ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

RESERVOIR OPERATIONAL PLANNING OF IRRIGATION DAMS FOR MICRO-HYDROPOWER DEVELOPMENT

(A Case Study Conducted on Haiba Micro-Irrigation Earth Dam in Tigray Regional State)

BY MULATU TIRUNEH

NOVEMBER 2005

ADDIS ABABA

ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

FACULTY OF TECHNOLOGY

DEPARTMENT OF CIVIL ENGINEERING

RESERVOIR OPERATIONAL PLANNING OF IRRIGATION DAMS FOR MICRO-HYDROPOWER DEVELOPMENT

(A Case Study Conducted on Haiba Micro-Irrigation Earth Dam in Tigray Regional State)

A Thesis Submitted to the School of Graduate Studies, Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Civil Engineering

BY MULATU TIRUNEH

NOVEMBER 2005

Declaration

I the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university. All sources of materials used for the thesis have been duly acknowledged.

Name: Mulatu Tiruneh

Signature: ____________________

Date: _______________

Place: Civil Engineering Department, Faculty of Technology, AAU.
Addis Ababa

ACKNOWLEDGMENT

This thesis is prepared under the advisory support of Dr.-Ing. Zelalem Hailu, Lecturer at Addis Ababa University in the Department of Civil Engineering and Ato Michael Abebe, Head, Dams and Hydropower Design Department in the Ministry of Water Resources. I therefore would like to express my sincere thanks to Dr.-Ing. Zelalem Hailu and Ato Michael Abebe for their intellectual and valuable contribution, their consistent guidance, feed back and comments on the various draft reports.

My thanks is also due to the Department of Civil Engineering, Faculty of Technology, Addis Ababa University, for facilitating my work in so many ways. I would like to thank all professors who gave me the post- graduate courses.

I would like to take this opportunity to extend my thanks to Tigray Regional State Water Development Commission and the respective line managers, team leaders and staff members who provided me with numerous valuable data and for their hospitable library service. I had a wonderful time and received a very keen support from the commission during my data collection, especially staffs who accompanied me on the field visits.

I would also highly appreciate and acknowledge the following institutions for providing data and information related to my research.

1. Ministry of Water Resources
2. Rural Energy Development and Promotion Center
3. National Meteorological Service Agency
4. Ethiopian Electric Power Corporation

Finally, I would like to express my indebted thanks to my wife Martha H/Mariam, my parents, sisters, brothers and friends who were always by my side and encouraging and helping me in taking off my burden.

TABLE OF CONTENTS

List of Tables

List of Figures

List of Abbreviations and Symbols

Abbreviations

SHP……………………..Small Hydropower

EREDPC……………….Ethiopian Rural Energy Development and Promotion Centre

EEPCO ………………..Ethiopian Electric Power Corporation

DP………………………Dynamic Programming

MW …………………….Mega Watt

MWh …………………..Mega Watt Hour

KW……………………..Kilo Watt

KWh ……………………Kilo Watt Hour

TWh…………………….Tera Watt Hour

MWR……………………Ministry of Water Resources

CSA…………………….Central Statistical Authority

Opt Rls…………………Optimal Release

MaxEnrgPrdcd……….Maximum Energy Produced

TRBIMPP………………Tekeze River Basin Integrated Development Master Plan Project

TRSBBWR…………… Tigray Regional State Bureau Water Resources

HHs…………………… Households

PH ……………………..Power House

STVC……………………Selam Technical and Vocational Centre

DSL…………………….Dead Storage Level

NPL…………………….Normal Pool Level

UNIDO…………………United Nations Industrial Development Organization

Symbols

i_t= reservoir inflow in a month t in units of 10^4 m^3

r_t= release in a month t in units of 10^4 m^3

$I_{rr,t}$ = irrigation water release in a month t

$r_{hp,t}$ = water released for power generation in a month t

S_t = initial storage volume in a month t in units of $10^4 m^3$

S_{t+1} = final storage volume at the end of month t in units of 104 m3

$\overline{S_t}$ = average storage volume during month t in units of $10^4 m^3$

s= instantaneous storage volume in units of $10^4 m^3$

h = instantaneous height of water above the turbine in m.

$\overline{h_t}$ = average height of water above the turbine in month t in m.

EV_t = evaporation from reservoir water in month t in units of $10^4 m^3$

SP_t = seepage water through the embankment of the dam in month t in units of $10^4 m^3$

$T_{ir,t}$= target water allocation for irrigation in month t in units of $10^4 m^3$

CC_{max}= the maximum conveyance capacity of the outlet structure in units of $10^4 m^3$

K= reservoir total storage capacity in units of $10^4 m^3$

K_d= dead storage capacity of the reservoir in units of $10^4 m^3$

K_w= minimum working storage capacity free of vortices in units of $10^4 m^3$

T= months in a year

n= months remaining for reservoir operation

Abstract

Modern forms of energy are simply not available in rural areas of Ethiopia, while traditional sources such as fuel wood, cow dung, and crop residue are being depleted rapidly thereby deepening the rural energy crisis. Compared with other new and renewable sources of energy, micro-hydropower has been recognized as being a viable and mature technology. It can be applied immediately on an economic scale in a flexible manner and can comparatively easily bring benefits to the population in isolated areas, who are so far not covered by national electricity supply grid.

About 84 percent of the Ethiopian people reside in rural areas and less than one percent of this population has access to electricity. However, a number of micro- irrigation dams have been constructed and planned for implementation, especially in Tigray and Amhara Regional States which could generate and provide electricity to the local population. A case study regarding reservoir operational planning had been conducted on Haiba dam, which is one of the fully implemented micro-irrigation earth dams in Tigray Regional State so as to integrate it with micro-hydropower. Accordingly a number of objectives were accomplished like formulation of discrete dynamic programming model, collecting, processing and analyzing meteorological data, collecting and preparing input data for the DP model.

A Visual Basic Program was written to solve the DP model. The main results obtained were monthly energy output, energy output duration curve and optimal reservoir operation guide curve. The optimal power output of Haiba reservoir has an electrification capacity of 50 to 650 households each using one light bulb of 40w each.

The results of this study showed that it is possible to produce a valuable amount of electric energy that is very useful in electrifying the rural community, from micro-irrigation dams without affecting its irrigation service by applying systems engineering as a planning tool. Based on the findings, conclusions and recommendations for further studies are drawn.

1. INTRODUCTION

1.1 General

Access to energy is a key element in rural development. However, despite two decades of attention to energy issues in Ethiopia in response to the international oil crisis of the 1970s, rural communities continue to be deprived of basic energy services (EREDPC, 2002). Modern forms of energy are simply not available in rural areas while traditional sources are being depleted rapidly thereby deepening the rural energy crisis.

Among the principal manifestations of the rural energy crisis is depletion of fuel wood resources. This leads to a decline in household welfare caused by an increased use of inferior fuels, higher fuel wood prices, and a reduction in the quality and variety of cooked meals. It also leads to a reduction in agricultural productivity as a result of the use of dung and crop residues for fuel instead of using them as a soil nutrient and to loss of human availability for productive work due to time spent on collecting fuels.

A number of factors are responsible for the prevailing rural energy crisis in the country. The high incidence of rural poverty, the wide geographical spread of rural settlements and the consequent lack of economies of scale, poor rural infrastructure and difficulty of access, absence of appropriate policy, strategy and institutional arrangement are among the key constraints (EREDPC, 2002).

The UN conference on new and renewable sources of energy spot lighted the importance of non-traditional forms and sources of energy in the development process of the developing countries. Compared with other new and renewable sources of energy, small and micro hydropower has been recognized as having a viable and mature technology. Unlike the other new and renewable sources, it can be applied immediately on an economic scale in a flexible manner, and can comparatively easily (and at reasonable cost) bring benefits to the population in isolated areas, who are so far not covered by national electricity supply grid (SHP in china, 1985). With the same source, it is noted that without upgrading the living conditions and standards of the rural population, very little can be achieved in terms of development. As one starting point, Micro-Hydropower could play a positive role towards accelerating a development process in developing countries, particularly, in the remote areas.

Moreover, according to EREDPC (2002), hydropower resource development has been given the first priority in the Ethiopian rural energy policy (this has been discussed in more detail in chapter two).

Despite all the above facts, a number of micro – irrigation earth dams have been constructed and planned to be constructed in different parts of the country especially in rural areas of Tigray and Amhara Regional states without taking into consideration the opportunity to integrate them with power generation so as to electrify the surrounding rural community.

If a reservoir has already been built for other purposes such as flood control, irrigation network, water abstraction for a big city, recreation area, etc., it may be possible to generate electricity using the bottom outlet as a penstock if the dam already has a bottom outlet as in figure 1.1. Otherwise, provided the dam is not too high, a siphon intake can be installed. Integral siphon intakes (Figure 1.2) provide an elegant solution in schemes with heads up to 10 meters and for units of no more than 1,000 MW, although there are examples of siphon intakes with an installed power up to 11 MW (Sweden) and heads up to 30.5 meters (USA).

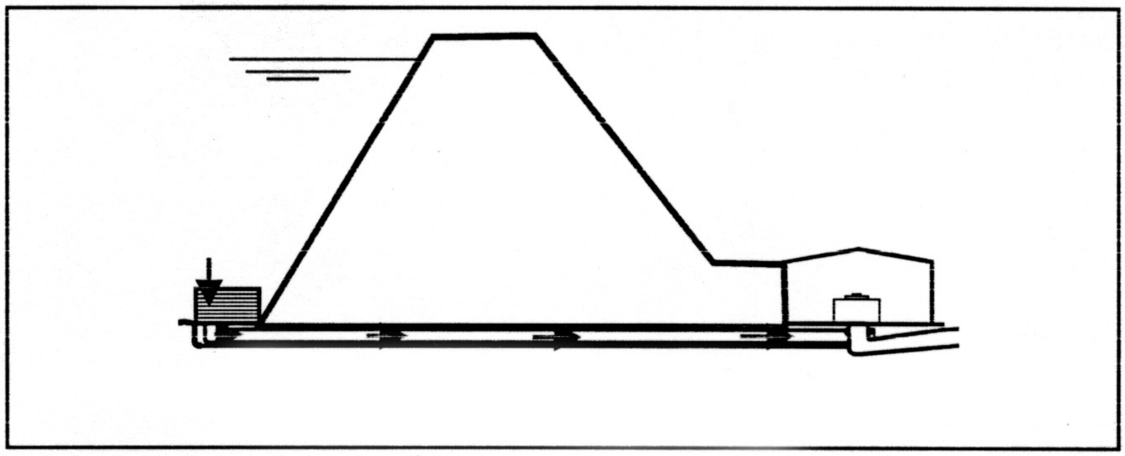


Fig. 1.1 Power House Located at the Base of the Dam

The turbine can be located either on top of the dam or on the downstream side. The unit can be delivered pre-packaged to the works, and installed without major modifications of the dam (Penche, 1998).

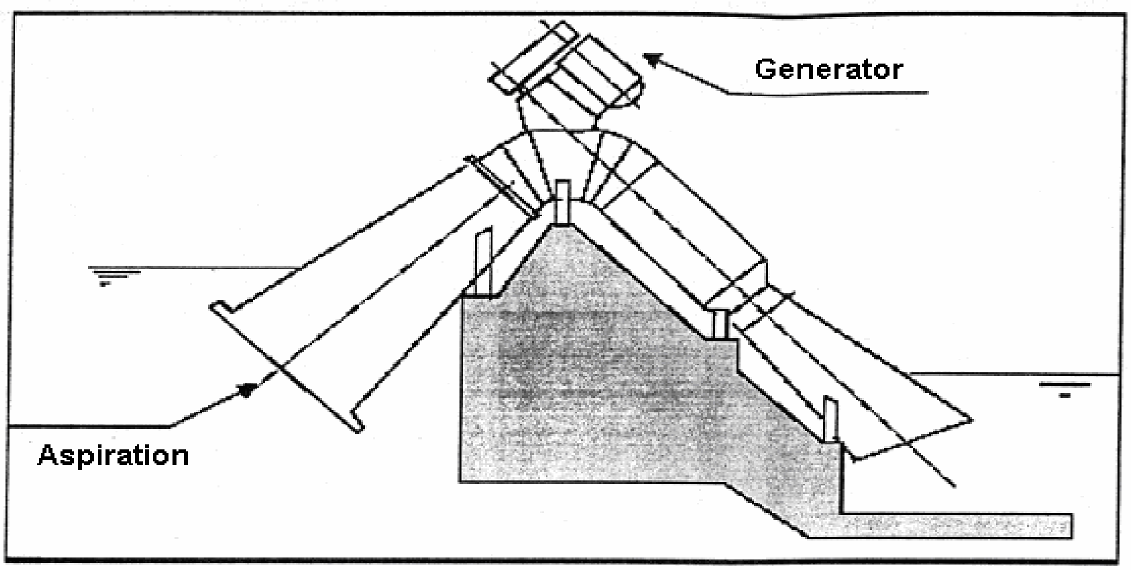


Figure 1.2 Siphon Intake (Generator Located on Top of the Dam)

The main questions are, therefore, how to harmonize the existing operational plan to the intended power generation and how to assess the optimum electrical power generation capacity of the dam at a given time (month) in a year.

Hence this thesis aims to assess the hydroelectric potential of Haiba micro-irrigation earth dam, which is found in Tigray regional state, without affecting the existing irrigation water supply by applying optimal reservoir operation techniques.

1.2 Statement of the Problem

The rural villages / 'Gots' like Adi Awusa (small rural town), Atsgebta and Endemeskel which are found surrounding the Haiba dam as well as government institutions like clinics, schools and development agents' offices and private flour mills in these villages do not have access to electricity. Due to this, they totally depend on traditional energy source, that is, biomass energy, for example, straw, wood, animal waste and so on and on petroleum products for their flour mills and night time illumination. Moreover, these traditional resources are being depleted rapidly due to deforestation, soil erosion and its fertility loss, population growth and so on, thereby deepening the rural energy crisis in the area.

On the other hand, Haiba dam is continuously releasing irrigation water through its bottom outlet from September to August and spills during the rainy season without producing any electric energy. Therefore, the turbine or the powerhouse can be located on the downstream side of the dam and can generate electric energy using the bottom outlet as a penstock without major modifications of the dam.

However, taking away from the reservoir for irrigation will result in the reduction of water for power generation. In most cases the time table of irrigation does not coincide with the electricity needs for household electrification. Moreover, the irrigation takes priority over power generation and thus a method has to be devised to harmonize power generation and irrigation.

1.3 Objectives of the Study

The overall objective of this study is to assess the potential of Haiba micro-irrigation earth dam for micro – hydropower development so as to electrify the surrounding rural community and to maximize the benefit of the stored water.

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

- Collecting, processing and analyzing meteorological data.
- Preparation of the input data for the DP model.
- Establishment of reservoir operation rule curve using the presently available meteorological information.
- Formulation of a discrete dynamic programming model which takes into account the release of water for both irrigation and hydroelectric power generation purposes.
- Writing a Visual Basic Program to solve the DP model.

1.4 Organization of the Thesis

The thesis is organized into eight chapters. Chapter one presents the introduction, statement of the problem and objectives of the study.

The second chapter discusses about micro hydropower development in Ethiopia. Potential and status of hydroelectric energy in general and its supply in rural areas is discussed in this chapter. The definition and advantages of micro hydropower are also dealt. Finally overview of rural electrification policies and strategies of Ethiopia are discussed in brief.

Chapter three and four deal with micro earth dam construction in Ethiopia and particularly in Tigray region and description of the study area respectively. In description of the study area salient features of Haiba micro irrigation earth dam are presented.

Chapter five deals with the data availability and analysis. The availability of meteorological and physical data is included along with the methods employed in the analysis.

Chapter six presents the reservoir operation modeling using dynamic programming. At the beginning of this chapter the different techniques of reservoir operation are discussed. The formulation of the dynamic programming model along with its objective function, constraints and algorithm are discussed in detail.

The results of dynamic programming model and discussion of the results are presented in chapter seven while summary, conclusions and recommendations are incorporated in chapter eight.

2. MICRO-HYDROPOWER DEVELOPMENT IN ETHIOPIA

2.1 Potential and Status of Hydroelectric Energy

Ethiopia, being one of the countries with the lowest GDP per capita has also the lowest per capita consumption of energy, particularly electric energy. The per capita electric consumption is 27.1 KWh (EEPCo, 2004).

On the other hand, Ethiopia has vast energy resources. The gross hydro based energy potential of the country is estimated at 650 TWh per year. It is estimated that out of this potential about 25 percent (162.5 TWh) could be exploited for power at economic costs and existing technologies (CESEN, 1986).

There are both traditional and modern energy sources in use in Ethiopia. Of the total energy produced in the country, 95 percent is from traditional sources like fuel wood, charcoal, agricultural residues and dry dung. The rest 5 percent is contributed by modern energy sources, notably petroleum products and electricity. The share of electricity is only 1 percent of the total national energy consumption in Ethiopia (EREDPC, 2002).

On the other hand, hydroelectricity accounts for about 98 percent of the total electricity supply in the country. However, it is only about 2 percent of the total hydropower potential of the country that is currently utilized (EEPCo, 2004).

According to CSA (2004), there are 625,496 domestic consumers connected to the public electricity system of EEPCo. The population of the country for 2003 was 73.04 million (or 14.6 million HHs). The proportion of the population with electricity connection from public sector was thus just 4 percent.

2.2 Electricity Supply in Rural Areas

According to CSA (2004), 84% of the Ethiopian people reside in rural areas where grid extension is not feasible and is largely dependent on biomass fuels for cooking, lighting and heating. Access to electricity in rural areas was limited to just 0.7 percent of the population or about 61,000 HHs in 1994. Moreover, even this few house holds consume very small amounts of electricity, usually lighting in the evenings (EREDPC, 2002).

Due to the vastness of the rural areas, the largely dispersed population and difficult communications, the total energy requirement is so large that no single energy component can meet it satisfactorily. Therefore, it is necessary to have a diversified energy policy based on increasing conventional energy generation and developing various new and renewable resources.

2.3 Definition of Micro-Hydropower

The capacity range of micro – hydropower plant is coordinated with the development of the national economy, and is especially related to the development of the rural economy and the level of rural electricity consumption. Accordingly different authors put different ranges. Some of the definitions are given as follows.

According to Harvey (1993), Micro – hydro schemes are small and usually do not supply electricity to the national grid at all. They are used in remote areas where the grid does not extend. Typically they provide power to just one rural industry, or one rural community. They range in size from 200 watts, just enough to provide domestic lighting to a group of houses through a battery charging arrangement, to 300 KW, which can be used for small factories and to supply an independent local 'mini – grid' which is not part of the national grid. And scheme ranging from 3 -10 MW is referred to as 'small hydro' power. Scheme with more than 10MW is referred to as 'full scale hydro' power.

According to Fritz (1984), small hydro projects are defined as systems of 15 - 30 MW or less capacity. Mini hydro refers to projects of 1MW capacity or less, and Micro hydro to projects of 100 KW capacities or less.

According to Ethiopian conditions, micro Hydro power is defined as having power generation capacity of less than 100 KW. This accords with definition by UNIDO and such countries as Turkey and Peru. Isolated hydropower sites having production levels higher than 100 KW are termed small hydropower. But the definition should not convey the wrong idea that an absolute demarcation is drawn between micro hydropower and upper production levels (Zelalem, 1992).

2.4 Advantages of Micro-Hydropower Plants

Socio - Economic Advantage

Cases have been identified where micro hydropower stations have acted in development pole which started with the supply of light to the village communities, stimulating the positive and active thinking of population to utilize the available electric power for semi industrial activities, and gradually acquiring and strengthening the mechanical and metal working capabilities of the population (SHP in china, 1985).

There is an increasing need in many countries for power supplies to rural areas, partly to support industries, and partly to provide illumination at night. Government authorities are faced with very high costs of extending electricity grids. Often micro-hydro provides an economic alternative to the grid. This is because independent micro-hydro schemes save on the cost of grid transmission lines and because of grid extension schemes often have very expensive equipment and staff costs. In contrast, micro -hydro schemes can be designed and built by local staff and smaller organizations following less strict regulations and using 'off-the shelf ' components or locally made machinery (Harvey, 1993).

Although the unit cost per installed kilowatt of generating capacity is higher for small scale projects, financing is often easier to obtain. These characteristics make micro hydro particularly attractive for least developed countries where near term installation of dispersed energy systems is essential for economic and social development (Fritz, 1984).

Physical and Technical advantages

Since the technology is simple, it has quick response to the needs of the community. It does not require massive hydraulic structures and has a short construction period.

As already explained the equipment and structures can be designed and built by local staff (experts from one's own country) and smaller organizations. Utilization of local materials for civil work is especially important in design of civil works and manufacture of electro mechanical equipment locally will certainly lead to reduced costs thereby making the project more feasible and sustainable.

One of the technical centers that have good capability in manufacturing hydro related equipment in Ethiopia is Selam Technical and Vocational centre (STVC). These are relatively simple cross flow turbines for a power range of 5-250 KW (STVC, 2000).

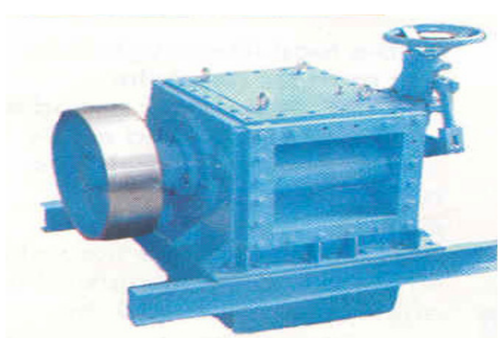


Figure 2.1 Cross Flow Turbine Manufactured by STVC (Source: STVC)

Most of the systems installed use direct shaft power running a grinding mill. Only a few are connected to generators (e.g 15 KW in Arbaminch Hospital). A 17 KW unit was also delivered to the international technology development group and installed the system in Kenya (Michael, 2004).

Environmental Advantages

According to Fritz (1984), when compared to large scale hydro projects micro hydro can be planned and built in less time and are less likely to create extensive environmental problems. Moreover, unlike fuel-driven industries, the water powered plants do not affect the environment with smoke and by products of fuel oil.

Through the use of local hydropower resources, problems related with deforestation could be minimized. This needs special attention since Ethiopia is one of the countries which are in deforestation risk zone. The extremely backward and wasteful pattern of energy consumption based mostly on biomass and particularly fuel wood has led to a high degree of ecosystem imbalance causing wide scale deforestation, environmental degradation, soil erosion and consequent loss of soil fertility and wide spread climatic changes with enormously disastrous social and economic consequences (Zelalem, 1992).

2.5 Overview of Energy Policies and Strategies of Ethiopia

According to EREDPC (2002), as part of overall programme of economic reforms, the government of Ethiopia formulated a national energy policy in 1994. The policy states the general objectives and priorities of the government in the energy sector. These include:

- Development of hydropower resources
- Shift from traditional fuels to modern fuels
- Establish standards and codes for efficient energy use
- Development of human resource and strong institutions
- Promote and support private sector participation in development of energy resources and
- Incorporate environmental considerations in development of energy programmers.

Increasing access to electricity in rural areas to significant levels clearly requires huge resources both from the government and non governmental sectors. The government in recognition of the above has formulated a rural electrification strategy with two components.

i. To extend the publicly owned grid system into rural areas, and

ii. To promote private sector – led off grid rural electrification i.e. in villages which are found where EEPCO can't cover them in the near future by extending its grid.

In implementation of the rural electrification strategy the government established a rural electrification fund by proclamation in 2003 as a permanent financial source with the following objectives:

1. To provide loan and technical services for rural electrification project carried out by private operators, cooperatives, and local communities and more specifically for those projects operating on renewable energy resources, and

2. To encourage the utilization of electricity for production and social welfare purpose in rural areas.

The sources of the fund shall be budget allocated by the government, loans and grants from international financial institutions, loans and grants from other governments, grants from non- governmental organizations and income from other different sources (EEA, 2004). One important point noted in the same is that the rural electrification program is justified by its potential contribution for the socio economic development of the rural areas of the country.

3. MICRO-EARTH DAM CONSTRUCTION IN ETHIOPIA AND PARTICULARLY IN TIGRAY REGION

Construction of Micro-dams in Ethiopia started in the late seventies to combat the recurrent drought in the country. Construction of micro dams by the Cuban engineering team had been carried out from 1978-1982 after the agreement made on the collaboration between the Ethiopian and the Cuban Governments, started just after the visit made by the Cuban President Fidel Castro Ruz to Ethiopian in September 1978. The dams constructed by the team had been working together with the Ethiopian Water Resource Authority's counter parts. During their stay in Ethiopia, they studied, designed and constructed 4 micro-dams. These are, Belbela, Wedecha, Tolly and Chichat dam. The first three are in the Awash River basin and the fourth one is in the Tekeze River basin. In addition to these dams a micro dam known as Diksis was built to provide drinking water to the Diksis state farm. It was commissioned in 1979 (Michael, 2004).

Since 1992 the responsibility for the development of small-scale irrigation schemes has been transferred to the regional governments. Sustainable Agricultural and Environmental Rehabilitation Commissions (COSAER) have been established in Tigray, Amhara and Southern Nations Nationalities and people's regional state. These Commissions have been conducting design and implementation of small – scale irrigation dams in their respective regions.

In Tigray and Amhara regional states a total of 48 and 6 small dams were constructed to irrigate 3194. 5 ha land. The detail description of these dams in Tigray is found in Table 3.1. Their storage capacity ranges from 0.1-3.10 Mm^3 and 38 similar projects have been studied in Tigray Regional state for subsequent implementation (TRSBWR, 2003).

Table 3.1 Fully Implemented Micro-dam Irrigation Schemes Existing in Tigray (Source: TRSBWR, 2003)

S/N	Site Name	Woreda	Capacity (Mm^3)	Dam Height (m)	Reservoir Area(ha)	Command Area (ha)
1	Mejae	H.Wejerat	0.30	13.50	6.00	14.00
2	Gereb-Mihiz	H.Wejerat	1.35	17.50	30.00	80.00
3	Mai-Gassa	H.Wejerat	1.30	12.70	42.12	70.00
4	Mai-Delle	H.Wejerat	1.77	15.00	35.00	90.00
5	Gum-Sellasa	H.Wejerat	2.03	11.50	48.00	110.00
6	Adi-Kenafiz	H.Wejerat	0.75	15.50		60.00
7	Mai-Haidi	H.Wejerat	0.24	9.20	5.65	9.00
8	Gra-Shito	H.Wejerat	0.30	10.00	6.72	16.00
9	Fledgling	H.Wejerat	0.28	14.00	6.60	20.00
10	Dur-Anbessa	H.Wejerat	0.13	18.00	14.00	61.00
11	Gereb-Segen	H.Wejerat	0.55	14.86	11.70	24.00
12	Shilant III	H.Wejerat	0.15	9.00		7.00
13	Meskebet	Laelay Adi	1.34	17.50	52.80	70.00
14	Mai Gundi	Laelay Mai	0.80	12.50		46.00
15	Ruba Feleg	Ats. Wenbe	0.90	17.50		80.00
16	Felaga	Ats. Wenbe	0.90	11.92	21.53	75.00
17	H.W.Cheber	Enderta		15.50		80.00
18	Era Quhila	Enderta				87.00
19	Haiba	H.Wejerat	3.10	16.00	95.00	100.00
20	MwL	H.Wejerat	1.40	19.00	31.00	100.00
21	Adi-Amharay	Enderta	0.96	14.70	31.50	60.00
22	Era	Wenberta	1.96	16.70		100.00
23	Sewhineda	Enderta	0.36	14.50	7.80	23.00
24	Teghane	Ats. Wenbe	1.08	11.00	60.00	
25	Mai-Negus	Laelay Mai	2.38	24.00	38.00	150.00
26	Laelay-Wukro	Wukro	0.93	11.00		50.00
27	Korir	Tsirea		15.00	32.00	100.00
28	Gereb-Awso	Enderta	0.11	10.50	2.12	9.00
29	Adi-Hilo	Enderta	0.10	11.40	2.50	9.00
30	Shilanat I	Enderta	1.61	23.00		98.00
31	Gindae	Wenberta	0.73	19.50		53.00
32	Adi-Shihu	Wenberta	1.00	10.80	36.00	40.00
33	Endazeoy	Enderta	0.18	12.34	4.05	13.00
34	Hashenge	Enderta	2.23	19.00	38.00	120.00
35	Arato	Enderta	2.59	20.00	40.00	120.00
36	Mai-Serakit	Enderta	0.49	11.00		31.00
37	Adi-Gela	Enderta	0.51	18.00		30.00
38	Embagedo	H.Wejerat	1.35	22.00	18.50	100.00
39	Embagedo	Dedba Dergeajen	1.78	20.00	36.00	80.00
40	Zamra Diversion	H.Wejerat				
41	Gereb-Birki	Enderta	1.01	17.80	17.00	88.00

continued

42	Shilanat IV H.Wejerat		2.86	24.00	31.50	171.00
43	Mai Egam		0.17	13.00		10.00
44	Gerb Shegalu		1.00	20.00		50.00
45	Higaetcheber		N.A	15.50		80.00
46	Lealay Yukro		0.93	11.00	50.00	
47	Betiquate		0.61	16.00	70.00	
48	Embagedo		1.78	20.00		80.00
	Total					**3194.50**

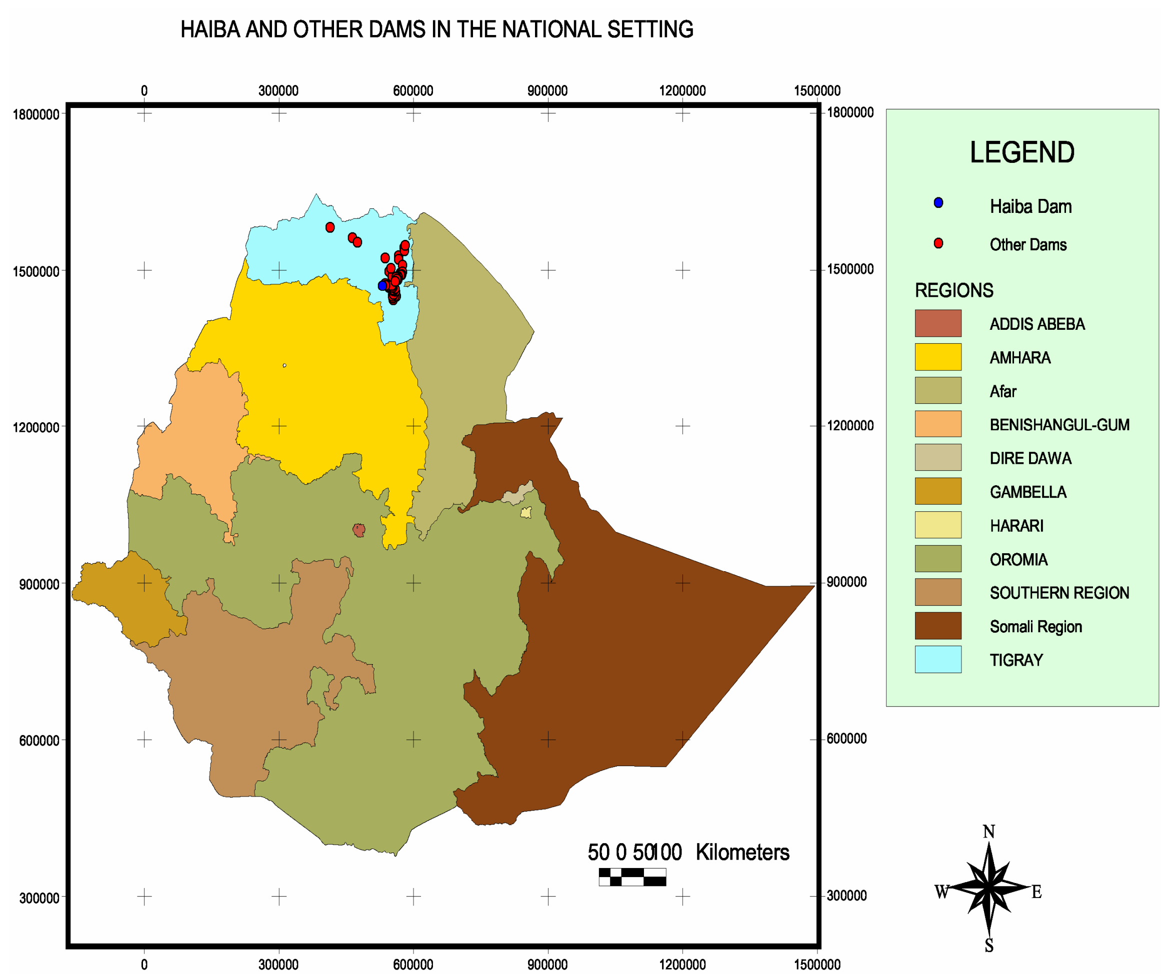


Figure 3.1 Fully Implemented Dams and their Distribution in Tigray Region

Most of the fully implemented dams (operational dams) are located in southern part of the region including Haiba dam as shown in figure 3.1. According to the information obtained from water resource development commission, this relatively high concentration of micro-dam construction in southern region is due to the food shortage existing in the area.

4. DESCRIPTION OF THE STUDY AREA

4.1 Location, Population and Climate

Haiba Earth Dam is found in Tigray Regional State, southern zone and Samre Woreda. Geographically it is located 13°17'19.6'' north and 39°16'44.7'' east with an altitude of 2264m amsl. The dam is found at 45km from Mekelle and at about 17 km from the Woreda town Samre.

It is a single purpose dam designed and constructed (commissioned) in 1996 and 1999 respectively to irrigate 100 hectare of land. Accordingly it is used for irrigation only. Both design and construction had been carried out by the Water Development Commission of the region the then SAERT/Sustainable Agriculture and Environmental Rehabilitation for Tigray.

The dam is one of the successful dams constructed by the commission. It has stored adequate quantity of water and spills during the rainy season.

Figure 4.1 Photographs Showing the Different Views of Haiba Reservoir

There are about six rural villages namely Assegbta, Astah, Hantebat, Enegabir, Endameskel and Mai-Senti in addition to one rural town (Adi Awuso) which do not have access to electricity. Their means of living is totally dependent on agriculture. According to the information obtained from the development agents of these villages, the total population living in these areas is estimated to be 1200 house holds with an average household family size of five. Average household farm size is 1.25 hectare (Sinkneh, 1996). According to the same source, there is a severe fuel wood shortage in this area. People collect fuel wood from distant places.

The agro-climate of Samre woreda is 'Dry Woyna Dega' type. The mean annual rainfall of the woreda is about 427.38mm and there are two main rainy seasons namely 'Meher' rain covering from June to September and 'Belg' rain covering from March to May. The average temperature of the area ranges from 9.94 - 22.65°C (Sinkneh, 1996).

4.2 Salient Features of Haiba Micro-Irrigation Earth Dam

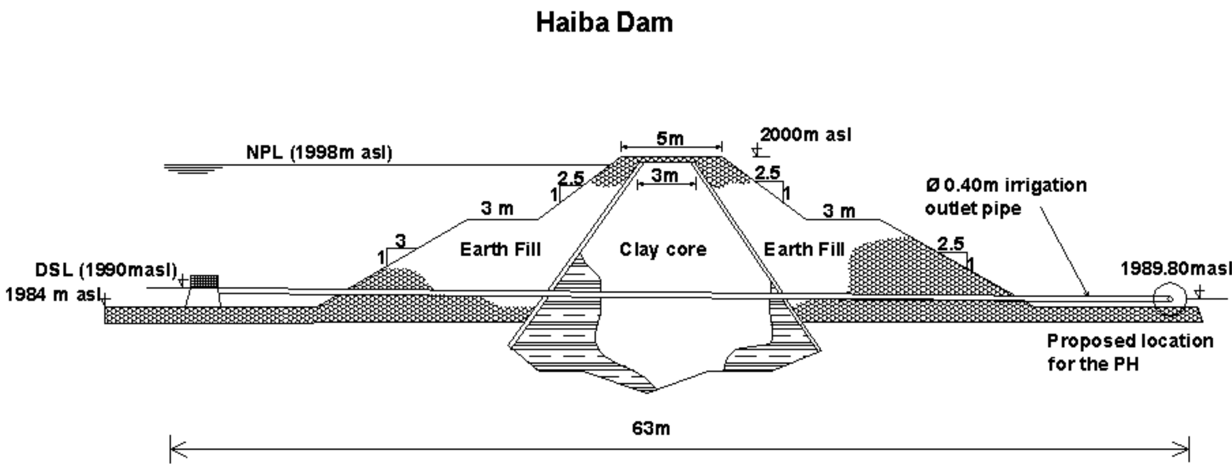


Figure 4.2 Schematic Diagram of Haiba Dam

Hydrology

Mean Annual Rainfall...427mm

Mean Annual Runoff...$402*10^4 m^3$

Catchment Area...$24.7 km^2$

Weighted average runoff coefficient............................0.26

Expected life of reservoir..48years

Dam

Dam type ....Earth fill

Dam height...16m

Dam crest length...162m

Dam crest width...5m

Dam crest elevation..2000m amsl

Dam bottom level...1984m amsl

Reservoir

Storage capacity...$3.11*10^6 m^3$

Dead storage capacity.. $46995 m^3$

Surface area...95 hectare

Normal pool level..1998m amsl

Dead storage level..1990m amsl

Spillway

Spillway type..Chute & Natural bed rock

Length of crest...50m

Discharge........................ ....$97 m^3/s$

Irrigation Outlet

Type..Circular Welded Steel Pipe

Elevation of its centre.......................................1989.8m amsl

Command Area..100 hectare

Rate of Sedimentation..................................$800 m^3/km^2/year$

4.3 Assessment of the Project Site during the Field Visit

During field visit, which was conducted at the beginning of April, 2005 the following site conditions were observed.

The structural aspects of the dam, such as the dam body, the spillway and the irrigation outlet have been found to be at good condition. The reservoir water level was at about 3.5m below the normal pool level and it was supplying water for irrigation purpose.

Figure 4.3 Photograph Showing Part of Spillway

Figure 4.4 Photograph Showing the Irrigation Outlet

According to the information obtained from the reservoir operator and development workers of the kebele, the reservoir has no definite rule of release and totally depends on the operator's personal decision and on the users' request. Generally the irrigation water is released from September to August 12 hours a day during day time.

In general, much of the information which was obtained from design document has been verified during the field visit and from the informal interview made with the farmers, reservoir operator and development agents.

5. DATA AVAILABLITY AND ANALYSIS

Data on meteorology such as rainfall and evaporation, monthly irrigation demand, seepage, elevation-area curve, elevation-storage curve, topography, and hours of operation of the reservoir are among the major ones that have been collected. Therefore, the meteorological data and runoff data availability, processing and analysis will be dealt within the following sections of this chapter. However, preparation of input data for dynamic programming model such as monthly inflows, monthly evaporation as well as data and information on irrigation demand, and seepage will be discussed in the next chapter.

5.1 Meteorological Data

5.1.1 Rainfall

The relevant precipitation in the research area is precipitation in the form of rainfall. Monthly precipitation data of four stations, namely Dengolat, Mekelle, Samre and Adigudom, have been collected from the National Meteorological services Agency of Ethiopia. Dengolat station is located within the catchment of Haiba reservoir at 6km from the dam. It is a point rainfall. The monthly inflow data for the reservoir is used from the data obtained from this meteorological station. However, the data is not processed and quality control is not made to it. Moreover, there are a number of missing data to this station. Due to this, rainfall data have been collected from other nearby stations which are found within the same agro-climatic condition as the Dengolat station. These are Mekelle, Samre and Adigudom meteorological stations located at 37km, 20km and 20 km respectively from it. These stations have been used to infill the missing data and to check its consistency. The rainfall data from these stations have been checked for their consistency and the missing data have been calculated. Eventhough the data collected covers recent period about 20 to 30 years, only the data from the

1992 to 2004 is continuous and is used for analysis. For example, for Dengolat station 9 - years of data that is from 1983 up to 1992 is missed.

In this study the mean monthly values have been determined and the missing monthly data have been filled using arithmetic average and normal ratio methods. Both the mean monthly values and the summarized annual rainfall values in mm are given in Annex – A. The graphs showing the monthly and yearly variability of rainfall at Dengolat station are given below. For other stations, the graphs are attached in Annex – B.

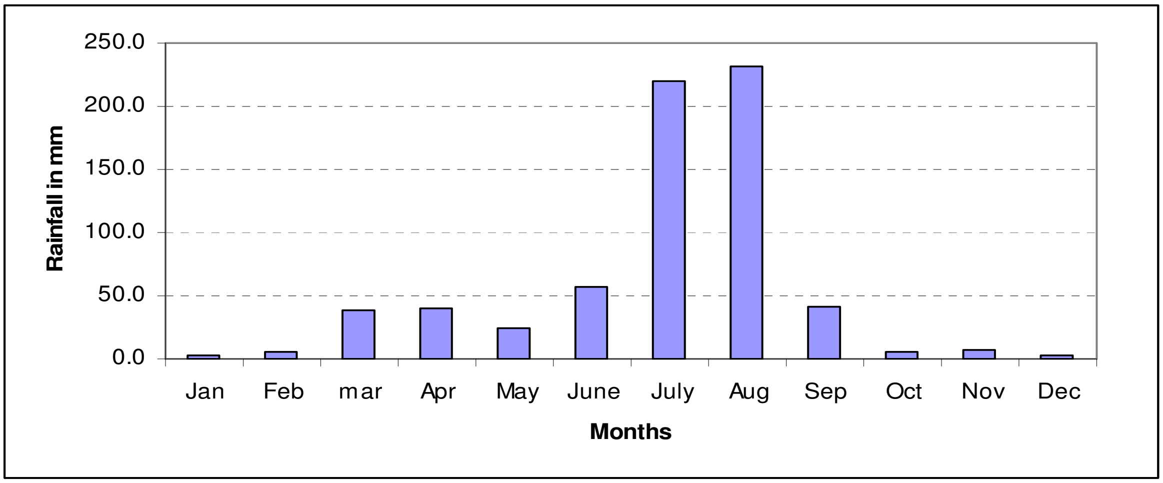


Figure 5.1 Mean Monthly Rainfalls at Dengolat Station

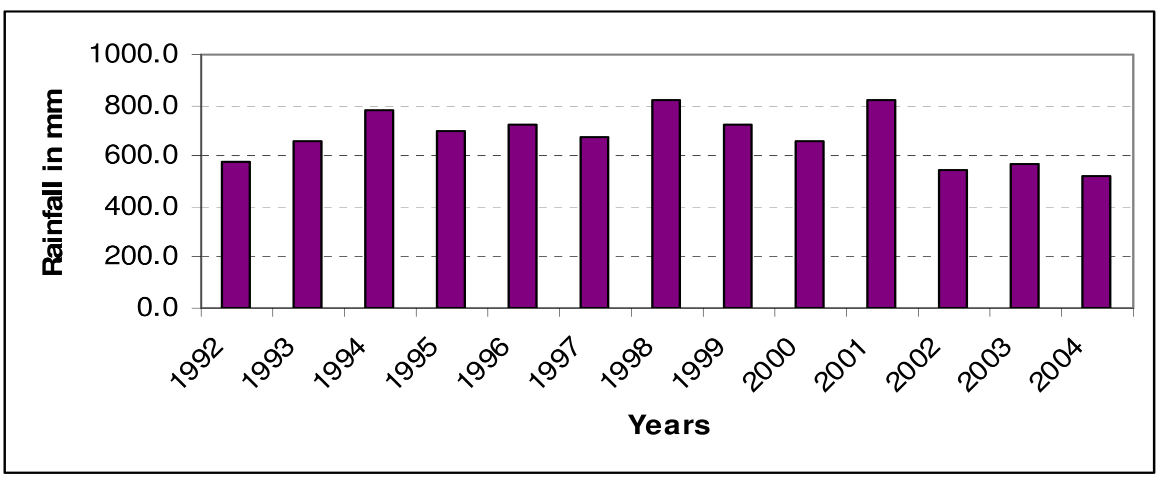


Figure 5.2 Annual Rainfalls at Dengolat Station

The figures given above indicate that the rainfall characterstics is a bimodal rainfall pattern. The main rainy season in the Haiba reservoir is from July to September while the second rainy season is from March to May.

A double mass curve technique is used to test the consistency and accuracy of rainfall records at all stations. After constructing the double mass curve, it is found that there is no inconsistency observed for all stations. The double mass curve constructed for Denogolat stations is presented below. Mekelle, Adigudom, and Samre are the base stations used in double mass curve analysis of Dengolat stations. For other stations, refer Annex - B.

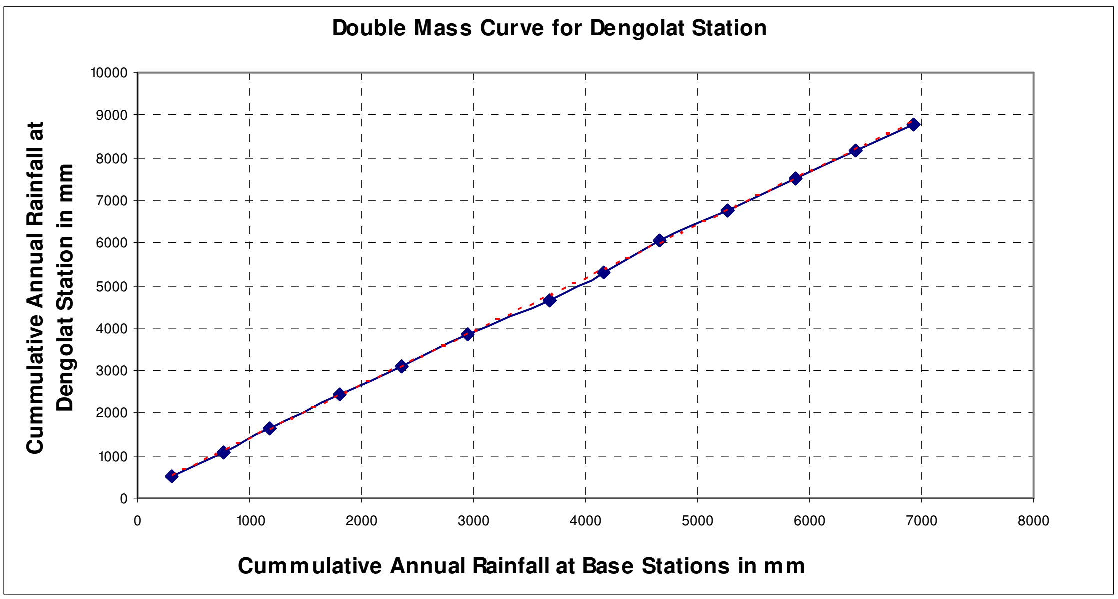


Figure 5.3 Double Mass Curve Plot for Dengolat Station

5.1.2 Evaporation

The evaporation loss from Haiba reservoir is estimated using evaporation data collected at Mekelle meteorological station. Pan evaporation data is available only for 1966 to 1969 and for 1992 to 1995. In between these two periods data is missing and not continuous. Therefore, the data between 1992 to 1995 has been used for analysis. The monthly average and annual evaporation have been determined and are given in Annex – A. Hence evaporation from the reservoir could be computed by the following formula:

$$EV_a = K_p EV_m \qquad (5.1)$$

Where: EV_a = actual evaporaton from the reservoir in mm

EV_m = measured evaporation from pan in mm

K_p = pan coefficient.

The annual pan coefficient for surface pan of class A is 0.7. The true coefficient on seasonal basis may vary from 0.6 to 0.8 (Reddi, 2002).

5.2 Runoff

Haiba catchment is a small catchment which is equipped neither with rain gauges nor a stream gauge facility at the outlet. Moreover, there is no information such as type of soil, type of covers, soil classification, infiltration capacity of soil, and so on. Hence, eventhough there are relatively more acceptable methods of estimating runoff from ungaged catchment such as infiltration method and runoff curve numbers method, here runoff coefficient method has been adopted.

Runoff Coefficient Method

The runoff can be directly computed approximately, by using an equation of the form.

$$Q = K.P \qquad (5.2)$$

Where: Q = runoff in mm or cm,

P = precipitation in mm or cm and

K= run off coefficient.

The runoff coefficient K depends upon the characteristics of the catchments. However, this formula cannot be rational, because the run off not only depends upon the precipitation, but also depends upon the recharge of the basin. But the equation gives more and more reliable results, as the imperviousness of the drainage area increases and the value of k, tends to approach unity (Garag, 2003). Various values of k, which are commonly used, are given in Annex -A from the same source.

6. DYNAMIC PROGRAMMING MODEL FOR RESERVOIR OPERATION

6.1 Reservoir Operation Techniques

6.1.1 Guide Curves for Reservoir Operation

Guide curve also called operating rule (policy) is a time schedule of releases from reservoirs. The purpose of operating rule for water resource systems is to specify how water is managed throughout the system. The establishments of such schedules, which indicate quantities of water to be affected through the action of the manger at defined points in time, is an important problem in water resources engineering. The problem is, of course, the selection of the operating procedure that will best achieve the stated objective (s) of the development scheme.

A set of operating rules established for the reservoir takes account of inflows, needs for water withdrawals and releases, storage volumes, and reservoir elevations.

Buras (1972) stated that it was customary for a long time to establish operating rules on the basis of personal judgment alone. No alternative procedures were tested. The rules were generally simple: (1) store all inflow unless needed to meet a target output; (2) when available, release water from storage to fulfill immediate needs; (3) study all damaging floods on record in the flood control analysis. As water resources systems became more complex, however, it became apparent that operating procedures consist of three (and possibly four) kinds of decisions. Storage and release of water must be apportioned among (1) reservoirs; (2) purposes; (3) time periods; and (4) depth layers from a reservoir to provide water of required quality. Furthermore, it was recognized that operating procedures are sequential decision problems and have to be treated as such.

There are two basic approaches for solving and analysis of operating procedures: simulation and optimization.

6.1.2 Simulation

Simulation relies on trial – and –error to identify near optimal solutions. The search for an optimal alternative is dependent on the engineer's ability to manipulate design variables and operating policies in an efficient manner. There may be no guarantee that a globally optimal alternative is found (Mays and Tung, 1992).

Simulation is not an optimizing procedure. Rather, for any set of design and operating policy parameter values, it merely provides a rapid means for evaluating the anticipated performance of the system. It is necessary for the analyst to specify the trial design (or, equivalently, to allow the computer to do so in accordance with some algorithm), where upon the simulation model yields estimates of the economic, environmental, and other responses associated with that trial. Simulation methods do not identify the optimal design and operating policy, but they are an excellent means of evaluating the expected performance resulting from any design and operating policy. Hence they are often used to assist water resource planners in evaluating those designs and operating policies defined by simpler optimization models (Loucks et al., 1981).

6.1.3 Optimization Techniques

The most commonly used optimization techniques in water resource problems are Langrange Multipliers, Linear Programming, Non-linear Programming, Dynamic Programming, Quadratic Programming and Geometric Programming. Each of these is highly dependent on the mathematical structure of the model. The choice of techniques usually depends on the characteristics of the reservoir system, on the availability of data, on the objective and constraints specified. Due to its primary relevance for this study only dynamic programming is briefly explained below.

6.2 Dynamic Programming

Dynamic programming (DP) is a mathematical technique that is often useful for making a sequence of interrelated decisions where nonlinearities in the objective function or constraints are present. It provides a systematic procedure for determining the combination of decisions which maximizes overall effectiveness. There is no standard mathematical formulation for dynamic programming, and general DP computer codes are usually not available. The procedures are not difficult, however, and a computational code can be written for each application. Although there are similarities in the construction of various DP problems, the specific approach and the necessary equations are tailored to suit the actual situations (Good man, 1984).

Dynamic programming transforms a sequential or multistage decision problem that may contain many interrelated decision variables into a series of single – stage problems, each containing only one or a few variables. In other words, the DP technique decomposes an N – decision problem into a sequence of N-separate, but interrelated, single decision sub problems. Decomposition is very useful in solving large, complex problems by decomposing a problem into a series of smaller sub problems and then combining the solutions of the smaller problems to obtain the solution of the entire model composition. The reason for using decomposition is to solve a problem more efficiently which can lead to significant computational savings. As a rule of thumb, computations increase exponentially with the number of variables, but only linearly with the number of sub problems (Mays and Tung, 1992).

Dynamic programming can overcome the short comings of enumeration of all combinations of the problem using the following concepts.

1. The problem is decomposed into sub problems and the optimal alternative is selected for each sub problem sequentially so that it is never necessary to enumerate all combinations of the problem.
2. Because optimization is applied to each sub problem, non optimal combinations are automatically eliminated.
3. The problems are linked together in a special way so that it is never possible to optimize over infeasible combinations.

The basic elements and terminologies in a dynamic programming formulation are introduced as follows.

1. Stages are the points of the problem where decisions are to be made. If a decision making problem can be decomposed into N sub problems, there will be N stages in dynamic programming formulation.
2. Decision Variables are courses of action to be taken for each stage. The number of decision variables in each stage is not necessarily one.
3. State variables are variables describing the state of the system at any stage. A state variable can be discrete or continuous, finite or infinite. The state variables of the system in a dynamic programming model have the function of linking succeeding stages so that, when each stage is optimized separately, the resulting decision is automatically feasible for the entire problem. Furthermore it allows one to make optimal decisions for the remaining stages without having to check the effect of the future decisions for decisions previously made.
4. Stage return is a scalar measure of the effectiveness of decision making in each stage. It is the function of the input state, the output state, and the decision variables of a particular stage.

5. Stage transformation or state transition is a single valued transformation which expresses the relationships between the input state, the output state and the decision.

6.3 Formulation of the Dynamic programming Model

6.3.1 Objective function and constraints

Objective Function

As already explained in chapter one, the objective of this study is to integrate the irrigation service of Haiba micro- irrigation dam with micro- hydropower development in the context of rural electrification. Moreover, the dam was initially constructed as a single purpose reservoir (irrigation), and hence it had been giving this service only since it was commissioned in 1999. Therefore, the addition of the new service, that is, production and supply of electrical energy shouldn't affect the irrigation as much as possible.

To maintain the above mentioned policy, the objective could be stated as maximization of return obtained from energy production maintaining the target allocation of water for irrigation. However, it is better not to relate the objective function in monetary terms because of the following reasons.

1. The benefits obtained from micro- hydropower development couldn't be easily expressed in monetary terms rather it can be explained in the role it plays in bringing a fast socio-economic development of the rural community as a whole, as it is already explained in detail in Chapter Two.
2. According to Rivelle (1999), annual production of electric energy or annual revenues from the sale of electric energy are really the same problem, but in the latter, the monthly production is weighted by its value in the electricity market place in that month.

The release for irrigation and hydropower energy production are to be made through the same conveyance structure. Generally the system can be represented by the following schematic diagram.

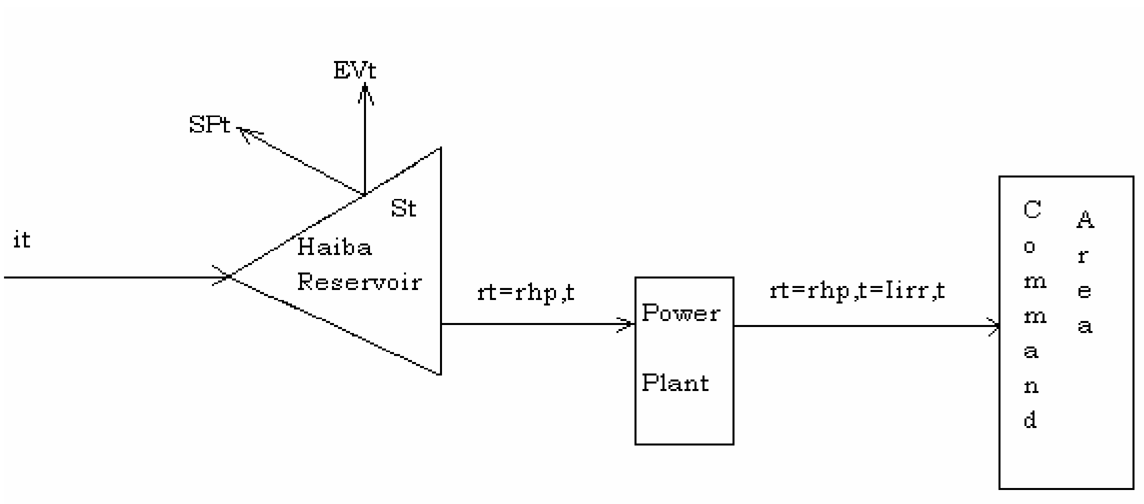


Figure 6.1 Schematic Diagram Representing the System

The electrical power produced in KW is given by the following formula:

$$P = \varepsilon\gamma Qh \quad \text{...} \quad (6.1)$$

Where:

$\gamma =$ Unit weight of water in (=9.81KN/m^3)

$h =$ head of water above the turbines in (m)

$Q =$ discharge through the turbines in(m^3/s)

$\varepsilon =$ overall efficiency of the hydropower scheme

The overall efficiency of hydropower scheme is equal to the product of the hydraulic efficiency, the turbine efficiency and the generator efficiency. For most of the schemes at the optimum conditions, the overall efficiency of the scheme is usually between 60 to 70 percent (Arora, 2002). For this study, 65 percent is used.

Now, if θ is seconds per month, then

$$Q = \frac{r_t x 10^4}{\theta} \quad \text{..} \quad (6.2)$$

Hence the monthly production of electric energy E_t in KWh is given by:

$$E_t = P\Delta t \quad \text{..} \quad (6.3)$$

where Δt is hours in a month. Now substituting equations 6.1 and 6.2 into 6.3 and letting α to be $(\in \gamma\Delta t / \theta)$, we obtain the following equation.

$$E_t = 10\alpha r_t h \quad \text{..} \quad (6.4)$$

where E_t is in MWh. In Haiba dam all the 16m dam height could not be utilized for power generation since the irrigation outlet is located 5.8m above the river bed. According to Rivelle (1999), the head of water above the turbines, h is obviously a function of the volume of water stored in the reservoir. The function is represented by the solid curve (storage-elevation curve) in figure 6.2 and is approximated by the dashed line, which may be written as linear function $h = h_o + ms$, where m is the slope of the straight line. Accordingly m is 0.02 and $h_o = 2.18$m.

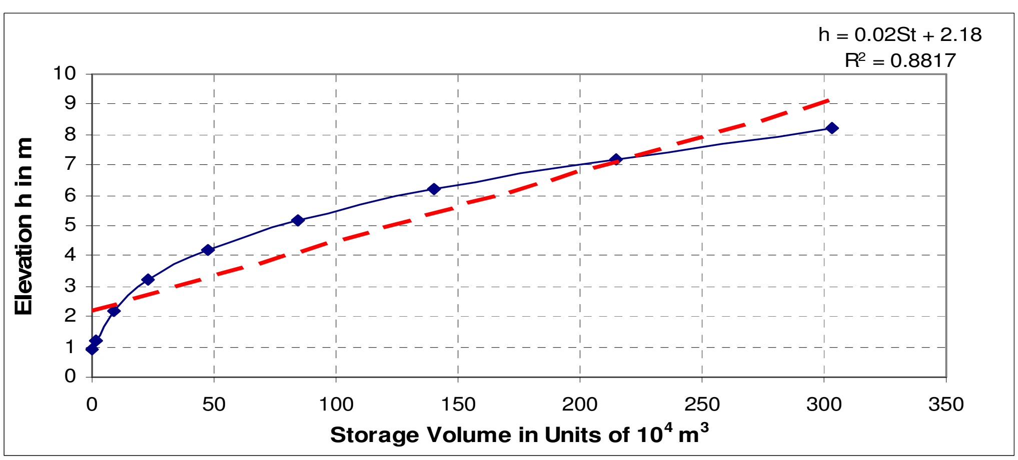


Figure 6.2 Storage-Elevation Curve

In the preparation of Figure 6.2, a minimum operating level which eliminates the formation of vortices has been calculated by applying a general rule-of-thumb guideline which is applicable for horizontal intakes. This general rule of thumb relates the submergence of the intake which is one of the parameters influencing the occurrence of intake vortices with the diameter of the pipe and is stated in the following statement. For a horizontal intake with S/D > 0.7, vortex problems are unlikely, where S is intake submergence and D is the diameter of the pipe (Gulliver and Arndt, 1991). Therefore, the minimum working elevation has been obtained by summing bottom level of intake, the diameter of the pipe and 0.7*D. Accordingly, the minimum working elevation and its corresponding minimum working storage free of vortices has been found to be 1990.70m and $8x10^4m^3$ respectively.

The average height in month t may be written as a function of average storage in month t.

$\overline{h_t} = h_o + m\overline{S_t}$ where $\overline{S_t} = \frac{S_t + S_{t+1}}{2}$ which implies that:

$$\overline{h_t} = h_o + \frac{m}{2}S_t + \frac{m}{2}S_{t+1} \quad \text{.......................................} \quad (6.5)$$

The final storage is related with the inflow, initial storage, release, evaporation and seepage by the mass balance equation, which is also used as a system transformation function, as follows.

$$S_{t+1} = S_t + i_t - r_t - EV_t - SP_t \quad \text{..........................} \quad (6.6)$$

Substituting equation 6.6 into 6.5 and the resulting equation into equation 6.4, and after rearranging, we obtain an expression for E_t in MWh as follows.

$$E_t = 5m\alpha r_t \left[\frac{2h_0}{m} + 2S_t + i_t - r_t - EV_t - SP_t \right] \text{ .... (6. 7)}$$

Therefore, the management objective is to maximize the total annual energy production, that is, equation 6.7 maintaining irrigation target allocation restriction and other constraints enumerated below, that is:

$$\text{Maximize } \sum_{t=1}^{T} 5m\alpha r_t \left[\frac{2h_o}{m} + 2S_t + i_t - r_t - EV_t - SP_t \right] \text{ ...... (6.8)}$$

Subject to the following constraints.

1. The release cannot exceed inflows plus initial storage minus losses due to evaporation and seepage, or in other words it limits the release to the water available.

$$r_t \le S_t + i_t - EV_t - SP_t, \text{ for all t .... (6.9)}$$

2. After releases, the remaining amount in storage must not exceed the reservoir capacity. In other words, it should force spill if the available water exceeds the reservoir capacity.

$$S_t + i_t - r_t - EV_t - SP_t \le k - k_w$$

$$\text{Or } r_t \ge S_t + i_t - EV_t - SP_t - K + K_w, \text{ for all t................ (6.10)}$$

3. Capacity restriction

$$S_t \le k - k_w \text{ for all t .... (6.11)}$$

4. Irrigation target allocation restriction

$$r_t \ge T_{irr,t}, \text{ for all t .... (6.12)}$$

5. Restriction of conveyance structures

$$r_t \leq CC_{\max}, \text{ for all t} \quad \text{......} \quad (6.13)$$

6. Non- negativity Constraint

$$r_t \geq 0, \text{for all t} \quad \text{......} \quad (6.14)$$

6.3.2 Determination of Maximum Conveyance Capacity of the Irrigation Outlet

For flow in a pipe, Bernoulli's equation between the water surface behind the dam and the irrigation outlet can be written as follows.

$$H_T = h_L + h_o \quad \text{......} \quad (6.15)$$

Where: H_T= total head needed to overcome the various head losses to produce discharge,

h_L = cumulative losses of the system, and

h_o = velocity head at the outlet.

Equation 6.15 can be expanded to express the various losses as follows.

$$H_T = h_t + h_e + h_f + h_g + h_o \quad \text{......} \quad (6.16)$$

Where: h_t= trash rack losses,

h_e = entrance losses,

h_f = friction losses,

h_g= gate or valve losses, and

Where the various losses are related to the individual components, equation 6.16 may be written as:

$$H_T = k_t\left[\frac{V_t^2}{2g}\right] + K_e\left(\frac{V^2}{2g}\right) + f\frac{L}{D}\left(\frac{V^2}{2g}\right) + K_g\left(\frac{V^2}{2g}\right) + K_o\left(\frac{V^2}{2g}\right) \quad \text{............ (6.17)}$$

Where:

K_t= trash rack loss coefficient,

K_e= entrance loss coefficient,

f= friction factor in Darcy- Weisback equation in pipe flow,

K_g= gate loss coefficient, and

K_o= Exit velocity head coefficient at the outlet.

Again from continuity equation, we obtain:

$$Q = A_t V_t = A_P V$$

where: A_t = area of the trash rack

A_p = cross-sectional area of the pipe

$$V_t^2/2g = (A_p/A_t)^2 \frac{V^2}{2g} \quad \text{.. (6.18)}$$

Then equation 6.16 becomes

$$H_T = \left[K_t\left(\frac{A_p}{A_t}\right)^2 + K_e + f\frac{L}{D} + K_g + K_o\right]\frac{V^2}{2g} \quad \text{............ (6.19)}$$

An average approximation of the trash rack loss, h_t can be obtained from the equation $h_t = K_t\left(\frac{V_t^2}{2g}\right)$: Where

$$K_t = 1.45 - 0.45\frac{a_n}{a_g} - \left(\frac{a_n}{a_g}\right)^2 \quad \text{.....................................} \quad (6.20)$$

Where: K_t = trash rack loss coefficient (empirical),

a_n= net area through the trash rack,

a_g = gross area of the racks and supports, and

V_t = velocity through the net trash rack area (USBR, 1987)

According to Yigzaw et al. (1996), a_n and a_g are equal to $2.1m^2$ and $2.25m^2$ and assuming that 50 percent of the trash area is clogged for maximum loss value, we obtain a value of K_t equal to 1.02.

Assuming flow at high Reynold's number, the Von Karman equation for friction factor is:

$$\frac{1}{\sqrt{f}} = 2 \log \left[3.7\frac{D}{\in}\right] \quad \text{...} \quad (6.21)$$

Where: D= Diameter of the pipe

$\in$ = average roughness height of the pipe wall in mm.

According to Yigzaw et. al (1996) the diameter of the outlet pipe and its length are given as 0.40m and 63m respectively and according to Penche (1998) $\in$ for welded steel is given to be 0.60 mm. Substituting these values into equation 6.21 gives 0.02 for f. According to the same source, the values of K_e, K_g and K_o could be assumed as 0.1, 0.1 and 1.0 respectively.

Substituting the values of each loss coefficient in equation 6.19 and using the relation Q=VA one can get the following expression.

$$Q = 0.27\sqrt{H_T} \quad \text{...} \quad (6.22)$$

The maximum conveyance capacity of the outlet structure can now be calculated using equation 6.22, taking H_T corresponding to the normal water level. Accordingly, the value of Q will be $0.77m^3/s$ which is equivalent to $200*10^4$ m^3 per month.

Discretization of storage and Release Levels

Each recursive equations should be solved for discrete values of storage and release values as follows.

From capacity restriction constrains, we know that S_t should be less than $303*10^4m^3$. Therefore, if we discretize it with $30*10^4m^3$, the values of each discretization will be 0, 30, 60, 90,120, 150, 180, 210, 240, 270, 300 and 303 in the order of 10^4m^3. And regarding to the discretization of the release r_t, $r_t \geq 0$ and $r_t \leq CC_{max}$ ($200*10^4m^3$), should be satisfied. Accordingly the discretization has been done as follows: 0, 20, 40, 60, 80, 100, 120, 140, 160, 180, and 200 m^3 in the order of 10^4.

6.3.3 Recursive Procedure and its Algorithm

The objective function, that is, equation 6.8 should be solved recursively at each stage for the reasons already explained at the beginning of this chapter. The stages are the time periods, and the states are the storage volumes. Substituting the values of all the constants in equation 6.8, it could be re-written as:

$$\text{Maximize } \sum_{t=1}^{12} 8.86 * 10^{-3} * m * r_t \left[2\frac{h_o}{m} + 2S_t + i_t - r_t - EV_t - SP_t \right]$$

and E_t in MWh as a function of S_t, S_{t+1} and r_t is expressed as:

$$E_t = 8.86 * 10^{-3} * m * r_t \left[2\frac{h_o}{m} + 2S_t + i_t - r_t - EV_t - SP_t \right] \quad ..... (6.23)$$

Equation 6.23 is also called a return function and should be solved at each stage for each discretization levels of storage and release.

Either a backward or forward moving sequence of recursive equations can be formulated, one for each stage of the process. Proceeding backward, a particular period is selected after which it is assumed that the reservoir no longer be operated. Let the arbitrary terminal period be period T, only one period of operation remains, which is the period on the far right of the time shown in the figure 6.3 below (Loucks et al., 1981).

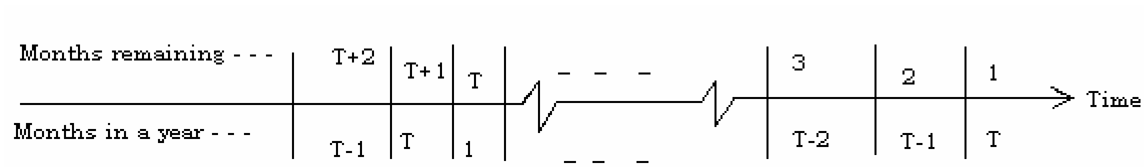


Figure 6.3 Relationship between periods t and n at each stage of reservoir operating problem

Let $f_T^1(S_T)$ be the maximum electrical energy produced from operating the reservoir in the last month of that last year, given an initial storage volume of S_T,

$$f_T^1(S_T) = \text{Maximum} \quad E_T\left(s_T, s_T + i_T - EV_T - SP_T - r_T, r_T\right) \quad ..... (6.24)$$

This must be solved for all discrete values of S_T and r_T subjected to different constraints. These values of $f_T^1(S_T)$ will be needed to solve the next recursive equation.

Moving backward in time (from right to left in figure 6.3) the next stage is the previous period T-1. There are now two periods /months remaining for reservoir operation. In this case the function $f_{T-1}^{2}(S_{T-1})$ represents the maximum energy with two months to go, given an initial storage of S_{T-1} in period T-1. Since $S_T = S_{T-1} + i_{T-1} - EV_{T-1} - SP_{T-1} - r_{T-1}, f_T^{1}(S_T)$ can be expressed in terms of the state variable S_{T-1}, the decision variable r_{T-1}, and the known average evaporation EV_{T-1} and seepage SP_{T-1}, the second recursive equation can be written as:

$$f_{T-1}^{2}\left(S_{T-1}\right) = \text{Maximum} \begin{bmatrix} E_{T-1}\left(S_{T-1,} S_{T-1} + i_{T-1} - r_{T-1} - EV_{T-1} - SP_{T-1}, r_{T-1}\right) \\ + f_T^{1}\left(S_{T-1} + i_{T-1} - EV_{T-1} - SP_{T-1} - r_{T-1}\right) \end{bmatrix}$$

...... (6.25)

Again this must be solved for all discrete values of S_{T-1} between 0 and k-K_w subjected to all constraints.

Continuing backward in time, the general recursive equation for each period t with n (n>1) periods/ months remaining can be written as

$$f_t^{n}(S_t) = \text{Maximum} \begin{bmatrix} E_t\left(S_t, S_t + i_t - r_t - EV_t - SP_t, r_t\right) \\ + f_{t+1}^{n-1}\left(S_t + i_t - EV_t - SP_t - r_t\right) \end{bmatrix} \quad \text{............ (6.26)}$$

The computations shall be repeated until the stationary solution is obtained, that is, at the stationary solution the optimal release r_t associated with each initial storage volume s_t will be the same as the corresponding r_t and S_t in the previous year (Loucks et al., 1981).

Once the stationary policy is obtained, a trace-back procedure is used to identify the optimal storage trajectory over the entire period of analysis, from which the optimal releases in each period can be found.

6.4 Preparation of Input Data for DP Model

The calculations of reservoir monthly inflow and monthly evaporation loss have been dealt within this section. Also monthly irrigation requirement and the seepage loss calculations made by the Tigray Regional state Water Development commission for Haiba dam have been discussed briefly.

Reservoir Inflow

Reservoir inflow comprises of storm runoff/catchment yield, direct precipitation on the reservoir and a very small quantity of base flow. The runoff is calculated using equation 5.2 and a runoff coefficient of 0.26 and an average monthly rainfall determined in the previous chapter. A very small amount of base flow was measured by floating method during the driest season by the study team when the project was studied. Hence, this flow has been considered in the calculation of the reservoir inflow. The direct precipitation on the reservoir has been added to the reservoir inflow after multiplying the average monthly rainfall by the reservoir area. Finally, as shown in Table 6.1, the base flow, the direct precipitation and the storm runoff are added together to get the reservoir inflow. Note that catchment yield during the driest months (October, November, December, January, and February) have been set to zero.

Evaporation loss

The monthly evaporation loss from Haiba reservoir is determined using equation (5.1). The average monthly evaporation obtained from evaporation pan at Mekelle meteorological station and an average pan coefficient of 0.7 have been used in the calculation and the result is shown in table 6.2.

Table 6.1 Monthly Reservoir Inflows

Months	Av. monthly Rainfall (mm)	Run off ('10^4m^3)	Direct PP_t ('10^4m^3)	Base Flow ('10^4m^3)	Total Inflow ('10^4m^3)
Jan.	2.8	0.00	0.27	1.31	2
Feb.	5.1	0.00	0.48	1.31	2
Mar.	37.9	23.38	3.60	1.31	28
Apr.	39.4	24.33	3.74	1.31	29
May	24.8	15.31	2.36	1.31	19
Jun.	56.6	34.98	5.38	1.31	42
Jul.	219.4	135.47	20.84	1.31	158
Aug.	231.9	143.22	22.03	1.31	167
Sep.	41.2	25.47	3.92	1.31	31
Oct.	5.7	0.00	0.54	1.31	2
Nov.	7.0	0.00	0.67	1.31	2
Dec.	2.8	0.00	0.26	1.31	2
Annual	**674.62**	**402.15**	**64.09**		

Table 6.2 Monthly Evaporation Losses from Haiba Reservoir

Months	Sep.	Oct	Nov.	Dec.	Jan	Feb	Mar	Apr	May	June	July	Augt	Annual
Evap. ('10^4m^3)	4	6	4	5	5	6	7	7	8	7	3	2	63

Seepage loss

Due to lack of data the seepage loss from Haiba reservoir is not computed. However, the seepage loss through the embankment was calculated during its design phase using the principle of Darcy's law of ground water flow, that relates the seepage discharge per unit width of the dam with the product of coefficient of permeability of the dam material and the focal distance obtained from the dam geometry. Accordingly the result obtained was 3034.6 m^3 per year which is equivalent to $0.03*10^4 m^3$ per month (Yigzaw et al., 1996).

Since this loss only accounts loss through the dam embankment and doesn't include seepage loss under the dam foundation and loss into the ground water, 50 percent of its value has been added to it for safety factor as an input for the DP model.

Irrigation Requirement

The values of monthly total irrigation requirement which were computed according to Sinkneh (1996) have been used as input for the DP model. The computation of reference crop evapotranspiration was based on Hargrave's method. In general this computation had accounted the type of crops grown, the command area, the cropping calendar, the effective rainfall, the crop coefficient and other important parameters like project efficiency and hours of operation of the reservoir. The summary of it is given in Table 6.3.

Table 6.3 Monthly Irrigation Requirements (MIR)

Month	Jan	Feb	mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Total
MIR in 10^4 m^3	21	25	16	3	4	9	3	8	26	19	17	21	171

6.5 The Visual Basic User Interface for the DP Model

The user interface of the DP Model which is prepared using the Visual Basic Code is given in Figure 6.4. The interface generally consists of two tabs: namely Hydrology and Irrigation tab and Reservoir Characteristics tab. It has a file menu which consists of Open, Save, Run DP and Exit sub-menus. The Open Sub-menu loads the program with the input data for both tabs. The

Run DP sub-menu is used to run the program and the Exit sum-menu is used to exit the program.

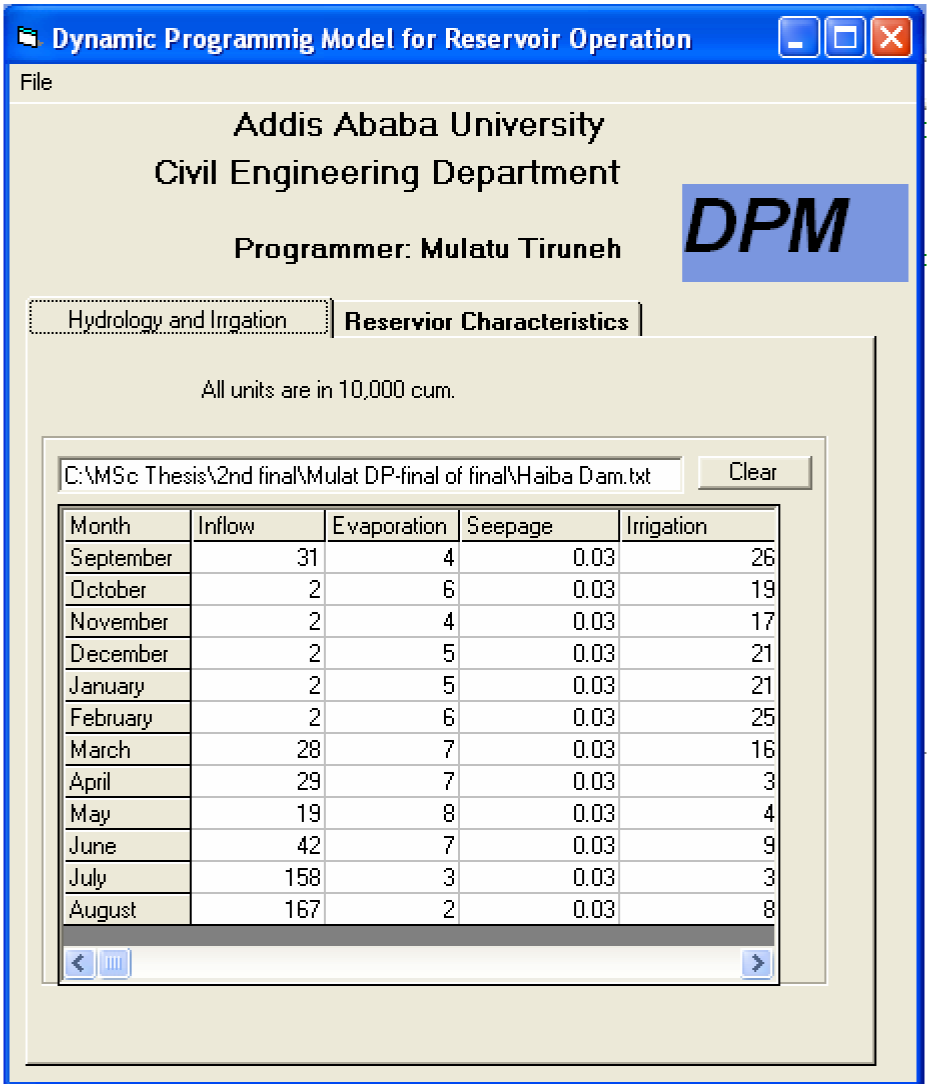


Figure 6.4(a) The Visual Basic User Interface for the DP Model: Hydrology and Irrigation Tab

It has also a Clear button to clear the hydrology and irrigation data and makes ready for new data entry. The reservoir characteristics tab consists of three main frames which are storage capacity, elevation storage curve and maximum conveyance capacity of the irrigation outlet.

The storage capacity frame consists of text boxes for entering the total storage capacity of the reservoir and the minimum working capacity of the reservoir free of vortices in units of 10^4 m^3. The elevation-storage curve frame consists of text boxes for entering the slope and y-intercept of the fitted graph of the elevation-storage curve. CC_{max} frame consists of text boxes for entering diameter of the pipe or penstock, length of the pipe, friction coefficient and maximum head available above the turbine when the reservoir is full.

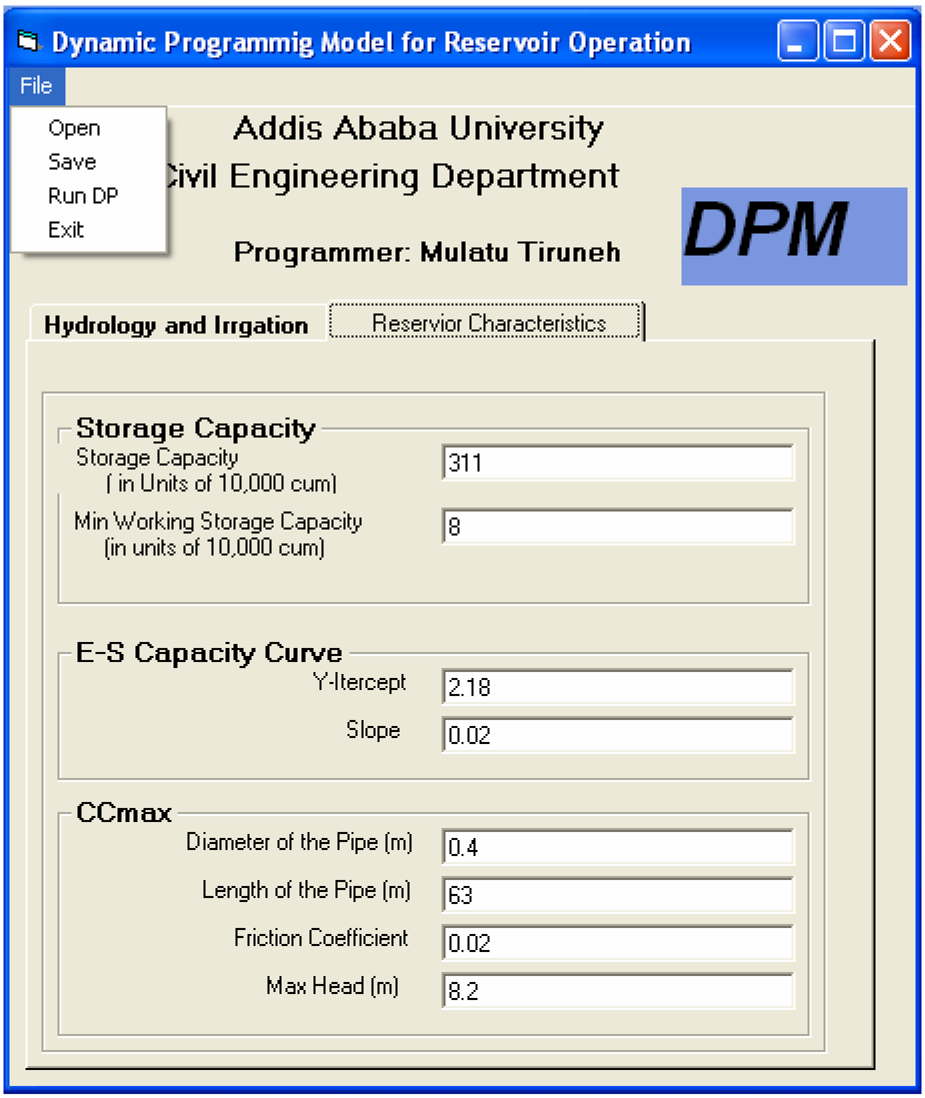


Figure 6.4(b) The Visual Basic User Interface for the DP Model: Reservoir Characteristics Tab

7. RESULT AND DISCUSSION

In chapter six the dynamic programming technique has been used to model the Haiba reservoir and this has been solved by a visual Basic Program written to solve this particular problem. The full result of this program is given in Annex A. Therefore in this chapter only the summary of the output of the dynamic programming model for stationary policy of Haiba reservoir operation, monthly energy output, energy duration curve, and reservoir operation guide curve are given and discussed.

7.1 Optimal Releases for Stationary Policy

After solving the recursive equations given in chapter six through only three years, the stationary solution for optimal release r_t for each month t associated with each discrete value of the initial storage volume S_t has been obtained. This has been particularly obtained in the second month of the third year. As it has been already explained in chapter six, the output has an optimal release r_t associated with each initial storage volume S_t the same as the corresponding r_t and S_t in the previous year. Only summary of it is given in Table 7.1. Where t=1 refers to the month of September and t=2 refers to the month of August and a 24-hr mode of energy supply is assumed.

Table 7.1 Summary of Stationary Policy Optimal Releases

Stationary Policy												
Optimal Releases in Units of $10^4 m^3$ per Month												
S_t	r_1*	r_2*	r_3*	r_4*	r_5*	r_6*	r_7*	r_8*	r_9*	r_{10}*	r_{11}*	r_{12}*
0	-	-	-	-	-	-	20	20	-	20	20	20
30	40	20	20	-	-	-	20	20	20	20	20	20
60	40	40	40	40	40	40	20	20	20	20	20	20
90	40	80	80	8 0	40	40	20	20	20	20	20	20
120	40	100	100	100	40	40	20	20	20	20	20	20
150	40	140	140	40	40	40	20	20	20	20	20	20
180	40	20	20	40	40	40	20	20	20	20	40	60
210	40	20	20	40	40	40	20	20	20	20	80	80
240	40	20	20	40	40	40	20	20	20	20	100	120
270	40	20	20	40	40	40	20	20	20	20	140	140
300	40	20	20	40	40	40	20	20	20	40	160	180
303	40	20	20	40	40	40	40	40	20	40	160	180

7.2 Monthly Energy Output

The monthly energy output of the dynamic programming model is given in Table 7.2. The yearly average energy production for the mean monthly inflow data is found to be 50.57 MWh.

The plot for monthly variability of the optimum energy output is shown in Figure 7.1. The variability is very high. The maximum energy output found is 18.81 MWh during the month of August whereas the smallest energy output is found to be 1.57MWh during the month of May. This is because of the wet season effect, that is, there is high amount inflow during the months of July and August as compared to very low amount of inflow during the other months of the year.

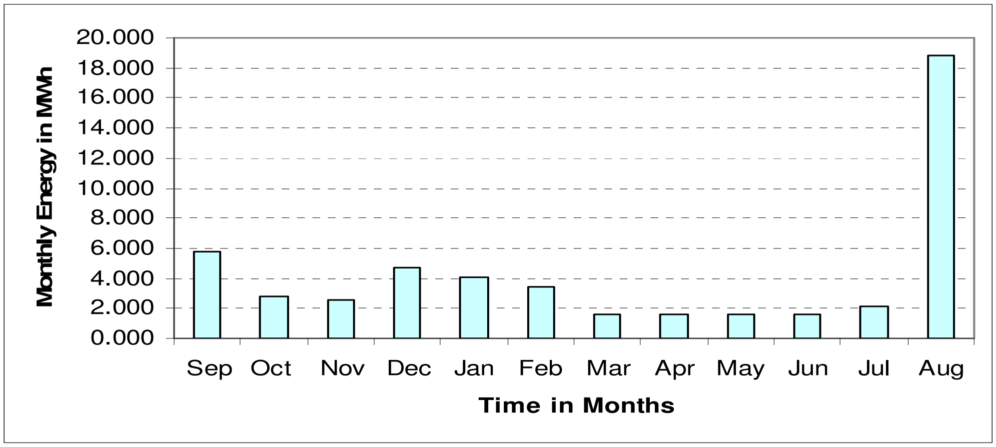


Figure 7.1 Plot of Mean Monthly Energy

The maximum and minimum monthly energy outputs can be explained in terms of their capacity to electrify the rural community as follows. The maximum and minimum monthly energy outputs are equal to 25kw and 2kw respectively. 25kw electric power is capable enough to illuminate 625 light bulbs of 40W each. This is enough electricity for about 312 households each using two light bulbs of 40w each. Whereas the minimum power, that is, 2kw is enough power for 50 light bulbs of 40w each which is again capable to illuminate 25 households each using two light bulbs of 40w each. This minimum energy is the firm energy which is available 100 percent of the time as shown in the energy output duration curve of Figure 7.2.

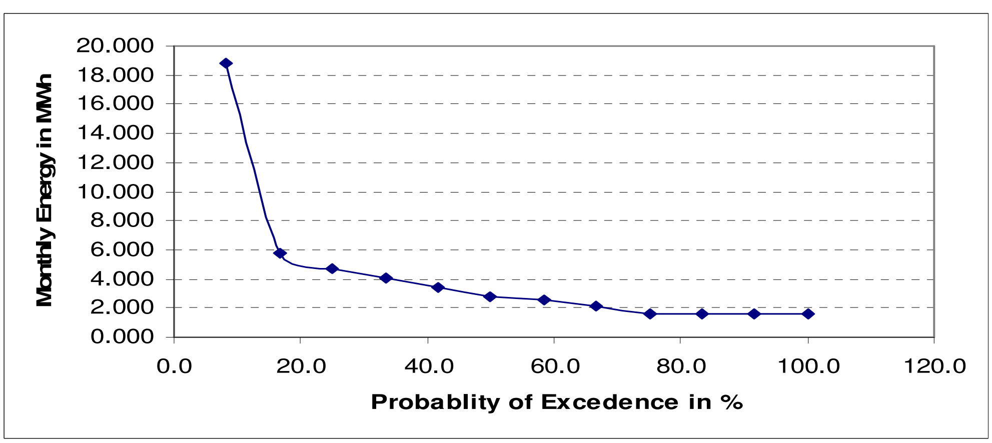


Figure 7.2 Energy Output Duration Curve

7.3 Reservoir Operation Guide Curve

As already explained in chapter six, reservoir operation guide curve is a guide line which proposes the status of the reservoir as a function of time for a period of one year. The major output of the dynamic programming model is the storage at a monthly time step.

Table 7.2 Monthly Optimal Energy Production and Other Parameters from Output of DP (Visual Basic Program)

Month	Release in 10^4 m3	Storage in 10^4 m3	Water level in m amsl	Energy in MWh
Sep	40	303	1998	5.742
Oct	20	290	1997.9	2.740
Nov	20	266	1997.6	2.577
Dec	40	244	1997.3	4.694
Jan	40	201	1996.8	4.085
Feb	40	158	1996.2	3.469
Mar	20	114	1995.5	1.582
Apr	20	115	1995.5	1.593
May	20	117	1995.6	1.568
Jun	20	108	1995.4	1.589
Jul	20	123	1995.7	2.120
Aug	140	258	1997.5	18.807
Sum	**440**			**50.57**

As discussed in Section 3.6, a trace-back procedure is used to identify the optimal storage trajectory over the entire period of analysis. For Haiba reservoir, the optimum for the whole system for the stationary solution is found to be 106.325 MWh for the month of September. The corresponding optimal initial storage and optimal releases for September are $303*10^4$ m^3 and $40*10^4$ m^3 respectively. Now the initial storage for October is found using the mass balance equation which is $290*10^4$ m^3. Hence, the optimal release corresponding to this initial storage is read from the output of the DP Model. This optimal release is $20*10^4$ m^3. Therefore the trace-back procedure continues as such until August. Now corresponding to each initial storage the elevation of water can be found from elevation-Storage curve. The final result is shown in Table 7.2.

From the water levels for each month (Table 7.2) the guide curve has been developed as shown in Figure 7.3. This curve can be interpreted as the most effective operation guide curve for those years of hydro-meteorological condition. This information will help to give an idea on how the reservoir should have been operated in the past and will give some information on how the reservoir operation should be in the future.

The normal pool level of Haiba reservoir is at 1998 m amsl and its dead storage level is at 1990m amsl. Whereas the optimum guide curve developed using the dynamic programming for its stationary policy falls in short of the normal pool level except at the beginning of the month of September, but it always falls above the dead storage level.

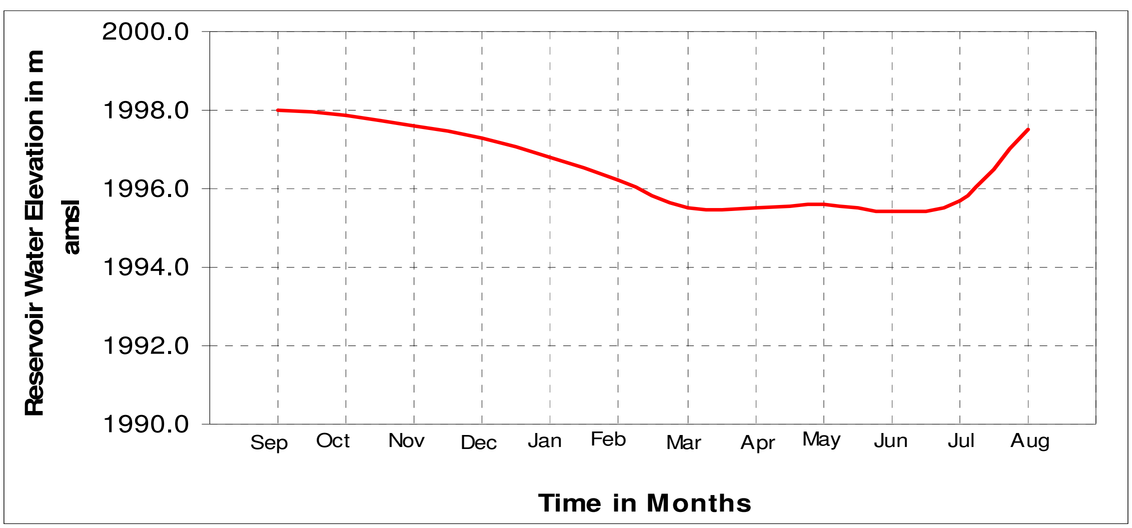


Figure 7.3 Guide Curve Developed Using Visual Basic Program

The optimal release obtained from the dynamic programming model for a particular month is generally much higher than the release required for total irrigation requirement of the system for the same month.

8. CONCLUSIONS AND RECOMMENDATIONS

8.1 Conclusions

From the results obtained as an output of dynamic programming, literature review and data processing and analysis made in the previous chapters, the following conclusions have been made.

1. It is possible and is actually very wise to use micro irrigation dams for micro- electric energy generation so as to electrify the rural community without affecting the existing irrigation requirement by applying systems engineering as a planning tool.
2. Much water has been lost from Haiba reservoir through the irrigation outlet and over the spillway annually without producing a valuable amount of electric energy that is very useful to the rural community.
3. The optimal power output of Haiba reservoir is within the range of micro-hydropower and has an electrification capacity of 50 to 644 rural households using one light bulb of 40W each.
4. The software developed using Visual Basic code to solve the dynamic programming model can still be used for any change in its hydrologic and irrigation as well as reservoir characteristics data.

8.2 Recommendations

Based on this study the following recommendations are drawn.

1. The actual inflow into Haiba reservoir is not explicitly known. This is because of two main reasons. These are firstly, staff gauge reading at the dam site is not taken and secondly, there are inadequate meteorological stations in the catchment. And hence other additional meteorological stations should be installed within the catchment so that an appropriate and applicable rainfall –runoff model for the catchment could be developed.
2. In this study the seepage loss from the Haiba reservoir is not as such included due to absence of data and appropriate method to estimate it. Only a constant value of seepage loss through its embankment for each month which was calculated during its design is considered. However, this value would have varied from month to month as the reservoir level changes. Moreover, the seepage loss into the groundwater should have been included. Therefore, a method has to be found to estimate this loss and include it in the analysis.
3. The irrigation releases for each month are directly taken from the agronomy and soil report made during the scheme's design. Eventhough some of the parameters used in irrigation requirement analysis have been verified during field visit, a thorough and careful revision and determination of it is essential and should be done during the design of the micro-hydropower plant.
4. Since there is a high variability of monthly energy output, it is better to include another source of energy such as diesel generator as a back up to increase the dependable power of the scheme so that the supply could be better in terms of both amount and consistency.

5. Other planning studies for different scenarios like 12- hour mode of energy supply versus 24- hr mode of energy supply and inclusion of night time storage for irrigation use should be conducted and compared before the implementation of the scheme.
6. The guide curve is established mainly on the basis of the design report especially data like irrigation requirement, elevation-storage curve and seepage losses. Therefore, it is recommended to update the data and run the program to obtain better results. Moreover, results could further be improved if many years of meteorological data are used. Since many years of continuous meteorological data is not available at the present, generating and using synthetic data series is an alternative in the future.
7. It is recommended to introduce day time loads such as storage cookers, grain mills, workshops, and pumping water supply schemes.

REFERENCES

Arora, K.R. (2002). Irrigation, Water Power and Water Resources Engineering. Standard Publishers Distributors, Delhi.

Buras, N. (1972). Scientific Allocation of Water Resources. American Elsevier Publishing, inc., New York.

CESEN (1986). Energy Sector Main Report.

CSA (2004). Statistical Abstract, Addis Ababa.

Denardo, E.V. (1982). Dynamic programming: Models and Applications. Prentice- Hall, inc., Englewood Cliffs, New Jersey 07632.

EEA (2003). Rural Electrification Fund: Final Project Operations Manual. ESD Ltd., Addis Ababa.

EEPCo (2004). Facts in Brief. Ethiopian Electric Power Corporation Corporate Relations, Addis Ababa.

EREDPC (2002). Integrated Rural Energy Development Program, Addis Ababa.

Fritz, J.J. (1984). Small and Mini Hydropower Systems. McGraw-Hill, New York.

Garg, S.K. (2003). Irrigation Engineering and Hydraulic Structures. Khanna Publishers, Delhi.

Good Man, A.S. (1984). Principles of Waters Resources Planning. Prentice-Hall, inc., Englewood Cliffs, New Jersey 07632.

Gulliver, J.S., and Arndt, R.E. (1991). Hydropower Engineering Handbook. McGraw-Hill,inc., New York.

Haan. C.T., Barfield, B.J., and Hayes, J.C (1984). Design Hydrology and Sedimentology for small catchments. Academic press, San Diego.

Haith, D.A. (1982). Environmental Systems Optimization. Johny Wiley and Sons, New York.

Harvey, A., et al (2002). Micro-Hydro Design Manual: A Guide to Small –scale Water power schemes. ITDG Publishing, London.

Linsely, R.K., and Frnazini, J.B. (1979). Water- Resources Engineering. McGraw-Hill, London.

Loucks, D.P., Stediner, J.R., and Haith, D.A. (1981). Water Resource Systems Planning and Analysis. Prentice-Hall, inc., Englewood Cliffs, New Jersey 07632.

Mays, L.W., and Tung, Y.K. (1992). Hydrosystems Engineering and Management. Mc-Graw-Hill inc., New York.

Michael, A. (2004). Irrigation Dams for Micro-Hydropower Development in the context of Rural Electrification, Symposium Proceedings on Renewable Energy in Ethiopia, GTZ and EREDPC, 26th_ 27th April 2004, Addis Ababa.

Michael, A.(2004). Micro-Dams in Ethiopia. Addis Ababa.

MWR (1998). Tekeze River Basin Integrated Development Master Plan Project. Addis Ababa.

Paulos., S. (1998). Establishing Water Release Rules for Koka Reservoir for Wet Seasons. Addis Ababa University School of Graduate, Addis Ababa.

Penche, C. (1998). Layman's GuideBook on how to develop a small hydro site, 2d ed. DG XVIII-97/010, Brussels.

Reddi, P.J. (2002) A text Book of Hydrology. Laxmi Publications (Pvt.) Ltd., New Delhi.

Rivelle, C. (1999). Optimizing Reservoir Resources including A New Model for Reservoir Reliability. John Willy and Sons, Inc., New York.

Sinkneh, E. (1996). Feasibility study Report of Haiba irrigation Scheme: Agronomy and soils. CO-SAERT, Mekelle.

SHP in China (1985). A survey prepared by Hanzahan Regional Centre (Asia Pacific) for small Hydro Power. Intermediate Technology Publications, 9 king street, London.

STVC(2000). Products Catalogue. STVC, Addis Ababa.

TRSBWR (2003). Fully implemented, studied and Designed Micro Dam Irrigation schemes, Mekelle.

USBR (1987). Design of Small Dams. U.S. Department of the interior, Washington. D.C.

Yigzaw, H., Abayneh, M., and Zelalem, A. (1996). Haiba Dam Design Report. Co-SAERT, Mekelle.

Zelalem, H. (1992). Micro-Hydropower under Ethiopian conditions. Addis Ababa University School of Graduate, Addis Ababa.

Annex-A: Tables

Table A.1 Mean Monthly Rainfall at Dengolat Station in mm

Year	Jan	Feb	mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1992	4.3	1.1	19.2	19.8	27.2	9.8	176.8	214.8	51.3	12.2	35.0	9.6	581.1
1993	7.0	23.4	55.5	88.5	40.6	33.2	131.6	172.3	94.0	10.8	0.0	0.9	657.8
1994	0.0	4.2	5.4	23.7	4.1	103.1	294.8	295.7	49.3	0.0	0.0	0.0	780.3
1995	0.0	2.5	59.2	71.5	30.3	8.9	256.0	193.4	67.8	2.1	0.0	7.8	699.5
1996	0.0	19.0	139.0	78.5	59.7	88.5	115.7	173.1	22.2	0.0	28.7	0.8	725.2
1997	0.0	0.0	27.6	61.1	27.3	45.6	269.5	160.1	12.7	42.5	24.9	0.0	671.3
1998	0.0	0.0	13.0	45.9	30.0	22.5	294.4	348.1	65.9	0.0	0.0	0.0	819.8
1999	18.9	0.0	3.4	14.4	0.0	18.7	311.8	344.9	15.5	0.0	0.0	0.0	727.6
2000	0.0	0.0	6.2	16.0	58.6	33.9	242.5	235.7	49.2	0.0	2.7	11.8	656.6
2001	0.0	0.0	31.0	14.5	34.8	120.5	338.5	273.5	11.6	0.0	0.0	0.0	824.4
2002	0.0	1.3	114.0	5.3	0.0	39.0	153.1	195.3	29.3	0.0	0.0	4.1	541.4
2003	0.0	14.2	6.6	51.1	2.9	123.5	103.8	199.6	65.8	0.0	0.0	0.8	568.3
2004	6.6	0.0	12.1	21.9	6.9	89.2	163.4	208.6	1.6	6.5	0.0	0.0	516.8
Total	36.8	65.7	492.2	512.2	322.4	736.4	2851.9	3015.1	536.2	74.1	91.3	35.8	
Average	*2.8*	*5.1*	*37.9*	*39.4*	*24.8*	*56.6*	*219.4*	*231.9*	*41.2*	*5.7*	*7.0*	*2.8*	*674.6*

Table A.2 Mean Monthly Rainfall at Mekelle Station in mm

Year	Jan	Feb	mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1992	8.7	2.1	38.5	1.0	30.7	6.2	140.7	233.1	1.3	2.1	54.2	8.3	526.9
1993	11.7	7.7	63.9	125.0	74.4	69.0	217.2	106.5	15.2	20.0	0.0	0.0	710.6
1994	0.0	5.3	0.4	43.8	0.1	67.6	147.9	317.8	70.1	0.0	1.8	2.0	656.8
1995	0.0	5.9	31.2	29.2	27.1	6.8	268.2	237.7	51.4	3.0	0.0	21.7	682.2
1996	1.4	0.0	59.5	12.5	92.2	47.9	109.2	224.0	7.1	0.0	31.4	1.1	586.3
1997	0.0	0.0	19.8	32.6	29.8	32.4	236.1	100.5	16.3	85.9	15.7	0.0	569.1
1998	10.0	1.2	0.0	10.6	22.0	48.0	289.0	318.8	31.7	22.0	0.0	0.0	753.3
1999	22.0	0.3	10.9	0.0	0.0	7.4	293.6	359.2	22.8	0.9	0.0	0.0	717.1
2000	0.0	0.0	0.0	10.4	24.6	5.4	201.4	282.0	15.8	2.2	10.3	3.5	555.6
2001	0.0	0.0	38.1	18.7	4.7	65.5	267.9	226.3	9.2	2.9	0.0	0.0	633.3
2002	12.5	0.0	35.5	4.2	23.0	60.8	95.5	206.6	28.0	0.0	0.0	0.3	466.4
2003	0.0	25.9	18.2	8.4	35.2	87.5	125.6	201.8	22.4	0.7	0.0	0.1	525.8
2004	7.4	3.7	35.2	20.5	7.1	25.4	64.3	221.1	1.4	3.1	0.8	0.0	390.0
Total	73.7	52.1	351.2	316.9	370.9	529.9	2456.6	3035.4	292.7	142.8	114.2	37.0	
Average	*5.7*	*4.0*	*27.0*	*24.4*	*28.5*	*40.8*	*189.0*	*233.5*	*22.5*	*11.0*	*8.8*	*2.8*	*598.0*

Table A.3 Mean Monthly Rainfall at Samre Station in mm

Year	Jan	Feb	mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1992	4.8	1.2	21.4	11.6	31.2	4.0	118.5	187.0	17.1	6.9	29.2	5.4	438.2
1993	5.7	10.2	30.3	88.1	39.5	32.1	120.1	93.9	43.6	10.7	0.0	0.2	474.4
1994	0.0	2.4	1.4	21.7	1.0	55.1	158.0	269.3	40.0	0.0	0.5	0.5	549.9
1995	0.0	4.2	32.7	35.6	14.4	3.9	178.5	203.7	33.6	6.3	0.0	7.6	520.6
1996	0.4	4.5	51.4	31.8	57.6	41.8	87.5	140.6	33.6	0.0	17.1	0.5	466.9
1997	0.0	0.0	17.4	35.9	20.9	22.7	181.5	96.7	7.4	47.4	11.1	0.0	441.0
1998	2.7	0.3	3.1	16.2	23.2	21.2	200.4	278.6	52.4	5.9	0.0	0.0	604.0
1999	10.4	0.1	3.7	3.4	0.0	7.4	224.6	262.6	15.8	0.2	0.0	0.0	528.2
2000	0.0	0.0	0.4	12.3	12.8	53.8	204.7	238.0	39.9	20.5	5.4	0.0	587.8
2001	0.0	0.0	0.0	0.0	0.0	115.1	271.3	200.7	30.5	0.0	0.0	0.0	617.6
2002	0.0	0.0	21.0	1.8	0.0	61.4	168.6	133.5	30.0	0.0	0.0	26.1	442.4
2003	0.0	8.7	9.9	6.4	18.2	98.9	142.8	145.0	28.0	0.0	0.0	0.0	457.9
2004	0.0	0.0	7.6	13.8	40.8	40.8	10.8	174.2	2.0	0.0	0.0	0.0	290.0
Total	24.0	31.5	200.3	278.6	259.6	558.4	2067.3	2423.9	373.9	97.9	63.2	40.4	
Average	*1.8*	*2.4*	*15.4*	*21.4*	*20.0*	*43.0*	*159.0*	*186.5*	*28.8*	*7.5*	*4.9*	*3.1*	*493.8*

Table A.4 Mean Monthly Rainfall at Adigudom Station in mm

Year	Jan	Feb	mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Annual
1992	5.0	1.2	22.3	22.3	55.8	0.0	131.6	249.2	15.3	11.6	21.5	3.2	539.0
1993	3.2	8.6	0.0	113.9	33.8	19.6	104.1	82.9	58.3	9.5	0.0	0.0	433.9
1994	0.0	0.0	0.0	14.8	0.0	42.3	163.7	386.1	32.3	0.0	0.0	0.0	639.2
1995	0.0	6.7	34.9	36.4	0.0	0.0	155.8	318.8	12.8	17.0	0.0	0.0	582.4
1996	0.0	0.0	8.3	33.1	63.7	27.1	104.4	134.0	89.4	0.0	6.5	0.0	466.5
1997	0.0	0.0	18.9	43.0	21.7	11.0	184.0	107.7	0.0	48.5	3.2	0.0	438.0
1998	0.0	0.0	0.0	8.4	34.4	10.4	180.0	374.6	95.7	0.0	0.0	0.0	703.5
1999	0.0	0.0	0.0	0.0	0.0	3.4	243.7	286.5	20.3	0.0	0.0	0.0	553.9
2000	0.0	0.0	0.0	19.6	41.5	40.1	166.9	187.3	32.9	0.0	3.2	0.0	491.5
2001	0.0	0.0	40.5	31.6	10.7	65.5	346.6	169.0	0.0	0.0	0.0	0.0	663.9
2002	0.0	0.0	0.0	0.0	0.0	21.8	92.4	113.8	49.7	0.0	0.0	10.2	287.9
2003	0.0	15.9	4.4	17.6	0.0	13.6	128.4	230.0	0.0	0.0	0.0	7.5	417.4
2004	0.0	0.0	7.5	12.5	0.0	27.6	38.3	145.9	0.0	0.0	0.0	0.0	231.8
Total	8.2	32.4	136.8	353.2	261.6	282.4	2039.9	2785.8	406.7	86.6	34.4	20.9	
Average	*0.6*	*2.5*	*10.5*	*27.2*	*20.1*	*21.7*	*156.9*	*214.3*	*31.3*	*6.7*	*2.6*	*1.6*	*496.1*

Table A.5 Output of the Dynamic Program

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=1												
S_t 0	1.286	2.431	3.434	4.295	5.014	5.591	6.027	6.321	-	-	6.321	160
S_t 30	1.499	2.856	4.072	5.145	6.077	6.867	7.516	8.022	8.387	-	8.387	180
S_t 60	1.712	3.281	4.709	5.996	7.14	8.143	9.004	9.723	10.301	10.737	10.737	200
S_t 90	1.924	3.707	5.347	6.846	8.203	9.419	10.493	11.424	12.215	12.863	12.863	200
S_t 120	2.137	4.132	5.985	7.697	9.267	10.695	11.981	13.126	14.128	14.989	14.989	200
S_t 150	2.349	4.557	6.623	8.547	10.33	11.971	13.47	14.827	16.042	17.116	17.116	200
S_t 180	-	-	7.261	9.398	11.393	13.246	14.958	16.528	17.956	19.242	19.242	200
S_t 210	-	-	-	10.249	12.456	14.522	16.446	18.229	19.87	21.369	21.369	200
S_t 240	-	-	-	-	-	15.798	17.935	19.93	21.783	23.495	23.495	200
S_t 270	-	-	-	-	-	-	19.423	21.631	23.697	25.621	25.621	200
S_t 300	-	-	-	-	-	-	-	-	25.611	27.748	27.748	200
S_t 303	-	-	-	-	-	-	-	-	25.802	27.96	27.96	200
n=2												
S_t 0	17.303	16.995	16.545	15.953	15.219	14.085	12.951	-	-	-	17.303	20
S_t 30	19.642	19.547	19.309	18.93	18.408	17.746	16.941	15.807	14.673	-	19.642	20
S_t 60	21.981	22.098	22.073	21.907	21.598	21.148	20.556	19.822	18.688	17.554	22.098	40
S_t 90	24.321	24.65	24.838	24.883	24.788	24.55	24.171	23.649	22.987	22.182	24.883	80
S_t 120	26.66	27.202	27.602	27.86	27.977	27.952	27.785	27.477	27.027	26.435	27.977	100
S_t 150	28.999	29.753	30.366	30.837	31.167	31.354	31.4	31.305	31.067	30.687	31.4	140
S_t 180	-	32.305	33.131	33.814	34.356	34.757	35.015	35.132	35.107	34.94	35.132	160
S_t 210	-	-	-	36.791	37.546	38.159	38.63	38.96	39.147	39.193	39.193	200
S_t 240	-	-	-	-	40.736	41.561	42.245	42.787	43.187	43.446	43.446	200
S_t 270	-	-	-	-	-	-	45.86	46.615	47.228	47.699	47.699	200
S_t 300	-	-	-	-	-	-	-	50.442	51.268	51.951	51.951	200
S_t 303	-	-	-	-	-	-	-	50.825	51.672	52.377	52.377	200

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=3												
S_t 0	19.298	-	-	-	-	-	-	-	-	-	19.298	20
S_t 30	21.861	21.187	20.383	-	-	-	-	-	-	-	21.861	20
S_t 60	24.706	24.033	23.36	22.626	-	-	-	-	-	-	24.706	20
S_t 90	27.846	27.173	26.499	25.826	25.152	24.348	-	-	-	-	27.846	20
S_t 120	31.329	30.656	29.983	29.309	28.636	27.963	27.229	-	-	-	31.329	20
S_t 150	35.107	34.434	33.76	33.087	32.414	31.74	31.067	30.394	29.589	-	35.107	20
S_t 180	39.229	38.555	37.882	37.208	36.535	35.862	35.188	34.515	33.842	33.108	39.229	20
S_t 210	43.634	42.971	42.297	41.624	40.951	40.277	39.604	38.93	38.257	37.584	43.634	20
S_t 240	48.099	47.649	47.057	46.383	45.71	45.037	44.363	43.69	43.017	42.343	48.099	20
S_t 270	52.564	52.327	51.947	51.426	50.763	50.09	49.417	48.743	48.07	47.397	52.564	20
S_t 300	-	57.005	56.838	56.53	56.079	55.487	54.814	54.141	53.467	52.794	57.005	40
S_t 303	-	57.473	57.327	57.04	56.611	56.04	55.367	54.693	54.02	53.347	57.473	40
n=4												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	22.038	21.148	-	-	-	-	-	-	-	-	22.038	20
S_t 60	24.979	24.143	23.306	-	-	-	-	-	-	-	24.979	20
S_t 90	28.257	27.421	26.584	25.748	24.858	-	-	-	-	-	28.257	20
S_t 120	31.836	31	30.163	29.327	28.491	27.654	-	-	-	-	31.836	20
S_t 150	35.752	34.916	34.079	33.243	32.407	31.57	30.734	29.844	-	-	35.752	20
S_t 180	39.969	39.133	38.296	37.46	36.624	35.787	34.951	34.114	33.278	-	39.969	20
S_t 210	44.523	43.687	42.85	42.014	41.177	40.341	39.505	38.668	37.832	36.995	44.523	20
S_t 240	49.201	48.524	47.705	46.869	46.032	45.196	44.36	43.523	42.687	41.85	49.201	20
S_t 270	53.879	53.415	52.808	52.06	51.224	50.388	49.551	48.715	47.879	47.042	53.879	20
S_t 300	58.468	58.305	57.912	57.376	56.699	55.881	55.044	54.208	53.371	52.535	58.468	20
S_t 303	58.957	58.794	58.422	57.908	57.252	56.455	55.618	54.782	53.946	53.109	58.957	20

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt Rls
n=5												
S_t 0	0.78	-	-	-	-	-	-	-	-	-	0.78	20
S_t 30	23.214	22.222	-	-	-	-	-	-	-	-	23.214	20
S_t 60	26.396	25.443	24.49	3.969	-	-	-	-	-	-	26.396	20
S_t 90	29.901	28.948	27.995	27.041	26.049	-	-	-	-	-	29.901	20
S_t 120	33.721	32.768	31.815	30.861	29.908	28.955	8.433	-	-	-	33.721	20
S_t 150	37.864	36.911	35.957	35.004	34.051	33.097	32.144	31.152	-	-	37.864	20
S_t 180	42.322	41.369	40.415	39.462	38.509	37.555	36.602	35.649	34.695	14.174	42.322	20
S_t 210	47.103	46.149	45.196	44.243	43.289	42.336	41.383	40.429	39.476	38.523	47.103	20
S_t 240	51.993	51.214	50.292	49.339	48.385	47.432	46.479	45.525	44.572	43.619	51.993	20
S_t 270	56.884	56.317	55.608	54.757	53.804	52.851	51.897	50.944	49.991	49.037	56.884	20
S_t 300	61.7	61.42	60.924	60.286	59.506	58.584	57.631	56.678	55.724	54.771	61.7	20
S_t 303	-	61.931	61.456	60.839	60.08	59.18	58.227	57.273	56.32	55.366	61.931	40
n=6												
S_t 0	1.563	-	-	-	-	-	-	-	-	-	1.563	20
S_t 30	24.302	23.164	-	-	-	-	-	-	-	-	24.302	20
S_t 60	27.711	26.605	25.5	4.741	-	-	-	-	-	-	27.711	20
S_t 90	31.436	30.33	29.224	28.118	26.981	-	-	-	-	-	31.436	20
S_t 120	35.483	34.377	33.271	32.165	31.06	29.954	9.195	-	-	-	35.483	20
S_t 150	39.845	38.739	37.634	36.528	35.422	34.316	33.211	32.073	-	-	39.845	20
S_t 180	44.53	43.424	42.318	41.213	40.107	39.001	37.895	36.79	35.684	14.925	44.53	20
S_t 210	49.53	48.425	47.319	46.213	45.107	44.002	42.896	41.79	40.684	39.579	49.53	20
S_t 240	54.634	53.708	52.642	51.536	50.43	49.324	48.219	47.113	46.007	44.901	54.634	20
S_t 270	59.737	59.024	58.17	57.174	56.068	54.963	53.857	52.751	51.645	50.54	59.737	20
S_t 300	64.773	64.34	63.699	62.915	61.99	60.923	59.818	58.712	57.606	56.5	64.773	20
S_t 303	-	64.872	64.252	63.49	62.586	61.54	60.434	59.329	58.223	57.117	64.872	40

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt Rls
n=7												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	-	-	-	-	-	-	-	-	-	0	-
S_t 60	-	24.897	-	-	-	-	-	-	-	-	24.897	40
S_t 90	-	28.593	27.427	6.098	-	-	-	-	-	-	28.593	40
S_t 120	-	32.584	31.418	30.252	29.086	-	-	-	-	-	32.584	40
S_t 150	-	36.918	35.752	34.586	33.42	32.254	10.925	-	-	-	36.918	40
S_t 180	-	41.546	40.38	39.214	38.048	36.882	35.716	34.55	-	-	41.546	40
S_t 210	-	46.518	45.352	44.186	43.02	41.854	40.688	39.522	38.356	17.027	46.518	40
S_t 240	-	51.784	50.618	49.452	48.286	47.12	45.954	44.788	43.622	42.456	51.784	40
S_t 270	-	57.313	56.228	55.062	53.896	52.73	51.564	50.398	49.232	48.066	57.313	40
S_t 300	-	62.841	61.969	60.955	59.8	58.634	57.468	56.302	55.136	53.97	62.841	40
S_t 303	-	63.394	62.543	61.551	60.417	59.251	58.085	56.919	55.753	54.587	63.394	40
n=8												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	-	-	-	-	-	-	-	-	-	0	-
S_t 60	-	2.091	-	-	-	-	-	-	-	-	2.091	40
S_t 90	-	6.02	3.561	4.465	-	-	-	-	-	-	6.02	40
S_t 120	-	29.887	28.735	5.315	6.29	-	-	-	-	-	29.887	40
S_t 150	-	34.189	33.048	31.906	10.857	8.398	9.302	-	-	-	34.189	40
S_t 180	-	38.785	37.644	36.503	35.362	34.21	10.79	11.765	-	-	38.785	40
S_t 210	-	43.725	42.584	41.443	40.302	39.16	38.019	16.97	14.511	15.415	43.725	40
S_t 240	-	48.959	47.818	46.677	45.536	44.395	43.254	42.112	40.96	17.541	48.959	40
S_t 270	-	54.537	53.396	52.255	51.114	49.973	48.832	47.69	46.549	45.408	54.537	40
S_t 300	-	60.41	59.268	58.127	56.986	55.845	54.704	53.563	52.421	51.28	60.41	40
S_t 303	-	61.005	59.874	58.733	57.592	56.451	55.31	54.168	53.027	51.886	61.005	40

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt Rls
n=9												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	-	-	-	-	-	-	-	-	-	0	-
S_t 60	-	2.091	-	-	-	-	-	-	-	-	2.091	40
S_t 90	-	4.422	3.561	4.465	-	-	-	-	-	-	4.465	80
S_t 120	-	6.226	6.247	5.315	6.29	-	-	-	-	-	6.29	100
S_t 150	-	31.502	9.217	9.238	9.259	8.398	9.302	-	-	-	31.502	40
S_t 180	-	36.078	34.958	33.806	11.701	11.722	10.79	11.765	-	-	36.078	40
S_t 210	-	40.975	39.855	38.735	37.615	15.33	15.351	15.372	14.511	15.415	40.975	40
S_t 240	-	46.188	45.068	43.948	42.828	41.708	40.556	18.452	18.473	17.541	46.188	40
S_t 270	-	51.723	50.604	49.484	48.364	47.244	46.124	45.004	22.718	22.74	51.723	40
S_t 300	-	57.574	56.455	55.335	54.215	53.095	51.975	50.855	49.735	48.583	57.574	40
S_t 303	-	58.17	57.05	55.93	54.81	53.69	52.57	51.45	50.33	49.2	58.17	40
n=10												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	0.907	-	-	-	-	-	-	-	-	-	0.907	20
S_t 60	1.12	2.098	-	-	-	-	-	-	-	-	2.098	40
S_t 90	4.426	4.443	3.572	4.479	-	-	-	-	-	-	4.479	80
S_t 120	6.237	6.254	6.272	5.329	6.307	-	-	-	-	-	6.307	100
S_t 150	9.22	9.238	9.256	9.273	9.291	8.419	9.327	-	-	-	9.327	140
S_t 180	34.664	33.515	11.704	11.722	11.74	11.758	10.815	11.793	-	-	34.664	20
S_t 210	39.533	38.43	37.328	15.344	15.361	15.379	15.397	15.415	14.543	15.45	39.533	20
S_t 240	44.731	43.629	42.527	41.425	40.276	18.466	18.484	18.501	18.519	17.576	44.731	20
S_t 270	50.239	49.136	48.034	46.932	45.83	44.728	22.743	22.761	22.779	22.796	50.239	20
S_t 300	56.075	54.973	53.871	52.769	51.667	50.564	49.462	48.314	26.503	26.521	56.075	20
S_t 303	56.671	55.569	54.466	53.364	52.262	51.16	50.058	48.93	26.801	26.819	56.671	20

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=11												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	0.9	-	-	-	-	-	-	-	-	-	0.9	20
S_t 60	2.062	2.084	-	-	-	-	-	-	-	-	2.084	40
S_t 90	4.387	4.408	4.429	4.451	-	-	-	-	-	-	4.451	80
S_t 120	6.187	6.208	6.229	6.251	6.272	-	-	-	-	-	6.272	100
S_t 150	9.149	9.171	9.192	9.213	9.234	9.256	9.277	-	-	-	9.277	140
S_t 180	12.966	11.609	11.63	11.651	11.673	11.694	11.715	11.736	-	-	12.966	20
S_t 210	37.775	36.69	15.23	15.252	15.273	15.294	15.315	15.337	15.358	15.379	37.775	20
S_t 240	42.942	41.861	40.78	19.706	18.349	18.37	18.391	18.413	18.434	18.455	42.942	20
S_t 270	48.396	47.315	46.234	45.153	44.068	22.608	22.63	22.651	22.672	22.693	48.396	20
S_t 300	54.201	53.12	52.039	50.958	49.877	48.796	27.722	26.365	26.386	26.407	54.201	20
S_t 303	54.796	53.715	52.634	51.553	50.472	49.391	48.257	26.663	26.684	26.705	54.796	20
n=12												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	1.878	-	-	-	-	-	-	-	-	1.878	40
S_t 60	-	4.202	4.121	4.039	-	-	-	-	-	-	4.202	40
S_t 90	-	6.003	5.921	5.84	5.758	-	-	-	-	-	6.003	40
S_t 120	-	8.965	8.884	8.802	8.721	8.639	8.558	-	-	-	8.965	40
S_t 150	-	11.403	11.322	11.24	11.159	11.077	10.996	10.914	-	-	11.403	40
S_t 180	-	15.004	14.922	14.841	14.759	14.677	14.596	14.514	14.433	14.351	15.004	40
S_t 210	-	40.085	19.185	17.917	17.835	17.753	17.672	17.59	17.509	17.427	40.085	40
S_t 240	-	45.518	44.356	43.168	22.073	21.992	21.91	21.829	21.747	21.666	45.518	40
S_t 270	-	51.28	50.118	48.955	47.793	26.893	25.624	25.543	25.461	25.38	51.28	40
S_t 300	-	57.351	56.189	55.026	53.864	52.701	51.514	30.419	30.337	30.256	57.351	40
S_t 303	-	57.968	56.805	55.643	54.48	53.318	52.152	30.759	30.678	30.596	57.968	40

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=13												
S_t 0	12.406	11.644	10.882	10.12	9.358	8.596	7.834	6.321	-	-	12.406	20
S_t 30	15.496	14.816	14.135	13.455	12.774	12.094	11.413	10.733	10.052	-	15.496	20
S_t 60	40.911	18.639	17.877	17.115	16.353	15.591	14.83	14.068	13.306	12.544	40.911	20
S_t 90	46.521	44.678	22.672	20.843	20.163	19.482	18.802	18.122	17.441	16.761	46.521	20
S_t 120	52.425	50.582	48.739	46.896	24.625	23.863	23.101	22.339	21.577	20.815	52.425	20
S_t 150	58.673	56.83	54.987	53.144	51.301	29.295	27.467	26.786	26.106	25.425	58.673	20
S_t 180	-	-	61.529	59.686	57.843	56	54.157	31.886	31.124	30.362	61.529	60
S_t 210	-	-	-	66.572	64.729	62.886	61.043	59.2	37.194	35.366	66.572	80
S_t 240	-	-	-	-	-	70.066	68.223	66.38	64.537	62.694	70.066	120
S_t 270	-	-	-	-	-	-	75.747	73.904	72.061	70.218	75.747	140
S_t 300	-	-	-	-	-	-	-	-	79.879	78.036	79.879	180
S_t 303	-	-	-	-	-	-	-	-	80.687	78.844	80.687	180
n=14												
S_t 0	56.759	53.782	50.805	47.828	44.826	21.917	20.021	-	-	-	56.759	20
S_t 30	61.529	60.395	57.418	54.441	51.464	48.487	25.772	22.689	20.793	-	61.529	20
S_t 60	66.607	65.473	64.339	61.362	58.385	55.408	52.431	49.429	26.52	24.624	66.607	20
S_t 90	70.172	69.038	67.904	66.77	65.636	62.659	59.682	56.705	53.728	31.013	70.172	20
S_t 120	75.888	74.754	73.62	72.486	71.352	70.218	67.241	64.264	61.287	58.31	75.888	20
S_t 150	80.091	78.957	77.823	76.689	75.555	74.421	73.287	72.153	69.176	66.199	80.091	20
S_t 180	-	85.311	84.177	83.043	81.909	80.775	79.641	78.507	77.373	74.396	85.311	40
S_t 210	-	-	-	87.884	86.75	85.616	84.482	83.348	82.214	81.079	87.884	80
S_t 240	-	-	-	-	93.742	92.608	91.474	90.34	89.206	88.072	93.742	100
S_t 270	-	-	-	-	-	-	96.952	95.818	94.684	93.55	96.952	140
S_t 300	-	-	-	-	-	-	-	103.448	102.314	101.18	103.448	160
S_t 303	-	-	-	-	-	-	-	104.405	103.271	102.137	104.405	160

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=15												
S_t 0	60.855	-	-	-	-	-	-	-	-	-	60.855	20
S_t 30	64.137	62.329	60.522	-	-	-	-	-	-	-	64.137	20
S_t 60	69.605	67.798	65.99	64.183	-	-	-	-	-	-	69.605	20
S_t 90	73.524	71.717	69.909	68.102	66.295	64.487	-	-	-	-	73.524	20
S_t 120	79.63	77.823	76.016	74.208	72.401	70.593	68.786	-	-	-	79.63	20
S_t 150	84.188	82.38	80.573	78.765	76.958	75.151	73.343	71.536	69.728	-	84.188	20
S_t 180	88.664	87.99	87.317	85.509	83.702	81.895	80.087	78.28	76.472	74.665	88.664	20
S_t 210	92.725	92.051	91.378	90.705	88.897	87.09	85.282	83.475	81.667	79.86	92.725	20
S_t 240	97.838	97.165	96.492	95.818	95.145	94.472	92.664	90.857	89.049	87.242	97.838	20
S_t 270	102.537	101.864	101.191	100.517	99.844	99.171	98.497	96.69	94.882	93.075	102.537	20
S_t 300	-	107.616	106.943	106.269	105.596	104.922	104.249	103.576	102.902	101.095	107.616	40
S_t 303	-	108.615	107.942	107.269	106.595	105.922	105.248	104.575	103.902	102.094	108.615	40
n=16												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	64.817	62.847	-	-	-	-	-	-	-	-	64.817	20
S_t 60	68.538	66.568	64.597	-	-	-	-	-	-	-	68.538	20
S_t 90	74.439	72.468	70.498	68.527	66.557	-	-	-	-	-	74.439	20
S_t 120	78.797	76.827	74.857	72.886	70.916	68.945	-	-	-	-	78.797	20
S_t 150	85.336	83.366	81.395	79.425	77.454	75.484	73.513	71.543	-	-	85.336	20
S_t 180	89.199	88.362	86.392	84.421	82.451	80.48	78.51	76.539	74.569	-	89.199	20
S_t 210	94.107	93.27	92.434	91.598	89.627	87.657	85.686	83.716	81.745	79.775	94.107	20
S_t 240	98.607	97.771	96.935	96.098	95.262	93.291	91.321	89.35	87.38	85.41	98.607	20
S_t 270	104.154	103.317	102.481	101.644	100.808	99.972	99.135	97.165	95.194	93.224	104.154	20
S_t 300	108.619	108.456	107.619	106.783	105.946	105.11	104.274	103.437	101.467	99.496	108.619	20
S_t 303	108.505	108.342	107.506	106.669	105.833	104.997	104.16	103.324	102.488	100.517	108.505	20

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=17												
S_t 0	0.78	-	-	-	-	-	-	-	-	-	0.78	20
S_t 30	66.291	64.204	-	-	-	-	-	-	-	-	66.291	20
S_t 60	70.253	68.166	66.078	3.969	-	-	-	-	-	-	70.253	20
S_t 90	76.381	74.293	72.206	70.118	68.031	-	-	-	-	-	76.381	20
S_t 120	80.98	78.893	76.806	74.718	72.631	70.543	8.433	-	-	-	80.98	20
S_t 150	87.746	85.658	83.571	81.483	79.396	77.309	75.221	73.134	-	-	87.746	20
S_t 180	91.849	90.896	88.809	86.721	84.634	82.546	80.459	78.371	76.284	14.174	91.849	20
S_t 210	96.984	96.031	95.078	94.124	92.037	89.95	87.862	85.775	83.687	81.6	96.984	20
S_t 240	101.726	100.773	99.819	98.866	97.913	95.825	93.738	91.65	89.563	87.475	101.726	20
S_t 270	107.499	106.546	105.592	104.639	103.686	102.732	101.779	99.691	97.604	95.517	107.499	20
S_t 300	112.205	111.925	110.972	110.018	109.065	108.112	107.158	106.205	104.118	102.03	112.205	20
S_t 303	-	111.833	110.88	109.926	108.973	108.02	107.066	106.113	105.16	103.072	111.833	40
n=18												
S_t 0	1.563	-	-	-	-	-	-	-	-	-	1.563	20
S_t 30	67.528	65.288	-	-	-	-	-	-	-	-	67.528	20
S_t 60	71.717	69.477	67.237	4.741	-	-	-	-	-	-	71.717	20
S_t 90	78.064	75.824	73.584	71.344	69.105	-	-	-	-	-	78.064	20
S_t 120	82.89	80.651	78.411	76.171	73.931	71.691	9.195	-	-	-	82.89	20
S_t 150	89.875	87.636	85.396	83.156	80.916	78.676	76.437	74.197	-	-	89.875	20
S_t 180	93.072	91.966	90.86	88.621	86.381	84.141	81.901	79.661	77.422	14.925	93.072	20
S_t 210	99.561	98.455	97.349	96.244	94.004	91.764	89.524	87.284	85.044	82.805	99.561	20
S_t 240	103.395	102.289	101.184	100.078	98.972	97.866	95.627	93.387	91.147	88.907	103.395	20
S_t 270	110.522	109.416	108.31	107.205	106.099	104.993	103.887	101.648	99.408	97.168	110.522	20
S_t 300	114.321	113.888	112.782	111.677	110.571	109.465	108.36	107.254	106.148	103.908	114.321	20
S_t 303	-	114.951	113.846	112.74	111.634	110.529	109.423	108.317	107.211	104.972	114.951	40

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=19												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	-	-	-	-	-	-	-	-	-	0	-
S_t 60	-	66.039	-	-	-	-	-	-	-	-	66.039	40
S_t 90	-	72.358	70.058	6.098	-	-	-	-	-	-	72.358	40
S_t 120	-	77.128	74.828	72.528	70.228	-	-	-	-	-	77.128	40
S_t 150	-	84.085	81.785	79.484	77.184	74.884	10.925	-	-	-	84.085	40
S_t 180	-	89.492	87.192	84.892	82.592	80.292	77.992	75.692	-	-	89.492	40
S_t 210	-	95.953	94.787	92.487	90.187	87.887	85.587	83.287	80.987	17.027	95.953	40
S_t 240	-	100.865	99.699	98.533	96.233	93.932	91.632	89.332	87.032	84.732	100.865	40
S_t 270	-	106.829	105.663	104.497	103.331	102.165	99.865	97.565	95.265	92.965	106.829	40
S_t 300	-	112.378	111.212	110.047	108.881	107.715	106.549	104.249	101.948	99.648	112.378	40
S_t 303	-	113.442	112.276	111.11	109.944	108.778	107.612	105.312	103.012	100.712	113.442	40
n=20												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	-	-	-	-	-	-	-	-	-	0	-
S_t 60	-	2.091	-	-	-	-	-	-	-	-	2.091	40
S_t 90	-	6.02	3.561	4.465	-	-	-	-	-	-	6.02	40
S_t 120	-	73.559	71.284	5.315	6.29	-	-	-	-	-	73.559	40
S_t 150	-	78.641	76.366	74.091	10.857	8.398	9.302	-	-	-	78.641	40
S_t 180	-	85.86	83.585	81.309	79.034	76.759	10.79	11.765	-	-	85.86	40
S_t 210	-	91.58	89.304	87.029	84.754	82.479	80.203	16.97	14.511	15.415	91.58	40
S_t 240	-	99.436	97.161	94.886	92.611	90.335	88.06	85.785	83.51	17.541	99.436	40
S_t 270	-	103.526	102.385	101.244	98.968	96.693	94.418	92.143	89.867	87.592	103.526	40
S_t 300	-	110.887	109.745	108.604	107.463	105.188	102.913	100.637	98.362	96.087	110.887	40
S_t 303	-	110.096	108.955	107.814	106.673	104.397	102.122	99.847	97.572	95.296	110.096	40

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=21												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	-	-	-	-	-	-	-	-	-	0	-
S_t 60	-	2.091	-	-	-	-	-	-	-	-	2.091	40
S_t 90	-	4.422	3.561	4.465	-	-	-	-	-	-	4.465	80
S_t 120	-	6.226	6.247	5.315	6.29	-	-	-	-	-	6.29	100
S_t 150	-	73.24	9.217	9.238	9.259	8.398	9.302	-	-	-	73.24	40
S_t 180	-	80.438	78.184	75.93	11.701	11.722	10.79	11.765	-	-	80.438	40
S_t 210	-	86.115	83.861	81.607	79.353	15.33	15.351	15.372	14.511	15.415	86.115	40
S_t 240	-	93.95	91.696	89.442	87.188	84.934	82.68	18.452	18.473	17.541	93.95	40
S_t 270	-	100.265	98.011	95.757	93.503	91.249	88.996	86.742	22.718	22.74	100.265	40
S_t 300	-	107.605	106.485	104.231	101.977	99.723	97.469	95.215	92.961	90.707	107.605	40
S_t 303	-	108.647	107.527	105.273	103.019	100.765	98.511	96.257	94.003	91.749	108.647	40
n=22												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	0.907	-	-	-	-	-	-	-	-	-	0.907	20
S_t 60	1.12	2.098	-	-	-	-	-	-	-	-	2.098	40
S_t 90	4.426	4.443	3.572	4.479	-	-	-	-	-	-	4.479	80
S_t 120	6.237	6.254	6.272	5.329	6.307	-	-	-	-	-	6.307	100
S_t 150	9.22	9.238	9.256	9.273	9.291	8.419	9.327	-	-	-	9.327	140
S_t 180	77.592	75.356	11.704	11.722	11.74	11.758	10.815	11.793	-	-	77.592	20
S_t 210	83.241	81.004	78.768	15.344	15.361	15.379	15.397	15.415	14.543	15.45	83.241	20
S_t 240	91.062	88.826	86.589	84.353	82.117	18.466	18.484	18.501	18.519	17.576	91.062	20
S_t 270	97.349	95.112	92.876	90.64	88.404	86.167	22.743	22.761	22.779	22.796	97.349	20
S_t 300	105.808	103.572	101.336	99.099	96.863	94.627	92.39	90.154	26.503	26.521	105.808	20
S_t 303	106.85	104.614	102.377	100.141	97.905	95.669	93.432	91.196	26.801	26.819	106.85	20

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt Rls
n=23												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	0.9	-	-	-	-	-	-	-	-	-	0.9	20
S_t 60	2.062	2.084	-	-	-	-	-	-	-	-	2.084	40
S_t 90	4.387	4.408	4.429	4.451	-	-	-	-	-	-	4.451	80
S_t 120	6.187	6.208	6.229	6.251	6.272	-	-	-	-	-	6.272	100
S_t 150	9.149	9.171	9.192	9.213	9.234	9.256	9.277	-	-	-	9.277	140
S_t 180	12.966	11.609	11.63	11.651	11.673	11.694	11.715	11.736	-	-	12.966	20
S_t 210	81.596	79.381	15.23	15.252	15.273	15.294	15.315	15.337	15.358	15.379	81.596	20
S_t 240	87.543	85.328	83.113	19.706	18.349	18.37	18.391	18.413	18.434	18.455	87.543	20
S_t 270	95.619	93.404	91.189	88.974	86.759	22.608	22.63	22.651	22.672	22.693	95.619	20
S_t 300	102.204	99.989	97.774	95.559	93.344	91.129	27.722	26.365	26.386	26.407	102.204	20
S_t 303	103.246	101.031	98.816	96.601	94.386	92.171	89.956	26.663	26.684	26.705	103.246	20
n=24												
S_t 0	-	-	-	-	-	-	-	-	-	-	0	-
S_t 30	-	1.878	-	-	-	-	-	-	-	-	1.878	40
S_t 60	-	4.202	4.121	4.039	-	-	-	-	-	-	4.202	40
S_t 90	-	6.003	5.921	5.84	5.758	-	-	-	-	-	6.003	40
S_t 120	-	8.965	8.884	8.802	8.721	8.639	8.558	-	-	-	8.965	40
S_t 150	-	11.403	11.322	11.24	11.159	11.077	10.996	10.914	-	-	11.403	40
S_t 180	-	15.004	14.922	14.841	14.759	14.677	14.596	14.514	14.433	14.351	15.004	40
S_t 210	-	81.972	19.185	17.917	17.835	17.753	17.672	17.59	17.509	17.427	81.972	40
S_t 240	-	90.027	87.73	85.434	22.073	21.992	21.91	21.829	21.747	21.666	90.027	40
S_t 270	-	96.569	94.272	91.976	89.679	26.893	25.624	25.543	25.461	25.38	96.569	40
S_t 300	-	105.262	102.966	100.669	98.373	96.076	93.78	30.419	30.337	30.256	105.262	40
S_t 303	-	106.325	104.029	101.732	99.436	97.139	94.843	30.759	30.678	30.596	106.325	40

continued

	R20	R40	R60	R80	R100	R120	R140	R160	R180	R200	MaxEnPrdcd in MWH	Opt RIs
n=25												
S_t 0	12.406	11.644	10.882	10.12	9.358	8.596	7.834	6.321	-	-	12.406	20
S_t 30	15.496	14.816	14.135	13.455	12.774	12.094	11.413	10.733	10.052	-	15.496	20
S_t 60	82.053	18.639	17.877	17.115	16.353	15.591	14.83	14.068	13.306	12.544	82.053	20
S_t 90	90.286	87.309	22.672	20.843	20.163	19.482	18.802	18.122	17.441	16.761	90.286	20
S_t 120	96.969	93.992	91.015	88.038	24.625	23.863	23.101	22.339	21.577	20.815	96.969	20
S_t 150	105.84	102.863	99.886	96.909	93.932	29.295	27.467	26.786	26.106	25.425	105.84	20
S_t 180	-	-	107.207	104.23	101.253	98.276	95.299	31.886	31.124	30.362	107.207	60
S_t 210	-	-	-	113.739	110.762	107.785	104.808	101.831	37.194	35.366	113.739	80
S_t 240	-	-	-	-	-	115.744	112.767	109.79	106.813	103.836	115.744	120
S_t 270	-	-	-	-	-	-	122.914	119.937	116.96	113.983	122.914	140
S_t 300	-	-	-	-	-	-	-	-	125.557	122.58	125.557	180
S_t 303	-	-	-	-	-	-	-	-	126.812	123.835	126.812	180
n=26												
S_t 0	103.536	99.425	95.314	91.203	87.092	21.917	20.021	-	-	-	103.536	20
S_t 30	107.951	106.817	102.706	98.595	94.484	90.373	25.772	22.689	20.793	-	107.951	20
S_t 60	114.518	113.384	112.25	108.139	104.028	99.917	95.806	91.695	26.52	24.624	114.518	20
S_t 90	116.595	115.461	114.327	113.193	112.058	107.947	103.836	99.725	95.614	31.013	116.595	20
S_t 120	123.8	122.665	121.531	120.397	119.263	118.129	114.018	109.907	105.796	101.685	123.8	20
S_t 150	126.514	125.38	124.246	123.112	121.978	120.843	119.709	118.575	114.464	110.353	126.514	20
S_t 180	-	133.223	132.088	130.954	129.82	128.686	127.552	126.418	125.284	121.173	133.223	40
S_t 210	-	-	-	134.307	133.173	132.038	130.904	129.77	128.636	127.502	134.307	80
S_t 240	-	-	-	-	141.653	140.519	139.385	138.251	137.117	135.983	141.653	100
S_t 270	-	-	-	-	-	-	143.375	142.241	141.107	139.973	143.375	140
S_t 300	-	-	-	-	-	-	-	151.36	150.226	149.091	151.36	160
S_t 303	-	-	-	-	-	-	-	152.763	151.629	150.495	152.763	160

Table A.6 Monthly Average and Annual Evaporation in mm for Mekelle Station

Month	**Sep.**	**Oct**	**Nov.**	**Dec.**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Augt**	**Annual**
1992	118.1	175.9	160.3	170.2	114.6	127.2	179.5	226.1	245.3	251.6	111.5	52.2	1932.5
1993	111.3	160.3	170.1	165.2	112.9	130.8	181.2	223.3	248.9	260.4	117.5	60.2	1942.1
1994	150	311.2	163.1	191	203	299.5	386.9	328.8	321.2	239.4	87.9	77.8	2759.8
1995	146	279.2	120	132	296.4	239.8	262.8	247.9	270.4	253.3	141.5	81.7	2471
Average	*131.4*	*231.7*	*153.4*	*164.6*	*181.7*	*199.3*	*252.6*	*256.5*	*271.5*	*251.2*	*114.6*	*68.0*	**2276.4**

Table A.7 Values of Runoff Coefficient

S/N	Type of Area	Value of K		
		Flat Land 0 to 5% slope	*Rolling Land 5 to 10% slope*	*Hilly Land 10 to 30% slope*
(a)	**Urban areas** 30% area impervious(paved) 50% area impervious(paved) 70% area impervious(paved)	 0.40 0.55 0.65	 0.50 0.65 0.80	 _ _ _
(b)	Single family residence in urban areas	0.3		
2	**Cultivated Areas** Open Sandy Loam Clay and Silt Loam Tight Clay	 0.30 0.50 0.60	 0.40 0.60 0.70	 0.52 0.72 0.82
3	**Pastures** Open Sandy Loam Clay and Silt Loam Tight Clay	 0.10 0.30 0.40	 0.16 0.36 0.55	 0.22 0.42 0.60
4	**Wooded land or Forested Areas** Open Sandy Loam Clay and Silt Loam Tight Clay	 0.10 0.30 0.40	 0.25 0.35 0.50	 0.30 0.50 0.60

Annex-B: Figures

Figure B.1 Mean Monthly Rainfall at Mekelle Station in mm

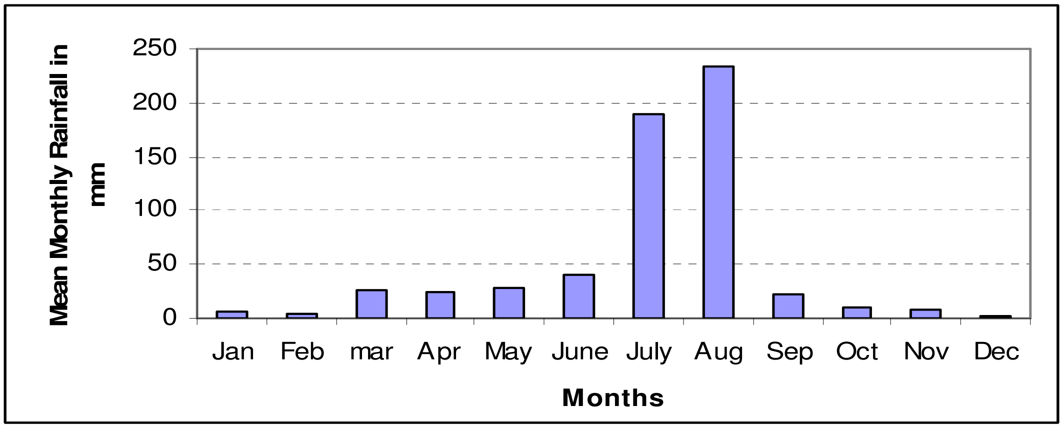


Figure B.2 Annual Rainfall at Mekelle Station in mm

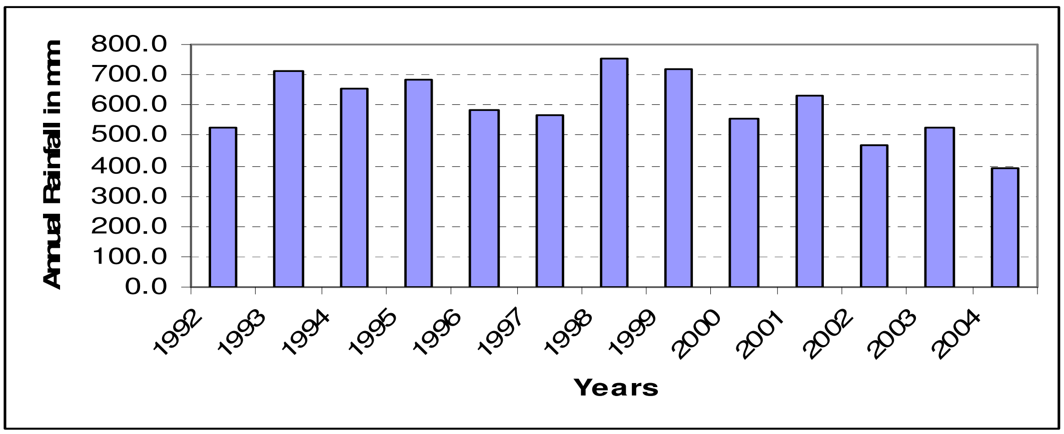


Figure B.3 Mean Monthly Rainfall at Samre Station in mm

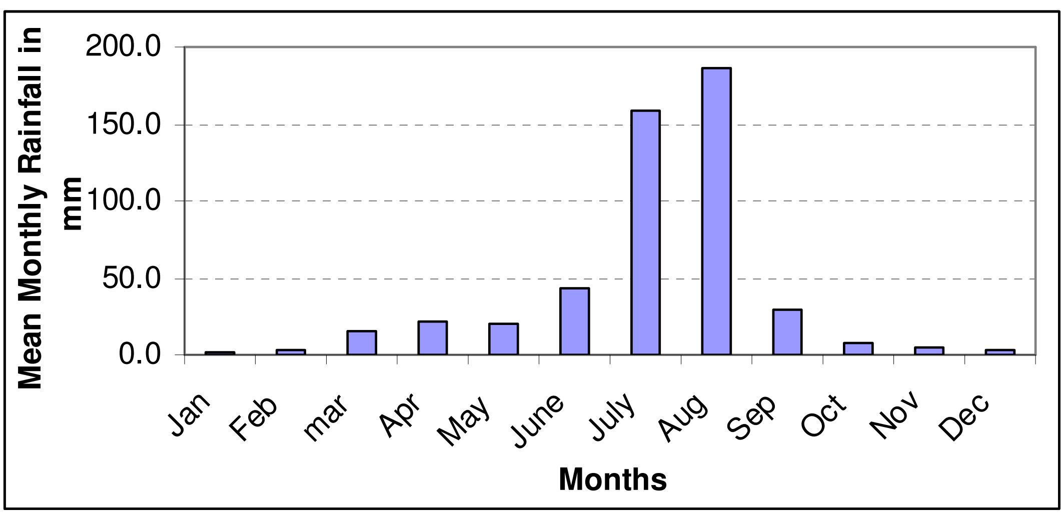


Figure B.4 Annual Rainfall at Samre Station in mm

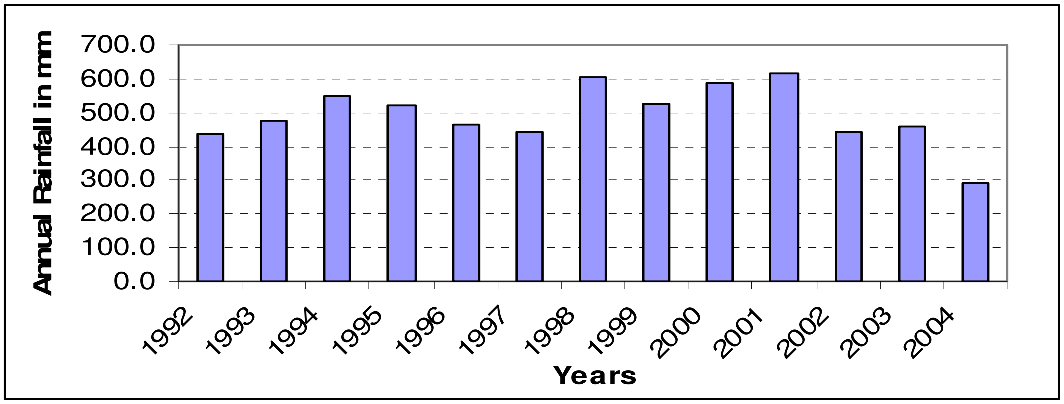


Figure B.5 Mean Monthly Rainfall at Adigudom Station in mm

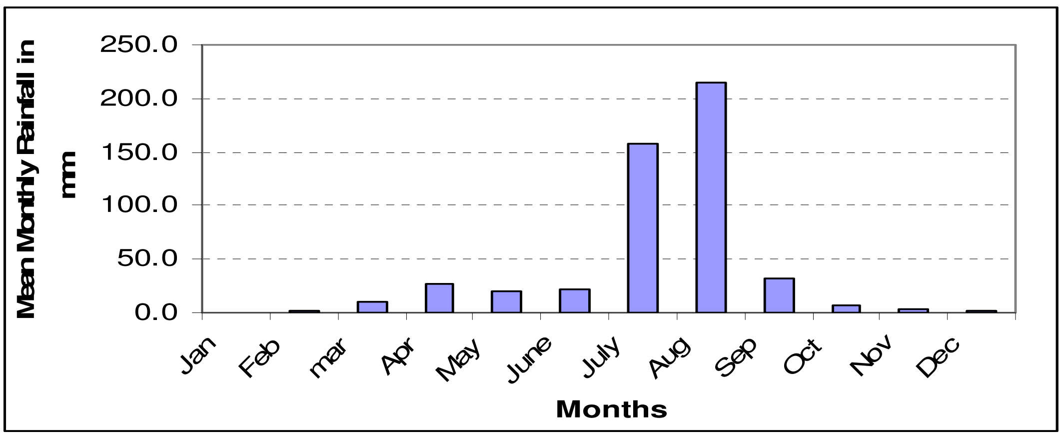


Figure B.6 Annual Rainfall at Adigudom Station in mm

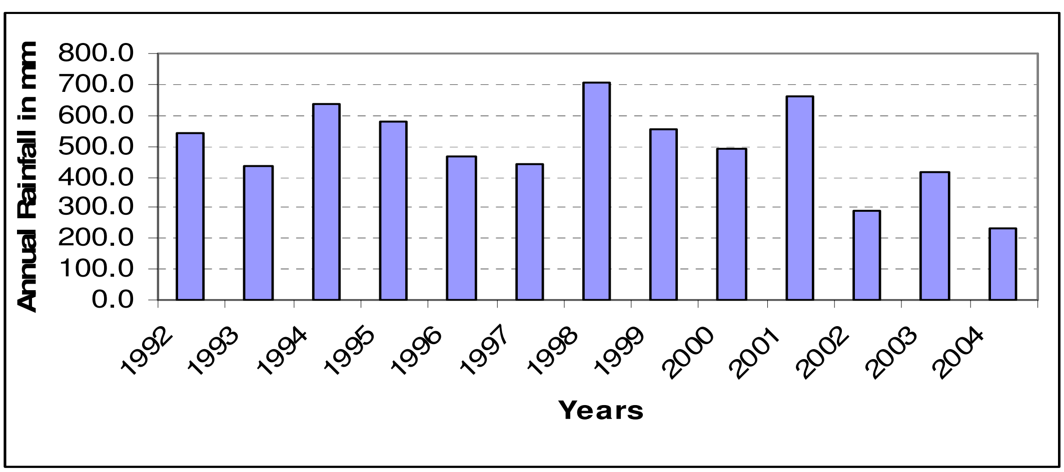


Figure B. 7 Double Mass Plot for Mekelle Station

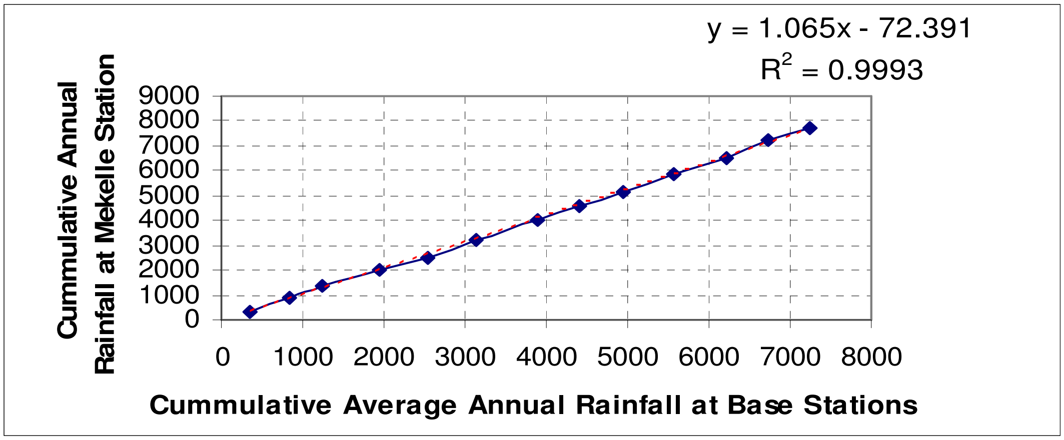


Figure B. 8 Double Mass Plot for Samre Station

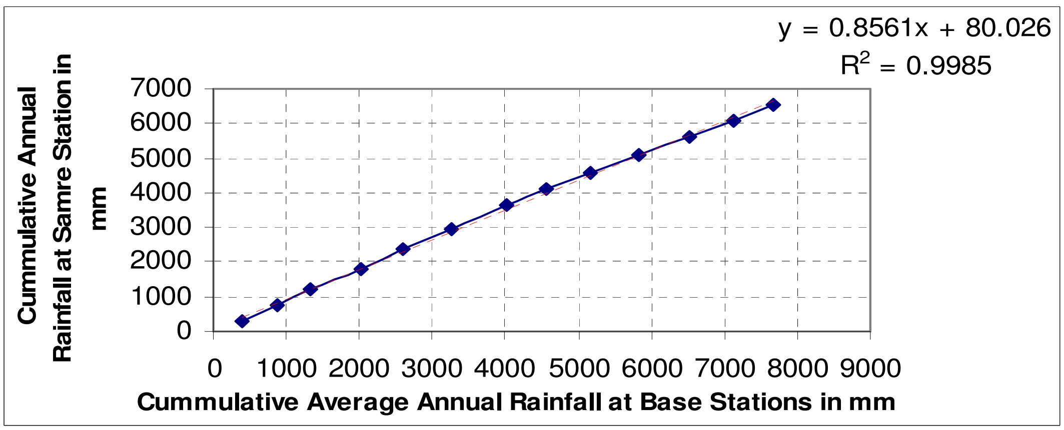


Figure B. 9 Double Mass Plot for Adigudom Station

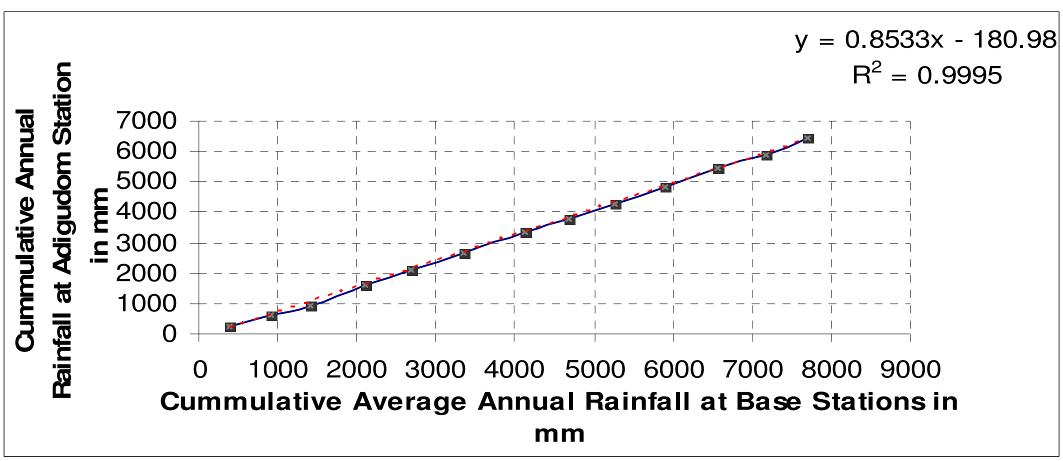
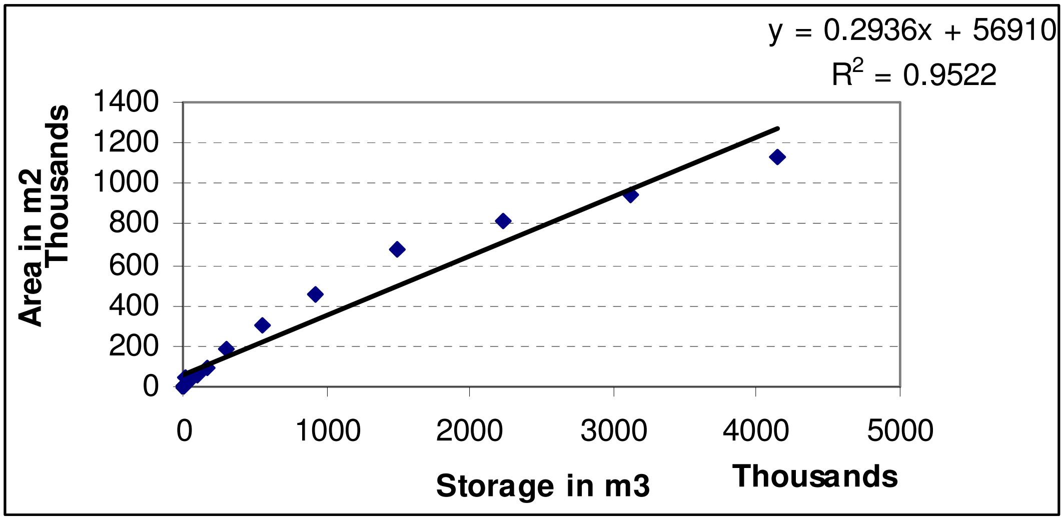


Figure B. 10 Area- versus- Storage Curve


y = 0.2936x + 56910
R^2 = 0.9522
Area in m2 Thousands
1400
1200
1000
800
600
400
200
0
0
1000
2000
3000
4000
5000
Storage in m3
Thousands

Annex-C: Visual Basic Program to Solve DP Problem
(Note that it is also applicable for other micro earth dams other than Haiba)

```
'Project:      MSc Thesis at AAU, Faculty of Technology, Department of Civil Engineering
'              Major: Hydraulics Engineeering.
'Date:         May 2005
'Programmer:  Mulatu Tiruneh
'Description:  Reservoir Operational Planning of Haiba Micro-Irrigation Dam for Micro-
'              Power Development using Dynamic Programming.

Option Explicit

Dim mvrtInflow(12)                         As Variant
Dim mvrtEvaporation(12)                    As Variant
Dim mvrtSeepage(12)                        As Variant
Dim mvrtEnergyProduced(1000)               As Variant
Dim mvrtOptimalReleases(1000)              As Variant
Dim mvrtInitialStorages                    As Double
Dim mvrtPossibleReleases                   As Double
Dim mvrtIrrTarRelease(12)                  As Double
Dim f(1000, 1000)                          As Variant
Dim mvrtStorageCapacity                    As Double
Dim mvrtMinWorkingStorageCapacity          As Double

Private Sub Command3_Click()
Dim i As Integer
For i = 1 To 12
MSFlexGrid1.TextMatrix(i, 1) = ""
 MSFlexGrid1.TextMatrix(i, 2) = ""
 MSFlexGrid1.TextMatrix(i, 3) = ""
 MSFlexGrid1.TextMatrix(i, 4) = ""
Next

End Sub

Private Sub open_Click()
On Error GoTo exitthissub
Dim filename As String
CommonDialog1.Filter = "*.txt|*.txt"
CommonDialog1.ShowOpen
filename = CommonDialog1.filename
Call fLoadFile(filename)
Text1.Text = filename
exitthissub:
End Sub

Private Sub runDP_Click()
'---------------------------------------Read Inputs From GUI------------------------------------
Dim i As Integer
Dim ElevCapintercept As Double
Dim ElevCapSlop As Double
Dim ActiveStorageCapacity As Double
Dim maximumConCapacity As Double
Dim Discrit1 As Integer
Dim Discrit2 As Integer
    'read Inflows, Seepage, Evaporation and Irrigation Release
Dim empty_field As Boolean
For i = 1 To 12
 If (IsNumeric(MSFlexGrid1.TextMatrix(i, 1)) = False) Then
  MsgBox "Invalid value is provided for Inflow Field for " & MSFlexGrid1.TextMatrix(i, 0), vbInformation, "Run Dp"
  GoTo exitSub
 End If
 If (IsNumeric(MSFlexGrid1.TextMatrix(i, 2)) = False) Then
  MsgBox "Invalid value is provided for Evaporation Field for " & MSFlexGrid1.TextMatrix(i, 0), vbInformation, "Run Dp"
  GoTo exitSub
```

```
 End If
 If (IsNumeric(MSFlexGrid1.TextMatrix(i, 3)) = False) Then
  MsgBox "Invalid value is provided for Seepage Field for " & MSFlexGrid1.TextMatrix(i, 0), vbInformation, "Run Dp"
  GoTo exitSub
 End If
 If (IsNumeric(MSFlexGrid1.TextMatrix(i, 4)) = False) Then
  MsgBox "Invalid value is provided for Irrigation Release Field for " & MSFlexGrid1.TextMatrix(i, 0), vbInformation, "Run
Dp"
  GoTo exitSub
 End If
Next

For i = 1 To 12
 mvrtInflow(i) = MSFlexGrid1.TextMatrix(i, 1)
 mvrtEvaporation(i) = MSFlexGrid1.TextMatrix(i, 2)
 mvrtSeepage(i) = MSFlexGrid1.TextMatrix(i, 3)
 mvrtIrrTarRelease(i) = MSFlexGrid1.TextMatrix(i, 4)
Next
      'Read Elevation storage Slope and Y intercept
ElevCapintercept = CDbl(eleinter.Text)
ElevCapSlop = CDbl(elevSlope.Text)
      'Read storage Capacity and Minimum Working capacity
mvrtStorageCapacity = CDbl(textStorageCapacity.Text)
mvrtMinWorkingStorageCapacity = CDbl(txtWcapa.Text)
      'Calculate Active Storage and Maximum Conveyance Capacity
ActiveStorageCapacity = Abs(textStorageCapacity.Text - txtWcapa.Text)
maximumConCapacity = (((12.4 * CDbl(MaxHeadtxt.Text) * (CDbl(diamtext.Text) ^ 4)) / ((0.14 * (CDbl(diamtext.Text) ^
4)) + 1.2 + (ftxt.Text * lentxt.Text / diamtext.Text))) ^ 0.5) * 259.2
       'Discrtization Cooeficients
Discrit1 = Int(ActiveStorageCapacity / 10)
Discrit2 = Int(maximumConCapacity / 10)
'-----------------------------------------------------------------------------------------
'-------------------Wrire Heading For the Output file-------------------------------------------------
Open App.Path & "\diba.CSV" For Output As #2
Dim tecc As String
For mvrtPossibleReleases = 20 To Int(maximumConCapacity) Step Discrit2
tecc = tecc & "," & "R" & mvrtPossibleReleases
Next
tecc = tecc & "," & "MaxEnPrdcd in MWH" & "," & "Opt Rls"
Print #2, tecc

Dim Countyears As Integer
Dim theindex As Integer

'==========================================================================================
theindex = 12
For Countyears = 1 To 30
Print #2, "n=" & Countyears
If (theindex = 0) Then
 theindex = 12
End If

'-----------------------------------------------------------------------------------------
Dim maxx As Double
Dim j As Integer
For mvrtInitialStorages = 0 To Int(ActiveStorageCapacity)
 For mvrtPossibleReleases = 20 To Int(maximumConCapacity) Step Discrit2
  If mvrtInitialStorages + mvrtInflow(theindex) - mvrtEvaporation(theindex) - mvrtSeepage(theindex) - mvrtStorageCapacity
+ mvrtMinWorkingStorageCapacity <= mvrtPossibleReleases And mvrtPossibleReleases <= mvrtInitialStorages +
mvrtInflow(theindex) - mvrtEvaporation(theindex) - mvrtSeepage(theindex) And mvrtPossibleReleases >=
mvrtIrrTarRelease(theindex) Then
    If (Countyears = 1) Then
```

```
     f(mvrtInitialStorages, mvrtPossibleReleases) = 8.86 * 10 ^ -3 * ElevCapSlop * (2 * ElevCapintercept / ElevCapSlop + 2 * mvrtInitialStorages + mvrtInflow(theindex) - mvrtEvaporation(theindex) - mvrtSeepage(theindex) - mvrtPossibleReleases) * mvrtPossibleReleases
    Else
     f(mvrtInitialStorages, mvrtPossibleReleases) = 8.86 * 10 ^ -3 * ElevCapSlop * (2 * ElevCapintercept / ElevCapSlop + 2 * mvrtInitialStorages + mvrtInflow(theindex) - mvrtEvaporation(theindex) - mvrtSeepage(theindex) - mvrtPossibleReleases) * mvrtPossibleReleases + mvrtEnergyProduced(mvrtInitialStorages + mvrtInflow(theindex) - mvrtEvaporation(theindex) - mvrtSeepage(theindex) - mvrtPossibleReleases)
    End If
  Else
    f(mvrtInitialStorages, mvrtPossibleReleases) = -100000
  End If
 Next mvrtPossibleReleases
Next mvrtInitialStorages
'---------------------------------------------------------------------------------
For mvrtInitialStorages = 0 To Int(ActiveStorageCapacity)
  '-------------Get the maximum--------------------
  maxx = 0
  For j = 20 To Int(maximumConCapacity) Step Discrit2
   If maxx < f(mvrtInitialStorages, j) Then
     maxx = f(mvrtInitialStorages, j)
   End If
  Next
  mvrtEnergyProduced(mvrtInitialStorages) = maxx
  '----------------------------------------------------
  For mvrtPossibleReleases = 20 To Int(maximumConCapacity) Step Discrit2
    If f(mvrtInitialStorages, mvrtPossibleReleases) = -100000 Then
      f(mvrtInitialStorages, mvrtPossibleReleases) = "-"
    End If
    If mvrtEnergyProduced(mvrtInitialStorages) = f(mvrtInitialStorages, mvrtPossibleReleases) Then
     mvrtOptimalReleases(mvrtInitialStorages) = mvrtPossibleReleases
    End If
  Next

  If mvrtEnergyProduced(mvrtInitialStorages) = -100000 Then
     mvrtEnergyProduced(mvrtInitialStorages) = 0
  End If
  If mvrtEnergyProduced(mvrtInitialStorages) = 0 Then
    mvrtOptimalReleases(mvrtInitialStorages) = "-"
  End If
'--------------------------
Dim tex As String
Dim kk As Integer
tex = "St" & mvrtInitialStorages
If (((mvrtInitialStorages Mod Discrit1) = 0) Or (mvrtInitialStorages = Int(ActiveStorageCapacity))) Then
 For kk = 0 To 9
  If IsNumeric(f(mvrtInitialStorages, 20 + kk * Discrit2)) Then
   tex = tex & "," & FormatNumber(f(mvrtInitialStorages, 20 + kk * Discrit2), 3)
  Else
   tex = tex & "," & f(mvrtInitialStorages, 20 + kk * Discrit2)
  End If
 Next

 If IsNumeric(mvrtEnergyProduced(mvrtInitialStorages)) Then
  tex = tex & "," & FormatNumber(mvrtEnergyProduced(mvrtInitialStorages), 3)
 Else
  tex = tex & "," & mvrtEnergyProduced(mvrtInitialStorages)
 End If

 If IsNumeric(mvrtOptimalReleases(mvrtInitialStorages)) Then
  tex = tex & "," & FormatNumber(mvrtOptimalReleases(mvrtInitialStorages), 3)
 Else
```

```
   tex = tex & "," & mvrtOptimalReleases(mvrtInitialStorages)
 End If

 Print #2, tex
End If
'---------------------------
Next mvrtInitialStorages

Print #2, vbCr
theindex = theindex - 1
Next
Close #2
exitSub:
End Sub

Private Sub exit_Click()
End
End Sub

Private Sub Form_Load()
MSFlexGrid1.ColWidth(1) = 1000
MSFlexGrid1.ColWidth(2) = 1000
MSFlexGrid1.ColWidth(3) = 1200
MSFlexGrid1.ColWidth(4) = 1200
MSFlexGrid1.TextMatrix(0, 0) = "Month"
MSFlexGrid1.TextMatrix(0, 1) = "Inflow"
MSFlexGrid1.TextMatrix(0, 2) = "Evaporation"
MSFlexGrid1.TextMatrix(0, 3) = "Seepage"
MSFlexGrid1.TextMatrix(0, 4) = "Irrigation "
Dim montt(12) As String
montt(1) = "September"
montt(2) = "October"
montt(3) = "November"
montt(4) = "December"
montt(5) = "January"
montt(6) = "February"
montt(7) = "March"
montt(8) = "April"
montt(9) = "May"
montt(10) = "June"
montt(11) = "July"
montt(12) = "August"

Dim i As Integer
For i = 1 To 12
MSFlexGrid1.TextMatrix(i, 0) = montt(i)
Next
End Sub
Sub fLoadFile(ByVal filename As String)
Dim inputdata As Double
Dim i As Integer
Dim j As Integer

Open filename For Input As #1
For i = 1 To 12
 For j = 1 To 4
  Input #1, inputdata
  MSFlexGrid1.TextMatrix(i, j) = inputdata
 Next
Next

Input #1, inputdata: textStorageCapacity.Text = inputdata
```

```
Input #1, inputdata: txtWcapa.Text = inputdata
Input #1, inputdata: eleinter.Text = inputdata
Input #1, inputdata: elevSlope.Text = inputdata
Input #1, inputdata: diamtext.Text = inputdata
Input #1, inputdata: lentxt.Text = inputdata
Input #1, inputdata: ftxt.Text = inputdata
Input #1, inputdata: MaxHeadtxt.Text = inputdata

Close 1
End Sub
Sub fSaveFile(ByVal filename As String)
Dim inputdata As Double
Dim i As Integer
Dim j As Integer
Dim tex As String

Open filename For Output As #1
For i = 1 To 12
tex = MSFlexGrid1.TextMatrix(i, 1)
 For j = 2 To 4
 tex = tex & "," & MSFlexGrid1.TextMatrix(i, j)
 Next
 Print #1, tex
Next
Print #1, textStorageCapacity.Text
Print #1, txtWcapa.Text
Print #1, eleinter.Text
Print #1, elevSlope.Text
Print #1, diamtext.Text
Print #1, lentxt.Text
Print #1, ftxt.Text
Print #1, MaxHeadtxt.Text
Close 1
End Sub
Private Sub MSFlexGrid1_KeyDown(KeyCode As Integer, Shift As Integer)
Dim tex As String
tex = MSFlexGrid1.TextMatrix(MSFlexGrid1.Row, MSFlexGrid1.Col):

Select Case KeyCode
 Case 46:    MSFlexGrid1.TextMatrix(MSFlexGrid1.Row, MSFlexGrid1.Col) = ""
 Case 13: If MSFlexGrid1.Row < 12 Then MSFlexGrid1.Row = MSFlexGrid1.Row + 1
 Case 8:
        If (Len(tex) >= 1) Then
        MSFlexGrid1.TextMatrix(MSFlexGrid1.Row, MSFlexGrid1.Col) = Left(tex, Len(tex) - 1)
        End If
 Case Else:
       If IsNumeric(MSFlexGrid1.TextMatrix(MSFlexGrid1.Row, MSFlexGrid1.Col) & Chr(KeyCode)) Then
        MSFlexGrid1.TextMatrix(MSFlexGrid1.Row, MSFlexGrid1.Col) = MSFlexGrid1.TextMatrix(MSFlexGrid1.Row,
MSFlexGrid1.Col) & Chr(KeyCode)
       End If
End Select
End Sub
Private Sub save_Click()
On Error GoTo exitthissub
Dim filename As String
CommonDialog1.Filter = "*.txt|*.txt"
CommonDialog1.ShowSave
filename = CommonDialog1.filename
Call fSaveFile(filename)
exitthissub:
End Sub
```