m}^3/\mathrm{s}] \qquad \text{----------------}4.7$$

In which ($V=0.125\sqrt{2gH}$) is optimum velocity in m/s (USBR formula) and A is cross sectional area of penstock and H is the maximum working head (50m).

Substituting 4.7 in to 4.6 and solving for diameter after rearranging will give diameter to be 20m, but since there are four units the diameter of penstocks were estimated to be 5m each .

After fixing the diameter of the penstocks the main physical data input to the model, i.e. head versus maximum capacity(see fig B-12b and fig B-9) for the penstocks has been generated using the orifice formula(equation 4.3) for different head over the penstocks.

4.3.8 Reservoir Operation rules

Operation Rules represent the flow goals and constraints upon the releases for each zone of the operation set. Each zone can contain a different set of rules depending on the flow limits and requirements of that zone within the regulation plan. The different operation zones of a reservoir available in ResSim model are the flood control, conservation and inactive (Dead storage zones)[8].

In HEC-RESSIM model different rules are available for different elements of a reservoir system.

In this study the release function rule(minimum) limits of release from Karadobi penstock has been set based on capacity of the system and minimum demand desired at particular time where the reservoir is at its minimum operating level. Accordingly, the minimum release ($545m^3/s$) that maximizes the power generation was determined by trial and error.

Hydropower rules: There are three different Hydropower rule types

Hydropower–Schedule rule: a regular monthly schedule of hydropower requirements in mega watt hours (38400MWH) were assigned.

The Hydropower – Time Series Requirement rule: This rule defines an irregular schedule of Hydropower requirements through the use of a DSS time-series record. As it is impossible to get time series data of hydropower requirements this rule was not applied in this study.

The Hydropower – Power Guide Curve rule: This rule define a function that describes the hydropower generation requirement with respect to the available storage in the reservoir. The power guide curve has been described as a function of percentage of storage available in the reservoir and plant factor in percentage. In this operation rule set up a constant value of plant factor 0.69 was set for varies percentage of storage.

Down stream control rule: it is a rule that regulates the operation of the down stream reservoir in terms of either flow or stage in this study a down stream operation rule has been applied to Roseires reservoir in terms of stage so that the minimum required operating level at Roseires(467m a.m.s.l) for Gravity irrigation at the down stream farms is maintained.

CHAPTER FIVE

SIMULATION, RESULT AND DISCUSSION

5.1 Simulation of reservoir operation rules

A simulation was performed for the period 1972-2002 using the time series information for Karadobi dam site as model input. In the simulation run of the model the total storage zone has been divided in to three zones the flood control, the conservation and dead storage zone. A trial constant value for the top level of flood control and minimum operating level has been set and a monthly varying top level of conservation zone (guide curve) that has been determined by spreadsheet application at reliability level of 98% was used as the starting Guide curve to minimize the number of trial .

As a first trial in this report a flood control level of 1146 m a.m.s.l, a minimum operating level of 1100 m a.m.s.l, a trial guide curve (Month verses storage level) and an average tail water level of 915 m a.m.s.l has been set to run the model and the result obtained reveals that at this particular trial values the plant factor was very much lower than the recommended value which is 0.69. As a result a lot of trials on the above parameters have been done and finally at dam height of 270m, normal maximum pool level of 1164 m a.m.s.l, minimum operating level of 1088 m a.m.s.l and Tail water elevation of 915 m a.m.s.l the recommender plant factor(0.7) has been achieved. The corresponding guide curve (top of conservation zone) for Karadobi reservoir is as shown in fig. 21 below.

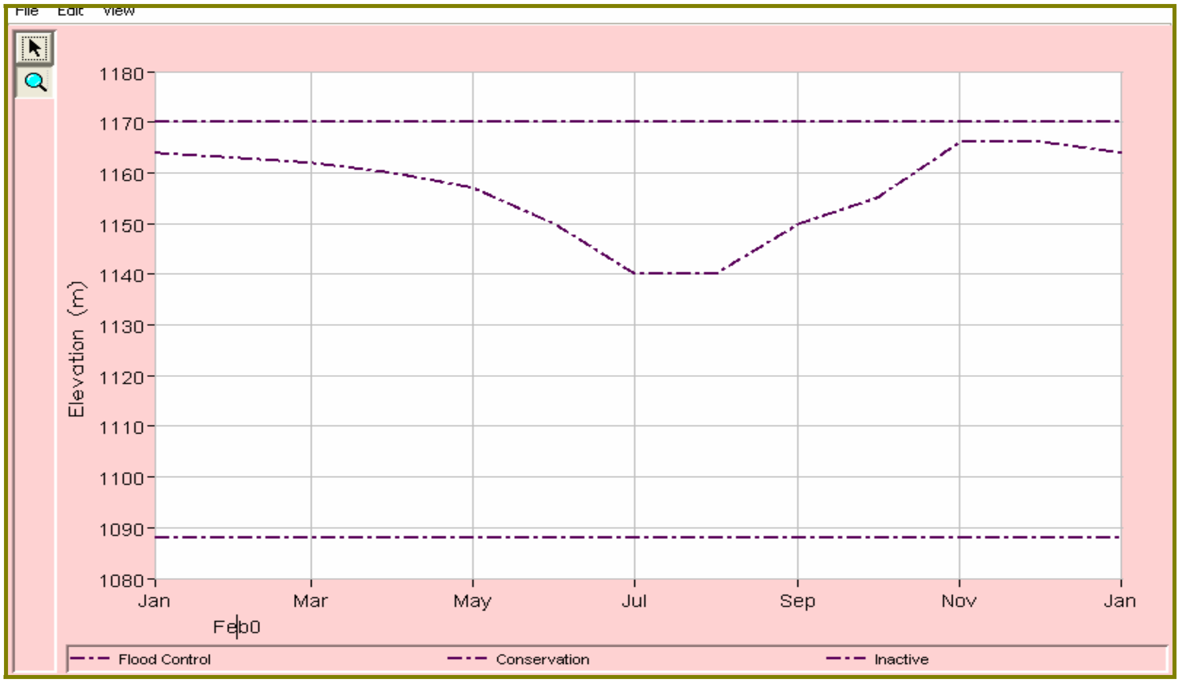
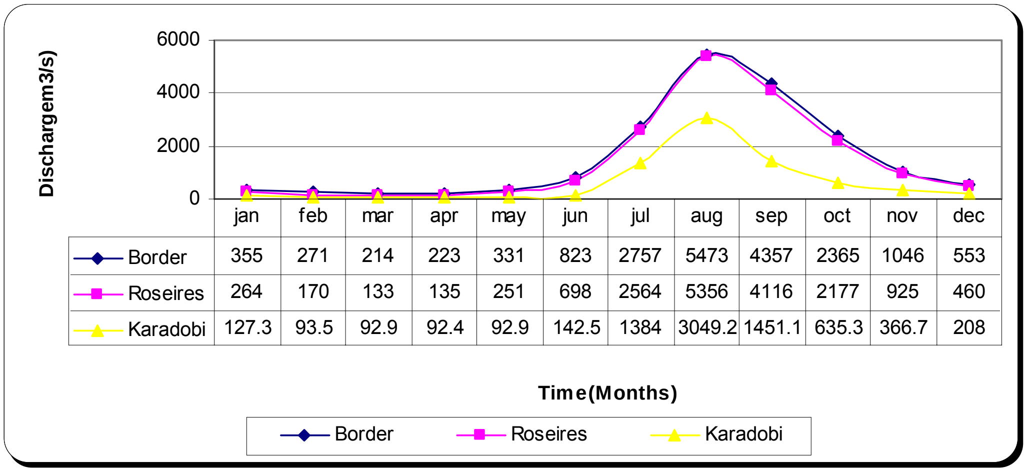


Figure 21 Karadobi reservoir Guide curve

5.2 Existing condition (The base scenario)

5.2.1 The existing inflow at Karadobi ,Border and Roseires

The historical mean monthly inflow data to Roseires reservoir were taken from the pre feasibility report (reference No.1), and the mean annual value for the record length of 31 year is calculated to be 1437m^3/sec (45.3Bm^3). This value is less than the inflow to border(50Bm^3),this indicates the losses between border and Roseires are significant. The mean annual inflow to Karadobi dam site is 645m^3/sec (20.34Bm^3), which is about 41% of that of the Border. Moreover, the existing sediment inflow rate to Roseires reservoir is 50Mm^3/year. The monthly inflow hydrograph at Roseires, Border and Karadobi are as shown in fig.24 below.

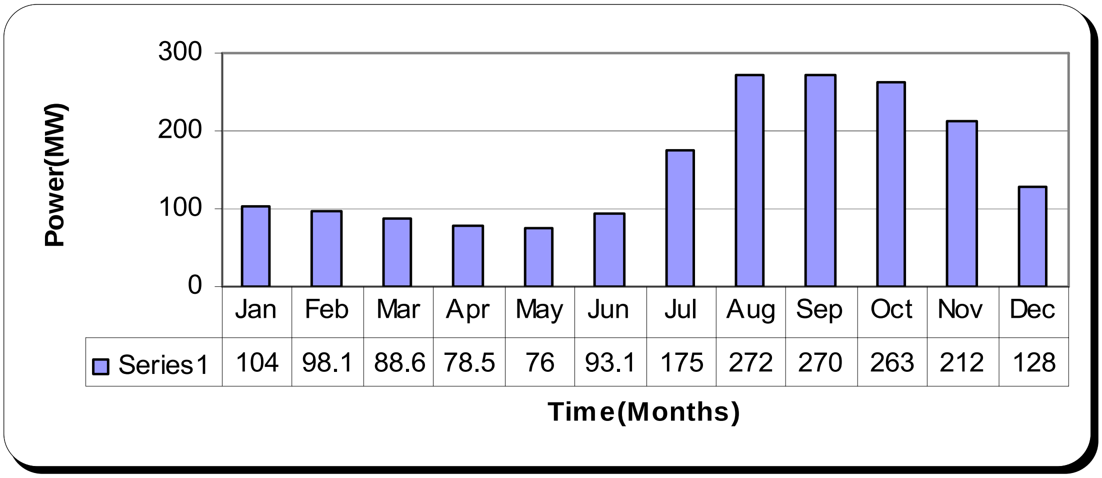


	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Border	355	271	214	223	331	823	2757	5473	4357	2365	1046	553
Roseires	264	170	133	135	251	698	2564	5356	4116	2177	925	460
Karadobi	127.3	93.5	92.9	92.4	92.9	142.5	1384	3049.2	1451.1	635.3	366.7	208

Figure 22 Inflow hydrograph at Karadobi, Ethiopian Border and Roseires

5.2.2 Power Estimate at Roseires for the historic inflow

Even though historical power generation data at Roseires is not available, the available natural inflow to Roseires reservoir along with the remaining input data such as reservoir physical characteristics and head versus maximum capacity relation for the dam appurtenant structures, installed capacity and efficiency were used to simulate power for the corresponding natural inflow to the reservoir. The result of the simulation for the natural flow shows that the mean monthly power generated at Roseires is 154.9MW. The result obtained after running the HEC-ResSim model was as shown in fig.25 below.



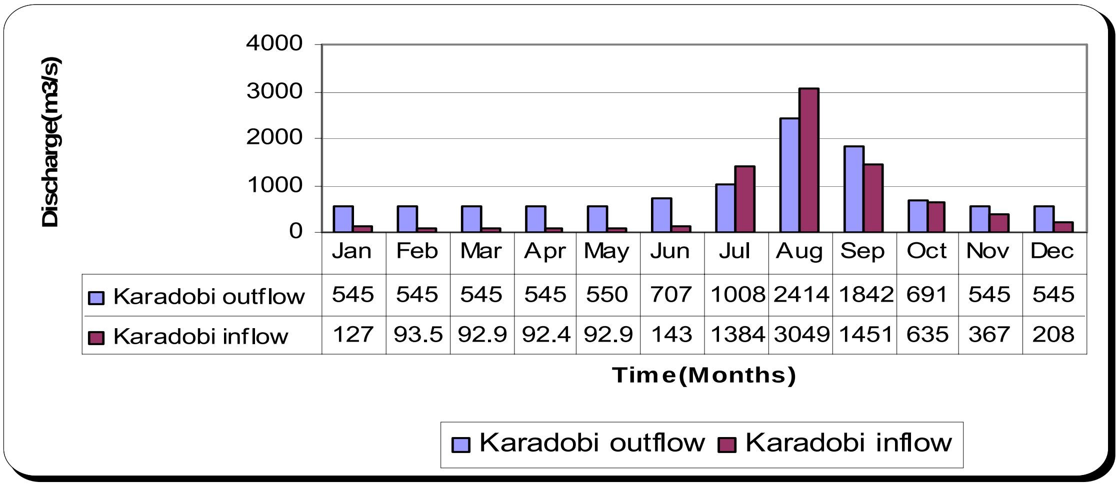
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▨ Series1	104	98.1	88.6	78.5	76	93.1	175	272	270	263	212	128

Figure 23 Power estimate at Roseires for Natural (historic) inflow

5.3 Down stream water use with Karadobi(regulated scenario)

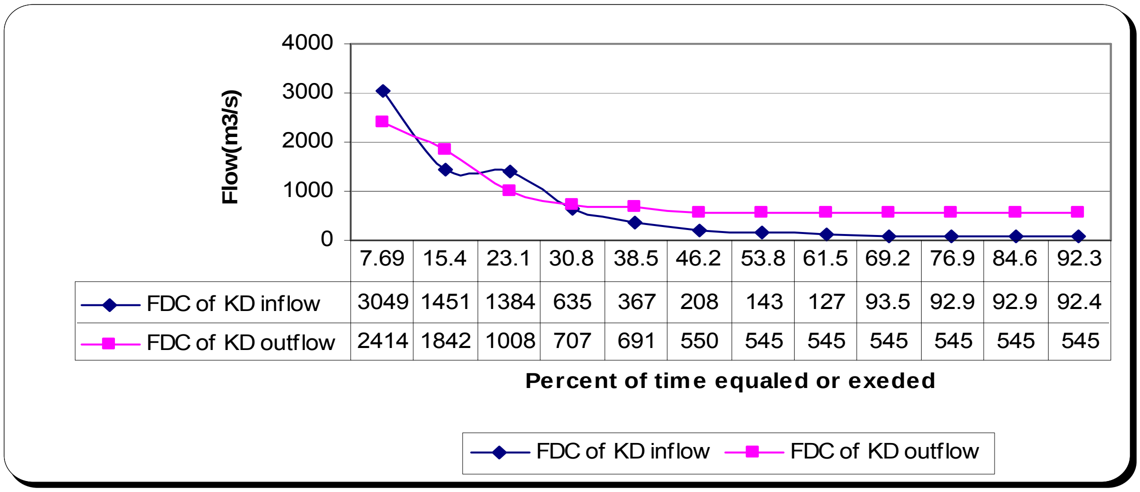
5.3.1 Karadobi out flow after regulation

The mean monthly inflow at Karadobi dam site was estimated to be 645m^3/sec and the mean monthly out flow from the reservoir after regulation has been estimated as 874m^3/sec and the 98% dependable flow after regulation is found to be 545m^3/sec. As can be seen from the monthly inflow distribution and Flow duration curve (fig.26 and 27) respectively, Karadobi will play a great roll in augmenting low flow and detaining high flows that may cause flooding.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▨ Karadobi outflow	545	545	545	545	550	707	1008	2414	1842	691	545	545
▨ Karadobi inflow	127	93.5	92.9	92.4	92.9	143	1384	3049	1451	635	367	208

Figure 24 Karadobi natural inflow and regulated out flow



	7.69	15.4	23.1	30.8	38.5	46.2	53.8	61.5	69.2	76.9	84.6	92.3
FDC of KD inflow	3049	1451	1384	635	367	208	143	127	93.5	92.9	92.9	92.4
FDC of KD outflow	2414	1842	1008	707	691	550	545	545	545	545	545	545

Figure 25 Monthly flow duration curve of Karadobi before and after regulation

5.3.2 Flow modification at Roseires after Regulation

The historical record at Kessie was extended to Karadobi dam site and used as input to the reservoir editor of the model. The output of the simulation indicates that Karadobi offers a high degree of regulation and modifies the natural flow pattern by augmenting the low flows that occur in dry period(December to June) and detaining high flows to the down stream areas during flood seasons(July to November). The average increase in monthly mean inflow discharge to Roseires reservoir during dry period has been estimated to be 397m^3/sec (1.12Mm^3 additional water per day). The average decrease in mean monthly discharge during flood seasons has been estimated as 938m^3/sec. Following fig. 28,29 describes detail result (output) of the model; besides, the modification inflow duration curve for the two scenarios is as shown fig. 30 .

Further more, from figure 30 it can be seen that the flow with 75% exceedence probability for the natural and regulated flows are170 and 636m^3/sec respectively.

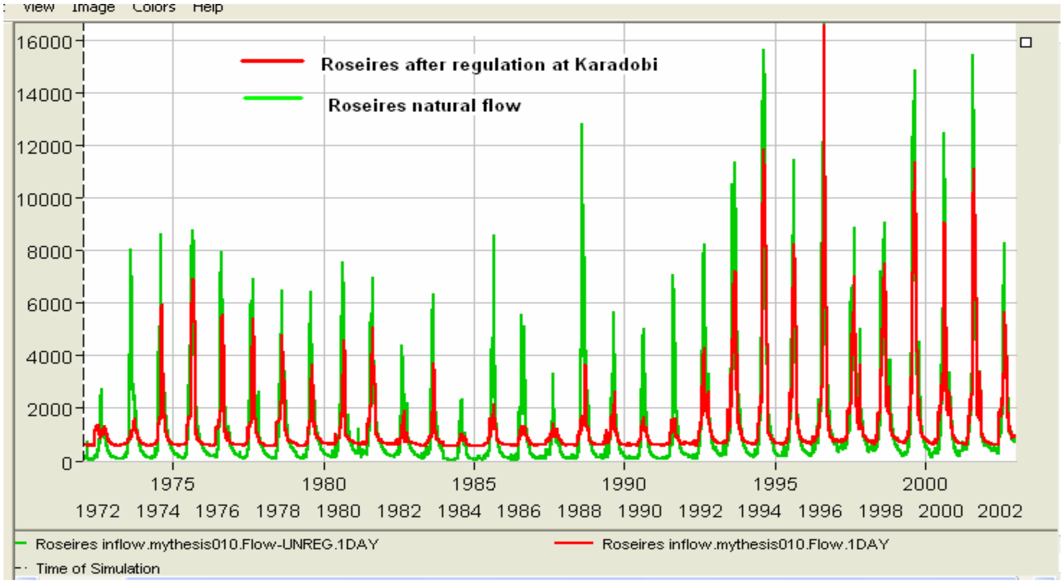
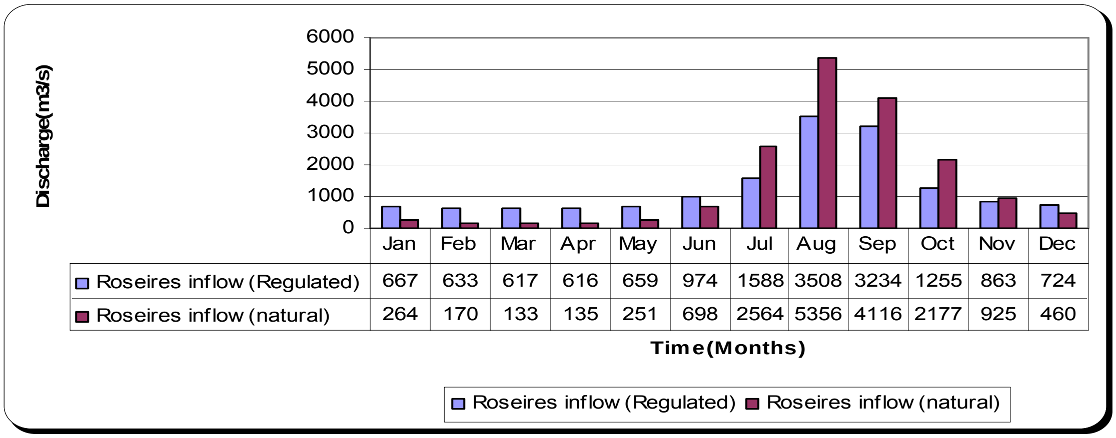
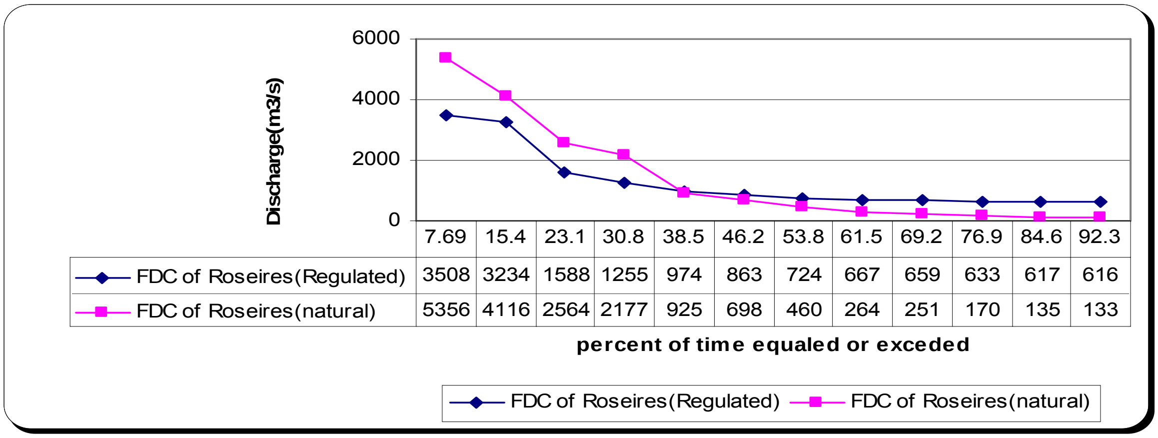


Figure 26 Model output for Roseires natural and regulated inflow



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Roseires inflow (Regulated)	667	633	617	616	659	974	1588	3508	3234	1255	863	724
Roseires inflow (natural)	264	170	133	135	251	698	2564	5356	4116	2177	925	460

Figure 25 Summary of model out put for Roseires natural and regulated flows



	7.69	15.4	23.1	30.8	38.5	46.2	53.8	61.5	69.2	76.9	84.6	92.3
FDC of Roseires(Regulated)	3508	3234	1588	1255	974	863	724	667	659	633	617	616
FDC of Roseires(natural)	5356	4116	2564	2177	925	698	460	264	251	170	135	133

Figure28 Flow duration curve for Roseires inflow before and after regulation

5.3.3 Power Generated at Karadobi

The plant has installed capacity of 1600MW. The regulation of Abbay at Karadobi enables the generation of this power at a plant factor of 0.7.This plant factor has been set after a lot of trial and error to in prove the value. The power that could be obtained at 98% reliability is 814MW.The monthly mean power table is attached in Appendix-A (Table-A27). The monthly power duration curve, monthly power distribution and power summary report for the site are as shown in fig .31, 32 and table 18 respectively.

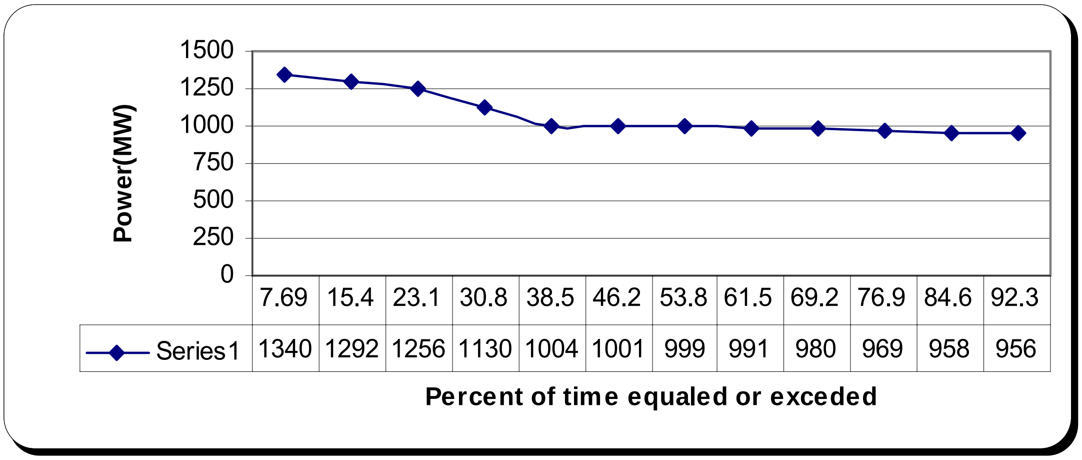


Figure 29 Monthly power duration curve for Karadobi

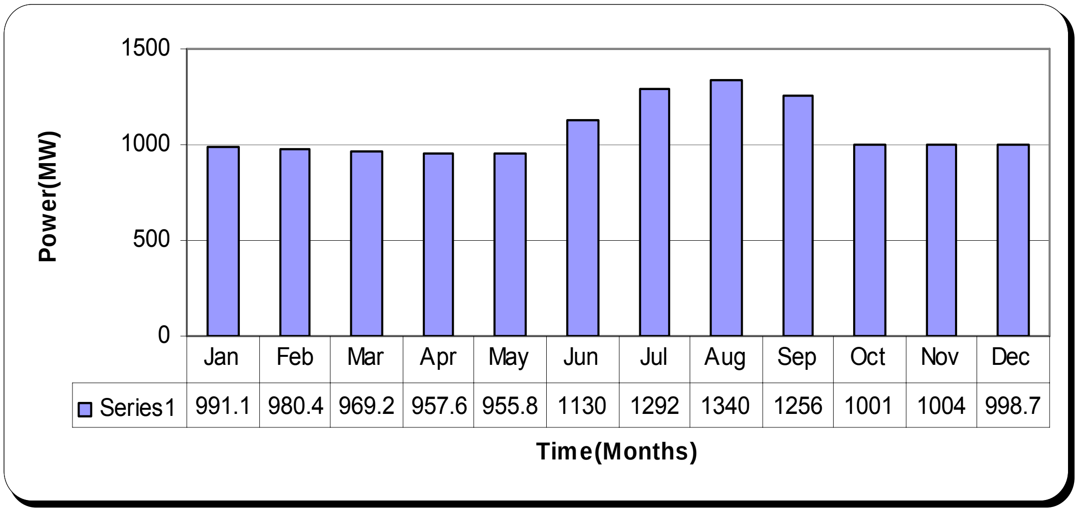
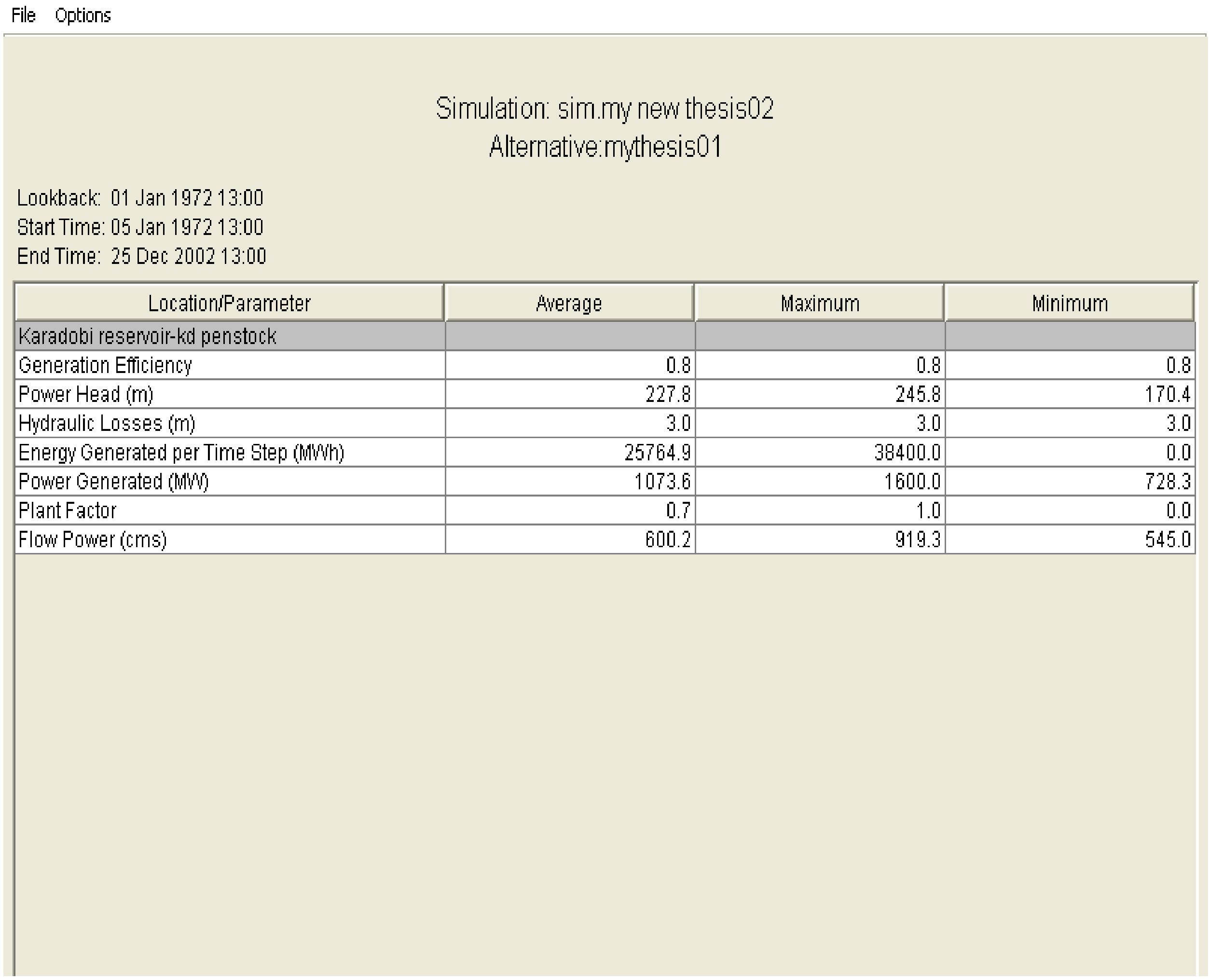


Figure 30 Mean monthly power at Karadobi

Table 18 Karadobi Power Summary Report



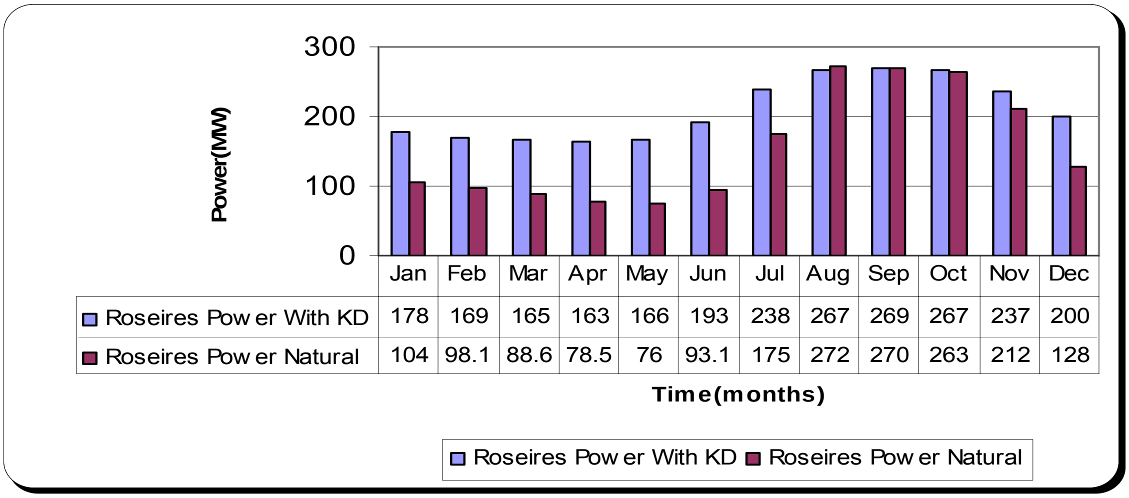
Simulation: sim.my new thesis02
Alternative:mythesis01

Lookback: 01 Jan 1972 13:00
Start Time: 05 Jan 1972 13:00
End Time: 25 Dec 2002 13:00

Location/Parameter	Average	Maximum	Minimum
Karadobi reservoir-kd penstock			
Generation Efficiency	0.8	0.8	0.8
Power Head (m)	227.8	245.8	170.4
Hydraulic Losses (m)	3.0	3.0	3.0
Energy Generated per Time Step (MWh)	25764.9	38400.0	0.0
Power Generated (MW)	1073.6	1600.0	728.3
Plant Factor	0.7	1.0	0.0
Flow Power (cms)	600.2	919.3	545.0

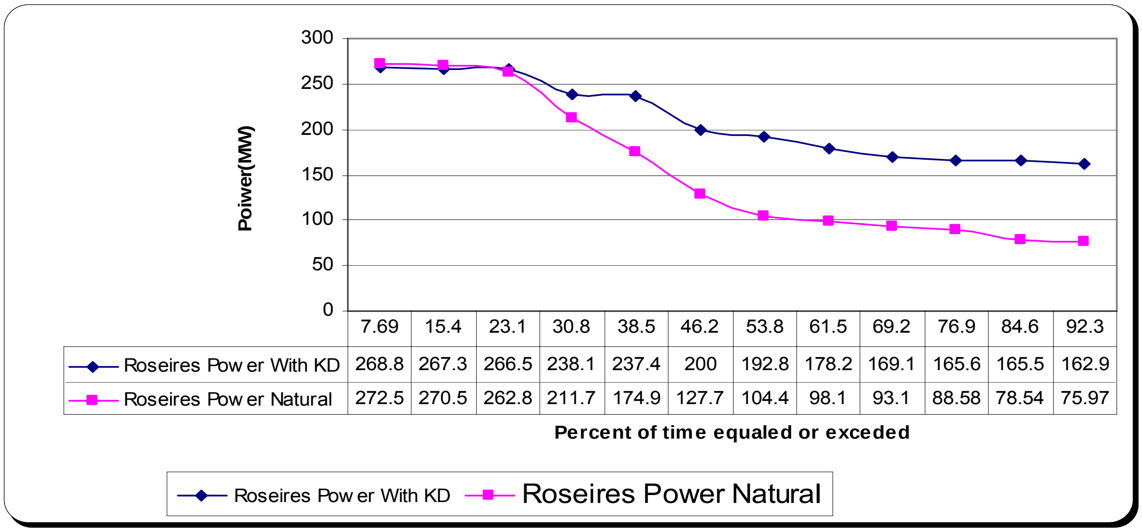
5.4.2 Power generation at Roseires

The same procedure as that of Karadobi was adopted for the regulated inflow to simulate power generation at Roseires reservoir keeping other physical characteristics constant. The result of the generated power for the mean monthly discharge of natural and regulated inflows (see fig.33, 34 and table19 below) to Roseires show that the regulation of Abbay at Karadobi will improve the power generation capability of Roseires by about 68.75% during the period from October to July. However, there is a reduction of about 2.0% during flood Seasons. The over All Result shows that Karadobi has a positive impact regarding power Generation at the down stream reservoir.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
▨ Roseires Pow er With KD	178	169	165	163	166	193	238	267	269	267	237	200
▨ Roseires Pow er Natural	104	98.1	88.6	78.5	76	93.1	175	272	270	263	212	128

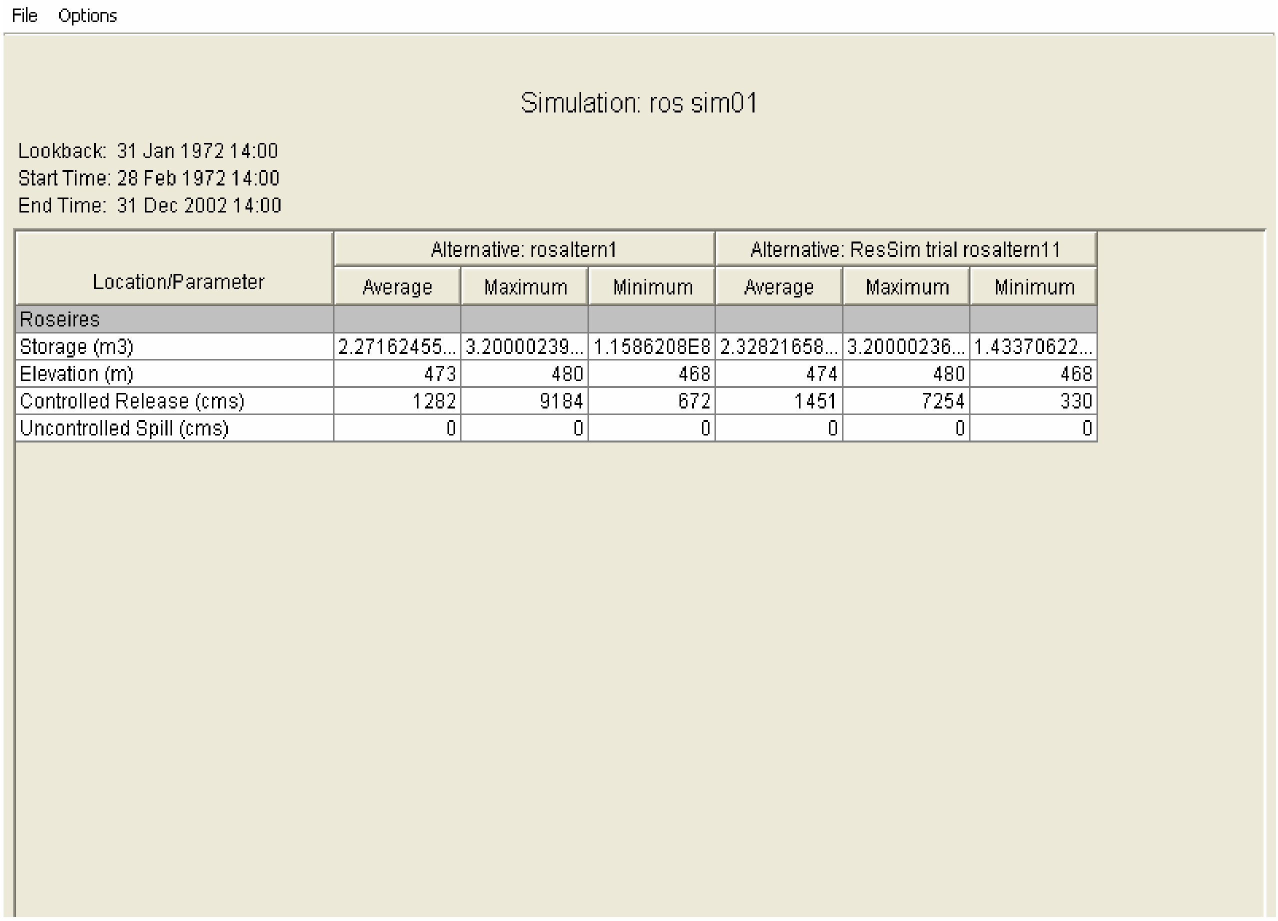
Figure 31 Power estimates for the regulated and natural inflow to Roseires reservoir



	7.69	15.4	23.1	30.8	38.5	46.2	53.8	61.5	69.2	76.9	84.6	92.3
◆ Roseires Pow er With KD	268.8	267.3	266.5	238.1	237.4	200	192.8	178.2	169.1	165.6	165.5	162.9
■ Roseires Pow er Natural	272.5	270.5	262.8	211.7	174.9	127.7	104.4	98.1	93.1	88.58	78.54	75.97

Figure 32 Power duration curve of Roseires

Table 19 : Roseires power report



Simulation: ros sim01

Lookback: 31 Jan 1972 14:00
Start Time: 28 Feb 1972 14:00
End Time: 31 Dec 2002 14:00

Location/Parameter	Alternative: rosaltern1			Alternative: ResSim trial rosaltern11		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Roseires						
Storage (m3)	2.27162455...	3.20000239...	1.1586208E8	2.32821658...	3.20000236...	1.43370622...
Elevation (m)	473	480	468	474	480	468
Controlled Release (cms)	1282	9184	672	1451	7254	330
Uncontrolled Spill (cms)	0	0	0	0	0	0

5.5 Karadobi Reservoir Sedimentation

Giving 15% allowance for bed load, the result of computation shows (section 3.7.1, table 13) that the total daily and total annual sediment inflows to Kessie station are 0.228Mm^3 and 84Mm^3 respectively. To transfer this value to the dam site the area ratio of the two sites (1.25) was used as a multiplying factor. As a result the annual sediment inflow rate to Karadobi dam site has been estimated to be 105Mm^3 Using the computed average trap efficiency of 94% (section 3.7.2, table 14) the annual sediment deposition in Karadobi reservoir will be 97.8 Mm^3. Thus the annual out flow rate from Karadobi reservoir is 6.2Mm^3.

There for Karadobi has great advantage for Roseires reservoir, which has already, lost 26% of its live storage and 37% of its total storage through sedimentation. The existing sediment inflow rate to Roseires reservoir is 50Mm^3/year.

CHAPTER SIX

SUMMARY, CONCLUSION AND RECOMMENDATIONS

6.1 Summary and Conclusion

The optimum guide curve was developed for Karadobi reservoir which maximizes the power generated from the system by minimizing spill. The guide curve was developed making use of HEC-ResSim model after a lot of trial and error procedures by changing some levels of the initial guide curve developed using spread sheet application.

The operation of Karadobi reservoir at the optimum guide curve will improve the inflow to the existing down stream reservoir (Roseires).

I. Because of regulating Abbay at Karadobi with the specified FSL and MOL the gain in discharge at Roseires will improve the power generated at Roseires by about 68.75% during dry season on monthly basis with only 2.0% reduction during flood seasons.

II. After regulation of Abbay at Karadobi the mean inflow during dry period (December to June) to Roseires reservoir will increase by about 397m^3/s. As a result it offers chance to operate Roseires reservoir at lower level with out losing the power and irrigation demand for which the system is designed. Moreover, the operation of Roseires at the lower level will enable to save a lot of water that has been lost through evaporation from the reservoir as it is located at an area of high temperature than Karadobi.

III. In addition to all the above advantage the operation and regulation of Abbay at Karadobi has a positive consequence on the sediment deposition of the down stream reservoirs. As stated in section 3.7.1 the existing sediment inflow rate to Roseires reservoir is about 50Mm^3/year but after the implementation of the Karadobi this rate will reduce since, the sediment outflow from Karadobi reservoir in order of 6.2Mm^3/year out of the total inflow of 104.1Mm^3/year.

IV. The increase in daily discharge(increase in water level flowing in the channel) to the down stream area has also a positive impact on pumped irrigation practice in

Sudan, since they will have chance to operate their pumps at a lower head than before.

V. Generally, it is possible to improve over all benefits of down stream reservoirs with out additional expansion or investing on the existing projects.

6.2 Recommendations

Based on this study the following recommendations can be drawn for the efficient utilization of the water resource and optimal operation of the reservoirs

- The reduction in inflow to Roseires reservoir during flood season may reduce the flooded area in the wet season; this may have a negative impact on the recession irrigation practice in the down stream areas, thus a detail investigation on change in the extent of flooded area need to be conducted by means of flood mapping studies.
- As there is no sediment data at the dam site the value generated for the nearest up stream station, (Kessie) was transferred to the dam site using the area ratio of the two sites. Therefore, it is essential to start sediment measurement before final design and construction.
- In this study, the dam height set by the pre-feasibility report has been increased by 20m to get the advantage of more power generation, though detail economical analysis is required to see its economical feasibility. As an alternative it is also possible to get some head by increasing the power tunnel length further down stream.
- To minimize the sediment accumulation rate in both reservoirs an integrated water shed management practice has to be done both up stream and down stream of Karadobi dam site.
- From the sediment distribution analysis(section 5.7 table 18) the reservoir will be filled to the current bottom out let level with in the early life of the reservoir there for the bottom outlet level need to be revised to a level not less than 1020m a.m.s.l.
- In order to keep the reservoirs pool level at the guide curve level it is recommended to release more water (generating more power) during high

flow season and to minimize release during low flow. In addition, for the situation of low flow the energy shortage that can be encountered should be compensated from other source in the net work.

- The guide curve is obtained from the simulation model (HEC-ResSim) by trial and error procedure rather than an optimization model. Therefore, the overall optimal curve might not be achieved. Thus, it is recommended that the guide curve need to be improved with experience gained in the long run during the real time operation of the reservoir or an optimization model need to be applied to revise this Guide curves.
- Appropriate inflow forecasting methods (models) need to be generated for accurate decision making in operating the reservoir and deciding the release from the reservoir.

6.3 Limitations

The main limitation encountered during this study was the problem of getting the design dimensions of the Roseires Dam Appurtenant structures and the physical characteristics of the reservoir. More over it was not possible to get an optimization model for the reservoir operation analysis and over all optimum guide curves.

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APPENDIX A: DATA AND RESULT TABLES

Table A-1 Roseires reservoir inflow After Regulation (m^3/sec)

	months												
Year	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**mean**
1972	646.8	598.6	574.7	579.3	574.5	1065.1	1309.8	972.5	1134.9	1073.8	800.1	660.2	**832.5**
1973	593.7	580.4	572.9	590.2	601.7	651.4	793	942.8	1248.5	1142.1	856.2	677	**770.8**
1974	618.8	587.8	573.6	582.4	602.6	685.8	1216.6	3821.8	3028.6	1077.3	792.7	671.4	**1188.3**
1975	615.1	604.6	594.7	588.7	592.6	674.1	1510.6	3608.8	6321.1	1681.9	777.2	674.7	**1520.4**
1976	626.9	610.1	604.6	569	577.7	1164.8	1429.8	3390.3	3660.8	896.3	822.6	663.5	**1251.4**
1977	624.9	605.7	600	589.6	587.8	654.7	1193.1	2359	4222	1130.1	804.9	668.3	**1170**
1978	607.5	573.1	562.9	560.8	576	1054.2	1523.1	2849.5	2914.1	1029.1	741.9	707.5	**1141.6**
1979	681.7	605.3	568.5	560.3	579.4	641.7	1306.8	2761.2	1974.2	921.2	839.6	715.7	**1013**
1980	664	640.9	622.7	633.7	631.9	805	948.6	1497.1	3761.6	1001.1	794.8	736.1	**1061.5**
1981	675.7	645.7	628.2	611.9	651.2	1015.1	1588.9	3569.8	3090	1004.8	783.3	726.8	**1249.3**
1982	663.2	636	629.3	603.3	633.6	760.2	727.6	1054.3	1242.3	822.5	719.6	667.8	**763.3**
1983	646.5	624.3	595.4	572	583.7	659.6	859.6	1406.1	2381.8	833.5	710.9	687.3	**880**
1984	581.3	564.6	555.3	552	559	594.9	759.1	840.3	794.2	645.7	583.2	571.8	**633.4**
1985	554.2	578.8	574.1	575.3	608.5	710.4	1044.5	1418.5	1369.4	858.7	682.4	631.5	**800.5**
1986	610.5	609.5	586.9	576.9	582.2	618.6	1013.3	1128.7	1082.6	838.8	690	618.1	**746.3**
1987	581.9	597.1	592.6	587.2	617.4	792	851.4	1120.3	970.3	977.1	777.9	658.3	**760.3**
1988	616.8	600.1	595.9	587.4	588.4	796.8	1197.7	1438.3	2874.1	1208.9	755.3	657.1	**993.1**
1989	613.1	591.9	596.3	597	880.1	738.9	1052.5	1541.4	1795.2	881.8	652.7	620.9	**880.1**
1990	593.5	608.1	610.8	599.3	602.7	610.6	940.2	1321.6	1181.3	879.4	656.1	616.7	**768.4**
1991	600.9	591	583	587	597.7	638.8	1067.7	1212.3	1194	843.9	673	623.4	**767.7**
1992	685.6	658.8	629.8	670.9	621.6	759.6	1371.2	2659.2	2224.4	1878.5	1077	829.8	**1172.2**
1993	727.3	668	649.4	664.6	707.7	1245.3	2223.1	4598.8	5443.1	1924.3	1101.8	805	**1729.9**
1994	713.8	661.5	641.6	634.7	668.2	1198.1	2166.2	9019.3	7967.3	1579.3	870.9	751.6	**2239.4**
1995	671.1	652.8	639.2	633.3	663.6	1215.7	2404.1	5445.5	4961	1171.4	834.1	734.1	**1668.8**
1996	721.4	680.6	639.2	758.3	923.9	1213.9	2356.7	9139.4	6589.8	1404.7	887.5	768	**2173.6**
1997	786.5	737.4	753.9	753.5	923.6	1881.2	2990.1	5415	3051.3	1802.1	1469.2	989.7	**1796.1**
1998	832.2	740.4	697.1	663.7	787.5	1673.4	3265.9	6218	3842	2072.8	1138	895.7	**1902.2**
1999	834.5	746.6	697.7	679	837.8	1294.7	2773.2	8813.6	6770.4	2046.9	1084.8	876.8	**2288**
2000	782.7	698.6	655.6	697.1	766.2	1580.4	2416.6	5549.2	4179.9	2217.9	1256.3	864.3	**1805.4**
2001	782.7	678.1	660.5	632.7	709.8	1530.3	2820.2	9391.8	5249.5	1787.4	1210.5	791.1	**2187.1**
2002	707.4	660.2	626.8	609.7	595.8	1273.6	2092.5	4236.3	3723.3	1270.6	921.4	889	**1467.2**
mean	**666.5**	**633.4**	**616.5**	**616.2**	**659.2**	**974.2**	**1587.5**	**3507.8**	**3233.6**	**1255**	**863.4**	**724.2**	**1278.1**

Table A-2 Roseires reservoir inflow before regulation at Karadobi (m^3/s)

	Month												
year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1972	276.1	167.4	104.4	111.9	181.9	479.6	1849	3594	2643	1190	638.5	335.2	**970.2**
1973	192.6	111	65.6	65.3	259.9	670.9	2002	6488	4614	2405	951.4	463.7	**1534.2**
1974	289.5	178.6	140.3	92.1	291.3	804.4	3261	6231	4629	2146	852.6	485.4	**1627.8**
1975	242.5	194.6	118.2	79.1	115	537	2771	6411	6848	2672	1034	548.5	**1806.1**
1976	339.5	208.2	160.5	107.8	228.5	566.7	2067	5650	3575	1455	958.3	467.8	**1323.8**
1977	261.7	177.9	126.6	97	174.2	670.1	3698	5842	4553	2369	1456	555.6	**1676**
1978	293.6	182	132.1	103.5	187.3	597.2	2766	4676	4159	2872	938.3	489.1	**1459.2**
1979	308.4	205.6	119.8	94	284	641.2	207.4	4557	3235	1617	706.8	371.2	**1192**
1980	215.9	144.7	100.1	123.8	169.4	500	2841	5591	3468	1728	688.7	371.9	**1338.9**
1981	210.1	127.6	99.2	96.3	181.3	410.9	2304	5153	4465	1953	708.7	361.4	**1347.4**
1982	228.4	139.3	119.6	83.3	119.3	397	1626	4076	2953	1962	695.6	349.2	**1069.7**
1983	186.5	126.2	89.4	95.1	157.6	419.8	1483	5448	3904	2122	805.9	377.1	**1276.1**
1984	206.4	125.7	71.1	47.7	108.9	703.7	2331	3228	2781	915.5	368.6	210.5	**930.3**
1985	118.5	79.9	55.7	87.8	272.6	538.6	2251	5708	4931	1694	663.2	362	**1405**
1986	200.2	127.8	108.3	113.5	538.4	546.3	2474	3774	3329	1402	530.5	273.5	**1125.5**
1987	154.7	102	130.9	118	300.4	944.4	1749	3755	2601	1560	738	347.1	**1048.1**
1988	189.6	148.7	146.5	84.4	101.4	808.6	4655	7360	5706	3741	1217	556.7	**2075.1**
1989	286.3	173.9	136.8	161.6	162.6	443.3	2345	4502	4110	1789	642.4	412.2	**1271.1**
1990	312.9	183.8	130.4	104.3	107.2	307	1742	4727	3740	1885	634.3	321.5	**1190.3**
1991	189.2	116.4	97	127.2	235.4	596.1	3128	5412	4268	1750	796.6	445.8	**1439.6**
1992	252.3	180.2	119.7	96.4	235.3	550.9	1567	4400	3938	2916	1249	612.3	**1350.6**
1993	341.7	208.4	133.4	267.7	417.8	1130	3135	5645	4885	2883	1280	584.3	**1752.5**
1994	332.3	197.2	130.6	105.8	269.6	741.1	3079	6624	5121	1657	835.3	412.6	**1635.4**
1995	190.8	122.6	99.8	133.8	199.9	544.8	1926	4840	3369	1417	621.5	331.2	**1157.2**
1996	208.3	129.1	130.2	183.2	509.3	1552	3877	6299	4347	2159	879.2	501.8	**1743.5**
1997	316.7	171.7	223.5	205.8	327.4	1047	3080	4500	2703	1828	1568	647.4	**1394.1**
1998	342.1	239.8	191.1	241.6	308	643.9	3161	7011	6011	4261	1525	729.2	**2068.5**
1999	431.2	288	169.2	118.3	320.6	862.7	3198	6285	4667	4341	1525	716.1	**1923.7**
2000	405.8	336.4	104.1	227.5	310.1	894.3	2897	6756	4178	3426	1523	687.4	**1824.4**
2001	334	187.6	280	307.8	350.4	1044	3576	6883	4727	2011	989.6	530.2	**1780.3**
2002	336	191.3	282.6	297.8	348	1045	2435	4600	3141	1372	663.6	404.3	**1267.5**
mean	**264.316129**	**170.116129**	**132.7967742**	**134.819355**	**250.74194**	**698.02**	**2563.92**	**5355.6774**	**4116.1**	**2177.37**	**925.3097**	**460.071**	**1451.7**

Table A-3 Karadobi Inflow (m^3/sec)

	Month												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1972	54.2	66.8	17.6	25	12.4	26.7	440	897.9	306.6	106.9	63.9	34.2	**171**
1973	69.9	44.1	25.7	15.8	40.2	62.5	942	3326.3	1154.5	540.7	309.6	185.2	**559.7**
1974	124.5	72.2	58.3	43	85.8	104.8	1930.2	3210.1	1301.4	688.6	383.9	242.4	**687.1**
1975	155.9	124.1	78.7	51.7	34.5	157.9	1386.8	3951.4	3365.3	1010.6	550.6	355.1	**935.2**
1976	236.4	149.3	118.6	98.3	96.7	79.8	896.4	3411.5	1548.6	591.2	483.9	265.1	**664.6**
1977	167	122.2	99.3	49.8	34.8	60	1370.1	3077.6	1929.3	821.4	675.8	317.6	**727.1**
1978	200.8	136.3	86.8	59.1	46.9	64.4	1358.2	2577.3	1333.7	737.5	354.1	233.2	**599**
1979	164.1	107.4	62.8	38.7	61.2	121	1724	2195.3	933.1	442.4	276.5	176.6	**525.3**
1980	112.3	76.5	57.3	59.6	27.6	57.9	748.5	2651.1	2210.8	761.1	412.6	247.1	**618.5**
1981	151.2	201.6	277.1	118.9	128.4	139.4	1865.7	2550.8	1448	535.1	337.3	219.6	**664.4**
1982	158.1	101.4	84.7	73.4	68.4	53.9	341.8	2049.5	953.7	687	287.9	176.5	**419.7**
1983	108.4	74.7	66.3	83	127.1	113.1	359.4	2530.5	1112.4	552.4	286.3	162.4	**464.7**
1984	28.1	12.8	4.7	2.1	13	73.4	494.9	661.7	342.9	77.6	36	21.9	**147.4**
1985	11.5	5.6	3.1	31.6	78.5	45.3	502.8	2155.6	1469.7	358.6	163.9	88.3	**409.5**
1986	47.5	30	24.2	38.7	58.4	154.9	1179.8	2107.9	1115.3	371.6	162	79.7	**447.5**
1987	39.8	21.9	43.5	37.2	54.3	74.7	133.1	1067.8	370.5	198.6	131.3	54	**185.5**
1988	25.2	18.1	7.6	5.8	1.6	8.5	1750.5	4766.5	2099.4	844.2	348	176.2	**837.6**
1989	104.3	55.6	49.8	65.4	22.5	27.9	572.6	1766.4	963.6	376.4	186.1	132.4	**360.2**
1990	56.2	35.7	23.3	22.7	9.3	7	493.8	1634.5	906.2	339.1	135.1	67.3	**310.8**
1991	34.8	21	29.4	28.9	28.8	29.2	37.3	2150.9	1480.8	526.4	243.9	129	**395**
1992	64.9	42.1	27.2	17.1	18.8	12.4	376.9	2600.9	1252.5	678.3	348.4	169.5	**467.4**
1993	164.4	102.2	66	235.2	205.6	205.6	1881.4	2285.7	2393.9	1001.2	503.8	272.5	**776.5**
1994	155.3	91.7	69.5	40.9	89.5	163.4	2717.7	5967.9	2870	907	508.8	194.3	**1148**
1995	80.3	57.7	66.4	119.8	96.4	105.9	1528.1	3662.5	1561.1	379.8	240.8	144.4	**670.3**
1996	93	63.9	109.9	144.5	242.9	543.5	2939.4	5376.3	1978.1	845.8	477.8	323.3	**1095**
1997	234.3	157.2	241.2	212	250.7	443.7	1987.6	2661.7	729.1	818.8	645	308.7	**724.2**
1998	234.3	157.2	241.2	212	250.7	443.7	1987.6	2661.7	729.1	818.8	645	308.7	**724.2**
1999	169.7	133.9	72.5	61	24.2	76.1	3122.9	5386.5	1844.7	1277	541.7	283.1	**1083**
2000	173.4	119.1	33.6	117.7	53.8	52.6	1695.9	4978.8	1614.3	1082.5	620	268.8	**900.9**
2001	92.5	109	383.5	392.9	331.1	510.4	4601.7	6226.4	1900	773	481.6	373.1	**1348**
2002	433.2	386.7	350.8	362.6	286.3	397.3	1536.5	3975	1766.7	543.4	526.6	436.2	**916.8**
mean	**127.3**	**93.5**	**92.9**	**92.4**	**92.9**	**142.5**	**1384**	**3049.2**	**1451.1**	**635.3**	**366.7**	**208**	**644.6**

Table A-4 Karadobi Outflow (m^3/sec)

	Month												
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	Annual
year													
1972	556.8	545	545	545	545	1077	1006.7	545	545	545	545	545	**628.8**
1973	545	545	545	545	545	545	545	590.8	545	545	545	545	**548.8**
1974	545	545	545	545	545	545	545	590.8	545	545	545	545	**548.8**
1975	545	545	545	545	545	545	998.1	3637.9	1699.5	545	545	545	**936.7**
1976	545	545	545	545	595.7	1133.3	1110.2	3220.3	2298.1	545	545	545	**1014**
1977	545	545	545	545	545	629.6	1041.9	2682.2	3004.8	545	545	545	**976.5**
1978	545	545	545	545	545	948.4	1114.6	2716.9	1807.3	545	545	545	**912.3**
1979	545	545	545	545	545	948.4	1114.6	2716.9	1807.3	545	545	545	**912.3**
1980	545	545	545	545	545	618.2	1105.5	2527.4	1094	545	545	545	**808.8**
1981	545	545	545	545	545	545	545	910.9	913.7	545	545	545	**606.2**
1982	545	545	545	545	545	949.3	1221.1	3371	2002.2	546.1	545	545	**992.1**
1983	545	545	545	545	545	545	545	910.9	913.7	545	545	545	**606.2**
1984	545	545	545	545	545	545	545	545	545	545	545	545	**545**
1985	545	545	545	545	545	545	545	545	545	545	545	545	**545**
1986	545	545	545	545	545	545	545	545	545	545	545	545	**545**
1987	545	545	545	545	545	545	545	545	545	545	545	545	**545**
1988	545	545	545	545	545	545	545	545	2139.4	545	545	545	**677.9**
1989	545	545	545	545	545	545	729	736.7	971.5	545	545	545	**611.9**
1990	545	545	545	545	545	545	729	736.7	971.5	545	545	545	**611.9**
1991	545	545	545	545	545	545	545	545	545	545	545	545	**545**
1992	545	545	545	545	545	545	545	545	545	545	545	545	**545**
1993	545	545	545	545	545	588	1022.5	2722.6	3338	590.7	545	545	**1006**
1994	545	545	545	545	545	882	1572.7	7901.8	5256.1	563.5	545	545	**1666**
1995	545	545	545	545	545	769.6	1102.1	3991.4	2619.9	545	545	545	**1070**
1996	545	545	545	545	545	617.9	1635.4	7284.8	3481.9	545	545	545	**1448**
1997	545	545	545	545	545	757.5	1288.2	1884.2	3704.3	1161.3	545	545	**1051**
1998	545	545	545	545	656.2	1131.9	1883.9	3704.2	1181.9	545	545	545	**1031**
1999	545	545	545	545	545	769.9	2019.1	7062.2	3733.2	563.5	545	545	**1497**
2000	545	545	545	545	545	567.1	1269.4	1112.9	5256.1	1816.8	545	545	**1153**
2001	545	545	545	545	545	913.2	2176.8	6636	2311.5	1816.8	545	545	**1472**
2002	545	545	545	545	545	977.4	1115.3	2835.9	1701.5	1816.8	545	545	**1022**
mean	**545.4**	**545**	**545**	**545**	**550.2**	**706.7**	**1008.1**	**2414.4**	**1842.3**	**690.7**	**545**	**545**	**873.6**

Table A-5 Table C-5Roseires power generation(MW) for Natural flow

	Months												
Year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1972	88	75.1	71.7	71.7	108.7	267.2	275	249.7	138.9	108.3	247	122.9	**152**
1973	104.7	96.4	83.2	72.1	71.7	71.7	126.3	274.4	275	275	239.6	122.9	**151.1**
1974	105.3	101.2	92.1	79.7	71.8	72.2	215.2	275	275	275	225.2	117.2	**158.7**
1975	105.3	100.1	91	77.9	71.7	71.7	154.8	275	275	275	249.5	132.2	**156.6**
1976	105.3	101.9	94.4	83.3	72.7	71.7	148.5	274	275	270	190.2	123.7	**150.9**
1977	105.3	100.5	91	78.2	71.7	71.7	195.5	275	275	275	267.6	164.2	**164.2**
1978	105.3	101.3	92.2	79.7	71.8	71.7	173.8	275	275	275	247	122.9	**157.6**
1979	105.3	101.7	93.6	80.7	71.8	71.7	155.7	274	275	273.1	181.8	109	**149.5**
1980	105.1	98	86.5	73.9	71.7	71.7	152.8	275	275	274.7	189.1	108.7	**148.5**
1981	105.1	97.6	85.6	73.3	71.7	71.7	119.3	275	275	275	205.5	109	**147**
1982	105.1	98.4	87.2	74.6	71.7	71.7	77.5	263.7	275	275	204.9	108.7	**142.8**
1983	105	97.5	84.7	72.6	71.7	71.7	134.2	275	275	240.1	116.6	108	**137.7**
1984	100.2	87.6	74.2	71.7	71.7	71.7	110.4	275	275	274.5	184.3	108.4	**142.1**
1985	100.2	87.6	74.2	71.7	71.7	71.7	110.4	275	275	274.5	184.3	108.4	**142.1**
1986	104.9	97.3	85.2	73.3	71.7	71.8	152.6	265.6	275	270.4	180	109.8	**146.5**
1987	104.5	94.7	81.5	72.1	71.7	71.7	149.1	265.6	275	270.4	180	109.8	**145.5**
1988	104.8	96.7	85.5	74.2	71.7	71.7	200.8	275	275	275	265.3	146.3	**161.8**
1989	105.3	101	91.7	79.9	72	71.7	144	275	275	275	190	108.4	**149.1**
1990	105.3	101	91.7	79.9	72	71.7	144	275	275	275	190	108.4	**149.1**
1991	105.3	101.6	92.7	80.2	71.8	71.7	86.6	268.8	275	275	195.9	108.4	**144.4**
1992	105.3	100	90.3	77.3	71.7	71.7	107.4	263.2	275	275	262.6	152.4	**154.3**
1993	105.3	102	94.3	83.8	79.7	101.8	240.1	275	275	275	263.6	152.7	**170.7**
1994	105.2	98.2	86.1	74.1	73.8	214.4	275	275	271.4	183.9	113.1	108.4	**156.6**
1995	105.1	97.2	84.8	73	71.7	71.7	115.3	272.3	275	268.4	160.2	108.4	**141.9**
1996	104.8	97.1	85.1	73.8	71.7	112.9	264.2	275	275	275	227.6	119.5	**165.1**
1997	105.3	101.5	93.3	85.4	78.6	92.1	235.1	275	275	275	266.3	179.2	**171.8**
1998	105.3	102.2	96.3	88.1	82.2	82.7	216.6	275	275	275	273.2	182.5	**171.2**
1999	107.1	102.3	97.7	87.8	77	81.5	228.5	275	275	275	273.2	181.4	**171.8**
2000	106.5	102.2	97.7	86.8	79.6	86.2	222.8	275	275	275	272.6	179.1	**171.5**
2001	105.3	99.5	95.3	93.1	108.2	243.7	275	275	275	221.8	156.9	128.1	**173.1**
2002	105.3	101.8	95.1	90.7	87.8	97.2	215.3	275	275	266.1	159.6	108.4	**156.4**
Mean	**104.38065**	**98.1032258**	**88.577419**	**78.535484**	**75.96**	**93.1**	**174.9**	**272.4613**	**270.49**	**262.78**	**211.7**	**127.658**	**154.9**

Table A-6 Roseires Power For Regulated flow (MW)

	month												
year	**jan**	**feb**	**mar**	**apr**	**may**	**jun**	**jul**	**aug**	**sep**	**oct**	**nov**	**dec**	**Annual**
1972	172.9	155	160.5	157.8	157.7	225.2	275	274.4	274.2	275	252.9	199	215
1973	171.1	160.4	157.6	159.1	163	171.5	198	238	273.5	275	263.6	208.8	203.3
1974	176.9	164.8	158.9	158.1	162.1	176.6	250.1	275	275	275	262.9	199.6	211.2
1975	175.6	166.5	164	161.8	161.6	173.6	258.5	275	275	275	275	243.6	217.1
1976	177.8	169	166.1	160.5	157	234.3	275	275	275	275	259.3	202.4	218.9
1977	175.9	168.1	164.8	162.6	161	170.2	245.3	275	241.1	266.9	266.8	200.8	208.2
1978	173.9	161.2	155.3	153.7	155.5	224.1	275	275	275	275	258.2	197.9	215
1979	189.8	175.3	160.3	154.3	155.8	167.2	249.4	275	275	275	254.9	212.2	212
1980	188.4	178.3	172.7	171.9	173.1	197.2	226.3	270.5	275	275	262.9	209	216.7
1981	192.8	180.4	174.1	169.4	172.8	229.3	275	275	275	275	260.6	206.2	223.8
1982	189.7	177.4	172.9	168.3	169.2	191.1	203.2	243.8	275	275	210.3	189.5	205.5
1983	179.7	173.7	166.5	159.4	158.1	170.4	208.7	270.3	275	275	234.3	232.7	208.7
1984	172.9	156.6	156.3	151.3	151.9	157.9	185.8	219	223.2	196.2	167.7	157.9	174.7
1985	153.9	155	157.6	157.1	162	180.8	240.6	275	275	275	209.9	179.3	201.8
1986	169.8	166.5	163.6	159.1	158.4	164.4	223.1	275	275	259.7	208.4	178.8	200.1
1987	163.9	161	162.7	161.3	164.7	193.4	224.9	263.5	273.7	266.2	239	195.8	205.8
1988	174.1	166.3	163.5	161.7	160.6	190.3	261.1	275	275	275	268.4	192.6	213.6
1989	173.4	164.6	162.4	163.1	203.2	220.7	245.1	275	275	272.1	208.8	174	211.5
1990	166	164.4	166.7	165.4	164.3	166	213.5	273.7	275	267.2	208.8	173.9	200.4
1991	166.4	162.9	160.5	160.1	162.2	169.3	233.7	275	275	264.1	206.6	177	201.1
1992	179.2	183.7	176.1	178	176.6	189.6	262.5	275	275	275	275	261.8	225.6
1993	212.4	190.4	180	179.7	187.9	253.8	275	275	275	275	275	261.1	236.7
1994	207.3	187.9	178.2	174.5	178.3	247.1	275	275	231.7	264.1	206.6	177	216.9
1995	188.4	178.3	172.7	171.9	173.1	197.2	226.3	270.5	275	275	262.9	209	216.7
1996	192.8	180.4	174.1	169.4	172.8	229.3	275	275	275	275	260.6	206.2	223.8
1997	189.7	177.4	172.9	168.3	169.2	191.1	203.2	243.8	275	275	210.3	189.5	205.5
1998	179.7	173.7	166.5	159.4	158.1	170.4	208.7	270.3	275	275	234.3	232.7	208.7
1999	172.9	156.6	156.3	151.3	151.9	157.9	185.8	219	223.2	196.2	167.7	157.9	174.7
2000	153.9	155	157.6	157.1	162	180.8	240.6	275	275	275	209.9	179.3	201.8
2001	163.9	161	162.7	161.3	164.7	193.4	224.9	263.5	273.7	266.2	239	195.8	205.8
2002	169.8	166.5	163.6	159.1	158.4	164.4	223.1	275	275	259.7	208.4	178.8	200.1
Mean	**178.17**	**169.06**	**165.47**	**162.89667**	**165.6**	**192.8**	**238.14**	**266.51**	**268.81**	**267.3**	**237.35**	**200.043**	**209.3**

able A-7 Sediment concentration data On Abbay River

River / Stream	Station / Nr.	Date & Time of Sampling	Flow (m^3/s)	Sediment Conc. (mg/l)
Abay	Bahir Dar	1-Mar-90	31.000	300.0000
Abay	Bahir Dar	1-Mar-90	31.100	225.9000
Abay	Bahir Dar	1-Mar-90	31.100	202.7000
Abay	Kessie	3-Mar-90	59.000	330.3000
Abay	Kessie	3-Mar-90	59.000	299.4000
Abay	Kessie	3-Mar-90	59.000	275.0000
Abay	Kessie	8-May-90	23.000	702.8000
Abay	Kessie	8-May-90	23.000	
Abay	Kessie	8-May-90	23.000	745.3000
Abay	Bahir Dar	3-Aug-90	153.900	239.1000
Abay	Bahir Dar	3-Aug-90	153.900	219.1000
Abay	Bahir Dar	3-Aug-90	153.900	285.3000
Abay	Kessie	20-Oct-90	330.700	934.3000
Abay	Kessie	20-Oct-90	330.700	189792.0000
Abay	Kessie	20-Oct-90	330.700	521.8000
Abay	Kessie	26-Sep-92	290	953.0000
Abay	Kessie	26-Sep-92	290	1245.2
Abay	Kessie	26-Sep-92	290	1662.5
Abay	Bahir Dar	8-Sep-93	436.800	161.9000
Abay	Bahir Dar	8-Sep-93	436.800	174.2000
Abay	Bahir Dar	28-Apr-93	18.100	50.2000
Abay	Bahir Dar	28-Apr-93	18.100	50.6000
Abay	Bahir Dar	28-Apr-93	18.100	50.3000
Abay	Bahir Dar	30-Sep-94	645.300	157.4000
Abay	Bahir Dar	30-Sep-94	645.300	154.9000
Abay	Bahir Dar	30-Sep-94	645.300	186.1000
Abay	Kessie	18-Jul-95	712.700	27621.2000
Abay	Kessie	18-Jul-95	712.700	35053.8000
Abay	Kessie	18-Jul-95	712.700	31910.8000
Abay	Kessie	25-Aug-95	1926.400	4884.9000
Abay	Kessie	25-Aug-95	1926.400	4889.0000
Abay	Kessie	25-Aug-95	1926.400	4924.4000
Abay	Kessie	21-Sep-95	627.300	5605.6000
Abay	Kessie	21-Sep-95	627.300	3383.9000
Abay	Kessie	21-Sep-95	627.300	36509.0000
Abay	Bure	28-Jul-04		22212.1000
Abay	Bure	28-Jul-04		23423.3000
Abay	Bure	28-Jul-04		21321.7000
Abay	Kesse	1-Aug-04	1392.200	10795.0000
Abay	Kesse	1-Aug-04	1392.200	10990.6000
Abay	Kesse	1-Aug-04	1392.200	11075.5000

Table 7A Continued

Abay	Bure	9-Aug-04		10750.2500
Abay	Bure	9-Aug-04		10673.5900
Abay	Bure	9-Aug-04		10339.7100
Abay	Kesse	13-Aug-04	1637.000	16396.6700
Abay	Kesse	13-Aug-04	1637.000	17940.5400
Abay	Kesse	13-Aug-04	1637.000	19451.7500
Abay	Kesse	28-Aug-04	980.200	5314.8600
Abay	Kesse	28-Aug-04	980.200	4887.0000
Abay	Kesse	28-Aug-04	980.200	4785.0000
Abay	Bure	29-Aug-04		5287.5600
Abay	Bure	29-Aug-04		4484.8800
Abay	Bure	29-Aug-04		4504.1500
Abay	Kesse	18-Sep-04	398225.000	2471.7100
Abay	Kesse	18-Sep-04	398225.000	2056.5800
Abay	Kesse	18-Sep-04	398225.000	1539.1400
Abay	Bure	19-Sep-04		4965.5800
Abay	Bure	19-Sep-04		4634.3900
Abay	Bure	19-Sep-04		4587.3200
Abay	Bure	2-Oct-04		1282.1400
Abay	Bure	2-Oct-04		1434.5200
Abay	Bure	2-Oct-04		1336.4700
Abay	Kesse	1-Oct-04	243386.000	2610.4800
Abay	Kesse	1-Oct-04	243386.000	2484.1900
Abay	Kesse	1-Oct-04	243386.000	2453.6400
Abay	Bahir Dar	15-Sep-04	116.400	209.7200
Abay	Bahir Dar	15-Sep-04	116.400	209.3800
Abay	Bahir Dar	15-Sep-04	116.400	240.4000
Abay	Bahir Dar	22-Sep-04	146.400	160.3100
Abay	Bahir Dar	22-Sep-04	146.400	138.4400
Abay	Bahir Dar	22-Sep-04	146.400	178.5700
Abay	Kesse	7-Oct-04	335.000	3511.6700
Abay	Kesse	7-Oct-04	335.000	3562.4400
Abay	Kesse	7-Oct-04	335.000	3099.7200
Abay	Bure	8-Oct-04		5039.7500
Abay	Bure	8-Oct-04		5462.5600
Abay	Bure	8-Oct-04		5017.8100
Abay	Kesse	22-Oct-04	165.500	349.6500
Abay	Kesse	22-Oct-04	165.500	372.9400
Abay	Kesse	22-Oct-04	165.500	393.8700
Abay	Bure	23-Oct-04		267.1600
Abay	Bure	23-Oct-04		312.3100
Abay	Bure	23-Oct-04		338.4100

Table A-8 Monthly Summary of rainfall data at Bahir Dar station

					Year						
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**mean**
Jan	0	0	0	9	0	0	0	0	1.5	1.1	**1.16**
Feb	0.7	0	0	0	0	0	1.2	0	2.85	0	**0.475**
Mar	28	19.4	18.8	0	0.3	1	8.2	0.3	4.72	0	**8.072**
Apr	10	29.1	0.6	8.1	90.3	22.7	15.9	0	37.2	9.9	**22.38**
May	99.2	237.5	107.6	50.5	61.2	130.2	2	1.2	32.86	13.5	**73.576**
Jun	261.6	121.7	196.5	130.9	153.7	245.5	437.2	239.2	184.04	143.4	**211.37**
Jul	295.2	233.5	384.1	393.6	314.2	379.6	461.8	616.2	189.1	115.4	**338.27**
Aug	359.3	217.5	358	485.7	517.2	562.1	395	445.1	348.8	56.5	**374.52**
Sep	211.9	179.7	240.6	196.3	225.8	142.5	154.9	258.3	248.9	85.1	**194.4**
Oct	39.9	135.5	115	197.3	179.3	92.7	17.8	74.2	72.6	0	**92.43**
Nov	26.7	23.4	0	3	27.8	12.5	0.5	5.2	9.3	1.1	**10.95**
Dec	0	10.1	0	0	0	16.9	1	5.7	0	0	**3.37**
Total annual	**1332.5**	**1207.4**	**1421.2**	**1474.4**	**1569.8**	**1605.7**	**1495.5**	**1645.4**	**1131.9**	**426**	**1331**
mean annual **1330.977**											

Table A-9 monthly summary of Rainfall Data at Debre Markos

					Year						
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**mean**
Jan	27.6	14.3	2.9	72.6	0	0	57	3.6	4.1	1.2	**18.33**
Feb	4.6	0	2.2	0	0	3.7	0	57.4	7.6	0.6	**7.61**
Mar	74.1	29.6	21	2.8	2.9	58.1	92.2	69.6	4.1	23.7	**37.81**
Apr	108	97.5	4.4	43.2	110.5	101.2	75.2	19.2	43.5	29	**63.17**
May	228	118.7	152.4	46.8	29.5	129.6	11.2	5.3	0.9	8.6	**73.1**
Jun	291.7	151	194.7	180.7	174.9	154.7	155.9	212	100.3	89.7	**170.56**
Jul	252.3	286.8	203.2	252.1	334.1	365.2	276.3	205.5	88.8	88.5	**235.28**
Aug	360.5	338.8	252.6	340.3	211.1	322.3	335.5	351.6	123.3	73.7	**270.97**
Sep	152.1	205.8	270.7	164.3	271	170.3	234.6	256.8	22	51.6	**179.92**
Oct	33.1	183.5	200.8	210.5	265.9	66.9	3.9	10.7	0	0.1	**97.54**
Nov	35.2	85	6.9	2.5	32.7	0	2.2	0.3	26.2	0	**19.1**
Dec	23.2	6.7	0	28.3	12.3	2.2	61.5	18.8	5.5	0	**15.85**
Total annual	**1590.4**	**1517.7**	**1311.8**	**1344.1**	**1444.9**	**1374.2**	**1305.5**	**1210.8**	**426.3**	**366.7**	**1189.2**
Mean annual **1189.24**											

Table A-10 Monthly summary of Rainfall data at Ambo Agricultural College

					Year						
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**mean**
Jan	15.5	28.7	74.3	8.4	0	0	78.7	41.7	18.2	1	**27.9**
Feb	4.2	0	10.4	0.1	0	12.5	16.9	100	2.4	0	**15.8**
Mar	117.8	31	40.6	39.5	9.3	60.5	55.6	54.8	10.3	0	**33.5**
Apr	95.7	83.1	30.7	20.1	51.5	70.4	56.3	154.1	10.8	13.5	**54.5**
May	196.3	59.7	151	99.2	93.7	177.9	39.5	9.4	10	9.6	**72.2**
Jun	179.5	132	133	108.4	121.2	148.5	178	209	53.4	73.2	**128.5**
Jul	187.3	92.1	167	195.9	186.4	197.9	172.2	134.2	58.3	48	**139.1**
Aug	153.2	183.4	148	132.9	191.6	243.1	187.3	142.7	105.4	64.8	**155.5**
Sep	75.3	59.2	112.2	95.9	131.2	110.5	40.3	76	31.4	13.6	**74.5**
Oct	54.4	87.5	93.4	119.9	83.7	41.8	3	9.3	0	0	**48.7**
Nov	21.3	22.1	16.5	1.3	20.7	5.4	0	1	0	0	**7.4**
Dec	9.8	2.2	2.5	0	14.8	11	17.2	0	9.6	0	**6.4**
total annual	**1110.3**	**781**	**979.6**	**821.6**	**904.1**	**1079.5**	**845**	**932.2**	**309.8**	**223.7**	**764.1**
mean annual 764.05556											

Table A-11 Summary of Mean Monthly Rainfall data at Fincha

				Year							
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**mean**
Jan	20.8	10.2	6.6	18.6	0	0	33.7	2.8	7.5	4.5	**10.47**
Feb	0	0	12.7	0	0	7.3	0.5	53.1	13.2	0	**8.68**
Mar	5	31	42.6	5.4	0.7	71.8	57.2	81.9	20.4	169.8	**48.58**
Apr	82.2	128	21.6	36.9	93.1	109.5	130.9	20.1	68.3	91	**78.16**
May	312.9	175.9	225.8	179.2	175.1	177.2	76.4	1.8	112.4	66.1	**150.28**
Jun	330	285.4	402.3	396.1	374.3	196.6	261.2	466	265.3	196	**317.32**
Jul	398.4	384.8	383.6	402.2	290	417.5	360.8	336.1	382.7	330	**368.61**
Aug	355.2	319	360.3	552.6	409.2	314.7	328.5	307.3	353.3	408	**370.81**
Sep	303.9	138.2	279.3	353.1	374.1	113.3	167.3	233.5	186.7	290	**243.94**
Oct	101.8	225.1	307.9	242.1	190	167.8	8.2	14.2	140	187	**158.41**
Nov	56.8	24.6	14.1	20.9	43.1	2.8	10	15	22.5	53	**26.28**
Dec	12.1	4.2	0	30.5	48.6	2.3	37.9	38.3	0.5	24	**19.84**
Total annual	**1979.1**	**1726.4**	**2056.8**	**2237.6**	**1998.2**	**1580.8**	**1472.6**	**1570.1**	**1572.8**	**1819.4**	**1801.4**
Mean annual 1801.38											

Table A-12 Summary of Mean monthly Rainfall at Gudrer

				year							
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**mean**
Jan	15.8	28.4	3.9	46.5	0	31.4	37	46.2	44.9	43.6	**29.77**
Feb	14.4	0	3.1	3.9	0	36.7	23.2	52.6	10.4	0	**14.43**
Mar	304.3	45.8	0	10.3	26.9	121	48.4	70.5	53.1	126.6	**80.69**
Apr	212.9	253.9	9.9	14.1	80.9	71.4	55.5	254.3	198.5	154.8	**130.62**
May	319.3	148	6.3	196	153	205	97.8	18.5	18.2	76.2	**123.83**
Jun	273.3	398	77.9	335.4	242.3	199.2	275.7	219.3	228.3	347.6	**259.7**
Jul	358.3	243.7	101.7	271.3	268.2	259.5	252.9	184.8	305.8	358.3	**260.45**
Aug	413.2	361.2	10.9	158.2	307.3	264.9	70.7	249.2	332.2	188.1	**235.59**
Sep	91.4	56.2	16.3	109.7	215.4	146.9	73.2	200.1	256.6	58.9	**122.47**
Oct	0	123.2	2.5	176.4	61	0.7	0	2.4	25	10.1	**40.13**
Nov	26.3	140.8	0	0	92	7.1	0	21.6	0	13.1	**30.09**
Dec	5.9	***6.7***	0	0	15	2.9	25.5	21.5	4.9	0	**8.24**
Total annual	**2035.1**	**1805.9**	**232.5**	**1321.8**	**1462**	**1346.7**	**959.9**	**1341**	**1477.9**	**1377.3**	**1336**
mean annual 1336.01											

Table A-13 Summary of Mean Monthly Rainfall at Filikliki

				year							
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**mean**
Jan	12	41.5	0	23	0	0	40.7	0	0	0	**11.72**
Feb	2	0	0	0	0	21.4	0	13.6	0	0	**3.7**
Mar	133.3	35.6	101.7	2.2	0	59	11.8	17.2	4	0	**36.48**
Apr	277.5	179.6	15.7	20.9	18.4	59.5	33.3	14	8.2	24.1	**65.12**
May	163.6	90	80.2	6.4	34.8	61.7	10.1	0	33.3	22.6	**50.27**
Jun	270.6	242.7	102.7	87.3	152.1	225.6	131	120	161.6	33.7	**152.73**
Jul	462.1	478.2	293.3	410	386.2	439.7	120.6	333	145.2	99.4	**316.77**
Aug	480.2	206.2	460.8	460	375.6	146.9	188.7	200.5	226.2	308	**305.31**
Sep	100.8	55.6	242.6	112.1	279.3	47.3	75.7	0	191.7	178.1	**128.32**
Oct	8.7	97.6	248	265.7	231.9	27.1	0	0	36.5	35.1	**95.06**
Nov	37.8	118.9	0	14.4	192.6	0	0	0	0	14.3	**37.8**
Dec	0	***24***	0	4.1	4.6	2.1	49.8	0	0	24.8	**10.94**
total annual	**1948.6**	**1569.9**	**1545**	**1406.1**	**1675.5**	**1090.3**	**661.7**	**698.3**	**806.7**	**740.1**	**1214.2**
mean annual 1214.22											

Table A-14Summary of mean monthly rainfall at Tokierenso

				year							mean
month	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**monthly**
Jan	28.7	103.9	30.4	20.7	0	7.2	25	10.9	73.3	54.7	**35.48**
Feb	1.8	6	1.2	0	0	2.4	21.2	32.8	6.7	2.2	**7.43**
Mar	152.3	32.3	10.2	2.3	0.2	168.2	71.4	121.9	7.2	84.6	**65.06**
Apr	96.5	122.8	25.7	13	129.8	95.8	46	123.7	130.8	154	**93.81**
May	202.8	47.9	105	108.9	124.2	178.6	22.1	7.3	48	125.8	**97.06**
Jun	169.8	180.9	291.6	180.9	211.6	258	449.9	293.9	283.2	244.6	**256.44**
Jul	203.7	168.4	260.9	206	204.7	223.2	317.9	363	239.4	253.6	**244.08**
Aug	193.1	159.3	208.3	132.5	257.6	225.6	244.9	394.9	264.2	185	**226.54**
Sep	144.5	60.4	89.2	53.3	84.5	83.8	63.2	402.6	265.4	258.3	**150.52**
Oct	6	145.6	91.2	191.1	131.3	80.8	2.4	0	0	50	**69.84**
Nov	48.6	123.6	0.6	0	23.9	15.1	0	57.6	0	49.7	**31.91**
Dec	9.9	***5.1***	0	0	3.6	1.3	49.2	121.6	138.2		**36.544**
total annual	**1257.7**	**1156.2**	**1114.3**	**908.7**	**1171.4**	**1340**	**1313.2**	**1930.2**	**1456.4**	**1462.5**	**1311.1**
mean annual					**1311.06**						

Table A-15 Climatological date of Debre Markos Station

	metrological elements						
	rainfall(mm)	**max.tem**	**min.tem**	**mean tem.**	**RH(%)**	**wind speed**	**sun sh.**
month							
Jan	18.33	23.8	9.1	16.45	42.4	1.242	9.1
Feb	7.61	25.7	10.4	18.05	34.1	1.467	9.7
Mar	37.81	25.7	11.5	18.6	47.6	1.467	8.2
Apr	63.17	25.4	12.5	18.95	49	1.554	7.8
May	73.1	24.9	11.6	18.25	53.2	1.411	7.7
Jun	159.69	21	11	16	77.7	1.36	6
Jul	230.04	19	11	15	85.3	1.207	4.2
Aug	270.97	19.1	10.9	15	85.5	1.17	4.3
Sep	179.92	20.7	10.2	15.45	78.9	1.123	6.9
Oct	97.54	21.6	9.9	15.75	61.8	1.298	8.1
Nov	19.1	22.6	8.9	15.75	50.8	1.265	9.4
Dec	15.85	23.2	8.6	15.9	44.6	1.22	9.7
mean	**97.8**	**22.7**	**10.5**	**16.6**	**59.2**	**1.32**	**7.6**

Table A-16 Historic data of Abbay at Border (m^3/s)

year	month												mean annual
	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec	
1972	296.5	160.9	90.4	102.7	162.5	461.3	2018.4	3830.5	2929.2	1314.5	645.4	313.8	**1027**
1973	297.9	212.5	165	164.7	368.4	798.6	2191.8	6887.3	4925.8	2613.6	1092.1	581.7	**1692**
1974	284.4	181	147.1	110.1	289.3	784.6	3179	6025.1	4604	2216.1	891.4	480.8	**1599**
1975	350.1	300	156.9	106.4	151.3	1457.2	5861.5	6302.5	2797.5	1584.6	1083.2	582.4	**1728**
1976	462.4	301.4	212.8	163	169.5	695.7	2577.4	6010.2	4987.6	1619.3	813.6	542	**1546**
1977	370.2	537.9	318.7	197.8	278.7	683.3	2890.8	4966.4	4181.7	2433	1572.5	677.9	**1592**
1978	533.3	429.7	170.2	320.7	318.7	671.2	2753.4	4599.5	4181.1	2897.5	955	503.3	**1528**
1979	419.1	311.5	221.7	194.7	393.6	767.5	313.4	4866.1	3482.4	1788.8	668.4	416.4	**1154**
1980	256.9	183.2	201.1	225.9	273.6	619.7	3070	5948.4	3726.3	1905	817.2	485.6	**1476**
1981	316.2	229.9	200.2	197.1	286.1	526.4	2507.9	5490	4769.8	2140.5	838.1	474.6	**1498**
1982	335.4	242.1	221.5	183.5	158	425.1	1664.6	3781.4	3166	2531.7	824.4	461.8	**1166**
1983	291.5	228.4	189.9	195.9	261.3	535.7	1231.9	4239.3	6770.9	3717.9	939.9	491	**1591**
1984	312.4	227.9	170.7	146.2	210.3	832.9	2536.2	3475.1	3007.2	1054.6	482.1	316.6	**1064**
1985	220.4	180	154.6	188.2	381.6	660.1	2452.4	6070.9	5257.6	1869.4	790.5	475.2	**1558**
1986	305.9	230.1	209.7	215.1	659.9	668.1	2685.9	4046.6	3580.8	1563.8	651.6	382.6	**1267**
1987	258.2	203.1	233.3	219.8	410.7	1084.8	1927	4026.7	2818.8	1729.2	868.8	459.6	**1187**
1988	294.8	252	249.7	184.7	202.5	942.7	4968.7	7800	6068.8	4012	1370.2	679	**2252**
1989	396	278.3	239.5	265.5	266.5	560.3	2550.8	4808.6	4398.3	1968.9	768.7	527.8	**1419**
1990	423.8	288.7	232.8	205.5	208.5	417.7	1919.7	5044.1	4011	2069.3	760.2	432.8	**1335**
1991	294.4	218.2	197.8	229.5	342.7	720.3	3370.4	5761.1	4563.6	1928	930.1	562.9	**1593**
1992	360.4	284.9	221.6	197.2	342.6	672.9	1736.5	4701.8	4218.2	3148.5	1403.6	737.2	**1502**
1993	454	314.5	235.9	376.5	533.6	1279.1	3377.7	6004.9	5209.4	3114	1436.1	707.9	**1920**
1994	444.1	302.7	233	207.1	378.5	872	3319.1	7029.7	5456.5	1830.7	970.6	528.2	**1798**
1995	296	224.6	200.8	236.4	305.6	666.6	2112.3	5162.3	3622.7	1579.5	746.8	443	**1300**
1996	314.3	231.4	232.6	288.1	629.4	1720.8	4154.4	6689.5	4646.3	2356.1	1016.6	621.6	**1908**
1997	427.8	276	330.3	311.7	439	1192.2	3320.2	4806.5	2925.5	2009.7	1737.5	774	**1546**
1998	454.4	347.3	296.3	349.2	418.7	770.3	3404.9	7434.7	6388	4556.3	1692.5	859.6	**2248**
1999	493.1	332.7	211.4	171.9	375.1	949.7	3238.3	6118.4	5642.6	3798.3	1630.3	653.9	**1968**
2000	267	133.5	102.6	281.7	305	956.3	2615.8	5607.4	3632.7	3492.2	1664.9	833.6	**1658**
2001	267	289.2	319.9	372.6	504.4	1377.1	2598.4	6801.2	5637	2902.3	1643.3	726.4	**1953**
2002	491.1	477.3	278	311.1	234.7	737.1	2927.1	5331.2	3453.5	1566	720.7	403.6	**1411**
mean	**354.5**	**271.3**	**214.4**	**223.2**	**331**	**822.8**	**2757.3**	**5473.1**	**4356.8**	**2364.9**	**1046**	**552.8**	**1564**

Table A-17 Beless mean monthly flow (m^3/sec)

						month							mean
year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**annual**
1972	**10.5**	5.4	2.6	3.3	3	13.3	36.8	66.9	109	89.1	36.5	14	**32.5**
1973	**0.6**	3.3	2.5	4.8	5.1	3.1	16.7	84.4	122.3	104	46.1	16.5	**34.1**
1974	**8.1**	4.1	2.5	5.2	6.6	20.8	102.3	214.9	179.6	34.6	17.7	15.7	**51**
1975	**7.7**	6.8	3.7	4.4	5	22.8	79.8	127.8	120.2	73.4	33.4	16.5	**41.8**
1976	**9.4**	7.1	6.2	2	3.4	13.3	58.3	182.7	129.6	38.9	41.8	14.6	**42.3**
1977	**9.2**	6.5	5.9	4.4	4.5	14.1	26.4	46.9	85.3	84.8	37.1	15.6	**28.4**
1978	**5.3**	0.9	0.3	0.4	0.9	4.4	67.6	120.9	137.7	66	6	11.2	**35.1**
1979	**17.8**	4.4	0.7	0.4	1.2	9.3	50.8	88.3	91	59.7	45	22.8	**32.6**
1980	**15**	11.7	8.9	10.9	10.4	43.2	73.3	112.6	78.2	59.5	37.1	26.5	**40.6**
1981	**16.7**	12.2	9.6	8.4	19.5	28	86.7	98.6	90.6	71.1	35.5	24.7	**41.8**
1982	**14.7**	11.1	9.6	6.8	11.7	30.6	29	42	26.4	311.9	77.1	27	**49.8**
1983	**12.5**	9.1	3	0.1	0	11.9	55.4	201.8	200.6	29.1	3.8	1.3	**44**
1984	**0.4**	0.4	0.1	0.1	0.2	5.3	49.4	64.7	75.6	21.2	1.5	0.7	**18.3**
1985	**0.3**	0.1	0	0	4.1	7.9	186.4	287.4	208.6	21.8	8.8	4.7	**60.8**
1986	**0.3**	0.3	0.1	0	7.3	150	133.2	119.2	25	25	4.9	1	**38.9**
1987	**0.3**	0.8	0.5	0.2	3.7	28.3	64.2	165.2	78.6	95.6	28.3	4.6	**39.2**
1988	**1.3**	0.7	0.5	0.1	0.5	9.3	344.1	394.1	276	68.3	14.2	4.6	**92.8**
1989	**2.3**	1.3	0.8	0.5	2.4	10.3	119.9	225.3	154.9	62.1	13.7	5	**49.9**
1990	**2.6**	1.5	0.9	0.4	0.3	2.5	89.9	280.2	106.7	33	1.8	1.8	**43.5**
1991	**1.3**	0.5	3.2	9.1	18.4	42.3	122.7	161.1	186.9	30.2	7.9	6.4	**49.2**
1992	**20.3**	8.6	4.3	4.2	9.3	30.1	237.2	1202.7	799.5	597.9	99.3	31.1	**253.7**
1993	**12.6**	5.8	4.2	3.2	23.7	279.9	646.7	1263.5	1099	422.8	87.5	22.6	**322.6**
1994	**10.8**	5.4	2.7	1.3	4.8	71.3	426.6	1096.2	808.8	159.8	40.3	16.6	**220.4**
1995	**7.1**	3.6	2.8	1.4	16	219.3	699.3	1191.3	557.7	150.7	30.3	13.8	**241.1**
1996	**6.6**	3.4	2.9	1.9	18.2	144.7	439.2	1729.7	941.2	283.4	51.5	21.6	**303.7**
1997	**42.8**	30.7	23.2	17.8	39.2	177.4	692.9	1029.4	624.3	732.9	295.2	80.8	**315.5**
1998	**42.6**	25.7	17.3	9.1	19.7	189	1004.1	1675.6	1199.9	780.1	183.5	81	**435.6**
1999	**48.3**	29.4	22	18.3	70	235.8	687.1	1548.7	730.5	682.4	164	80.5	**359.7**
2000	**50.3**	33.7	23.2	25.4	59.6	217.4	633.3	1699.7	758.2	863	229	93.5	**390.5**
2001	**59.4**	43	33.5	17.9	33.9	317.2	900.3	2101.6	975.5	711.3	238	92.4	**460.3**
2002	**58**	38.6	28	19	13.5	133.7	525.7	970.7	759.8	272.4	92	46.3	**246.5**
Mean	**16**	**10.2**	**7.3**	**5.8**	**13.4**	**80.2**	**280.2**	**599.8**	**378.6**	**227**	**64.8**	**26.3**	**142.5**

Table A-18 Didesa mean monthly flow (m^3/sec)

						Months							mean
year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**annual**
1972	19.3	13.4	8.8	9.8	9.5	21.7	38.3	54.3	71	63.3	38.4	22.8	**30.9**
1973	3.9	10.2	8.6	12.5	11.5	9.4	23.6	59.5	75.9	69.3	43.7	24.8	**29.4**
1974	16.8	11.4	8.8	7.5	9.4	26.9	67	102.2	93.2	35.5	25	24.1	**35.7**
1975	16.3	15.2	10	12	12.9	27.5	59.6	77.5	75.1	56.6	36.6	25	**35.3**
1976	18.2	15.7	14.4	7.6	9.9	21	48.8	92.1	77.4	39.5	40.6	23.3	**34.1**
1977	18.1	14.9	14.1	12	12	22.6	32.4	44.3	62	61.9	38.1	24.2	**29.7**
1978	5.3	0.9	0.3	0.4	0.9	4.4	67.6	120.9	137.7	66	6	11.2	**35.1**
1979	12.4	4.8	2.9	3.1	4.6	11	51.7	74.1	80.3	49.5	14.1	18	**27.2**
1980	26.1	11.5	4.2	3.1	5.5	16.4	41.8	62.9	64.4	50.9	43.5	29.8	**30**
1981	23.7	20.6	17.7	19.8	19.3	41.6	56	72.4	59.1	50.9	39.1	32.5	**37.7**
1982	23.4	20.1	18.4	15.1	20	34.7	33.4	41.8	32.3	32.8	20.9	16	**25.7**
1983	21.4	17.9	7.4	1.1	0.8	17.4	46.3	95.4	94.7	31.4	11	6.1	**29.2**
1984	3.3	3.2	1.8	1.5	2.2	11.8	42	52.3	57.3	22.2	6.4	4.1	**17.3**
1985	2.4	1.5	1.6	3	10	35.3	80.8	112.8	143.4	38.9	14.3	6.9	**37.6**
1986	3.2	2.3	3.6	3.2	3.5	22.8	99.6	97.7	77.6	115.2	25.1	8.8	**38.6**
1987	2.2	1.8	3.6	3.5	7.6	31.7	50	83	57.5	61.6	31.8	10.1	**28.7**
1988	6.7	6.3	4.7	2.5	8.9	59	81	146.5	188.6	193	21.7	10.1	**60.7**
1989	5.9	4.5	1.7	4.4	3.1	12.1	62.3	94.4	105	35.6	9.6	5.1	**28.6**
1990	6.8	35.5	28.8	8.8	3.7	20.1	93.9	210.5	139.6	47.2	8.1	3.5	**50.5**
1991	2.7	2.6	2.5	4.8	11	29.5	113.8	194.8	101.5	52.3	5.2	3.3	**43.7**
1992	2.9	6.1	4.8	3.4	13.7	32.3	102.9	142.6	128.1	110.1	63.7	39.1	**54.1**
1993	22.7	7.1	6.2	14.5	30.2	97.1	124.7	140.4	129.4	95.9	67.5	36.9	**64.4**
1994	17.1	5.6	6.3	8.7	14.1	43.2	102.3	142.4	108.6	22.1	10.3	6.1	**40.6**
1995	4.8	5	6.2	9.2	18.2	33.6	70.9	101.5	127.7	37.9	12.6	12.6	**36.7**
1996	4.8	5	6.2	9.2	18.1	33.5	71	101.7	127.7	37.9	12.6	12.6	**36.7**
1997	7.9	5.7	8.7	11.6	20.6	54.9	81.9	128	78.8	98	72.5	21	**49.1**
1998	10.5	5.6	7.6	4.9	11.6	42.5	101.6	155	115.4	122.7	34.3	7.9	**51.6**
1999	4.9	2.7	3.1	3.7	20.5	57.2	90.4	91.4	82.6	112.8	18.7	6.8	**41.2**
2000	3.8	2.2	1.7	3.7	15.4	45.8	107.8	115.3	93.3	78.1	31.6	8.2	**42.2**
2001	4.7	4	4.2	5.6	20.7	87.4	123.2	120.1	114.1	79.2	23	8.4	**49.5**
2002	6.4	2.8	2.4	3.5	2.4	24.3	71.6	95.3	75.2	25.5	10.7	5.6	**27.1**
Mean	**10.6**	**8.6**	**7.1**	**6.9**	**11.4**	**33.2**	**72.2**	**104**	**96**	**64.3**	**27**	**15.3**	**38**

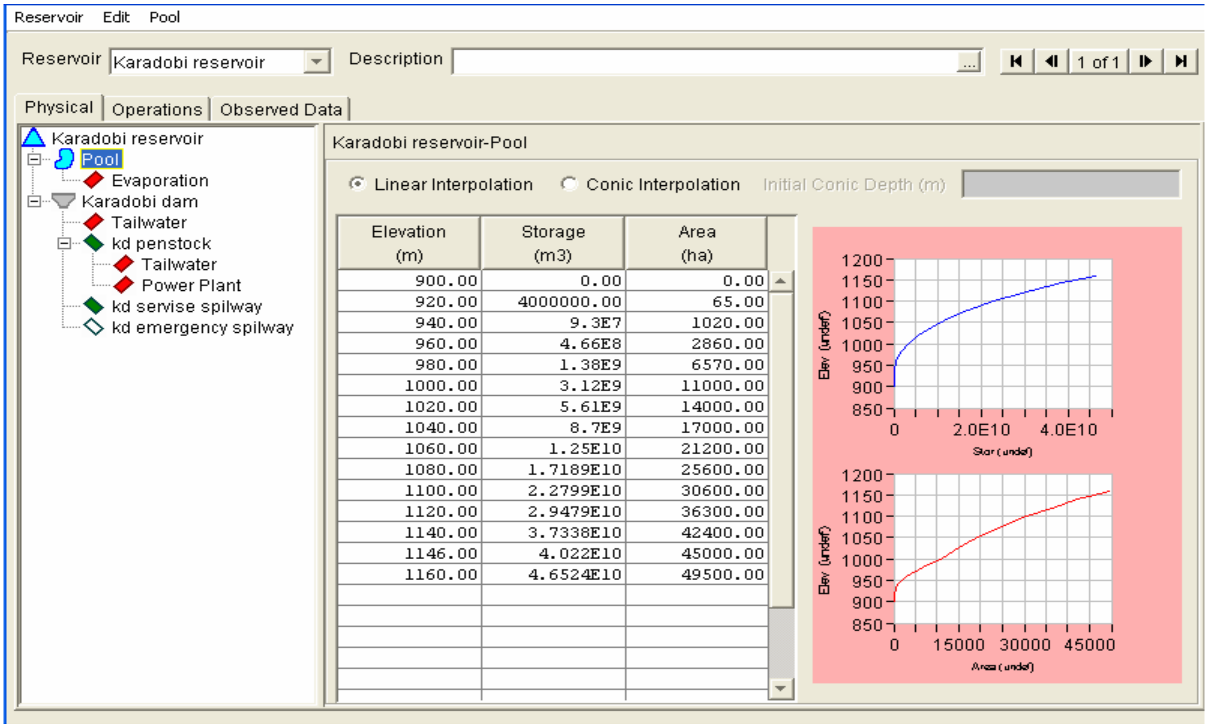
Table A-19 Monthly Flow of Dabuse (m^3/sec)

						months							mean
year	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**annual**
1972	57.3	32.7	17.1	21	19.4	69.9	166.8	280.1	425.1	357.2	166.1	73.3	**140.5**
1973	41.1	21.2	16.6	29.4	41.4	100.4	213.9	274.1	469.3	408.4	202.8	84.2	**158.6**
1974	46.2	25.6	16.9	26.2	46.5	100.8	178.3	314.8	478	415.6	193.2	80.7	**160.2**
1975	43.9	39.5	33.7	27.2	30.6	93.2	325	486.5	462.2	301.8	154.1	84.7	**173.5**
1976	52.2	41.4	36.8	13.7	22.6	61.3	234.2	497.9	435.1	248	185.8	76.1	**158.8**
1977	51.4	38.1	35.1	27.5	27.6	73.6	126.7	206.3	344.6	343.1	167	80.6	**126.8**
1978	41	21.2	14.3	13.1	25.3	221.6	303.2	346.4	382.6	324.7	170.7	131.9	**166.3**
1979	90.6	30.8	17.7	12.1	29.1	74.7	174.5	321.8	364.7	254	199.4	111.5	**140.1**
1980	43.9	39.5	33.7	27.2	30.6	93.2	325	486.5	462.2	301.8	154.1	84.7	**173.5**
1981	85.6	65.6	53.5	47.2	67.7	127.2	346.3	390.3	363.3	294.4	163.1	119.5	**177**
1982	36.2	76.9	60.5	53.3	39.6	62.3	142.7	135.8	187.9	126.3	158.8	104.1	**98.7**
1983	66.7	50.9	37.7	25.3	38	97.2	221.9	314.9	307	216.4	144.7	135.2	**138**
1984	25	14.9	8.3	5.1	13.3	39.8	139.7	168.8	114.3	46	29.1	21.4	**52.1**
1985	7.6	31.5	27.5	26.9	54.7	136.7	273.9	517.1	406.9	221.9	108.3	73.6	**157.2**
1986	59.9	59.6	36.2	28.9	36.2	57	245	363.8	296.9	231.9	120.7	67.9	**133.7**
1987	31.1	51.8	43.4	38	69.2	196.1	196.7	328.9	291.3	267.6	161.6	93.5	**147.4**
1988	60.6	49.3	45.1	39.5	34.9	199	268.8	360.5	335	291.1	166.2	89.8	**161.6**
1989	60.2	41.2	48.8	47.3	365.2	147.3	268.5	522.5	416.1	211.8	79.4	64.5	**189.4**
1990	38.1	31.8	32.7	43.8	54.4	51.1	249	290.2	271.2	224	92.2	65	**120.3**
1991	51.3	42.2	31.1	29.3	25.4	30	314	338.5	313.4	207.3	107	67.4	**129.8**
1992	121.1	97.3	74.3	122.7	46.8	188.1	560.5	781.5	700.7	600.4	342.3	205.7	**320.1**
1993	140.9	108.1	94	104.2	123.8	344.3	588.6	738.5	708.1	521.9	363.5	193.1	**335.7**
1994	136	103.7	86.7	80.5	113.8	351.9	529.4	801.9	694.2	374.2	266.4	176.7	**309.6**
1995	111.4	98.4	86	76.9	95.2	349.4	579.9	928.3	696.8	406.1	236.4	159.8	**318.7**
1996	164.8	122.4	139.6	208.3	358.2	494.3	792.6	868.6	621.8	398.7	269.6	187.4	**385.5**
1997	187.8	154.8	182.9	177.5	277.7	466.1	692.6	683.5	602.8	481.9	437.5	324.8	**389.2**
1998	225.5	161.7	128.6	98.7	213.4	348.5	633.9	909.4	661.2	586.9	341.2	253.7	**380.2**
1999	232.7	167.8	125.1	116.7	220.3	375.1	696.2	857.1	629.6	666.6	328.7	238.2	**387.8**
2000	177.2	113	83.4	131.3	154.1	307.6	307.6	841.2	626.1	714.5	392.8	201	**337.5**
2001	114.9	84	76.9	63.3	126.1	375.3	470.8	654.3	737.1	507.4	287	136	**302.8**
2002	94.3	70.7	49.5	41.1	35.9	300.2	472.2	679.5	654.5	384.7	265.2	310.9	**279.9**
mean	**87**	**67.3**	**57.2**	**58.2**	**91.5**	**191.4**	**356.1**	**506.1**	**466.5**	**352.8**	**208.2**	**132.2**	**214.5**

Table A-20 Karadobi Power Generation (MW)

							months						mean
years	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
1972	1045.6	1033.9	1021.7	1008.2	994.9	1551.7	1494.9	965.7	959.3	959.3	948.7	935	**1077**
1973	920.8	907.3	893	877.6	862.1	845.9	842.7	937.3	999.8	1013.2	1014.1	1008.5	**926.9**
1974	999.7	989.2	977.6	965.9	954.3	943.7	1472.4	1600	1343.3	1019.1	1023.5	1020.3	**1109**
1975	1013	1003.9	993.6	981.7	969.3	1044.3	1600	1600	1600	1029.4	1038.1	1039.7	**1159**
1976	1035.9	1028.6	1019.1	1008.6	1049	1600	1600	1600	1372.8	1017.2	1022.1	1021.1	**1198**
1977	1014.3	1005.5	995.2	983.9	971.4	1065.7	1548.2	1600	1446.8	1020.5	1036.2	1037	**1144**
1978	1031.8	1023.7	1013.7	1002	989.7	1414.4	1600	1600	1377.9	1021	1024.6	1020.8	**1177**
1979	1013.5	1004.4	993.4	981	969	1044.3	1600	1600	1223.1	1010.6	1009.4	1003.3	**1121**
1980	994.00	983.30	971.70	960.30	948.3	933.90	933.50	1,411.60	1,487.00	1,020.50	1,027.60	1,024.90	**1058**
1981	1017.5	1007.5	1005.9	996.6	987.5	1414.3	1600	1600	1389.7	1016.1	1016.9	1012.6	**1172**
1982	1004.9	995.6	984.9	973.7	962.6	951.6	942.5	1331.2	1222	1013.6	1016.1	1010.1	**1034**
1983	1000.8	990.1	978.6	967.5	957.2	949.5	938.7	1328.9	1285.1	1014.1	1014.5	1008.4	**1036**
1984	997.1	983.8	970.3	957.1	943	928.3	923.2	937.7	939.9	932	918.2	903.3	**944.5**
1985	887.6	872.9	857.8	840.2	823.2	807.6	797	847.2	924.3	933.9	927.9	916.8	**869.7**
1986	903.1	888.9	874.3	858.9	841.8	826.7	836.8	904.3	953.7	963.3	958.5	948.9	**896.6**
1987	935.2	920.7	906.3	891.8	877.2	864.8	850.7	858.8	878.5	873	864.4	849.8	**881**
1988	832.4	814.6	797.2	780.9	762.1	741.3	749.4	924.9	1482.9	1022.4	1029.4	1024.3	**913.5**
1989	1014.8	1003.7	991.5	979.6	967.3	955	1172.7	1149.8	1222.1	1006.8	1002.8	994.1	**1038**
1990	983.1	971.1	959.1	946.2	931.3	916.6	906.6	941.9	974.1	981.6	975.1	965.1	**954.3**
1991	953.3	939.6	924.9	909.9	894.9	880.2	865.8	888	959.1	976.8	975.7	968.4	**928**
1992	958.1	946.2	931.5	916.5	901.5	886.6	875.9	925.2	988.2	1004.6	1009.6	1004.3	**945.7**
1993	995.90	986.60	975.70	966.50	961.0	1,010.70	1,503.80	1,600.00	1,540.80	1,043.90	1,036.40	1,035.60	**1138**
1994	1028.7	1019.1	1007.9	995.6	984.2	1350.4	1600	1600	1574.2	1024.5	1033.5	1031.9	**1188**
1995	1,021.70	1,010.20	998.40	987.20	977.6	1,221.50	1,600.00	1,600.00	1,402.30	1,008.80	1,005.80	998.20	**1153**
1996	988.1	976.9	965.9	957.1	950.6	1037.8	1600	1600	1477.3	1023.4	1031.6	1031.7	**1137**
1997	1,027.60	1,019.50	1,013.10	1,007.20	1147.6	1,600.00	1,600.00	1,600.00	1,221.60	1,010.00	1,027.30	1,029.60	**1192**
1998	1,025.00	1,016.90	1,010.60	1,004.60	1,084.5	1,600.00	1,600.00	1,600.00	1,221.60	1,010.00	1,027.30	1,029.60	**1186**
1999	1023.4	1014.8	1004.7	992.3	979.9	1222	1600	1600	1442.6	1028.8	1048	1047.6	**1167**
2000	1041.1	1032.5	1020.3	1009.2	1019.4	1600	1600	1600	1342.9	1016	1023.7	1020	**1194**
2001	1009.9	997.8	989.9	986.4	981.3	1371.5	1600	1600	1351.4	1013.3	1014.4	1010.7	**1161**
2002	1,006.50	1,002.70	997.80	992.60	986.70	1,435.10	1,600.00	1,600.00	1,343.40	1,010.40	1,009.70	1,007.20	**1166**
mean	**991.1**	**980.4**	**969.2**	**957.6**	**955.8**	**1130**	**1292.1**	**1340.4**	**1256.4**	**1001.2**	**1003.6**	**998.7**	**1073**

APPENDIX B: DATA AND RESULT FIGURES



Reservoir: Karadobi reservoir

Karadobi reservoir-Pool

● Linear Interpolation ○ Conic Interpolation

Elevation (m)	Storage (m3)	Area (ha)
900.00	0.00	0.00
920.00	4000000.00	65.00
940.00	9.3E7	1020.00
960.00	4.66E8	2860.00
980.00	1.38E9	6570.00
1000.00	3.12E9	11000.00
1020.00	5.61E9	14000.00
1040.00	8.7E9	17000.00
1060.00	1.25E10	21200.00
1080.00	1.7189E10	25600.00
1100.00	2.2799E10	30600.00
1120.00	2.9479E10	36300.00
1140.00	3.7338E10	42400.00
1146.00	4.022E10	45000.00
1160.00	4.6524E10	49500.00

Fig B- 1 Karadobi Reservoir Pool input data(Storage-elevation-Area curve)

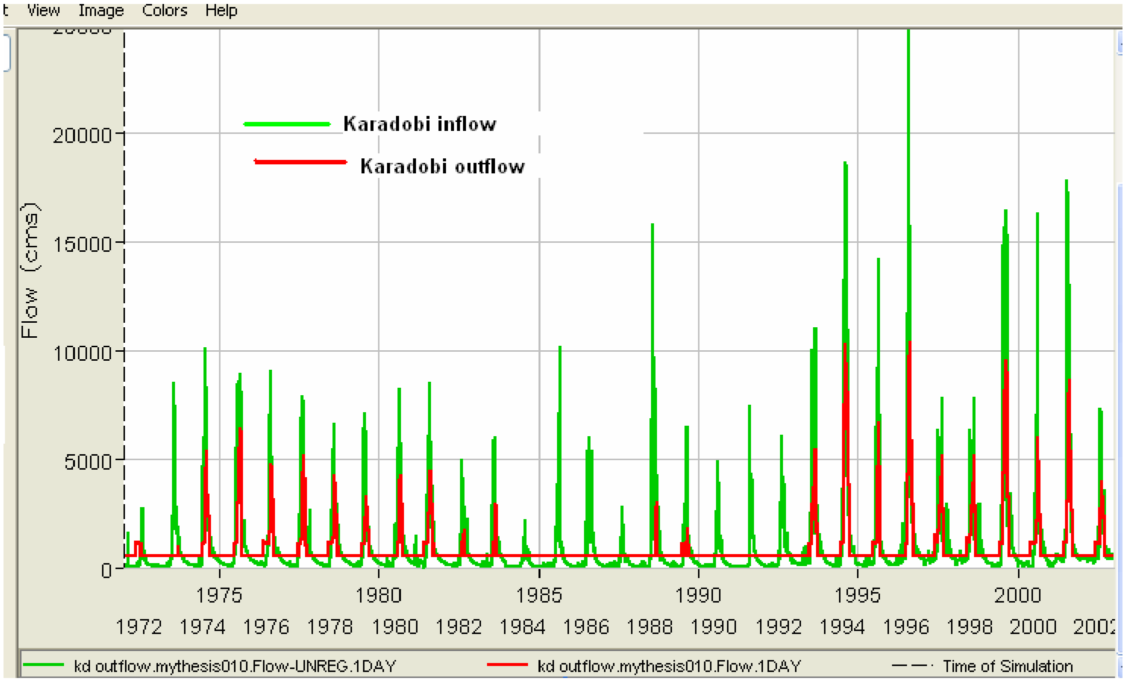


Fig B- 2 Karadobi Inflows and Outflow

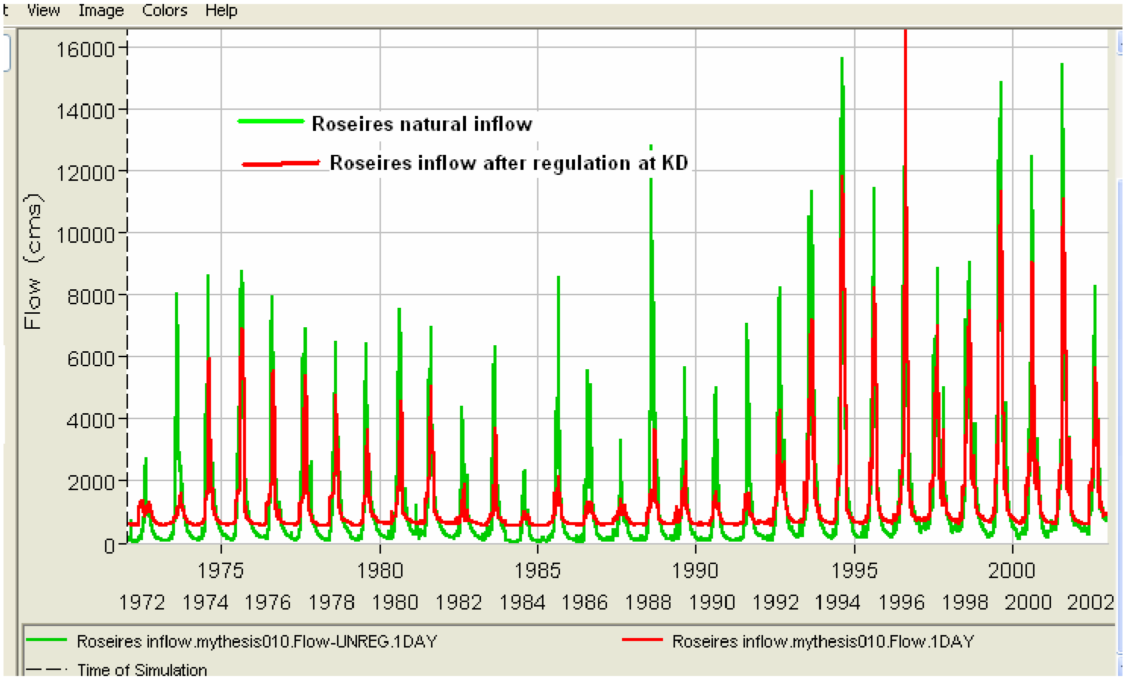


Fig B-3 Roseires inflow before and after regulation

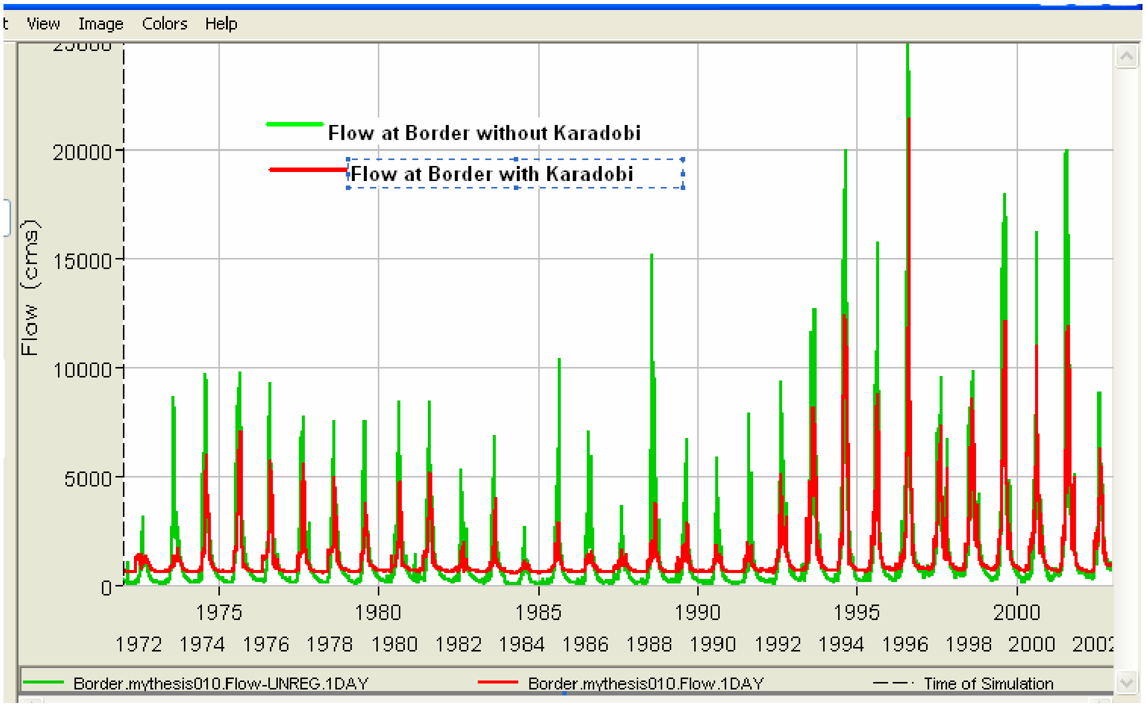
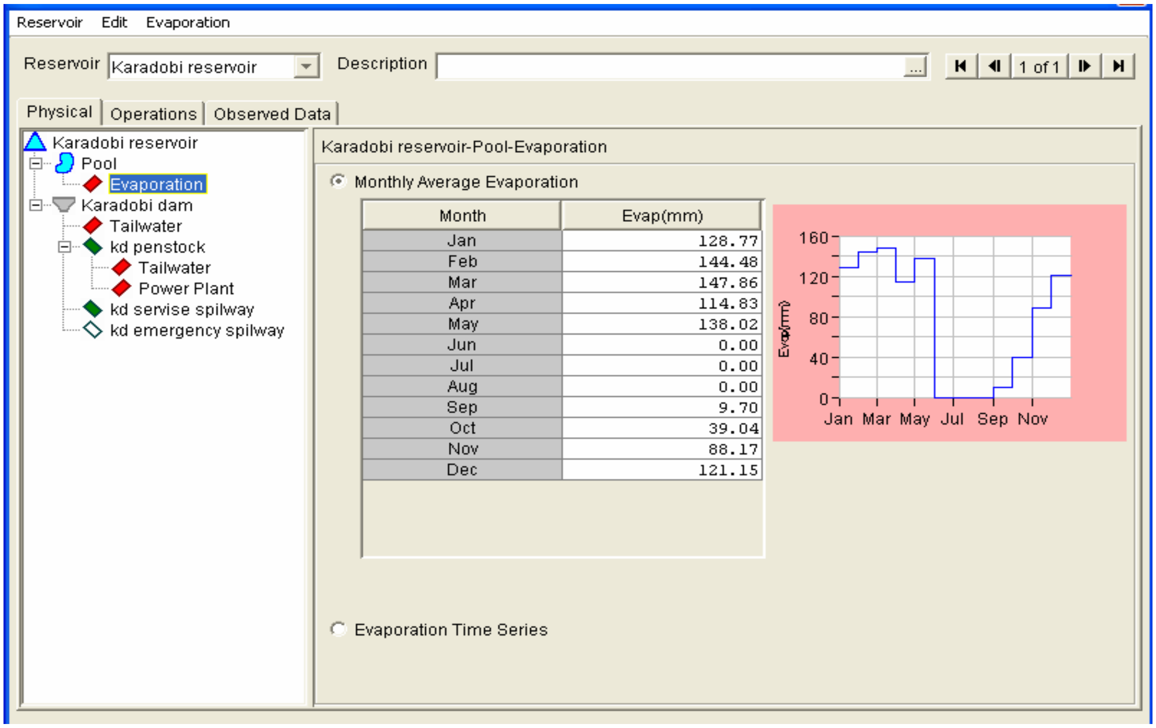


Fig. B- 4 Flow at Border with and without Karadobi



Reservoir: Karadobi reservoir

Description:

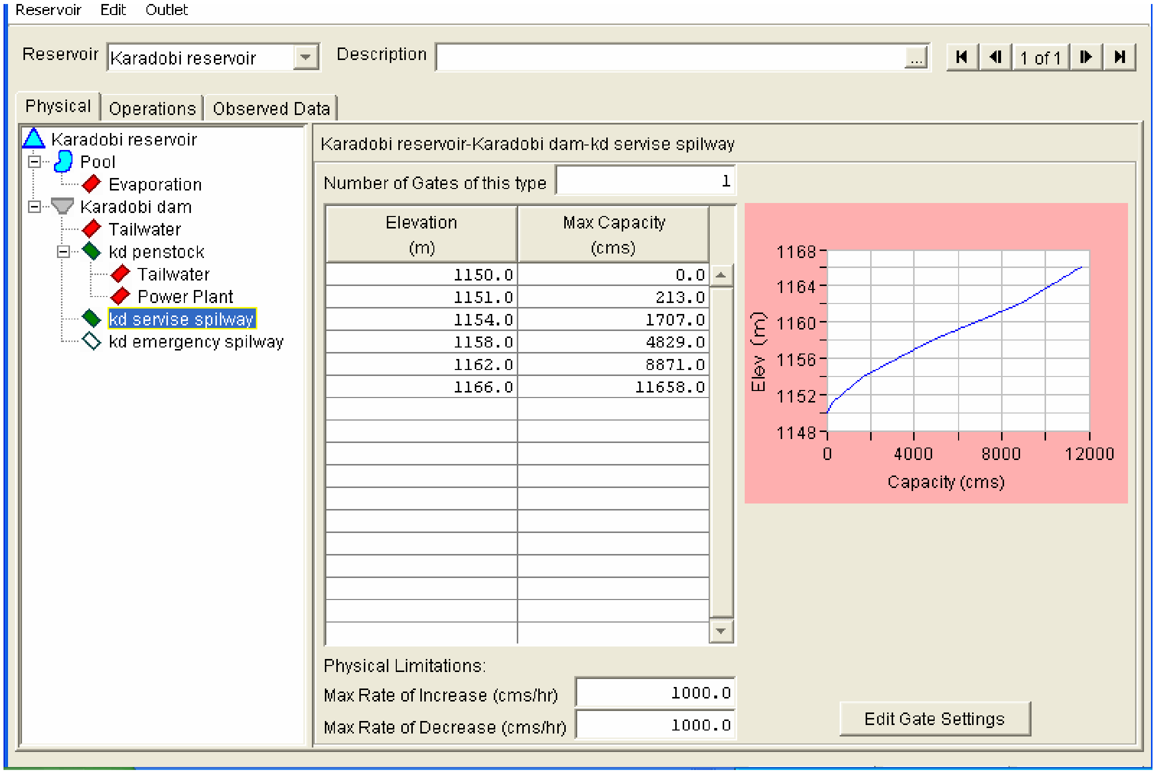
Karadobi reservoir-Pool-Evaporation

● Monthly Average Evaporation

Month	Evap(mm)
Jan	128.77
Feb	144.48
Mar	147.86
Apr	114.83
May	138.02
Jun	0.00
Jul	0.00
Aug	0.00
Sep	9.70
Oct	39.04
Nov	88.17
Dec	121.15

○ Evaporation Time Series

Fig B- 5 Evaporation input to Karadobi Reservoir



Reservoir: Karadobi reservoir

Description:

Karadobi reservoir-Karadobi dam-kd servise spilway

Number of Gates of this type: 1

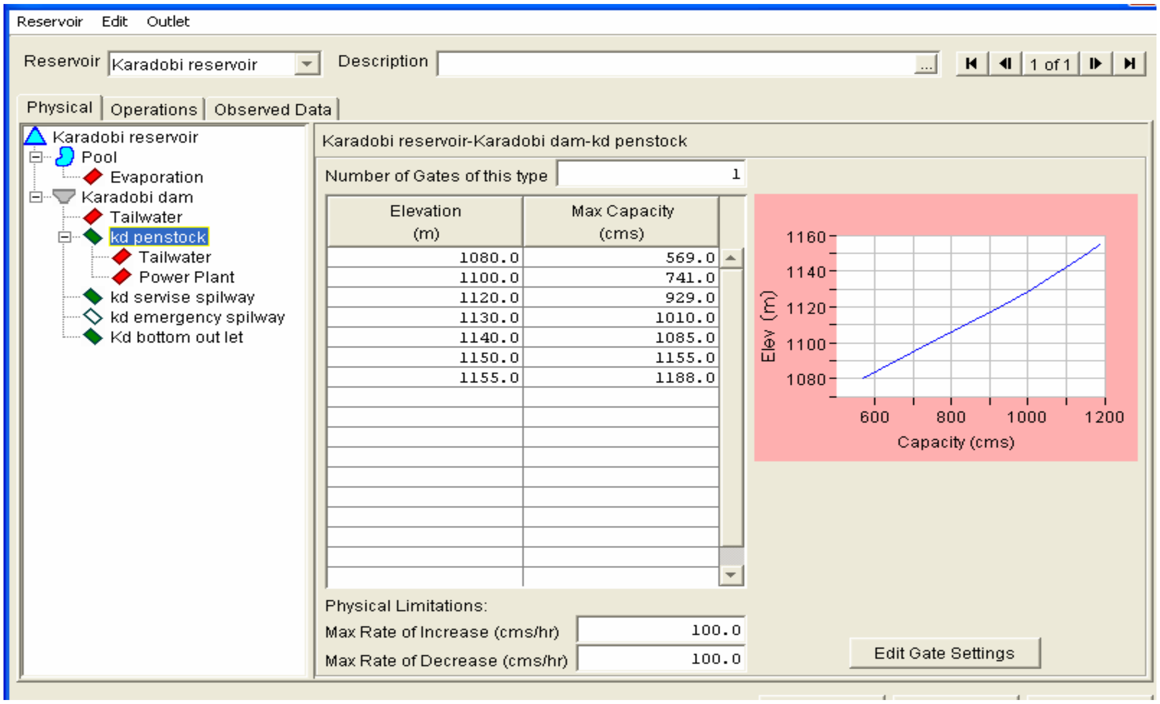
Elevation (m)	Max Capacity (cms)
1150.0	0.0
1151.0	213.0
1154.0	1707.0
1158.0	4829.0
1162.0	8871.0
1166.0	11658.0

Physical Limitations:

Max Rate of Increase (cms/hr): 1000.0

Max Rate of Decrease (cms/hr): 1000.0

Fig B- 6 Karadobi spillway capacities –Elevation Curve



Reservoir: Karadobi reservoir

Description:

Karadobi reservoir-Karadobi dam-kd penstock

Number of Gates of this type: 1

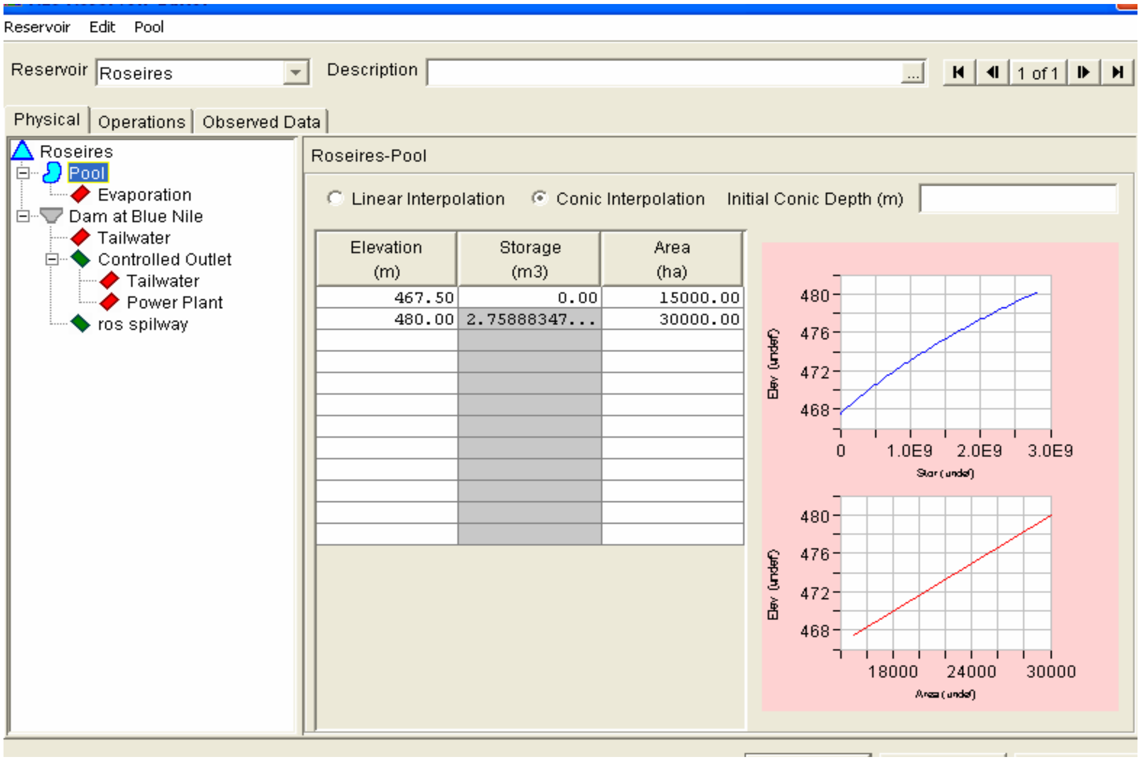
Elevation (m)	Max Capacity (cms)
1080.0	569.0
1100.0	741.0
1120.0	929.0
1130.0	1010.0
1140.0	1085.0
1150.0	1155.0
1155.0	1188.0

Physical Limitations:

Max Rate of Increase (cms/hr): 100.0

Max Rate of Decrease (cms/hr): 100.0

Fig B-7 Elevation maximum capacity curve for Karadobi penstock



Reservoir: Roseires

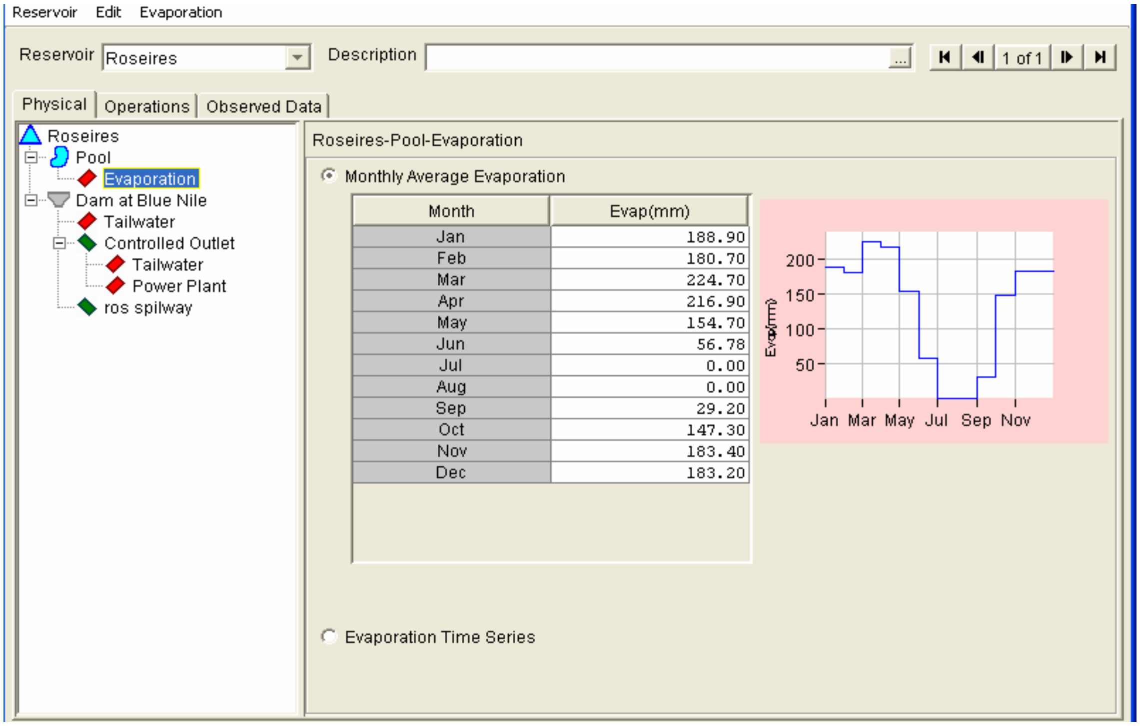
Description:

Roseires-Pool

○ Linear Interpolation ● Conic Interpolation Initial Conic Depth (m):

Elevation (m)	Storage (m3)	Area (ha)
467.50	0.00	15000.00
480.00	2.75888347...	30000.00

Fig. B-8 Roseires Reservoir pool Elevation –Area-Capacity Relation (interpolated)



Reservoir: Roseires

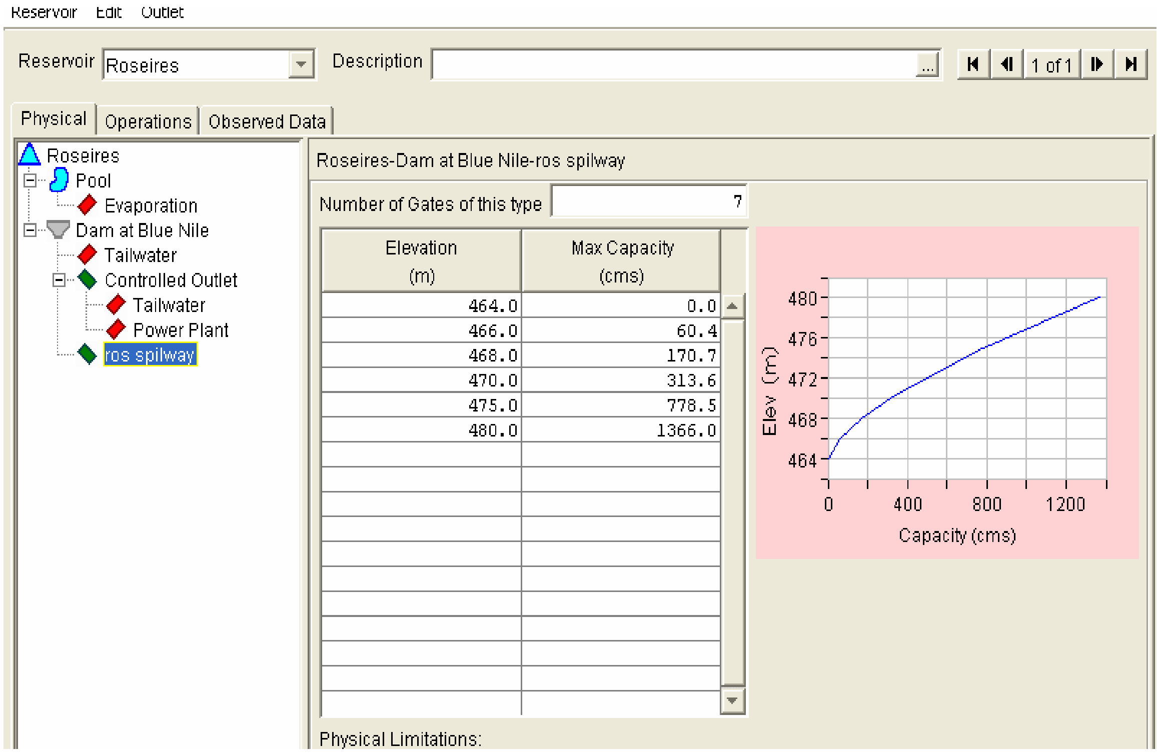
Roseires-Pool-Evaporation

● Monthly Average Evaporation

Month	Evap(mm)
Jan	188.90
Feb	180.70
Mar	224.70
Apr	216.90
May	154.70
Jun	56.78
Jul	0.00
Aug	0.00
Sep	29.20
Oct	147.30
Nov	183.40
Dec	183.20

○ Evaporation Time Series

Fig. B-9 Roseires Pool Evaporation



Reservoir: Roseires

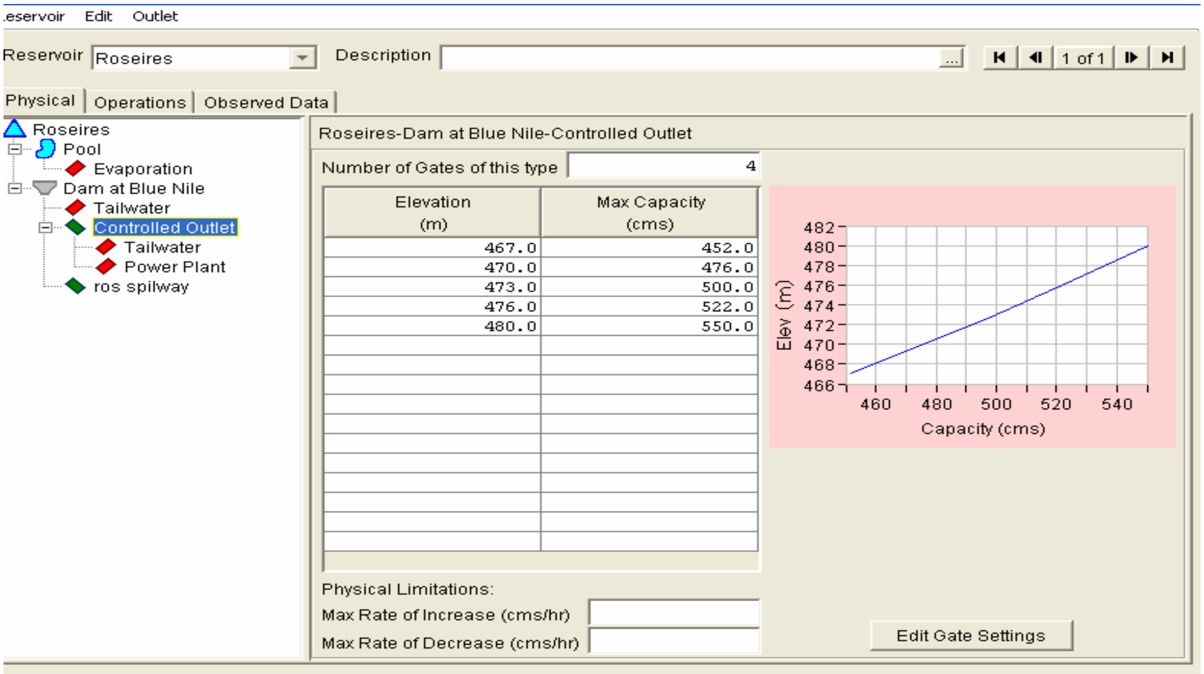
Roseires-Dam at Blue Nile-ros spilway

Number of Gates of this type: 7

Elevation (m)	Max Capacity (cms)
464.0	0.0
466.0	60.4
468.0	170.7
470.0	313.6
475.0	778.5
480.0	1366.0

Physical Limitations:

Fig. B-10 Roseires spillway Elevation maximum capacity curve



Reservoir Roseires

Description

Roseires-Dam at Blue Nile-Controlled Outlet

Number of Gates of this type 4

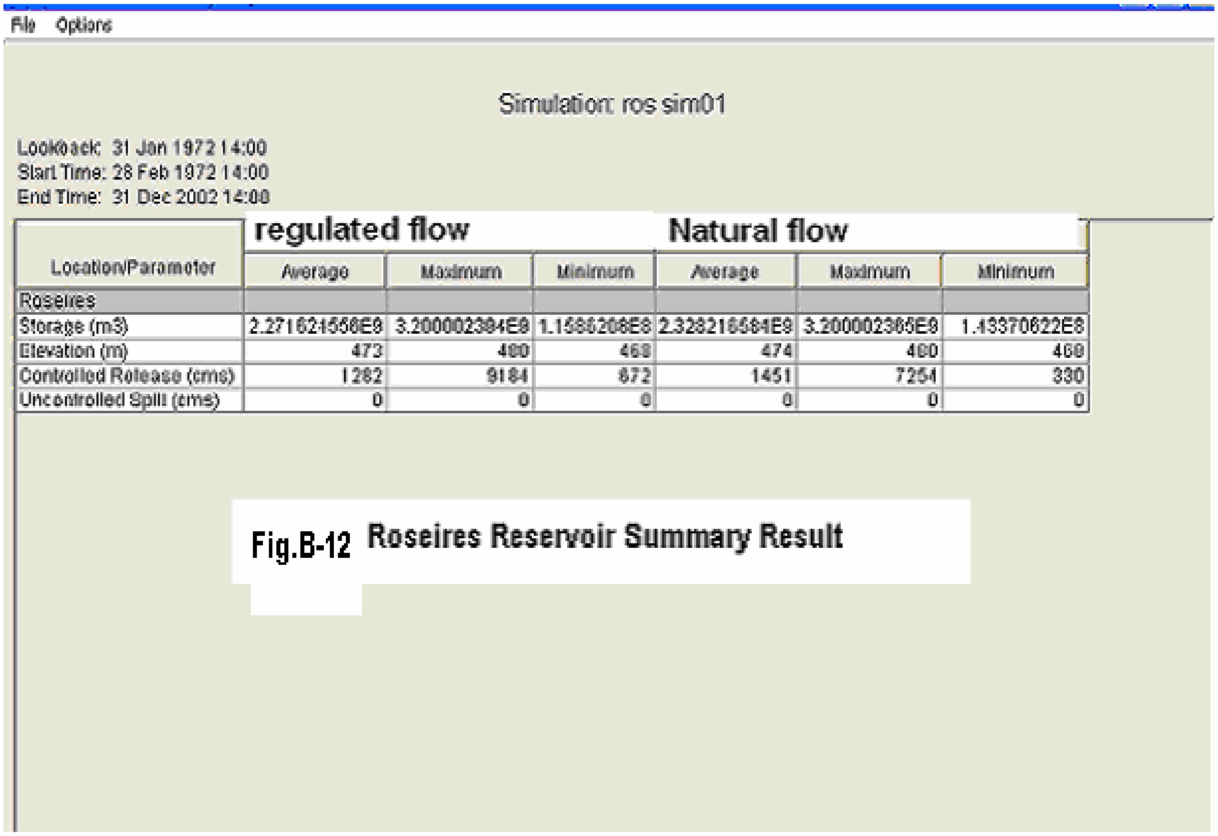
Elevation (m)	Max Capacity (cms)
467.0	452.0
470.0	476.0
473.0	500.0
476.0	522.0
480.0	550.0

Physical Limitations:

Max Rate of Increase (cms/hr)

Max Rate of Decrease (cms/hr)

Fig B-11 Roseires Penstock Head- capacity curve



Simulation: ros sim01

Lookback: 31 Jan 1972 14:00
Start Time: 28 Feb 1972 14:00
End Time: 31 Dec 2002 14:00

Location/Parameter	regulated flow			Natural flow		
	Average	Maximum	Minimum	Average	Maximum	Minimum
Roseires						
Storage (m3)	2.271621556E9	3.200002384E9	1.1586208E9	2.328216584E9	3.200002365E9	1.43370622E9
Elevation (m)	473	480	468	474	480	468
Controlled Release (cms)	1282	9184	672	1451	7254	330
Uncontrolled Spill (cms)	0	0	0	0	0	0

Fig.B-12 Roseires Reservoir Summary Result

Fig.B-12 Roseires Reservoir Summary Result

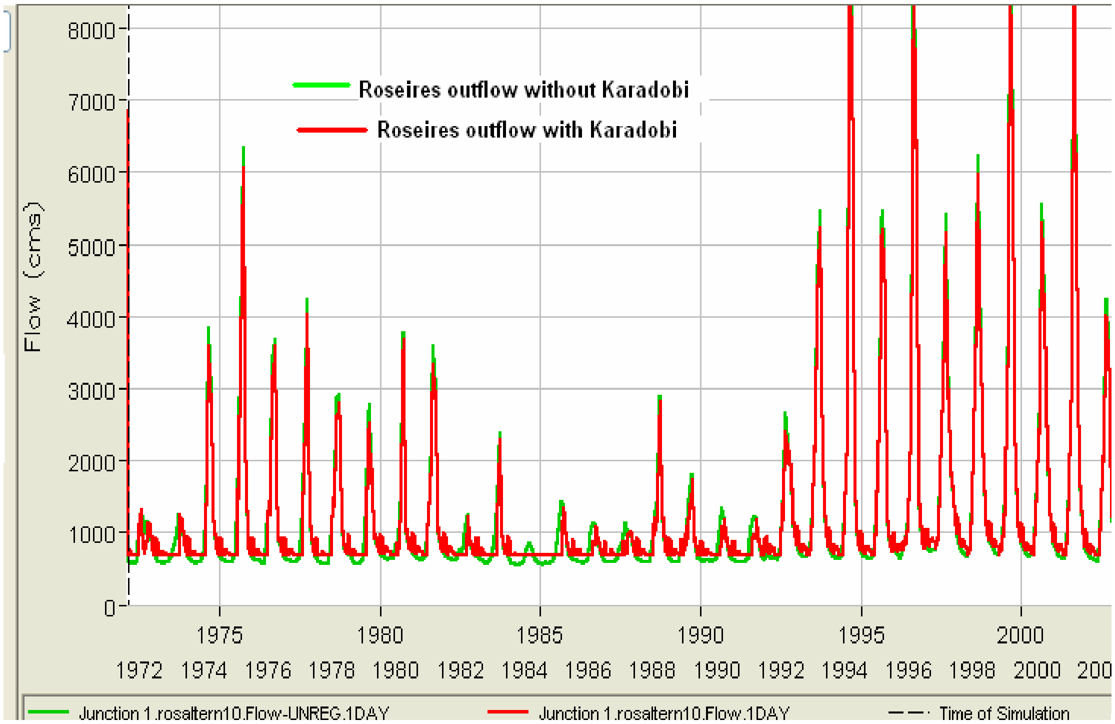


Fig B-13 Roseires Out flow for Natural and Regulated flows

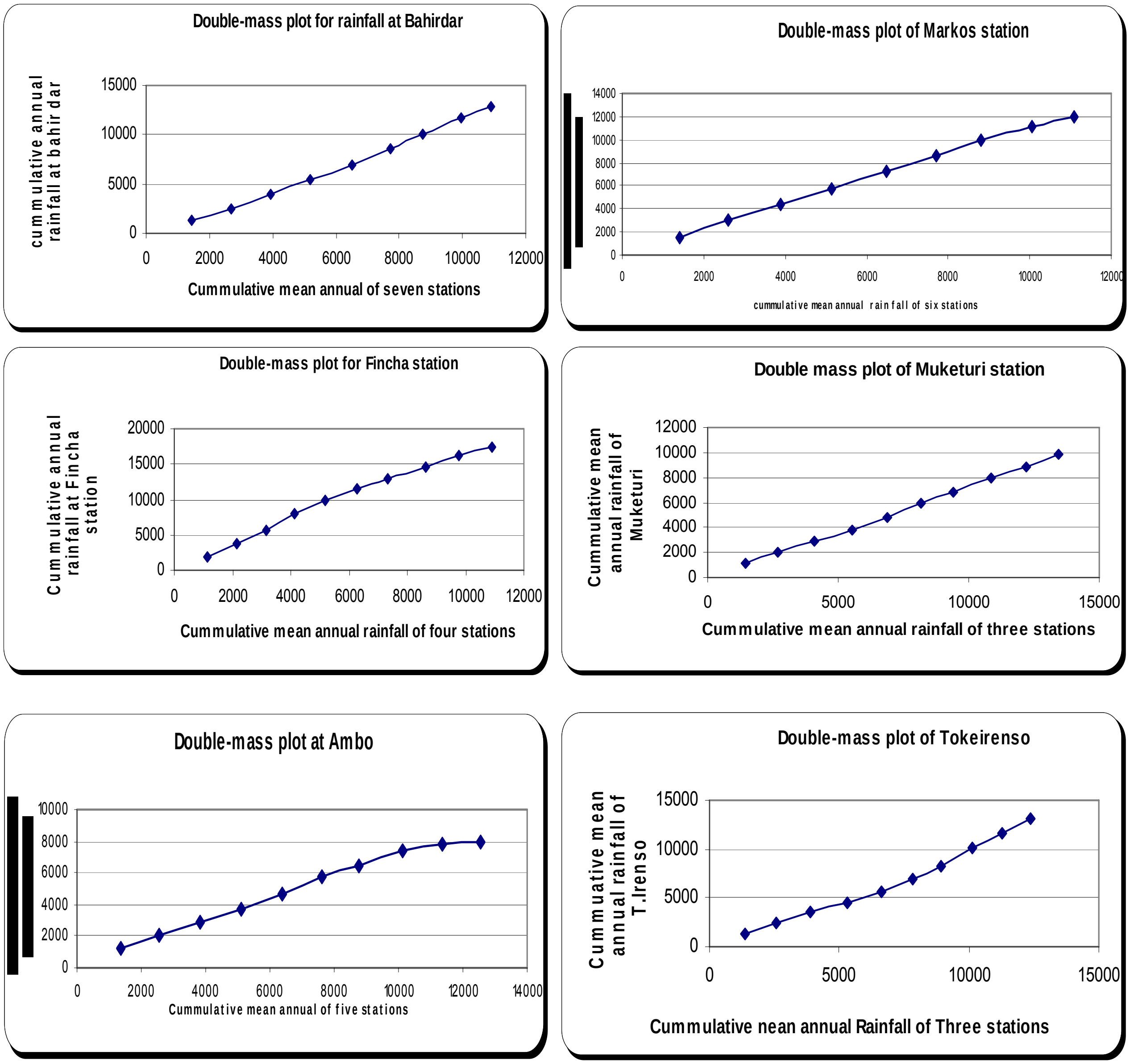


Fig. B-15 Double mass plot of the Rainfall stations around Karadobi dam site

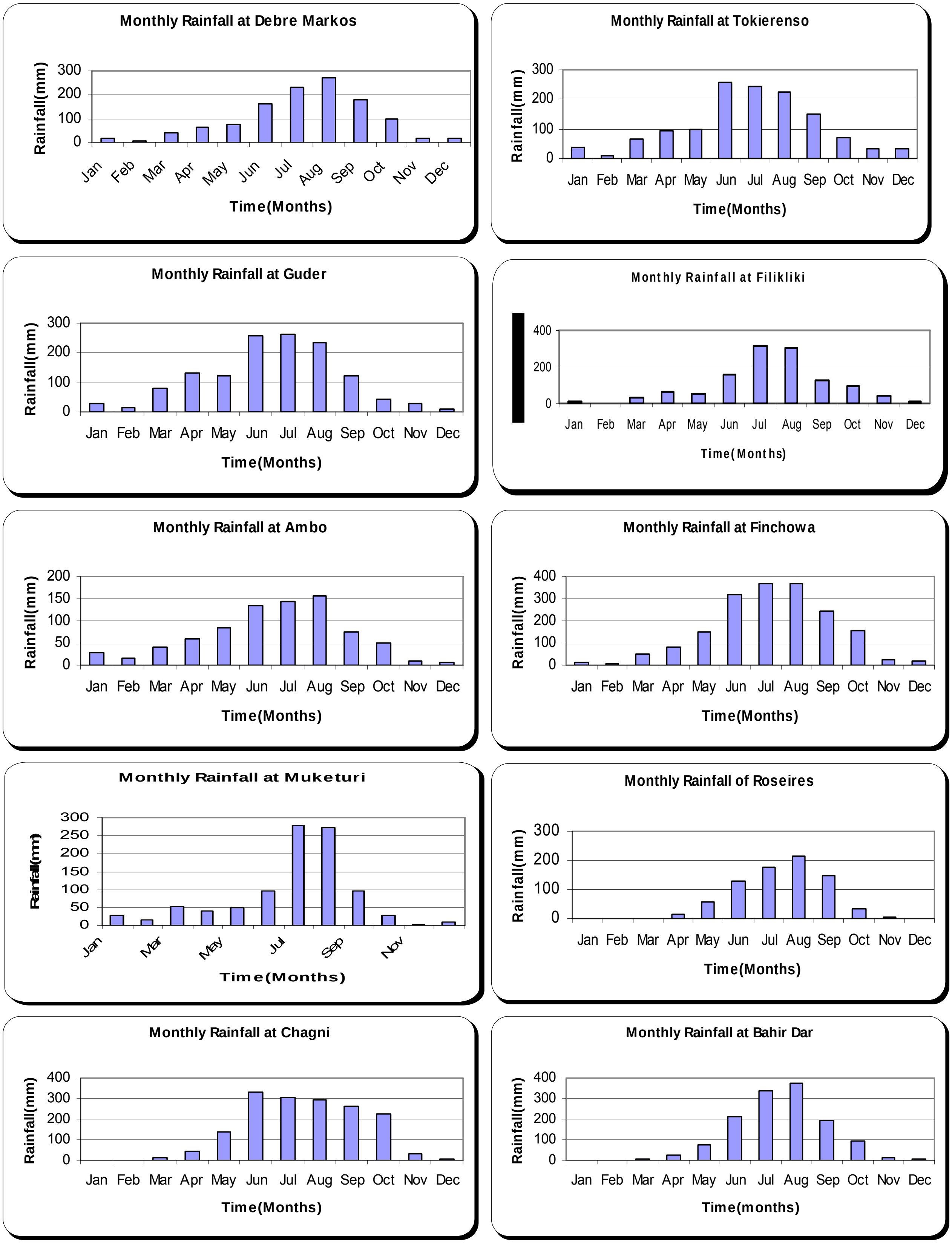


Fig.B-16 Monthly Rainfall Plot of Selected stations

APPENDIX C: STANDARD TABLES AND CHART

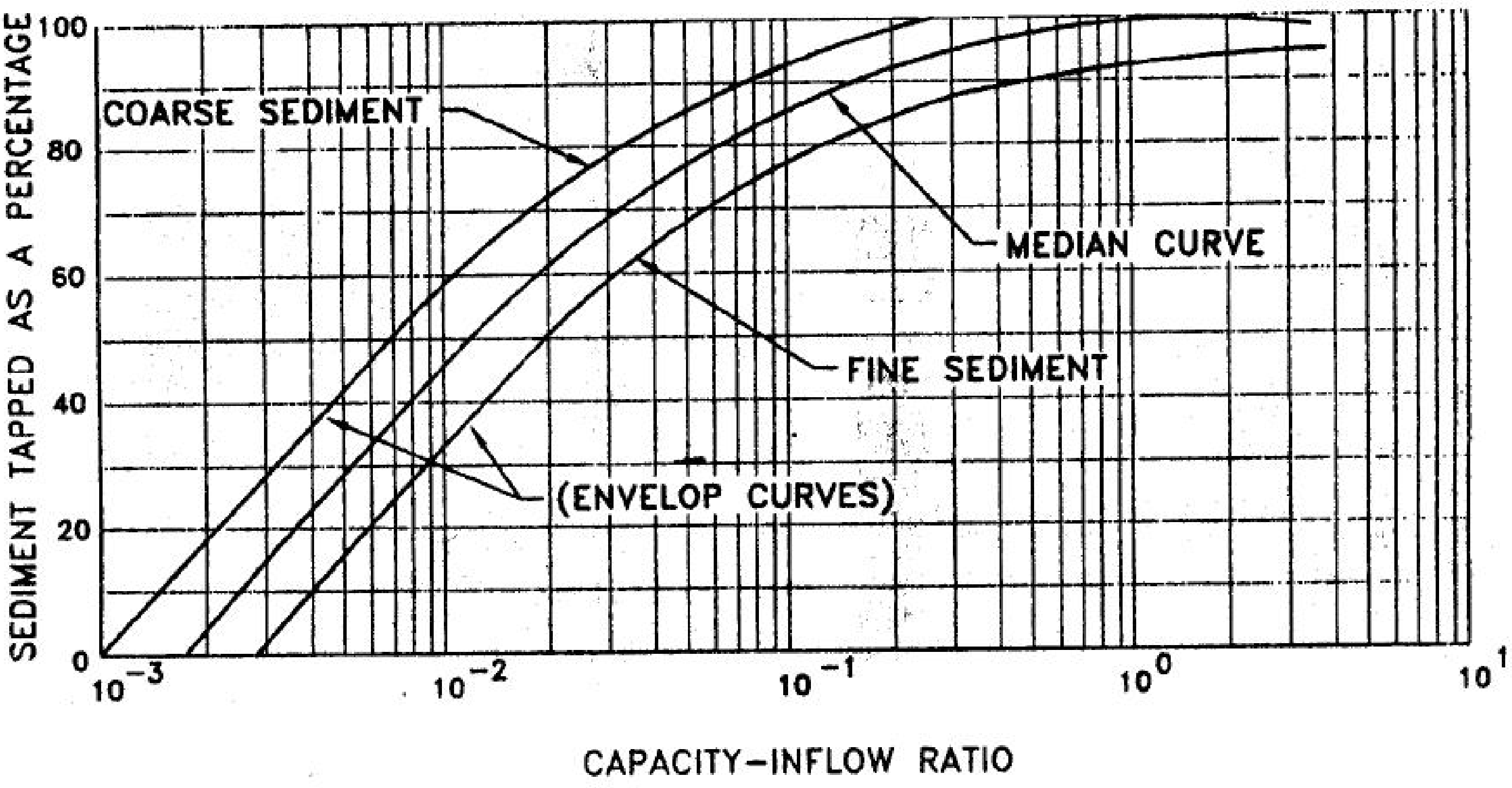
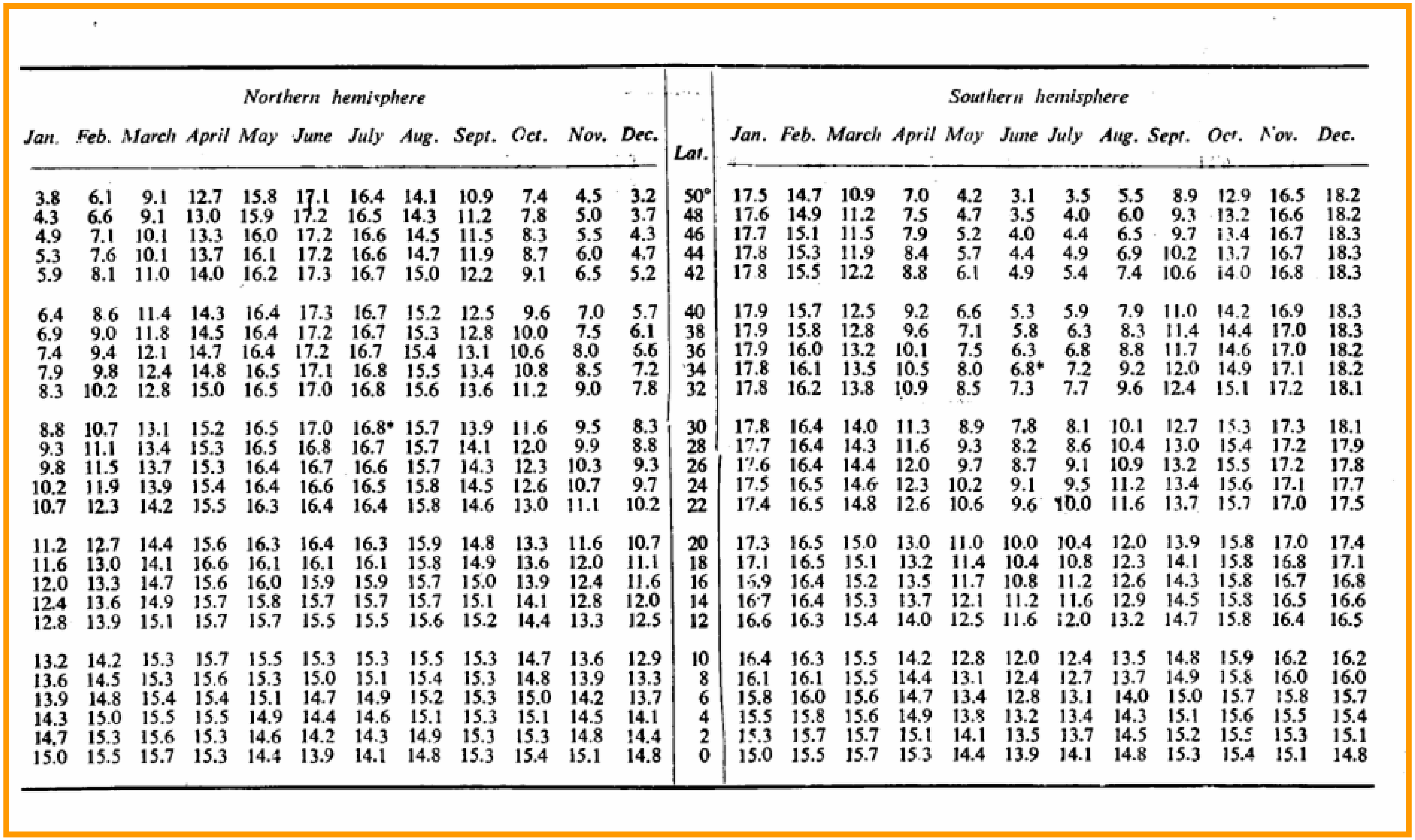


Fig C-1 Trap efficiency as related to capacity – inflow ratio



Northern hemisphere													Southern hemisphere											
Jan.	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Lat.*	*Jan.*	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*
3.8	6.1	9.1	12.7	15.8	17.1	16.4	14.1	10.9	7.4	4.5	3.2	50°	17.5	14.7	10.9	7.0	4.2	3.1	3.5	5.5	8.9	12.9	16.5	18.2
4.3	6.6	9.1	13.0	15.9	17.2	16.5	14.3	11.2	7.8	5.0	3.7	48	17.6	14.9	11.2	7.5	4.7	3.5	4.0	6.0	9.3	13.2	16.6	18.2
4.9	7.1	10.1	13.3	16.0	17.2	16.6	14.5	11.5	8.3	5.5	4.3	46	17.7	15.1	11.5	7.9	5.2	4.0	4.4	6.5	9.7	13.4	16.7	18.3
5.3	7.6	10.1	13.7	16.1	17.2	16.6	14.7	11.9	8.7	6.0	4.7	44	17.8	15.3	11.9	8.4	5.7	4.4	4.9	6.9	10.2	13.7	16.7	18.3
5.9	8.1	11.0	14.0	16.2	17.3	16.7	15.0	12.2	9.1	6.5	5.2	42	17.8	15.5	12.2	8.8	6.1	4.9	5.4	7.4	10.6	14.0	16.8	18.3
6.4	8.6	11.4	14.3	16.4	17.3	16.7	15.2	12.5	9.6	7.0	5.7	40	17.9	15.7	12.5	9.2	6.6	5.3	5.9	7.9	11.0	14.2	16.9	18.3
6.9	9.0	11.8	14.5	16.4	17.2	16.7	15.3	12.8	10.0	7.5	6.1	38	17.9	15.8	12.8	9.6	7.1	5.8	6.3	8.3	11.4	14.4	17.0	18.3
7.4	9.4	12.1	14.7	16.4	17.2	16.7	15.4	13.1	10.6	8.0	6.6	36	17.9	16.0	13.2	10.1	7.5	6.3	6.8	8.8	11.7	14.6	17.0	18.2
7.9	9.8	12.4	14.8	16.5	17.1	16.8	15.5	13.4	10.8	8.5	7.2	34	17.8	16.1	13.5	10.5	8.0	6.8*	7.2	9.2	12.0	14.9	17.1	18.2
8.3	10.2	12.8	15.0	16.5	17.0	16.8	15.6	13.6	11.2	9.0	7.8	32	17.8	16.2	13.8	10.9	8.5	7.3	7.7	9.6	12.4	15.1	17.2	18.1
8.8	10.7	13.1	15.2	16.5	17.0	16.8*	15.7	13.9	11.6	9.5	8.3	30	17.8	16.4	14.0	11.3	8.9	7.8	8.1	10.1	12.7	15.3	17.3	18.1
9.3	11.1	13.4	15.3	16.5	16.8	16.7	15.7	14.1	12.0	9.9	8.8	28	17.7	16.4	14.3	11.6	9.3	8.2	8.6	10.4	13.0	15.4	17.2	17.9
9.8	11.5	13.7	15.3	16.4	16.7	16.6	15.7	14.3	12.3	10.3	9.3	26	17.6	16.4	14.4	12.0	9.7	8.7	9.1	10.9	13.2	15.5	17.2	17.8
10.2	11.9	13.9	15.4	16.4	16.6	16.5	15.8	14.5	12.6	10.7	9.7	24	17.5	16.5	14.6	12.3	10.2	9.1	9.5	11.2	13.4	15.6	17.1	17.7
10.7	12.3	14.2	15.5	16.3	16.4	16.4	15.8	14.6	13.0	11.1	10.2	22	17.4	16.5	14.8	12.6	10.6	9.6	10.0	11.6	13.7	15.7	17.0	17.5
11.2	12.7	14.4	15.6	16.3	16.4	16.3	15.9	14.8	13.3	11.6	10.7	20	17.3	16.5	15.0	13.0	11.0	10.0	10.4	12.0	13.9	15.8	17.0	17.4
11.6	13.0	14.1	16.6	16.1	16.1	16.1	15.8	14.9	13.6	12.0	11.1	18	17.1	16.5	15.1	13.2	11.4	10.4	10.8	12.3	14.1	15.8	16.8	17.1
12.0	13.3	14.7	15.6	16.0	15.9	15.9	15.7	15.0	13.9	12.4	11.6	16	16.9	16.4	15.2	13.5	11.7	10.8	11.2	12.6	14.3	15.8	16.7	16.8
12.4	13.6	14.9	15.7	15.8	15.7	15.7	15.7	15.1	14.1	12.8	12.0	14	16.7	16.4	15.3	13.7	12.1	11.2	11.6	12.9	14.5	15.8	16.5	16.6
12.8	13.9	15.1	15.7	15.7	15.5	15.5	15.6	15.2	14.4	13.3	12.5	12	16.6	16.3	15.4	14.0	12.5	11.6	12.0	13.2	14.7	15.8	16.4	16.5
13.2	14.2	15.3	15.7	15.5	15.3	15.3	15.5	15.3	14.7	13.6	12.9	10	16.4	16.3	15.5	14.2	12.8	12.0	12.4	13.5	14.8	15.9	16.2	16.2
13.6	14.5	15.3	15.6	15.3	15.0	15.1	15.4	15.3	14.8	13.9	13.3	8	16.1	16.1	15.5	14.4	13.1	12.4	12.7	13.7	14.9	15.8	16.0	16.0
13.9	14.8	15.4	15.4	15.1	14.7	14.9	15.2	15.3	15.0	14.2	13.7	6	15.8	16.0	15.6	14.7	13.4	12.8	13.1	14.0	15.0	15.7	15.8	15.7
14.3	15.0	15.5	15.5	14.9	14.4	14.6	15.1	15.3	15.1	14.5	14.1	4	15.5	15.8	15.6	14.9	13.8	13.2	13.4	14.3	15.1	15.6	15.5	15.4
14.7	15.3	15.6	15.3	14.6	14.2	14.3	14.9	15.3	15.3	14.8	14.4	2	15.3	15.7	15.7	15.1	14.1	13.5	13.7	14.5	15.2	15.5	15.3	15.1
15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8	0	15.0	15.5	15.7	15.3	14.4	13.9	14.1	14.8	15.3	15.4	15.1	14.8

Figure C-2 Extra-terrestrial radiation (Ra) expressed in equivalent evaporation in mm/day (AM. Michael 1978)