RESERVOIR OPERATIONAL PLANNING FOR RWEGURA HYDROPOWER PLANT IN BURUNDI

BY

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A Dissertation in Partial Fulfillment of the Requirements for the Degree of Master of Science in Hydraulics/Hydropower Engineering at Arba Minch University

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CERTIFICATION

The undersigned certified that he has read and hereby recommend the acceptance by Arba Minch University a thesis entitled: ***Reservoir Operational Planning for Rwegura Hydropower Plant in Burundi***, in partial fulfillment of the requirements of the degree of Master of Science in Hydraulics & Hydropower Engineering.

Dr. Nigussie Teklie Girma

(Supervisor) Signature……………………

Date…………………………

DECLARATION AND COPY RIGHT

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

Signature…………………………………

DEDICATION

Dedicated to my spouse Niyomwungere Félicité and my children.

ACKOWLEGMENT

I owe this achievement of mine to the Almighty God.

I would like to take this opportunity to sincerely thank the supervisor Dr.Nigussie Teklie Girma, for his guidance and advice through this work. From his input to this work and his continuous advice I have been greatly encouraged.

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ABSTRACT

Every Country in the world needs energy for its development. Energy constitutes an asset for sustainable socio-economic development of Burundi. Therefore, energy demand is greatly increasing in the Country. Developing hydropower plants to satisfy the energy demand needs effective attention. The newly planned and existing hydropower plants have to be used efficiently. One way to achieve this target is managing the reservoir in order to optimize the energy generation. In this study, Rwegura reservoir is modeled using Dynamic programming and Hec-ResSim 2.0 simulation model.

The necessary hydro-meteorological data have been collected and analyzed. The reservoir evaporation has been estimated using Aerodynamic method. The runoff data have been extended for the period of operation using rainfall-runoff relationship of 4 years (1980-1983) continuous recorded runoff and rainfall. Monthly computed runoffs of 20 years which correspond to the previous operational period were used in DP model and in modeling Rwegura reservoir by Hec-ResSim2.0.

As an optimization technique, Dynamic programming is used to derive the optimal guide curve. This optimal guide curve is used as a rule curve operation during the detailed reservoir simulation using Hec-ResSim2.0.

The outputs of DP model and Hec-reservoir simulation model are presented and discussed. The results show an annual average inflow, an annual average release and an annual average evaporation of respectively 53.47MCM, 50.06MCM and 3.27MCM within the reservoir. Further more, an improvement of energy production of 11.68 GWH per year is possible. Therefore new recommendations have been set to achieve this objective.

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LIST OF ABREVIATIONS

NE : North East

SE : South East

DP : Dynamic Programming

MCM : Millions Cubic Meters

Sq.km: square km

CHAPTER 1 INTRODUCTION

1.1 Back ground

As a requirement for life, water has been a source of continuous preoccupation for humans since the beginning of mankind. Planning for Water Resources Management is related to decisions with long-term socioeconomic as well as ecological effects. That means that the concept of sustainable development should play an important role in planning.

Due to the population growth of Burundi, the need of energy is increasing whereas the energy sources are limited. Therefore a careful management and planning of available energy sources is required. Hydropower is one of the important sources of energy of Burundi and optimization of output power of existing plants as well as construction of new hydropower projects will contribute to improve the energy consumption.

Whether it is an existing or newly constructed water reservoir for multipurpose or single purpose, an optimal operation of reservoir plays an important role in water resources development. A re-evaluation and improvement of a reservoir management by applying optimal reservoir operation techniques has great economical value. RWEGURA reservoir is a single purpose reservoir and greatest hydropower reservoir in Burundi with $24x10^6m^3$ of capacity.

In this study, the main concern is to derive an optimal rule curve for Rwegura reservoir that leads to an efficient utilization of water for power generation. An improvement of power production would contribute to reduce the actual energy deficit which is estimated about 25%.

1.2 Study area

The watershed of the reservoir is located in the North-West of Burundi between 2120 and 2621m of altitude, and between 2°55’S and 3^o20’S of latitude and 29°40’E to 29^o55’ E of longitude. The reservoir watershed extends on a surface area of 80.7 Km^2. It is characterized in general by steep slope and covered by the natural forest of Kibira at 50%.

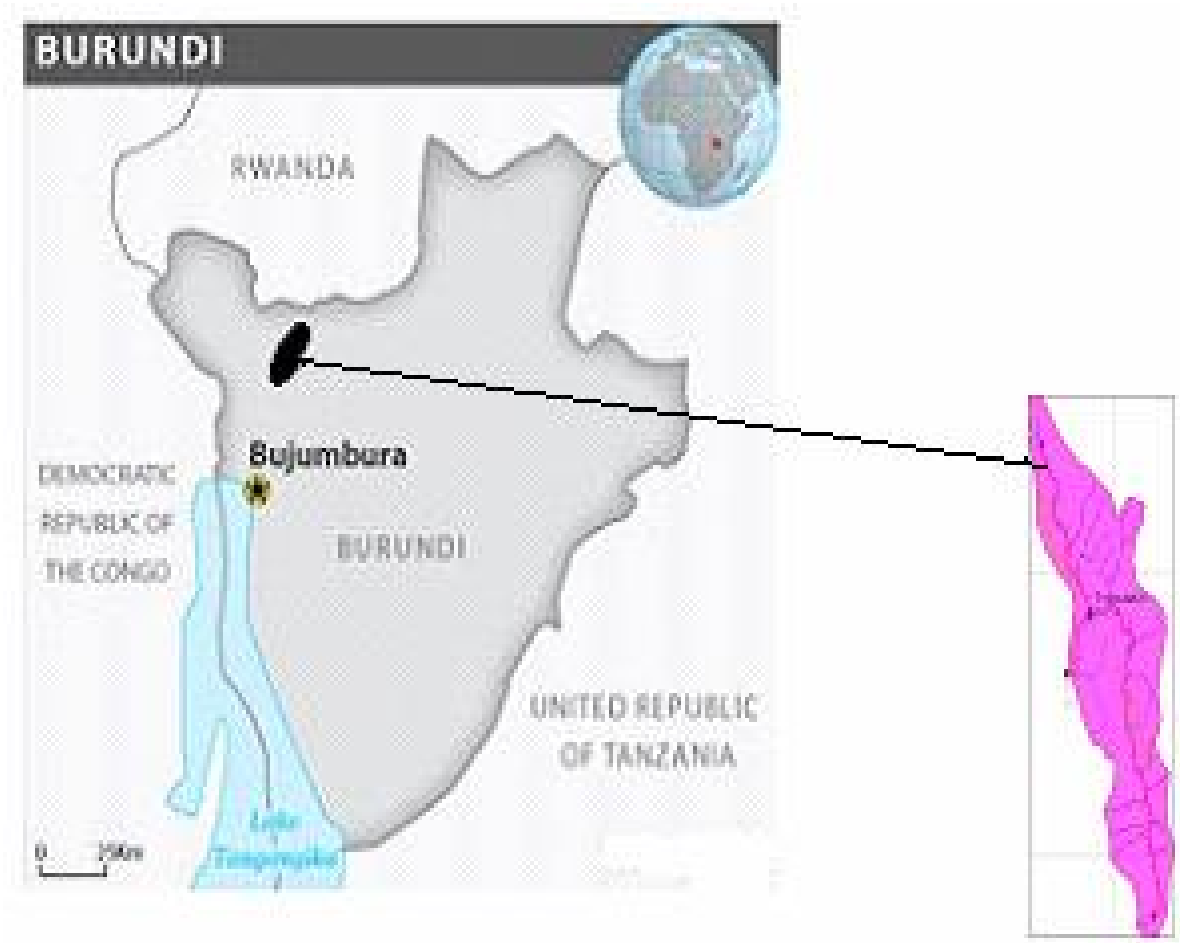

Figure1.1 Rwegura watershed location

1.3 Statement of the problem

The shortage of energy and the increasing of energy demand in Burundi are the main issues to overcome for ensuring a sustainable socio-economic development. The consumption of energy per capita is the lowest in Africa with 293KWH per year. The deficit of energy is estimated to 25%. A well management of existing energy sources and construction of new power stations would help to compensate for the deficit.

Rwegura reservoir operates to regulate the power production of the interconnected schemes of the Country; its releases depend upon the instantaneous demand in the Power Network with a less care to the water balance in the reservoir. This situation leads to an anarchic operation of the reservoir and low energy production of the power plant. The fluctuation of energy production has also a negative impact on the importation of energy [See Table1.1].

As it can be viewed in this table, if the gap of energy demand remains the same, the importation of energy depends mainly on the production of Rwegura plant which is used to regulate the total power production.

Therefore a re-evaluation of the reservoir management by applying optimal rule operation is required to improve the power production and an efficient utilization of water.

Table1.1: Yearly energy production and importation in MWh

Plant	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
RWEGURA	**40496.91**	**50190.52**	**41380**	**49966.85**	**58546.2**	**68082.3**	**48710.8**	**43874.7**	**49270.3**	**35823.12**
MUGERE	33,797.8	46,197.3	39,742.3	35,873.3	36,410.6	44,368.9	44,474.3	39,643.2	42,889.5	51,224.4
RUVYIRONZA	0.0	23,777.3	8,599.8	6,100.0	3,760.7	2,844.1	3,610.0	1,204.8	2,327.8	0.0
IMPORTED	**45,843.8**	**31,703.7**	**50,266.5**	**47,483.2**	**46,238.5**	**39,903.7**	**57,025.2**	**71,103.2**	**70,916.8**	**58,817.6**
TOTAL	**120138.6**	**151868.8**	**139988.6**	**139423.4**	**144956**	**155199**	**153820.3**	**155825.9**	**165404.3**	**145865.1**

*Note:The plant **Ruvyironza** was under reparation in 1997 and 2006 .*

1.4 Objective of the study

The main objective of the study is:

- **To develop an optimal rule curve operation of Rwegura reservoir,**

The specific objectives are:

- Developing Rwegura reservoir water balance,
- Evaluation of historical power production and power capability of Rwegura hydroelectric plant.

CHAPTER 2 LITTERATURE REVIEW

2.1 General

There are few resources of energy in Burundi. As 90% of the population is rural, wood and peat account 94% of energy consumption .Peat offers an alternative to increasingly scarce firewood and charcoal as a domestic energy source. The government is promoting peat production and tries to invest in renewable energy sources such as solar electricity and biogas.

The most important source of energy is hydroelectric energy with an installed capacity of 54.3MW from which 37MW are locally installed and 17.3MW are imported from Democratic Republic of Congo. A thermal power station has been also installed to produce 5.5MW.

Existing Hydropower plants

Table2.1 Power Plants capacities in Burundi

Name	**River**	**Installed capacity capacity (MW)**
Local plants		
Rwegura	gitenge	18
Mugere	Mugere	8
Nyemanga	Jiji	4
Ruvyironza	Ruvyironza	2.2
Marangara	-	0.24
Buhiga		0.8
Gikonge	Mubarazi	0.85
Sanzu	Sanzu	0.07
Autres (27 mcroPP)		2.93
External plants		
Ruzizi1&2	Ruzizi	17.3
TOTAL		**54.39**

2.2 Hydropower development of Burundi

2.2.1 General

Development of water power is only one of the many aspects of water resources. The main drawback of hydropower development is that the Hydropower plant can not be built economically at all places of demand, i.e near the centre. The suitable site for hydropower development may be at a considerable distance from load centre. The power has to be generated and then carried to the place of demand. In this process of transmission, there is a certain loss which can not be avoided. But with the development of regional and national power grid, different power stations may be integrated in a system and the losses been minimized. The Burundi electrical network map is presented in the Figure2.1 below.

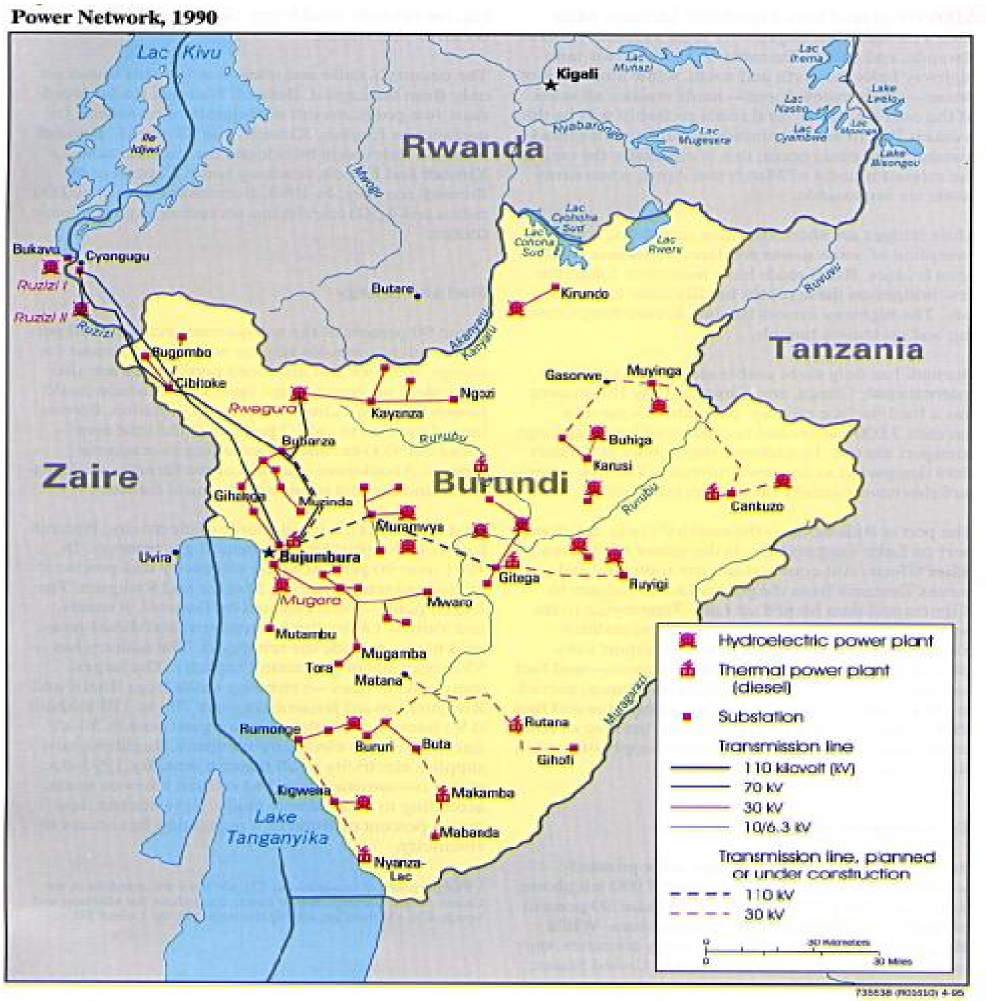

Figure 2.1 Burundi electric network map in 1990.

Note that actually the four main hydropower plants (Rwegura, Mugere, Nyemanga and Ruvyironza) are interconnected with the full above skills through which all planned lines had been constructed. An other line had also been added to join Tora station to Matana line to complete this interconnection.

2.2.2 Hydropower potential in Burundi

In Burundi, the hydropower development is at a low level and its improvement is a must to promote a sustainable development of the country. The alternatives energy sources are limited and all available hydropower potential is not exploited. A comprehensive evaluation of hydropower potential was completed in 1993.According to that study, the theoretical potential is 1,371MW and the harness able potential is 300MW, with an average annual production of 1,640GWH. Although this potential is fairly modest in absolute term, it represents actually 10 times the country's consumption of electricity and should therefore ensure the development of electrification for a long term. Rwegura reservoir watershed is located in the Rusizi basin with which its hydropower potential is illustrated in the Table2.2. The projected power demand for Burundi is shown in Table2.3 and Figure2.2 while the current power need is given in Table2.4.

Table2.2 Hydroelectric potential in Rusizi river basin exclusively at Burundi soil

(REGIDESO, LAHMEYER INT.

River name	Number of reservoirs	Estimated capacity(MW)
Kitenge/Kagunuzi	3(among with Rwegura)	100
Kaburantwa	1	20
Mpanda	2	19

Table 2.3 Projected energy demand for Burundi (Up to year 2020)

[US Department of Energy, EIA/DOE, 2003]

year	High(GWH)	Medium(GW	Low(GWH)
2002	133.5	133.5	133.5
2005	156.7	153.5	147.8
2010	207.1	196.6	179
2015	267.8	246.7	213.2
2020	340.4	304	249.6

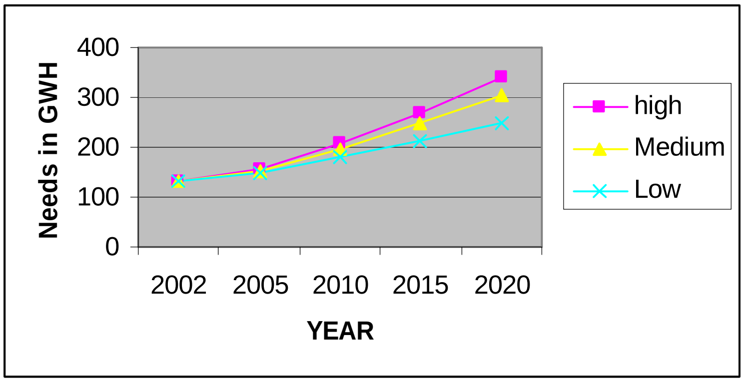

Figure2.2 Energy demand evolution up to 2020

Table2.4 Current power needs in Burundi

Potential in MW	Installed capacity in MW	Net production in MW(available)	Estimated demand in MW	Deficit in MW
300	54.3	37	50	13

2.3 Theory on hydropower generation

Hydropower is known as a traditional renewable energy resource, and is based on the flow of natural circulating water and its drop from a higher to a lower land surface.

This constitutes its potential energy. In order to convert this potential energy into applicable electric energy, the water flow must enter and drive a hydraulic turbine, transforming the hydro energy into mechanical energy. The later again drives a connected generator, transforming the mechanical energy into electric energy.

2.3.1 Net head

The head in hydropower design should be elaborated because of its importance. The design head (gross head) may be defined as the difference between the upper average water level z_u (at the intake) and the lower average water level z_1(at tailrace).Then the acting head or net head is the design head minus the head loss($\sum \Delta h_i$):

$$H_n = z_u - z_1 - \sum \Delta h_i \quad \text{..............................}\mathbf{(2.1)}$$

2.3.2 Head losses

There are two kinds of head losses: friction loss and local losses.

- The friction loss is generally expressed as:

  $\Delta h_i = JL(m)$, …………………..(2.2)

  Where:

  J is hydraulic gradient

  L is length of conduit (m)

In closed conduits, the Darcy-Weisbach equation or Manning's equation can be used:

- Darcy-Weisbach expression :

$$\Delta h_i = f\frac{L}{4R}\frac{V^2}{2g}$$ ……………………………(2.3)

Where:

f is the friction coefficient

R is the hydraulic radius

V is the average velocity in the conduit (m/s)

- Manning's expression:

$$H_L = \frac{10.3n^2LQ^2}{D^{5..333}}$$ ……………………………. (2.4)

Where:

-HL is the head loss in m,

-n is the Manning's coefficient,

-L is the length of the conduit

-Q is the discharge in m^3/s,

-D is the diameter of the conduit.

- Local losses are expressed by:

$$\Delta h_2 = \frac{xV^2}{2g},$$ ……………………………(2.5)

Where x is the coefficient of local losses, including losses of the trash rack, entrance, bends, gradual expansions (contraction), bifurcation, abrupt contraction and expansion, gates and valves, etc.

Energy is expressed as:

$$E = gh\ QHt$$ ……………………………(2.6)

Where

- γ is the specific weight of water;
- η is the overall efficiency;
- Q is the discharge over turbine;
- H is the net height over turbine;
- t is time in hours.

$E = 9.81 h QHt$, *E(KWH)* ……………………………(2.7)

2.3.3 Plant factor

One of the parameter of a hydropower station that reflects its performance, and a key input into the design process, is the plant factor.

The plant factor is the ratio of mean annual output (over a number of years of operation) of a power station to its maximum annual output if it operates at full capacity for the whole year. It may be define also by the ratio of the average discharge that passes through the turbines and the penstock capacity.

The instantaneous output of the power station is directly related to the flow through its turbines. If the turbine's maximum capability was set to only match the mean annual flow, then for any period where the flow is higher than the mean (assuming little or no water storage is available) some of the flow will be "**spilt**" and the overall output will be less than it would have been if the penstock, turbines, generators, etc were larger.

To ensure reasonable economics of investment in the power station, including Dams, spillways, etc it is usual to provide for the capacity of the penstock, turbines, generators, etc to be capable of using a "**higher flow**" than the annual mean flow.

Historically hydropower station components have usually sized to give an overall plant factor of about 50 to 55%. Some schemes, especially those where there is an out-of-river canal, may have a greater plant factor than 50%. While this will usually result in less water passing through the canal/power station to generate electricity than would be the case if a lower plant factor was selected.

Rwegura plant factor

Rwegura was constructed earlier before others plants and the need of energy at that time was a very big issue. The objective of the planner was to produce much energy as possible to deal with the demand. The design penstock capacity was set at 4.57m^3/s while the maximum flow ever observed was 5.2m^3/s and a base flow of 0.8m^3/s. The design annual average flow was estimated at 1.8m^3/s with an average plant factor of 40%. Then, the installed plant capacity is 18MW.

2.4 Reservoir operation and operation policy

2.4.1 General

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

2.4.2 Guide curve for reservoir operation

For any reservoir there is usually a filling period and a release period which follows the pattern from year to year. From observations, a reservoir should be filled and emptied according to a certain pattern of similar kind in order to be used efficiently. Therefore a guide curve is necessary and helps to indicate the water levels or storage in each month of the year. Then operating rules may be derived using available information on the reservoir. In this study it is intended to derive a single rule curve that will be used for reservoir operation of Rwegura hydropower plant using the water level information.

2.4.3 Rwegura reservoir operation

Rwegura reservoir is the main storage of water for power production in Burundi with a capacity of 24 MCM. It is used for hydropower generation only and allows regulating the power in the interconnected network especially during peak loads. Its operation is subjected to a shortage of energy in the country and the variability of energy demand. From observed power or water levels information for the previous period, it is evident that the reservoir operates without any rule. The daily power varies from 6MW up to 18MW depending on the demand. Rwegura Plant operates most of time 18hours per day from 7AM to 24PM.

2.4.4 Models for reservoir operation

There are three main methods that have been developed in planning, design and operation of reservoir systems. They are:

1° Simplified methods for non-sequential problems,

2° Simulation models: these methods can handle much more complex system and can preserve much more fully the stochastic, dynamic characteristics of reservoir systems,

3° Optimisation models: they are tools for solving many problems but need a greater number of assumptions and approximations to be mathematically tractable.

Both simulation and Optimisation models are suitable for sequential decision problems.

2.4.4.1 Dynamic programming

Discrete Dynamic Programming (DDP) in which the variables are allowed to take only discrete values will be used in case study.

The constraints in reservoir optimization models include a masse-balance equation, maximum and minimum storage levels, maximum and minimum releases, flow carrying capacities of hydraulic structures etc.

The simulation follows the continuity or storage equation given by:

$$S_{t+1} = S_t + Q_t - E_t - R_t - O_t \leq K \text{ ,................................(2.8)}$$

Where

-S_t the available water or storage at the beginning of period t,

-Q_t the inflow during the period t,

-E_t the evaporation loss,

-K the capacity of the reservoir,

-O_t the spill (overflow);

-R_t the release during period t,

The objective function is given as forward recursive equation or backward recursive equation.

The operational objective is to maximize the total net benefit during a year.

Maximize $\sum_{t=1}^{T} B_t(S_t, R_t)$,

Where $B_t(S_t, R_t)$ is the net benefit during period t for given values of S_t and R_t, and T is the number of periods in a year (12 months).

According to Vedula,S.(2005), the general recursive equation for any period t is written as:

- Back recursion

$$f_t^n(S_t) = \max\left[B_t(S_t, R_t) + f_{t+1}^{n-1}(S_t + Q_t - R_t)\right], \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.9)$$

Subjected to $0 \le R_t \le S_t + Q_t$
$S_t + Q_t - R_t \le K$

- Forward recursion

$$f_{t+1}^{n+1}(S_{t+1}) = \max\left[B_{t+1}(S_t + Q_t - R_t, R_{t+1}) + f_t^n(S_t)\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.10)$$

Subjected to $0 \le R_t \le S_t + Q_t$
$S_t + Q_t - R_t \le K$

Or $$\sum_{t=1}^{T} B_t(S_t, R_t) = \sum_{t=1}^{T} p_u E_t \ ,$$

Where p_u is the unit KWh price and E_t the energy produced over period *t*.

Therefore, maximize yearly net benefit becomes to maximize the yearly energy production. In the study we intend to derive an optimal operating rule which provides a maximum of yearly energy production using forward recursive equation for twelve months time series.

2.4.4.2 Hec-reservoir simulation model

According to the user Manual, Hec-ResSim 2.0 is used to simulate reservoir operations including all characteristics of a reservoir and channel routing decision support. The criteria for reservoir release decisions, an operation set, are drawn from a set of discrete zones and rules. The zones divide the reservoir by elevation and contain a set of rules that describe the goals and constraints that should be followed when the reservoir pool elevation is within the zone.

2.4.4.2.1 ResSim Modules

ResSim offers three separate sets of functions called Modules that provide access to specific types of data within a watershed. These modules are **Watershed Setup**, **Reservoir Network**, and **Simulation**. Each module has a unique purpose and an associated set of functions accessible through menus, toolbars, and schematic elements. Figure2.3 illustrates the basic modeling features available in each module.

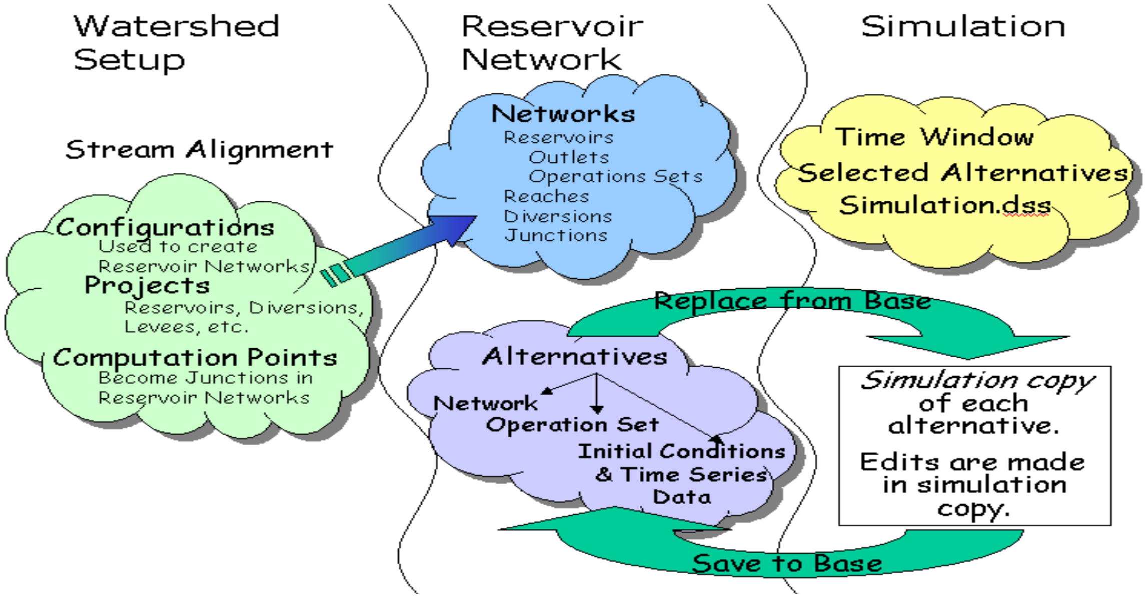

Figure 2.3 ResSim modules

2.4.4.2.2 Watershed module setup

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

2.4.4.2.3 Reservoir Network module

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

2.4.4.2.4 Simulation Module

The purpose of the Simulation module is to isolate output analysis from the model development process. Once the reservoir model is complete and the alternatives have been defined, the Simulation module is used to configure the simulation. The computations are performed and results are viewed within the Simulation module.

CHAPTER 3 DATA PROCESSING, AVAILABILITY AND ANALYSIS

3.1 Hydro-meteorology data processing

The quality of hydrological computations depends on the availability of hydrological and meteorological data, their resolution in time and space as well as their accuracy. The data must be homogeneous, correct and complete with no missing. Computation of basic element of hydrological regime, including characteristics of stream flow, precipitation, evaporation, dynamic of the water mass balance, sediment transport and discharge etc, are essential for design, construction and operation of water projects. The safety and efficiency depend upon the reliability of those data.

Rwegura Reservoir has a small watershed with only 80.7 Km^2 and has one meteorological station. The one gauging station was working up to 1983 and is actually submerged within the reservoir.

3.1.1 Filling missing rainfall data.

There are no missing data for rainfall. All precipitations from 1965 up to 2006 were recorded whereas our period of interest is from 1986 up to 2006 that corresponds to the previous running period of Rwegura Plant.

3.1.2 Filling missing data of runoff

Effectively, the available runoff data (1980-1983) at the gauging station do not match the period of analysis. Or for reservoir operation, inflow data during the real operation period are required.

It is, therefore, a must to generate the runoff data for the concerned period by extension of existing runoff at the gage station.

3. 1.2.1 Extension of runoff series

The rainfalls as well as runoff are two components of a hydrologic cycle. In fact the runoff occurs mostly as a result of rainfall. As such it is possible to develop a relation between rainfall and runoff. The rainfall-runoff relationship may be used to:

i. estimate runoff volumes; and
ii. extension of runoff records or series.

The extension of runoff series occurs when many times the runoff data at a particular river discharge measurement site is available for a few years. But the rainfall records at the nearest station may be available for many years, which reflect our case study. In such situations the runoff data can be extended for other years for which only rainfall data is available. A graph is drawn with monthly or annual runoff as abscissa and monthly or annual rainfall as ordinate for the years for which runoff data are available and a curve is plotted. Making use of this curve for other years, runoff can be read off against their rainfall values. [Joseph, L.H.P. (1982)].

Estimating runoff or discharge from rainfall measurement is very much dependant on the timescale being considered. For short durations (hours) the complex interrelationship between rainfall and runoff is not easily defined, but as the time period lengthens, the connection becomes simple until, on an annual basis, a straight line correlation may be obtained. The time interval used in the measurement of the two variables affects the derivation of any relationship, although with continuously recorded rainfall and stream discharge this constraint is removed and only the purpose of the study influences the choice of time interval [Elisabeth, M.S. (1994)].

3.1.3 Reservoir evaporation

Through a water free surface, there is always continuous exchange of water molecules to and from the atmosphere; the hydrologic definition of evaporation is restricted to the net rate of vapor transport to the atmosphere. Rates of evaporation vary depending on meteorological factors such as: solar radiation, air temperature, vapor pressure, wind, and minimally by atmospheric pressure. Since solar radiation is an important factor, evaporation also varies with season, time of day, and sky condition. As pressures drop, evaporation rises, but altitude has little effect because of counterbalancing changes in temperature. Fast rates of evaporation at high altitudes are caused, in large measure, by greater wind velocities.

Evaporation can be estimated using different methods such as water budget method, energy- budget method, aerodynamic method, combination methods and pan evaporation method. Each method is limited due to difficulties in estimating required input parameters.

Reservoir evaporation rate is needed as an input in reservoir operation simulation. Thus, according to the data in our hand, aerodynamic and Penman methods are developed to compute the evaporation rate of RWEGURA reservoir.

3.1.3.1 Aerodynamic determination of reservoir evaporation

Numerous empirical formulas have been derived which express evaporation as a function of atmospheric elements such as wind speed, vapor pressures, barometric pressure etc, in some respects. Many of the formulas are based on Dalton's law of evaporation **[**Gordon, M.F. (1966)]:

$$E = (e_s - e_a)(a + bV) \text{, ……………………………………………3.1}$$

The most formulae used, is the Rohwers'formulae:

$$E = 0.771(1.465 - 0.000732 * P_a)(0.44 + 0.0733 * V_{0.6})(e_s - e_a) \ldots\ldots\ldots\ 3.2$$

Where - E (mm/day),

-e_s (mmHg) is saturation vapor pressure of water,

-e_a (mmHg) is actual vapor pressure of the air,

-P_a (mmHg) is the barometric air pressure of the site,

-$V_{0.6}$ (km/h) is wind speed at 0.6m over land,

The level of wind measurement is often higher than 0.6m, and then the conversion of wind speed from level z_1 to level z_2 is given by:

$$\frac{V_{z1}}{V_{Z2}} = \left(\frac{z_1}{z_2}\right)^{0.143} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

The saturation vapor pressure can be estimated as:

$$e_s = 33.8639\left[(0.00738T + 0.8072)^8 - 0.000019|1.8T + 48| + 0.001316\right] \ldots\ldots\ 3.4$$

Where e_s is in (mbar) and T in degree Celsius.

The vapor pressure of air is computed as:

$$e_a = \frac{R_H e_s}{100},$$

-R_H is the relative humidity (%),

The moist air pressure is given by:

$$P_a = 101300\left(\frac{288 - 0.0065z}{288}\right)^{5.26}$$,…………………………….. 3.5

Where -P_a is the mean atmospheric air pressure in (Pa),

-z is the elevation of the location in masl.

3.1.3.2 Penman method

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

$$E_o = \frac{\Delta R_n + gE_a}{\Delta + g}$$ [mm/day] ……………………………3.6

Where:

EO = daily evaporation in mm/day

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

R_n = Net radiation in mm/day

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

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

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

$$\Delta = \frac{4098e_s}{(T + 237.3)^2}$$ [kp/^{o}c]……………………………….3.7

Where:

T= air temperature, ^oc

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

$e_s = Exp\left(\frac{16.78T - 116.9}{T + 237.3}\right)$ [KP]………………………………… 3.8

The psychometric constant is given by:

g= $0.0016286\frac{p}{l}$ [kp/^{o}c]…………………………………3.9

Where:

λ =the latent heat of vaporization computed from

λ= 2.501-0.002361T [MJ/kg………………………………3.10

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

P=$101.3\left(\frac{288 - 0.0065Z}{288}\right)^{5.259}$ [KP]………………………………… 3.11

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

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

$R_n = R_{ns} + R_{nl}$ [mm/day]……………………………………3.12

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

$R_{ns} = R_t(1-r)$ [mm/day]………………………………………3.13

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

$R_t = R_a\,(0.25+0.5n/N)$ [mm/day] …………………………………..3.14

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

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

$$R_{nl} = -t\,(T + 273.2)^4 \left(0.1 + 0.9\frac{n}{N}\right)\left(\frac{0.34 - 0.14\sqrt{e_d}}{l}\right)$$

[mm/day] …….3.15

In which

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

e_d is vapour pressure at dew point and computed from:

$e_d = \dfrac{e_s RH}{100}$ [KP]…………………………………………………………….3.16

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

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

Ea=$6.43(a + 0.536u_2)D_{vp}$ [mm/day]…………………..3.17

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

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

$D_{vp} = \left(\dfrac{e_{s(T\max)} + e_{s(T\min)})}{2}\right)\left(1 - \dfrac{RH}{100}\right)$ [KP] …………………3.18

In which, $e_{s\,(Tmax)}$ and $e_{s\,(Tmin)}$ are computed from equation 3.8 for $T=T_{max}$ and $T=T_{min}$ respectively

For the present study the evaporation computed using the above method and spreadsheet application and the result is summarized in (table (3.7) below.

3.2 Data availability and analysis

Data of interest have been collected. They are data on hydrology and meteorology. These data have been provided by the national Geographic Institute of Burundi (IGBU). Rwegura hydrological station has the following characteristics:

- Altitude:2301m
- Latitude:$2^0$55’ S
- Longitude:$29^0$31’E
- Atmospheric pressure: 776 mbar

3.2.1 Climatological data at Rwegura station

The mean monthly data of maximum and minimum temperature, maximum and minimum relative humidity, solar radiation and wind speed are presented in Table 3.1 below.

Table 3.1 Climatological data

Data type	J	F	M	A	M	J	J	A	S	O	N	D
Max.Temp	20.5	20.9	20.6	19.8	19.3	19.5	19.6	20.8	21.1	20.9	20.1	20.3
Min.Temp	11.7	11.8	11.8	11.9	11.8	11.0	10.7	11.4	11.7	11.8	11.7	11.6
Mean Temp	16.1	16.3	16.2	15.9	15.6	15.2	15.2	16.1	16.4	16.3	15.9	15.9
Wind m/s	0.83	0.78	0.77	1.05	1.20	1.22	1.60	0.90	0.75	1.40	1.00	0.75
Sunshine(hours)	154	150	183	137	143	187	253	211	190	159	143	137
Max R.H (%)	94.4	93.2	95	96.2	93.4	87.8	83.8	80.6	82.2	89	94.6	94.2
Min R.H (%)	69.8	66.6	72.6	74.6	72.4	64.4	59.6	54.2	53	65	71	70

3.2.2 Rainfall data

Rwegura watershed is small with a surface area of 80.7 km^2 and has only one meteorological station. The relevant precipitation is in the form of rainfall. Daily precipitations were used to compute the mean monthly rainfall for a period of 41 years since 1965. Burundi is characterized by two main seasons: the wet season (8 months) from October to May and the dry season (4 months) from June to September. The rainfall distribution varies from month to month. The highest rainfalls are observed in November-December and March-April with a peak in April. The lowest rainfall is observed in July-August. A slight variation of annual rainfall is observed and the mean annual rainfall is about 1500mm.

The mean monthly and yearly rainfall is illustrated in the Table of Appendix D. The variability of rainfall at Rwegura watershed is shown by the graphs in Figure 3.1 and Figure 3.2 as follow.

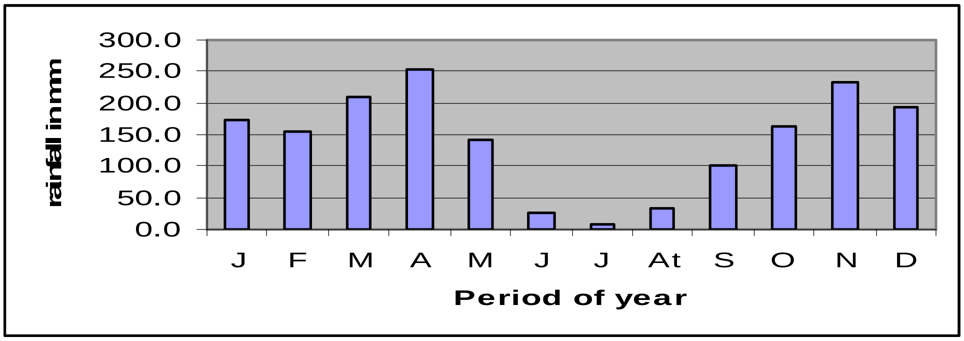

Figure 3.1.Mean monthly rainfall at Rwegura station

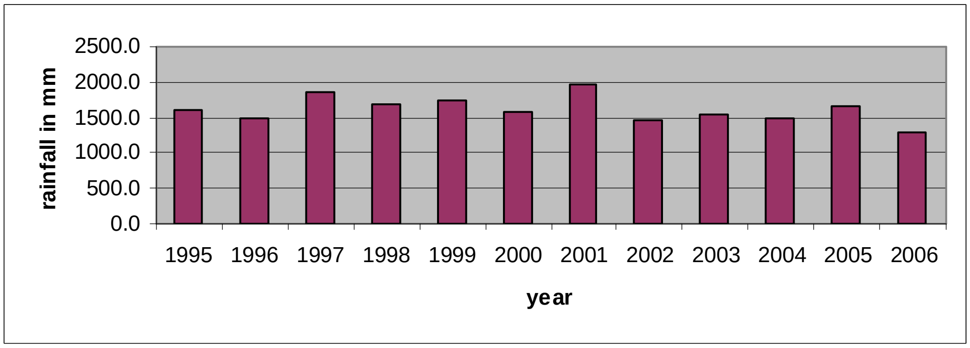

Figure3.2. Mean annual rainfall at Rwegura station

3.2.3 Runoff data

Two streams Gitenge and Mwokora flow into the reservoir. The single gauging station was located at the confluence of the two streams. Unfortunately, this gauging station was submerged after the filling of the reservoir in 1986.The discharge measurements from 1980 up to 1983 are available and do not match the reservoir operation period which started in 1986. For this reason, it is necessary to generate the data that extend on the period of operation especially for the analysis.

The existing daily recorded inflows (1980-1983) are shown in the Table of Appendix E and the corresponding mean monthly inflows are presented in Table3.2 below.

Table3.2 Recorded average monthly inflow data at the gage station

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1980	**m^3/s**	1.15	1.25	1.92	1.83	1.68	1.36	0.87	0.87	0.80	1.22	1.56	1.50
	mm	*36.87*	*40.10*	*61.71*	*58.62*	*54.02*	*43.61*	*27.89*	*27.89*	*25.58*	*39.16*	*50.11*	*48.28*
1981	**m^3/s**	1.27	0.97	1.62	2.32	2.31	1.22	0.90	0.86	1.19	1.01	1.03	1.19
	mm	40.74	31.12	52.11	74.66	74.16	39.23	28.84	27.78	38.31	32.44	33.21	38.27
1982	**m^3/s**	1.22	1.00	1.33	2.65	2.13	1.14	0.89	0.82	0.81	1.22	1.73	1.94
	mm	39.33	32.27	42.61	85.21	68.57	36.64	28.74	26.20	26.14	39.13	55.53	62.39
1983	**m^3/s**	1.17	1.39	1.89	2.56	2.29	1.34	1.94	2.04	2.15	3.75	2.76	2.54
	mm	37.70	44.62	60.77	82.30	73.54	43.19	62.44	65.54	69.03	120.40	88.51	81.70

3.2.3.1 Flow extension

The technique used to extend the available runoff data to the real period of operation is to use the rainfall- runoff relationship [see section 3.1.2.1] where both rainfall and runoff are in mm. Monthly flow and rainfall were used and an non-linear regression equation was found much accurate than a linear equation. The relation is illustrated by Figure 3.4 in the following:

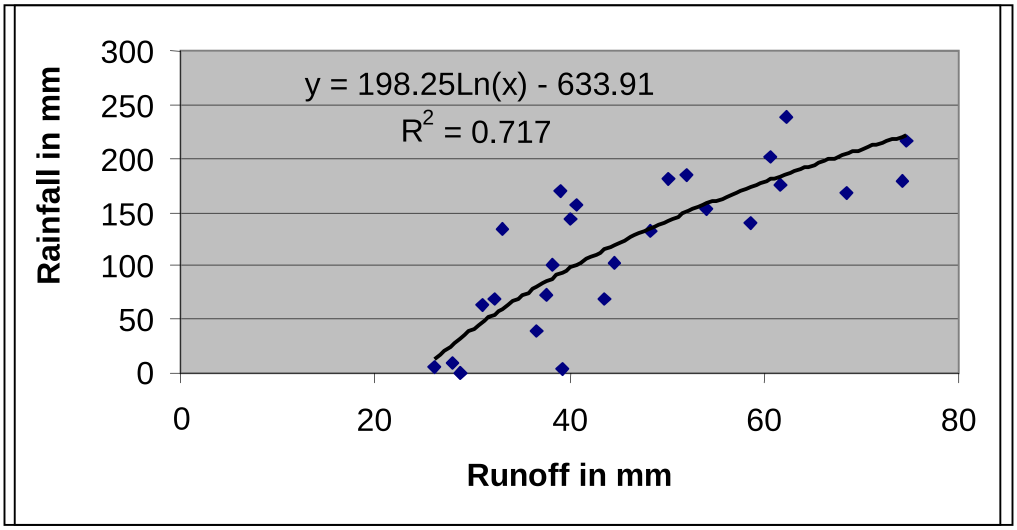

Figure 3.3.Monthly rainfall-runoff curve

A coefficient of determination of R^2 =0.717 is found and a correlation factor of R=0.846 is obtained. According to Michael Kasenow (2001), this value represents a good correlation.

Therefore, this curve may be used to generate the discharges for the extended period of the reservoir operation. The computed runoffs are illustrated in Table of Appendix J.

3.2.3.2 Graphical comparison of computed and observed monthly average flow

After extension of flow, the monthly hydrographs of computed and observed discharges are plotted in Figure 3.5. A slight difference of flow value is seen. This is due to a change of rainfall pattern but also to the period of average flow computation much greater (21 years) than the period of flow observation (4 years only). Indeed, the correlation factor (0.846) of rainfall-runoff curve which is lesser than 1 may influence the results. The average annual generated runoff is estimated at 53.3MCM.

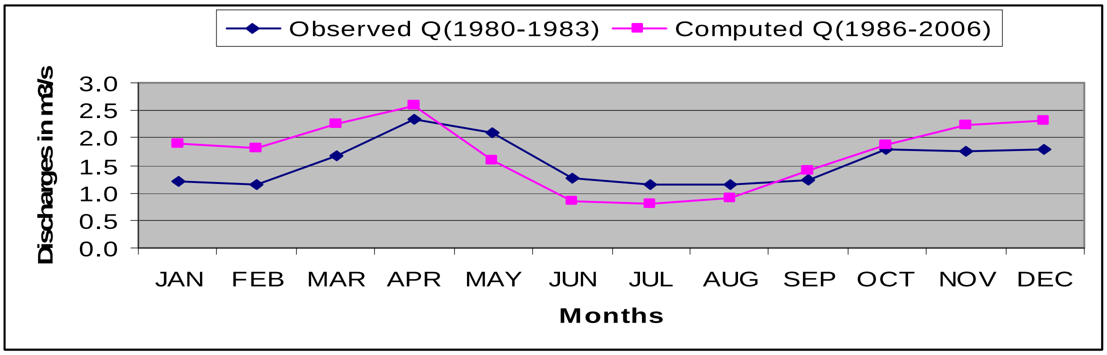

Figure 3.4 Monthly computed and observed flow

3.2.4 Rwegura reservoir evaporation

Rwegura reservoir evaporation loss is determined by using the aerodynamic and Penman methods. The gauging station was situated within the reservoir near to the Dam. The inflow is computed from rainfall-runoff curve using the total rainfall over the Reservoir watershed which includes the surface area of the reservoir itself. Therefore the precipitation over the body of the reservoir is taken into account while converting the rainfall into runoff. Hence, the estimated evaporation is net evaporation and will be used in modeling Rwegura reservoir. The mean monthly rate evaporation is presented in Table 3.3.

Tab 3.3 Mean monthly evaporation rate in mm of Rwegura reservoir

	Penman method(mm)	Aerodynamic method(mm)
JAN	134.1	37.1
FEB	143.2	42.2
MAR	147.3	32.9
APR	125.1	32.8
MAY	116.0	39.7
JUN	124.2	54.1
JUL	144.8	71.7
AUG	149.3	69.8
SEP	156.0	69.4
OCT	143.5	59.5
NOV	131.3	38.1
DEC	125.8	36.8
An.	1640.7	584.1

The design annual average evaporation was set at 1500mm. By comparing the two methods, Penman method gives high values of rate evaporation and these values are near the values found for previous studies in the area. Then the results of Penman method will be used to estimate Rwegura reservoir evaporation.

3.2.5 Physical data

3.2.5.1 Rwegura hydropower plant and its salient features

Rwegura hydropower plant is located on the river Gitenge at the confluence of Gitenge river upper branch and Mwokora River in the North-West of Burundi.

The project design was conducted by Siemensaktiengesellschaft and Lahmeyer Int. in 1983-1986.

The main features are given below:

- **Hydrology**

Mean annual rainfall:	1693.3 mm
Catchments area :	76sq.km
Mean annual discharge:	1.8m^3/s

- **Dam**

Dam type:	Earth dam
Dam height:	40.5m
Dam crest elevation:	2155.5masl
Dam bottom elevation:	2115masl

- **Reservoir**

Storage capacity:	$24x10^6m^3$
Usable storage capacity:	$17x10^6m^3$
Dead storage:	$7x10^6m^3$
Surface area at normal level elevation:	2.4sq.km
Maximum level elevation:	2152.20masl
Normal level elevation:	2152.0masl

Minimum level (dead) elevation: 2140.5masl

Ø **Spillway**

Spillway type: vertical shaft ungated

Top elevation: 2152.2masl

Inner diameter: 1.5m

Ø **Conveyance system**

Penstock capacity: $4.57m^3/s$

Penstock length: 990m

Tunnel diameter (inner): 2.8m

Tunnel length: 2042m

Ø **Power station**

Ground elevation: 1645masl

Power house location: on ground

Number of Units: 3

Turbine type: Pelton

Turbine speed N: 750rev/min

Net head on the turbine: variable

Maximum turbine discharge: $1.53m^3/s$ each

Installed capacity: 18MW

Tail race elevation: 1643masl

Overall efficiency: 0.86

CHAPTER 4 RWEGURA RESERVOIR OPERATION MODELING

4. 1 Dynamic Programming

Since the main objective of this study is to develop an optimal guide curve for Rwegura reservoir, a simple rule curve may specify the next period release based on the storage level in the current month. Therefore, the following objectives must be achieved:

- Maximizing yearly energy production
- Minimizing energy deficit
- Minimizing reservoir spill.

4.1.1 Developing DP Algorithm

The DP for determining the optimal release policy over 12 months will be implemented using the following computational steps:

1. Specify the initial storage ST1 with Kmin<ST1<K., K=reservoir capacity

   $7Mm^3 < ST_1 < 24\ Mm^3$

2. Descritize the storage space for each month, the useful storage is divided into 7 for each month.
3. For each month, assume 7 values of releases whereas the inflow It is a constant,

   -The release R_t is constrained to $0 \leq R_t \leq Rmax$ or $0 \leq Q_t \leq 4.57\ m^3/s$

   Where:

   Q=4.57 m3/s is the maximum capacity of the penstock

4. Starting by period t=1, Month of July (starting of dry season),

   -Compute the storage for each assumed feasible release (7).

   $St+1=ST1+It-Rt-Et,\ 0<St+1<24\ Mm^3$

-Compute the water level related to the computed storage,

- Compute also the net head, the net head that may be expressed as: Elevation-(losses+tailwater level)or

  $H=El-(H_L+1643m)$.

- Calculate the output energy, *$E=9.81\eta Rt*H$*,

5. Assume one of the storage as an optimum by preference the one which maximize the energy,

6. Store the optimum storage for the period t=1(July) at the beginning of period t=2(August),

7. Repeat the computation in steps 3, 4, 5 and 6 for t=2, 3…T using the recursive formula. Only the optimal storage transient yielding the highest return is stored for further analysis.

8. Once the final stage t=T (June) is computed , verify if the storage at the end of period T is equal to the initial assumed storage at the beginning , ST(June)=ST1, if not go back to step 5 and choose an other optimum storage value and repeat steps 6, 7 and 8. After much trial, this step is satisfied.

9. A trace back procedure is used to identify the optimal storage trajectory over the entire period of analysis, from which the optimal releases and corresponding storages in each period can be found.

10. An optimal guide curve of water level or optimal storages for the reservoir may be drawn.

4.1.2 Power head loss determination

The net head is used in power expression and its calculation is a must. The loss due to friction for a circular conduit can be expressed as:

$$H_L = \frac{10.3n^2LQ^2}{D^{5..333}} \quad \text{……………………………… (4.1)}$$

Where:

-HL is the head loss in m,

-n is the Manning’s coefficient,

-L is the length of the conduit

-Q is the discharge in m^3/s,

-D is the diameter of the conduit.

If $k1 = \frac{10.3n^2 L}{D^{5..333}}$, then $H_L = k1 * Q^2$,

Other local losses due to bends, valves, trash racks, etc may be approximated by:

$H' = k2 * Q^2$ …………………………… (4.2)

The value of K2 may be assumed at 0.0004 for this case [see estimation of K2 in Appendix A].

The total loss is given by:

$H = (k1+K2)\, Q^2$…………………………… (4.3)

4.1.3 Power demand

The electric network of Burundi is an interconnected scheme. Then all hydropower plants are interconnected and knowing the contribution in term of power for each is a must for the purpose of planning the power supply. Except Rwegura hydropower plant, others Plants are run-of -the river plants and their power production varies seasonally with the rainfall pattern. Rwegura reservoir is then used to regulate the power production for the interconnected scheme. The seasonal energy contribution of Rwegura Plant has been fixed as illustrated in the Table 4.1 and Figure 4.1 and might be considered when planning the reservoir operation.

Table 4.1 Monthly power demands from Rwegura hydropower plan

Month	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
%	8.42	8.42	6.5	6.5	6.5	8.4	10	10	10	8.42	8.42	8.42	100

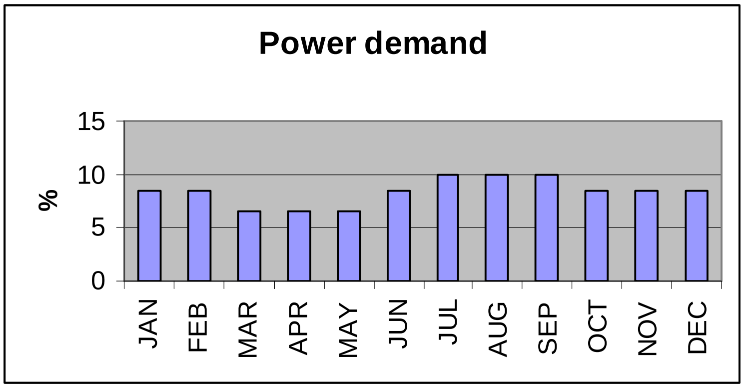

Figure 4.1 Plot of power demand

4.1.4 Inflow data

For DP modeling of the reservoir, mean monthly inflows for the last period of the reservoir operation are used (20 years: 1987-2006). These inflows are presented in Table 4.2.

Table 4.2 monthly average inflows in $x10^6m^3$

AVERAGE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
INFLOW	4.9	4.7	5.9	6.7	4.1	2.2	2.1	2.4	3.6	4.9	5.8	6.0

4.2 Modeling Rwegura reservoir by Hec-ressim2.0

Hec-Ressim 2.0 is a powerful tool for reservoir operation simulation especially for hydropower production. Using the rule curve derived from the DP model, the software allows computing the optimal energy which would have been produced during the previous considered period of the hydropower plant operation. If an improvement of energy production is observed, then the application of the rule curve for the reservoir operation for the future production is required.

4.2.1 Rwegura watershed setup

The purpose of the watershed setup is to provide a common frame work for watershed creation and definition. The map layer that describes the georeferenced area of the watershed was imported from Arc view GIS Figure 4.2. SI unit and GMT+2 were used respectively as unit system and international time zone.

The physical arrangement such as streams, computation points, and junction points were drawn using the tools provided in the model.

Figure 4.2 Rwegura watershed setup

4.2.2 Rwegura reservoir network

The objective of developing the reservoir network is to connect the computation points with routing reach between junctions. A reservoir network is built to connect all watershed elements and added features such as Dam, reservoir pool and controlled outlet.

The reservoir network is also used to enter the data: physical data, operation data and observed data. The most important are: time series data, reservoir capacity-area-elevation curves, reservoir evaporation, controlled and uncontrolled outlet capacity curves, plant characteristics, reservoir pool elevation, etc. The network of Rwegura reservoir watershed is illustrated by Figure4.3.

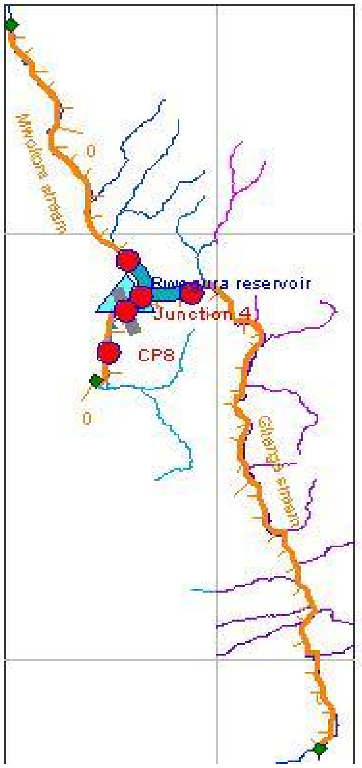

Figure 4.3 Rwegura Network setup

4.2.3 Data base preparation for Rwegura reservoir Network

4.2.3.1 Physical data

The main components of the project are the reservoir body, the earth Dam and the outlet for power generation.

4.2.3.1.1 Spillway Capacity.

An uncontrolled vertical shaft spillway is incorporated within the dam to spill the excess of water downstream the dam. The discharge passing the spillway is a function of water level into the reservoir. For a free flow, the discharge can be computed using the formula:

$$Q = \frac{2}{3} C_d \sqrt{2g} p D_c H^{\frac{3}{2}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.4)}$$

Where

H= the water head above the top of the spillway,

D_c= the top opening diameter of the spillway,

C_d=the discharge coefficient,

According to Vischer and Hager citing Indelkofer(1978), C_d may be expressed as a function of H/D_s:

$$\frac{2}{3} C_d = 0.515 \left(1 - 0.2 (\frac{H}{D_S}) \right) \text{for } 0.2 < H / D_S < 0.5. \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{(4.5)}$$

Where

Ds= the diameter of the spillway,

S=the depth of water from the bottom of the reservoir up to the top of the spillway

4.2.3.1.2 Penstock capacity determination

The release for power generation is discharged through a controlled outlet .The layout of the conveyance system is made of Tunnel, surge tank and penstock. The penstock maximum capacity is a function of net head. However the minimum discharge depends upon the minimum instantaneous release.

The maximum capacity can be determined using the formula:

$$Q = C\frac{pD^2}{4}\sqrt{2gH} \;\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(4.6)}$$

Where C= Coefficient of discharge,

D=diameter of penstock,

H=available net head.

4.2.3.1.3 Reservoir records

Reservoir water level, storage capacity, water surface area relationships are very useful when modeling the reservoir operation. According to the design study these relations are illustrated by the Figure 4.4, Figure 4.5 and Figure 4.6 below.

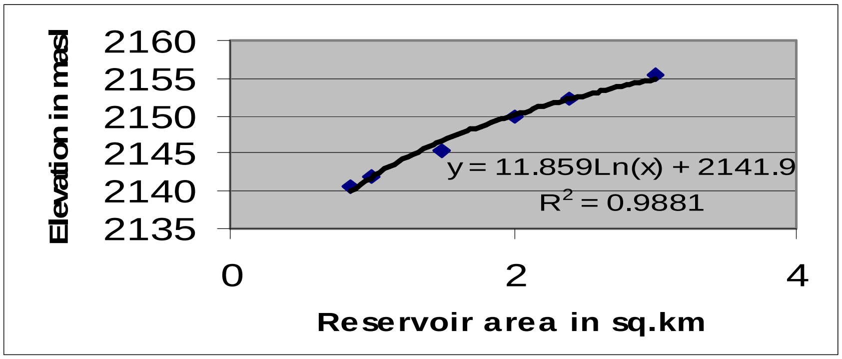

Figure 4.4 Elevation vs Area

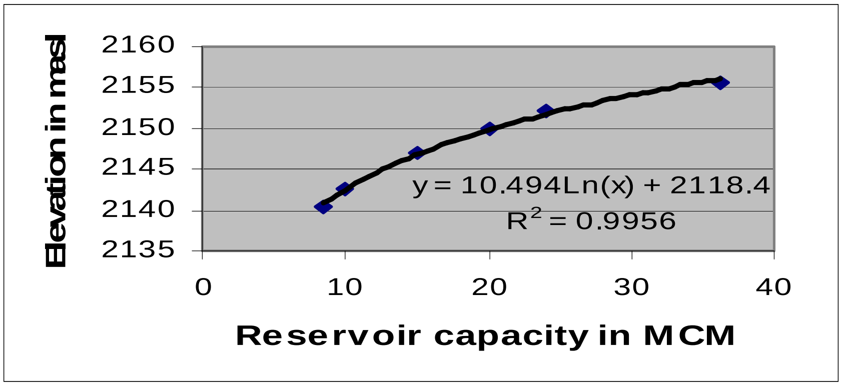

Figure 4.5 Elevat ion vs storage

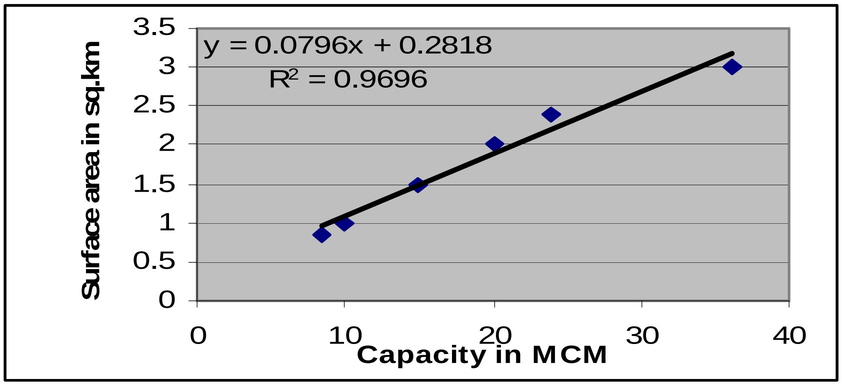

Figure 4.6 Area vs Capacity

4.2.3.1.4 Power plant characteristics

The power plant installed capacity is 18 MW, the overall efficient fixed at 86%, the tail water level at the routing reach fixed at 1643masl. All water through the controlled outlet is used for power generation.

4.2.3.2 Reservoir Operation zones

Three storage zones are defined. They are: flood control zone, conservation zone and inactive zone. They are separated by different water index levels. When modeling the reservoir with Hec-ResSim 2.0, the optimal rule operation is used and the related monthly levels define the top of conservation zone [see Chap.5.1]. The top levels of zones are illustrated in Tablele4.3 below.

Table.4.3 Reservoir index levels

	Elevation(masl)
Top Dam	2155.5
Top Max.pool	2153.5
Top.Conservative pool	2152.2
Top of Inactive pool	2140.5

4.2.3.3 Time series data.

Sequential time series data are required for different control points of the network. The monthly inflow data into the reservoir through the control point CP6 for the period of simulation (1987-2006) constitute the input data. The others such as observed power record, observed outflow record, observed elevation etc. is optional for the only purpose of comparison. A sample of inflows data and observed power records for the latest previous 8 years are respectively shown in the Table 4.4 and Table 4.5.

Table 4.4 Monthly inflow [m3/s] time series data.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1999	2.06	1.54	3.28	2.09	1.00	0.80	0.76	1.74	1.23	1.06	3.82	2.14
2000	1.57	1.68	2.18	1.39	1.20	0.76	0.76	0.79	0.94	1.91	3.57	3.77
2001	2.30	1.44	2.00	1.68	1.87	0.90	0.92	1.08	2.89	1.98	1.98	3.51
2002	3.60	1.46	1.68	2.67	1.25	0.76	0.76	0.76	1.03	1.30	1.85	1.86
2003	1.69	1.47	2.16	2.42	1.59	0.80	0.76	0.76	1.87	1.77	1.82	1.68
2004	1.44	1.54	2.29	2.38	0.76	0.76	0.84	0.84	2.09	1.27	1.81	2.98
2005	2.77	0.94	2.39	1.46	1.51	0.80	0.81	0.86	1.69	1.96	2.14	3.05
2006	1.04	1.67	1.52	1.61	2.13	0.81	0.79	0.79	0.91	1.14	2.65	2.13

Table 4.5 Observed Power productions in MWH.

	1999	2000	2001	2002	2003	2004	2005	2006
JAN	3062.5	3509.7	4030.9	8451.9	4328.9	3713.6	3198.3	2456.0
FEB	3088.9	3269.9	4683.3	6082.1	3940.5	3576.9	4070.9	2359.6
MAR	3526.0	4692.6	3781.6	4101.6	4431.1	3589.3	4266.0	3059.4
APR	3535.5	4957.3	5644.1	7003.1	3828.3	3660.5	4022.9	2421.4
MAY	3113.1	5260.0	6877.4	8123.4	3166.2	3920.1	4252.9	2453.3
JUN	3391.4	4279.0	5036.5	5827.8	3749.5	3500.2	4796.9	2432.5
JUL	3698.4	4574.2	5691.7	5691.7	5185.8	4269.1	4750.1	2997.5
AUG	4032.0	4494.3	5059.9	5059.9	4342.3	4292.6	4391.9	3171.0
SEP	3689.6	4801.6	4692.8	4692.8	4239.7	3689.9	4128.7	3520.0
OCT	3559.0	3621.4	4511.9	4511.9	4213.4	3337.3	4223.6	3560.2
NOV	3167.9	3500.0	4190.7	4190.7	3842.6	3128.7	3971.6	3471.9
DEC	3515.7	3006.9	4345.4	4345.4	3442.5	3196.5	3196.5	3920.3
AN.	41380.0	49966.9	58546.2	68082.3	48710.8	43874.7	49270.3	35823.1

The water levels data are daily recorded by the operator of the reservoir. At the end of each month, the water levels are given in the Table 4.6 below. It is seen that during these 8 last years of operation, the water levels into the reservoir is different from month to month and year to year.

Table 4.6 Observed reservoir water levels (masl)

	1999	2000	2001	2002	2003	2004	2005	2006
JAN	2149.5	2150.8	2151.2	2151.9	2147.8	2147.6	2150.0	2146.0
FEB	2149.1	2151.2	2151.1	2151.9	2148.6	2147.2	2149.8	2146.3
MAR	2149.1	2151.2	2151.1	2151.9	2148.6	2147.7	2149.8	2146.7
APR	2150.4	2151.5	2152.1	2152.2	2148.9	2148.4	2150.7	2147.9
MAY	2151.5	2151.6	2152.2	2151.8	2151.2	2150.0	2151.5	2150.4
JUN	2151.4	2150.9	2151.6	2151.1	2151.0	2149.6	2151.0	2150.4
JUL	2150.8	2149.9	2151.2	2151.2	2150.0	2148.7	2150.0	2150.0
AUG	2150.3	2148.7	2150.6	2149.3	2149.1	2147.5	2149.1	2149.5
SEP	2149.9	2147.6	2150.9	2148.5	2148.2	2147.0	2148.1	2148.6
OCT	2149.4	2147.0	2150.6	2148.0	2147.8	2146.5	2147.3	2147.8
NOV	2149.3	2147.6	2151.7	2148.0	2147.5	2146.5	2146.6	2148.9
DEC	2150.5	2149.5	2151.9	2148.1	2147.6	2148.4	2145.8	2151.0

CHAPTER 5 RESULTS AND DISCUSSION

5.1 Results of dynamic programming

As mentioned before, DP is used to derive the optimal guide curve for Rwegura reservoir operation. Much iteration has been done and the computation procedure is illustrated in the Table 5.1 below [see steps Chapter 4].

The iteration had consisted of varying the starting storage **ST1** for the starting month and deriving the related curve and computing the yearly energy. The reservoir evaporation **Et** is estimated for each month using the related starting storage (**ST1**). Then the cumulative storage **St** is computed using the continuity equation **St=ST1+It-Rt-Et**. The elevation is computed using the formula reservoir storage-elevation curve. The net head H_{net} is computed and the energy calculated using the formula of energy: $\mathbf{E=9.81\eta R_t*H_{net}}$

The retained optimal alternative parameters are shown by the shaded figures in the table 5.1.

The inflows, the releases and evaporation are set in millions cubic meters (MCM).

Tab 5.1 DP computations

	St=ST1+IT-RT-ET	Active ST	Inflow IT	ET =e(0.0796ST1+0.28)	Assumed RT	St,start - St,end	constraint	El=10.494ln(St)+2118.4	Hnet=El-1643-KQ^2	Energy (Mwh)
Jan	19.68	12.68	4.9	0.22	2.60	-2.29	ok	2149.67	501.80	3057.5
2.6≤RT≤11.84	19.48	12.48	4.9	0.22	2.80	-2.09	ok	2149.56	500.91	3286.9
ST+IT-RT-ET≤24	19.28	12.28	4.9	0.22	3.00	-1.89	ok	2149.45	499.97	3515.1
ST1=Stop,DEC.	18.28	**11.28**	**4.9**	0.22	**4.00**	**-0.89**	**ok**	**2148.89**	**497.07**	**4659.6**
17.6	17.78	10.78	4.9	0.22	4.50	-0.39	ok	2148.60	496.78	5239.0
	13.28	6.28	4.9	0.22	9.00	4.11	ok	2145.54	497.14	10485.4
	10.48	3.48	4.9	0.22	11.80	6.91	ok	2143.06	497.14	13747.6
Feb	20.13	13.13	4.7	0.25	2.60	-1.88	ok	2149.91	502.04	3059.0
2.6≤RT≤11.84	19.93	12.93	4.7	0.25	2.80	-1.68	ok	2149.80	501.15	3288.5
ST+IT-RT-ET≤24	19.73	12.73	4.7	0.25	3.00	-1.48	ok	2149.70	500.22	3516.8
ST1=Stop,JAN.	18.93	**11.93**	**4.7**	0.25	**3.80**	**-0.68**	**ok**	**2149.26**	**497.44**	**4429.9**
18.28	18.23	11.23	4.7	0.25	4.50	0.02	ok	2148.87	491.27	5180.8
	13.73	6.73	4.7	0.25	9.00	4.52	OKt	2145.89	491.84	10373.6
	10.93	3.93	4.7	0.25	11.80	7.32	OK	2143.50	491.84	13601.0
March	21.96	14.96	5.9	0.27	2.60	-3.05	ok	2150.82	502.95	3064.5
2.6≤RT≤11.84	21.76	14.76	5.9	0.27	2.80	-2.85	ok	2150.72	502.07	3294.5
ST+IT-RT-ET≤24	21.56	14.56	5.9	0.27	3.00	-2.65	ok	2150.63	501.15	3523.3
ST1=Stop,FEB.	21.06	**14.06**	**5.9**	0.27	**3.50**	**-2.15**	**ok**	**2150.38**	**498.56**	**4089.3**
18.93	19.56	12.56	5.9	0.27	5.00	-0.65	ok	2149.60	492.00	5765.1
	15.56	8.56	5.9	0.27	9.00	3.35	ok	2147.20	492.19	10381.0
	12.76	5.76	5.9	0.27	11.80	6.15	ok	2145.12	492.19	13610.7
Apr	24.91	17.91	6.7	0.25	2.60	-3.63	no	2152.14	504.27	3072.6
2.6≤RT≤11.84	24.71	17.71	6.7	0.25	2.80	-3.43	no	2152.05	503.40	3303.2
ST+IT-RT-ET≤24	24.51	17.51	6.7	0.25	3.00	-3.23	no	2151.97	502.49	3532.8
ST1=Stop,MAR.	24.01	17.01	6.7	0.25	3.50	-2.73	OK	2151.75	499.93	4100.6
	18.51	11.51	6.7	0.25	9.00	2.77	OK	2149.02	492.28	10382.9
	15.71	8.71	6.7	0.25	11.80	5.57	OK	2147.30	492.28	13613.2
May	25.25	18.25	4.1	0.26	2.60	-1.30	no	2152.28	504.41	3073.4
2.6≤RT≤11.84	25.05	18.05	4.1	0.26	2.80	-1.10	no	2152.20	503.55	3304.2
ST+IT-RT-ET≤24	24.85	17.85	4.1	0.26	3.00	-0.90	no	2152.11	502.63	3533.8
ST1=Stop,APR.	23.85	**16.85**	**4.1**	0.26	**4.00**	**0.10**	**OK**	**2151.68**	**499.86**	**4685.7**
24.01	23.35	16.35	4.1	0.26	4.50	0.60	OK	2151.46	499.37	5266.2
	18.85	11.85	4.1	0.26	9.00	5.10	OK	2149.21	499.37	10532.5
	16.05	9.05	4.1	0.26	11.80	7.90	OK	2147.53	499.37	13809.2
June	1.34	-5.66	2.2	0.26	2.60	22.67	ok	2121.46	503.80	3069.7
2.6≤RT≤11.84	22.99	15.99	2.2	0.26	2.80	1.02	ok	2151.30	503.80	3305.8
ST+IT-RT-ET≤24	22.79	15.79	2.2	0.26	3.00	1.22	ok	2151.21	503.80	3542.0
ST1=Stop,MAY.	22.04	**15.04**	**2.2**	0.26	**3.75**	**1.97**	**ok**	**2150.86**	**503.80**	**4427.5**
23.85	21.29	14.29	2.2	0.26	4.50	2.72	ok	2150.49	503.80	5312.9
	16.79	9.79	2.2	0.26	9.00	7.22	ok	2148.00	503.80	10625.9
	13.99	6.99	2.2	0.26	11.80	10.02	ok	2146.09	503.80	13931.7

Cnt

	St=ST1+IT-RT-ET	Active ST	Inflow IT	Et=e(0.0796ST1+0.28)	Assumed RT	St,start-St,end	constraint	El=10.494ln(St)+2118.4	Hnet=El-1643-KQ^2	Energy(Mwh)
Jul	21.22	14.22	2.1	*0.28*	2.60	0.78	ok	2150.46	503	3064.6
2.6≤RT≤11.84	21.02	14.02	2.1	*0.28*	2.80	0.98	ok	2150.36	503	3300.4
ST+IT-RT-ET≤24	20.82	13.82	2.1	*0.28*	3.00	1.18	ok	2150.26	503	3536.1
ST1=22	20.32	13.32	2.1	*0.28*	3.50	1.68	ok	2150.00	503	4125.5
	19.02	**12.02**	2.1	*0.28*	**4.80**	**2.98**	**ok**	**2149.31**	**503**	**5657.8**
	14.82	7.82	2.1	*0.28*	9.00	7.18	ok	2146.69	503	10608.4
	12.02	5.02	2.1	*0.28*	11.80	9.98	ok	2144.49	503	13908.8
Aug	18.55	11.55	2.4	*0.27*	2.60	0.46	ok	2149.05	501	3055.3
2.6≤RT≤11.84	18.35	11.35	2.4	*0.27*	2.80	0.66	ok	2148.93	501	3290.3
ST+IT-RT-ET≤24	18.15	11.15	2.4	*0.27*	3.00	0.86	ok	2148.82	501	3525.3
ST1=Stop,July.	17.65	10.65	2.4	*0.27*	3.50	1.36	ok	2148.53	501	4112.9
18.82	16.15	**9.15**	**2.4**	*0.27*	**5.00**	**2.86**	**ok**	**2147.59**	**501**	**5875.5**
	12.15	5.15	2.4	*0.27*	9.00	6.86	ok	2144.61	501	10575.9
	9.35	2.35	2.4	*0.27*	11.80	9.66	ok	2141.86	501	13866.2
Sept	16.90	9.90	3.6	*0.25*	2.60	-0.40	ok	2148.07	500.20	3047.8
2.6≤RT≤11.84	16.70	9.70	3.6	*0.25*	2.80	-0.20	ok	2147.94	500.07	3281.4
ST+IT-RT-ET≤24	16.50	9.50	3.6	*0.25*	3.00	0.00	ok	2147.82	499.95	3514.9
ST1=Stop,AUGUST.	14.80	**7.80**	**3.6**	*0.25*	**4.70**	**1.70**	**ok**	**2146.68**	**499.82**	**5505.2**
16.15	12.75	5.75	3.6	*0.25*	6.75	3.75	ok	2145.11	499.82	7906.5
	10.50	3.50	3.6	*0.25*	9.00	6.00	ok	2143.07	499.82	10542.0
	7.70	0.70	3.6	*0.25*	11.80	8.80	ok	2139.82	499.82	13821.7
Oct	16.90	9.90	4.9	0.20	2.60	-2.07	ok	2148.07	500.20	3047.8
2.6≤RT≤11.84	16.70	9.70	4.9	0.20	2.80	-1.87	ok	2147.94	499.29	3276.3
ST+IT-RT-ET≤24	16.50	9.50	4.9	0.20	3.00	-1.67	ok	2147.82	498.34	3503.6
ST1=Stop,SEPT	14.70	**7.70**	**4.9**	0.20	**4.80**	**0.13**	**ok**	**2146.60**	**494.88**	**5566.8**
14.8	15.00	8.00	4.9	0.20	4.50	-0.17	ok	2146.82	489.22	5159.1
	12.00	5.00	4.9	0.20	7.50	2.83	ok	2144.47	489.10	8596.5
	7.70	0.70	4.9	0.20	11.80	7.13	ok	2139.81	489.10	13525.2
Nov	17.71	10.71	5.8	0.19	2.60	-3.04	ok	2148.56	500.69	3050.8
ST+IT-RT-ET≤24	17.31	10.31	5.8	0.19	3.00	-2.64	ok	2148.32	498.84	3507.1
ST1=Stop,OCT.	16.31	**9.31**	**5.8**	0.19	**4.00**	**-1.64**	**ok**	**2147.70**	**495.88**	**4648.4**
14.7	15.81	8.81	5.8	0.19	4.50	-1.14	ok	2147.37	489.77	5165.0
	11.31	4.31	5.8	0.19	9.00	3.36	ok	2143.86	488.98	10313.3
	8.51	1.51	5.8	0.19	11.80	6.16	ok	2140.87	488.98	13521.9
Dec	19.50	12.50	6	0.21	2.60	-3.57	ok	2149.57	501.70	3056.9
2.6≤RT≤11.84	19.30	12.30	6	0.21	2.80	-3.37	ok	2149.47	500.82	3286.3
ST+IT-RT-ET≤24	19.10	12.10	6	0.21	3.00	-3.17	ok	2149.36	499.88	3514.4
ST1=Stop,NOV.	18.10	11.10	6	0.21	4.00	-2.17	ok	2148.79	496.97	4658.6
16.31	17.60	**10.60**	**6**	0.21	**4.50**	**-1.67**	**ok**	**2148.50**	**496.68**	**5237.8**
	13.10	6.10	6	0.21	9.00	2.83	ok	2145.40	495.96	10460.5
	10.30	3.30	6	0.21	11.80	5.63	ok	2142.88	495.96	13714.9

5.1.1 Computed optimal energy

The optimal yearly average energy computed using mean monthly inflow data was found equal to 58.83 GWH. The designed average yearly energy was set at 64.5 GWH. The slight difference between the DP computed and the designed yearly average energy values may due to the inflow estimation difference from the design and during this study. Otherwise the out put of DP shows that the estimation of energy production that was carried out during the design was reasonable.

In other hand, the actual average yearly energy produced for the last period (1987-2006) is 50.60GWH and represents only 86% of estimated energy.

The water loss by seepage was not taken into account and was estimated at $0.02m^3/s$ during the design. The annual average inflow is estimated at 53.3 MCM whereas the annual average release is estimated at 50.35 MCM. The yearly average loss of water by evaporation is found equal 2.91 MCM. The results are given in Table 5.2.

Tab 5.2 DP results

	Elevation	Release	Inflow	Evaporation	Energy(MWH)
JAN	2148.89	4.00	4.90	0.22	4659.57
FEB	2149.26	3.80	4.70	0.25	4429.86
MAR	2150.38	3.50	5.90	0.27	4089.31
APR	2151.75	3.50	6.70	0.25	4053.17
MAY	2151.68	4.00	4.10	0.26	4685.72
JUN	2150.86	3.75	2.20	0.26	4427.46
JUL	2149.31	4.80	2.10	0.28	5657.81
AUG	2147.59	5.00	2.40	0.27	5875.51
SEP	2146.68	4.70	3.60	0.25	5505.24
OCT	2146.60	4.80	4.90	0.20	5566.81
NOV	2147.70	4.00	5.80	0.19	4648.36
DEC	2148.50	4.50	6.00	0.21	5237.85
		50.35	**53.30**	**2.91**	**58836.66**

5.1.2 Guide curve

Monthly water levels related to the optimum energy are used to draw the guide curve. As it can be seen the maximum water level is 2151.75masl slightly under the minimum flood control level which is fixed at 2152.2 masl. This has been done to reduce or avoid the loss of water by spilling and maximize the release for power generation. As a rule curve, the storage or the water level in the reservoir would be the same at the beginning of each year independently of inflows pattern. Figure 5.1 illustrates the derived guide curve.

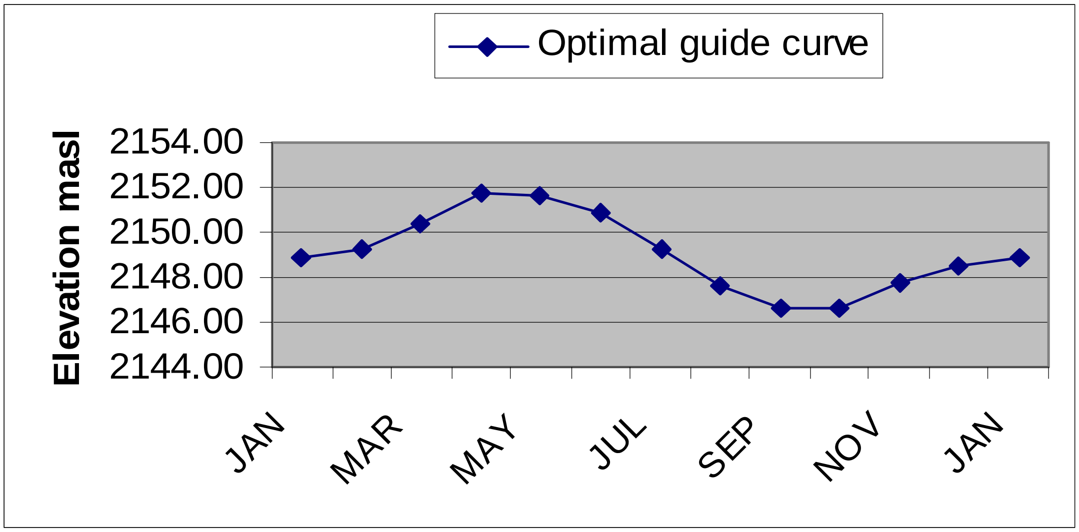

FIGURE 5.1 Optimal guide curve for Rwegura reservoir operation

By comparing the actual operation of the reservoir (previous 8 years: 1999-2006) with the derived optimal rule curve, it is observed that the actual operation does not follow any rule as the water index levels vary from year to year. In other hand, the requirement of seasonal energy demand is not fulfilled .As result; the yearly energy production will vary accordingly. Figure 5.2 shows the recorded reservoir water levels of actual production in comparison with the optimal guide curve.

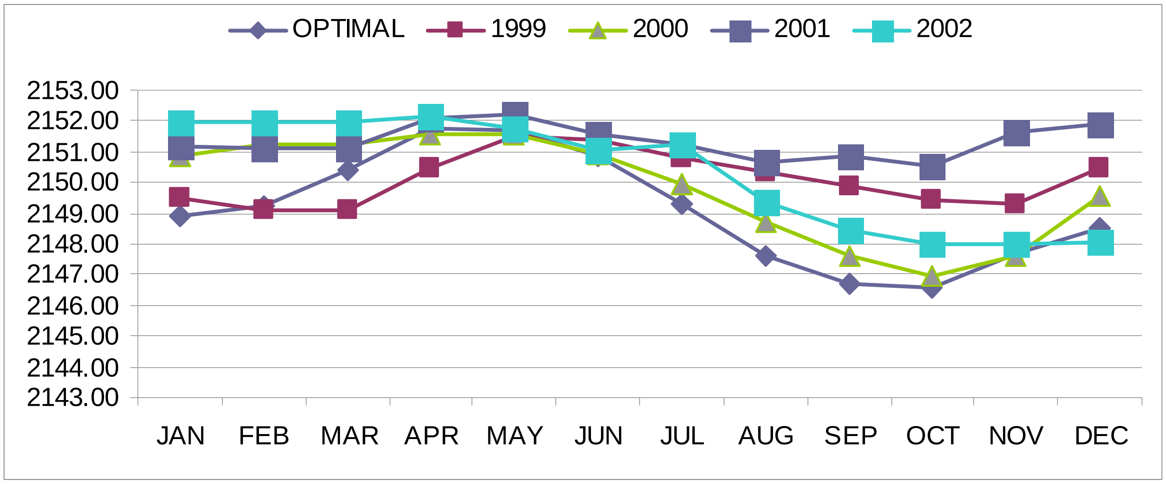

FIGURE 5.2 .a Reservoir Water level (masl)

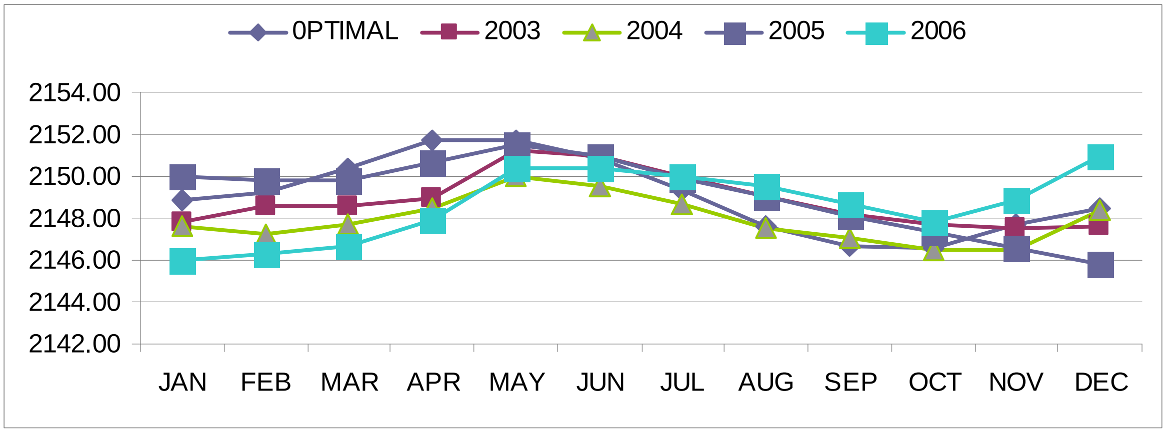

FIGURE 5.2.b Reservoir water level (masl)

5.2 Results of Hec-ResSim 2.0 model

DP modeling was done using average monthly inflows. It is therefore important to simulate the reservoir operation on the basis of daily data using the rule curve provided by DP computations. This step is very important while it tests whether the proposed rule curve is really optimal or not when comparing the simulated and the observed energy of a given period of operation.

5.2.1 Daily power and flow results

Daily power and flow output of the simulation show that the maximum daily power of 18MW corresponding to the Power Plant capacity is achieved rarely for the simulation period. The average daily power is very low with a value of 7.1MW and a plant factor of 0.4. The explanation is simple, the inflow into the reservoir is very low in general and especially for the simulation period [see Appendix J] comparing with the release requirement to achieve a plant factor equal 1(18 MW, Q=4.57m^3/s) or preferably an average plant factor much higher. The results of simulation are illustrated by Figure 5.3 and Table 5.3.

The minimum power was set at 6MW which correspond to an operation of one of the 3 installed turbines except some rare cases where the instantaneous minimum power output draws down under 6 MW.

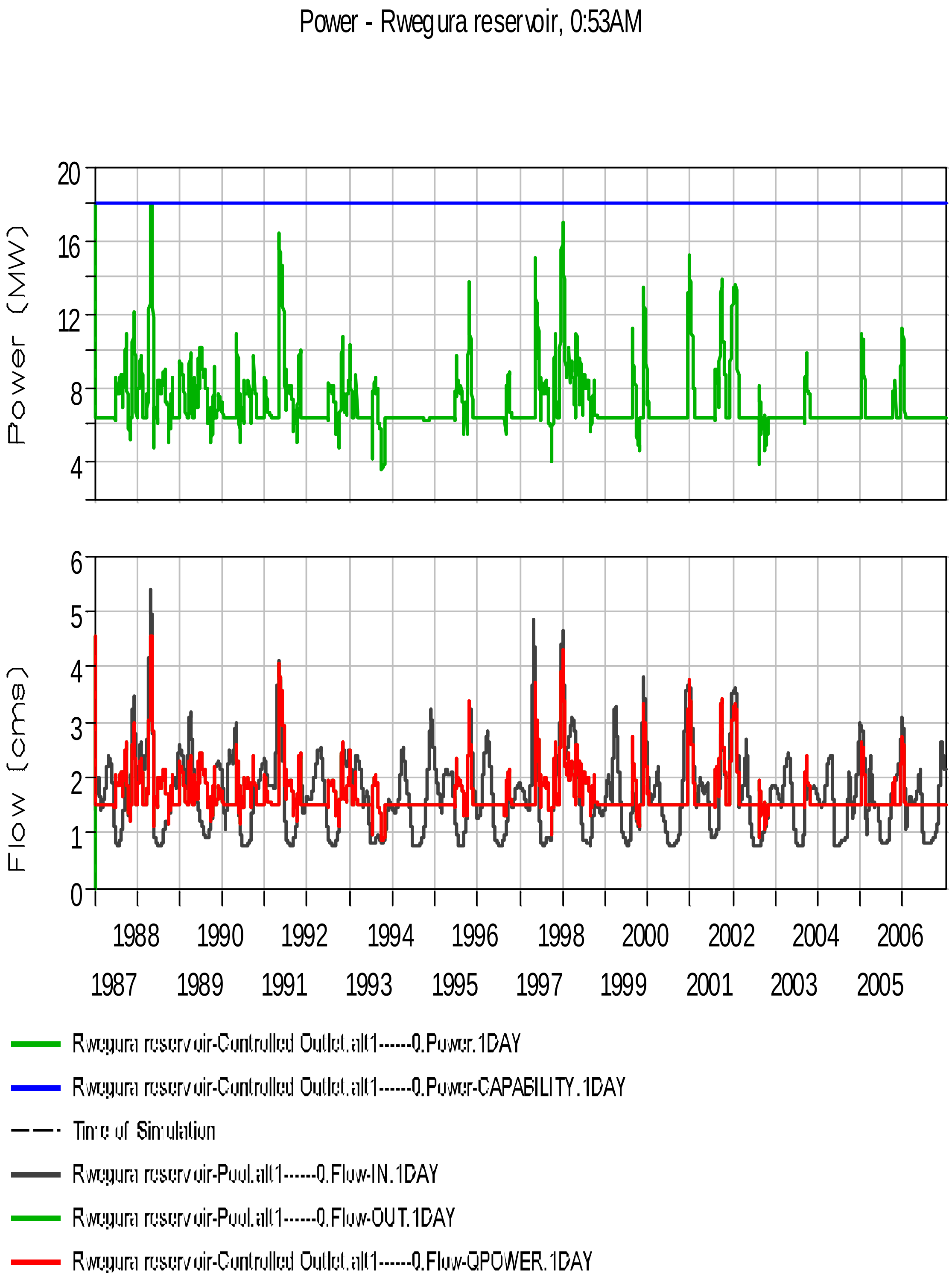

Figure 5.3 Simulated daily power and flow

Table 5.3 Simulated daily power output

	Average	Maximum	Min
Generation Efficiency	0.9	0.9	0.9
Power Head (m)	499.7	506.4	467.9
Hydraulic Losses (m)	5.7	37.7	1.8
Energy Generated per Time Step (MWh)	170.6	432.0	0.0
Power Generated (MW)	7.1	18.0	3.6
Plant Factor	0.4	1.0	0.0
Flow Power (cms)	1.7	4.6	0.8

Actually, the plant is operating most of time 18hours per day from 7AM up to 24PM. This operation management may be explained by two main reasons: firstly to allow infilling of the reservoir for 6hours (24h: 6h) without releasing and secondly the demand of energy at this time period is very low and can be covered by the others interconnected Plants.

If the operation time is reduced to 18 hours per day and by keeping the same energy out put, using the optimal rule curve, the daily power output increases as the release increases.

5.2.2 Energy output

The yearly average simulated energy was found equal 62.28 GWH and the yearly average observed energy is equal to 50.60 GWH. This represents only 81.2% of simulated energy. The optimal simulated energy represents 96.5% of design annual energy (64.5GWH).

Tab5.4 yearly simulated and observed energy (MWH)

YEAR	SIMULATED	OBSERVED
1987	64025.20	53927.49
1988	71673.98	55271.80
1989	66887.92	56895.57
1990	61659.00	57115.20
1991	68846.50	60327.86
1992	60402.99	54812.08
1993	56752.59	54287.69
1994	55262.94	31484.03
1995	62085.77	50223.74
1996	56737.61	51418.17
1997	67605.73	40496.91
1998	71340.86	50190.52
1999	60417.89	41380.00
2000	59953.66	49966.85
2001	69044.99	58546.20
2002	62238.89	68082.30
2003	57465.19	48710.80
2004	55419.84	43874.70
2005	61213.76	49270.30
2006	56629.10	35823.12
mean	62283.22	50605.27

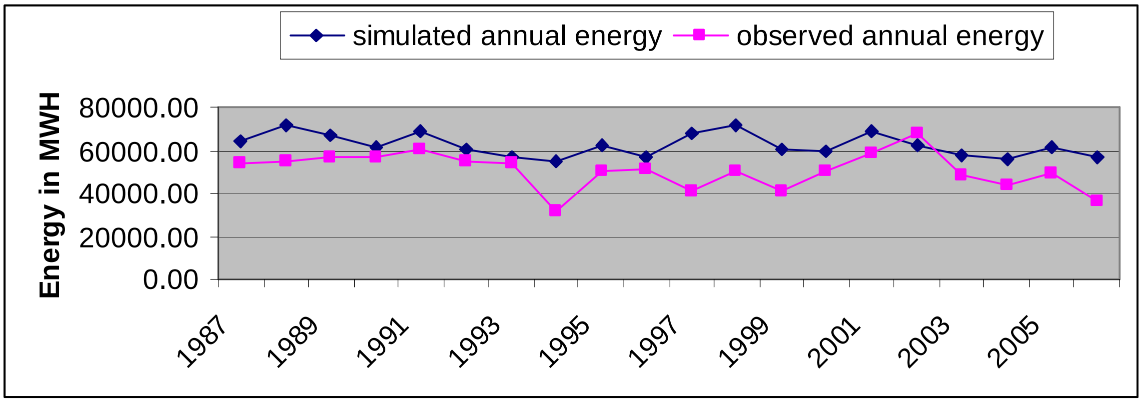

Fig 5.4 Plot of simulated and observed energy

5.2.3 Reservoir water balance results

The simulated inflows, outflows and evaporation are computed and presented in the Tab 5.5 and Figure 5.5.

Table5.5 Reservoir water balance

YEAR	Flow in	Release	Evaporation
1987	54.45	51.42	3.38
1988	61.95	58.15	3.50
1989	57.66	53.85	3.50
1990	52.95	49.21	3.44
1991	57.36	55.70	3.45
1992	53.86	48.12	3.30
1993	45.06	44.97	3.38
1994	50.29	44.68	2.62
1995	52.95	49.75	3.37
1996	48.29	45.13	3.25
1997	60.14	54.88	3.33
1998	57.93	57.76	3.44
1999	55.56	48.60	3.15
2000	51.87	48.45	3.16
2001	59.63	55.98	3.36
2002	51.83	49.96	3.34
2003	49.58	45.85	3.19
2004	48.29	44.30	3.01
2005	53.46	49.16	3.25
2006	46.38	45.31	3.02
mean	53.47	50.06	3.27

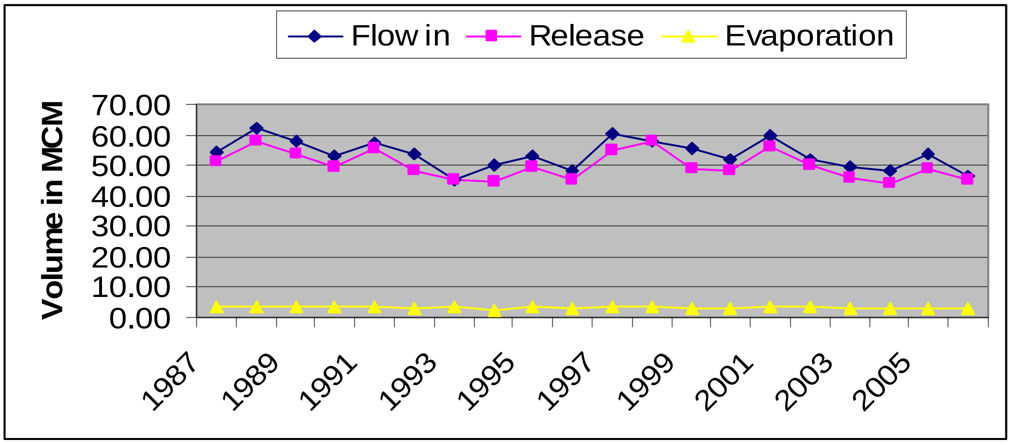

Figure 5.5 Annual simulated flows for the operation period in x10^{6}m^3

5.3 Discussion of the results

The results of the hydro-meteorological analysis give a mean annual evaporation of the reservoir area about 3.27MCM as estimated during the simulation and the annual mean inflow within the reservoir is found to be about 53.47MCM. The project was designed using a yearly dependable flow of 56 MCM.

The optimal guide curve developed using DP model indicates that the maximum water level in the reservoir is about 2151.75masl slightly below the flood control level which is 2152.2 masl. This shows that a small part of the useful storage is empty through the year.

The average yearly simulated optimum energy that can be generated following the developed guide curve is about 62.28GWH. Over the past operational period, without considering the starting year in which only few months match this period, the average annual energy produced is about 50.60GWH. This indicates that an improvement of about 11.68GWH per year is possible.

The plant was designed for an average yearly energy of 64.5GWH. It is seen that the optimum simulated energy represents 96.5% of the design energy. In the other hand a big difference separates the design or the optimum energy with the recorded energy. This shows that the plant is actually operating under its capacity. This may result to an anarchic operation of the reservoir which does not follow any rule and the storage is not exploited properly to maximize the power production. This can be illustrated by the water level information into the reservoir for the previous period of operation in Figure 5.2. The same Figure shows that most of time in the year, the water level is kept near the top of conservation zone and as result, the loss by evaporation increases.

The yearly average inflow was found equal to 53.47MCM and the release estimated at 50.06MCM while the evaporation is found equal 3.27MCM. As illustrated by the figure 5.3, there is not excess water to spill. Moreover, if the release is not carefully managed by following the rule curve, it will be difficult or will take time to store water without interrupting the production.

CHAPTER 6 CONCLUSION AND RECOMMANDATIONS

6.1 Conclusion

During this study, the hydro-meteorological data of Rwegura reservoir catchments has been collected and analyzed. The recorded production data of the plant were also collected and used in this study. Dynamic programming technique and HEC-ResSim2.0 reservoir simulation model have been used to model Rwegura reservoir. The reservoir operation guide curve has been developed. The results of simulation of this power reservoir are addressed and discussed.

The actual operation indicates that the yearly average energy production is about 50.6GWH which is 81.2% of the optimal average annual energy production estimated at 62.28GWH. Therefore, an operation which follows this optimal rule curve would surely guarantee a maximum production. The loss by evaporation was set at 6.1% of reservoir inflow while other loss by leakage and subsurface loss are expected to be very small.

6.2 Recommendations

Based on this study, the following recommendations are necessary:

- The developed optimal guide curve is reliable and can be used in real time operation for efficient operation of Rwegura power plant.
- The water loss by evaporation and other losses are negligible and then an operation based on the optimal guide curve will ensure a maximum energy production.
- An operation extended on 18 hours per day can contribute to improve the daily power plant factor as the excess of flow during the break

(low demand period:00 to 6h) would be added to the release of next day and so on. This proposition is an alternative to deal with the daily increase of power demand.

- As it was mentioned, the only gauging station of the streams upstream the reservoir was submerged after the completion of the power project. It is therefore suggested to the planners to construct two new gauging stations one on the stream Gitenge and another on the branch stream Mwokora. This will help to know the real inflow into the reservoir and would be useful for further implementation of others projects downstream the power plant.

- In order to follow the optimal guide curve in operating Rwegura reservoir, the following procedures are recommended:

  1. Observe the reservoir water level at the beginning of the month under consideration.

  2. Compare the water level reading with the reservoir guide curve.

  3. Estimate the energy expected during the period (using graph of monthly production).

  4. Estimate the energy in excess (or shortage) of the guide curve during that month.

  5. Compare the available energy in excess (or shortage) with the expected energy. Then decide the release depending on:

    - **Condition1**: If there is excess energy than the expected energy supply, produce as much of the available energy as possible in that month until the water level coincides with the guide curve.

    - **Condition2:** If there is less energy into the reservoir than the expected energy during that month, produce less than expected energy until the reservoir level coincides with the guide curve.

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APPENDICES

Appendix A: Local loss coefficient computation K

$$\Delta h = KQ^2$$

Intake loss is approximated as: $\Delta h = x\dfrac{V^2}{2g}$

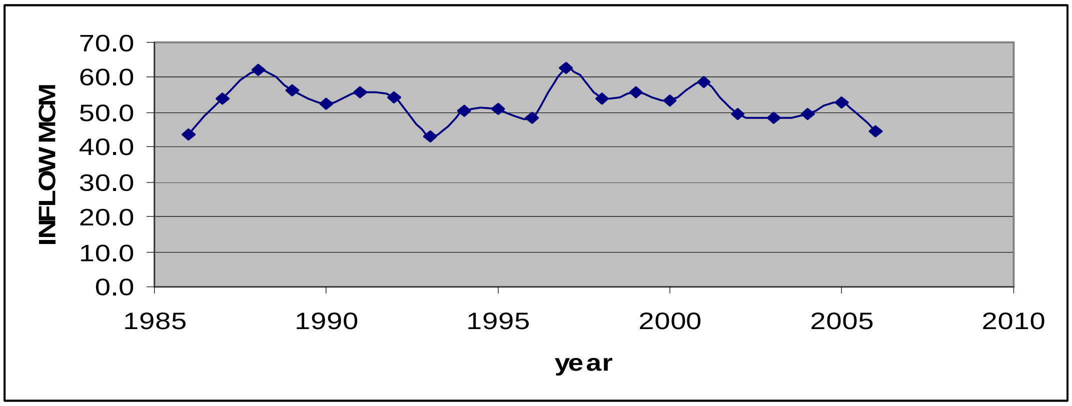
x =0.25(for case study), $V = \dfrac{Q}{A}$, where A is the tunnel cross-section

Then $\Delta h = x\dfrac{Q^2}{2g * A^2} = \dfrac{0.25}{2*9.81*(p*2.8^2)/4} * Q^2 = 0.00034Q^2$,

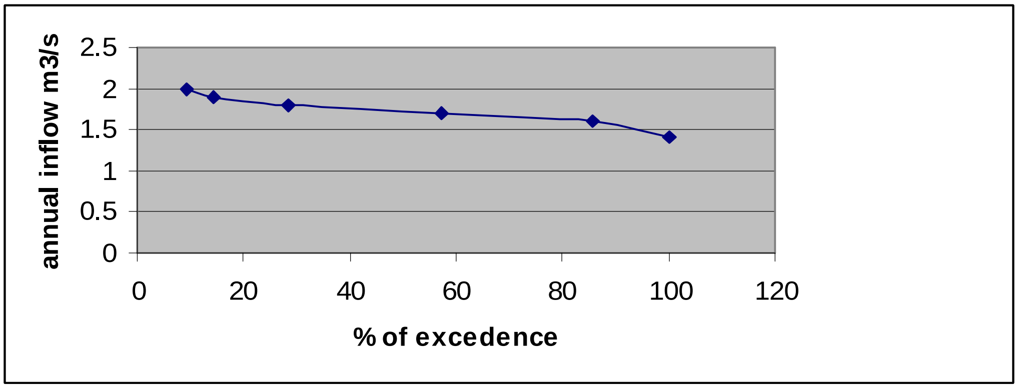
K is taken approximately equal 0.0004

The trash racks loss can be neglected as the approach velocity into the reservoir is very small (near 0).

Appendix B: Computed annual runoff hydrograph for Rwegura reservoir (submerged station)



Appendix C: Computed annual flow duration curve



Appendix D: Recorded rainfall at Rwegura station in mm

year	J	F	M	A	M	J	J	At	S	O	N	D	annual
1961	182.8	165.9	186.1	241.3	108.4	0.0	0.0	0.0	47.8	326.0	494.3	264.8	**2017.4**
1962	195.8	137.7	288.0	295.2	237.4	148.7	20.8	93.4	69.6	205.9	263.4	169.8	**2125.6**
1963	252.3	195.9	198.4	310.8	268.4	11.7	11.4	5.1	126.0	57.1	278.8	363.2	**2079.1**
1964	89.4	5.1	188.4	216.1	88.6	65.7	89.4	22.7	40.9	248.8	88.6	65.7	**1209.4**
1965	137.0	186.6	258.7	386.6	96.1	0.0	0.0	22.1	139.6	134.1	180.1	63.0	**1603.9**
1966	130.4	184.7	356.2	265.4	102.1	8.1	0.0	30.2	85.3	150.4	192.5	186.5	**1691.8**
1967	138.2	97.2	220.2	204.7	277.1	19.6	10.5	4.7	165.5	110.7	387.1	265.8	**1901.3**
1968	171.6	212.7	206.8	432.3	157.3	54.6	1.5	1.1	61.4	193.4	298.0	161.3	**1952.0**
1969	260.8	357.2	216.3	204.1	133.5	0.5	0.0	19.5	35.1	165.1	142.7	74.6	**1609.4**
1970	274.2	152.8	300.0	294.9	141.9	16.5	18.6	9.2	73.4	94.0	143.5	214.9	**1733.9**
1971	166.9	62.4	217.2	469.8	283.8	14.4	27.5	109.6	86.2	154.7	224.0	150.3	**1966.8**
1972	181.7	195.0	175.9	163.1	90.6	127.8	0.0	41.5	156.0	191.4	265.3	162.1	**1750.4**
1973	191.9	70.3	96.4	284.9	128.5	26.7	0.0	1.0	252.3	279.2	250.1	177.4	**1758.6**
1974	198.2	200.2	91.3	288.8	239.0	28.8	0.0	2.9	240.2	114.9	268.9	223.0	**1896.2**
1975	163.8	97.0	194.1	303.7	97.9	13.5	13.2	4.3	56.4	203.1	104.6	198.0	**1449.6**
1976	88.6	118.0	214.0	230.4	171.1	24.5	23.2	87.3	136.8	145.5	162.4	195.7	**1597.5**
1977	163.5	118.2	188.5	192.8	109.2	7.0	21.0	90.7	11.0	63.7	312.3	258.1	**1536.0**
1978	122.4	167.0	337.5	236.2	79.6	13.4	0.0	32.2	82.3	169.2	159.4	235.0	**1634.2**
1979	233.3	236.1	154.6	275.0	220.0	36.0	0.0	12.9	27.0	114.0	131.0	215.0	**1654.9**
1980	156.6	142.8	174.9	140.3	152.0	69.7	0.0	9.3	74.6	179.6	181.6	131.8	**1413.2**
1981	156.6	63.7	185.4	216.7	178.6	4.4	0.0	116.8	99.7	159.6	133.5	165.0	**1480.0**
1982	164.9	69.7	206.1	344.7	167.7	39.4	0.0	5.2	156.2	169.9	346.1	238.8	**1908.7**
1983	72.0	103.4	201.4	317.0	92.9	14.5	0.0	28.1	75.8	203.9	149.1	207.4	**1465.5**
1984	232.1	119.3	223.0	187.8	38.2	0.0	20.0	64.2	81.1	170.4	180.4	93.1	**1409.6**
1985	234.2	208.5	188.2	354.9	79.3	21.6	0.0	0.0	144.4	49.0	246.7	152.2	**1679.0**
1986	153.8	253.6	165.7	337.4	160.0	41.8	0.0	1.6	122.4	285.5	233.7	116.5	**1872.0**
1987	189.7	121.4	155.9	225.6	193.3	9.3	3.2	72.1	201.6	88.9	300.6	178.9	**1740.5**
1988	244.9	204.6	244.1	387.3	38.9	0.0	0.0	90.6	79.0	194.6	168.6	240.3	**1892.9**
1989	220.4	169.9	281.4	204.6	143.0	94.9	47.0	33.2	78.6	205.0	919.5	194.9	**2592.4**
1990	62.6	233.3	213.7	269.7	75.5	2.6	0.0	28.9	174.8	161.7	200.9	221.3	**1645.0**
1991	178.3	173.7	169.3	335.0	266.6	39.1	1.8	4.4	75.3	226.0	113.3	151.6	**1734.4**
1992	144.8	179.6	234.2	236.1	154.2	30.4	0.0	0.0	66.4	245.8	207.7	235.6	**1734.8**
1993	152.5	224.6	208.3	130.4	164.4	13.3	7.0	42.1	8.3	29.9	144.7	124.7	**1250.2**
1994	110.0	149.3	239.4	185.5	126.3	0.8	0.0	2.4	48.0	184.9	284.5	213.4	**1544.5**
1995	169.3	112.6	206.5	196.4	199.3	73.9	0.8	0.0	88.8	292.5	172.6	99.9	**1612.6**
1996	110.2	222.3	260.9	189.9	35.2	8.0	2.2	45.0	149.4	126.9	171.8	180.1	**1501.9**
1997	162.9	128.5	119.4	366.0	213.7	10.7	2.4	37.6	21.8	243.2	187.4	357.9	**1851.5**
1998	219.4	252.9	275.0	244.6	148.3	23.0	16.0	2.4	133.8	136.1	104.2	123.1	**1678.8**
1999	*197.2*	*139.0*	*289.4*	*200.2*	*53.4*	*9.3*	*0.3*	*163.5*	*95.1*	*64.8*	*319.6*	*204.9*	**1736.7**
2000	*143.5*	*156.5*	*208.3*	*118.6*	*90.2*	*0.6*	*0.2*	*6.4*	*41.2*	*181.5*	*306.0*	*316.7*	**1569.7**
2001	*218.8*	*125.4*	*190.8*	*156.5*	*178.2*	*33.1*	*37.1*	*69.8*	*263.8*	*189.5*	*189.5*	*302.7*	**1955.2**
2002	*307.8*	*128.8*	*156.2*	*248.1*	*97.2*	*0.0*	*0.0*	*0.0*	*59.6*	*105.7*	*175.4*	*176.5*	**1455.3**
2003	*157.8*	*129.5*	*206.5*	*228.7*	*145.3*	*8.6*	*0.2*	*0.0*	*178.0*	*167.0*	*172.0*	*156.0*	**1549.6**
2004	*126.6*	*139.2*	*218.0*	*226.0*	*0.4*	*0.0*	*19.4*	*18.4*	*199.6*	*101.8*	*171.5*	*270.4*	**1491.3**
2005	*255.9*	*42.3*	*226.4*	*129.4*	*135.6*	*9.1*	*11.2*	*23.2*	*158.3*	*187.5*	*204.2*	*274.8*	**1657.9**
2006	*61.3*	*154.8*	*137.0*	*147.6*	*203.8*	*13.0*	*8.1*	*7.9*	*35.2*	*80.1*	*247.0*	*203.8*	**1299.6**
mean	**172.8**	**154.5**	**210.3**	**252.6**	**142.7**	**25.8**	**9.0**	**31.8**	**104.4**	**164.2**	**230.0**	**195.1**	**1693.3**

Appendix E: Recorded discharges at Gitenge gauge station in m^3/s

YEAR:1980

date	J	F	M	A	M	J	J	A	S	O	N	D
1	0.87	1.66	3.16	1.99	1.32	2.38	0.98	0.98	0.75	1.43	0.87	1.21
2	0.92	1.43	3.38	1.82	1.43	5.3	0.92	0.92	0.75	0.75	0.81	0.98
3	0.98	1.43	2.82	1.66	1.43	2.6	0.98	0.98	0.75	0.7	1.09	0.98
4	0.92	1.21	2.32	1.49	1.71	1.94	0.98	0.98	0.75	0.7	1.09	0.98
5	0.98	1.15	2.27	1.38	1.94	1.71	0.92	0.92	0.75	0.7	0.92	1.49
6	0.92	1.66	2.1	1.77	2.1	1.38	0.92	0.92	0.75	0.7	1.21	1.38
7	0.87	1.71	2.05	3.16	1.71	1.21	0.92	0.92	0.75	0.7	0.92	2.32
8	0.87	1.43	1.71	3.93	1.49	1.43	0.92	0.92	0.75	0.7	1.28	1.99
9	1.38	1.43	1.38	3.38	2.32	1.43	0.92	0.92	0.75	0.7	1.43	1.77
10	0.92	0.98	1.32	1.94	2.1	1.43	0.92	0.92	0.92	0.7	1.49	2.16
11	0.87	1.49	1.49	1.94	2.38	1.38	0.92	0.92	0.75	1.04	1.43	1.54
12	0.87	1.15	2.6	2.05	2.32	1.38	0.87	0.87	0.92	0.87	1.25	1.43
13	0.87	1.49	2.27	2.21	2.05	1.09	0.87	0.87	0.87	0.87	1.04	1.6
14	0.87	1.09	2.38	1.99	2.21	1.09	0.87	0.87	0.75	1.15	1.15	1.49
15	0.87	1.21	1.71	1.71	1.94	1.09	0.87	0.87	0.81	1.15	0.98	1.38
16	0.87	1.21	1.49	1.94	2.32	1.09	0.87	0.87	0.81	1.94	1.77	1.54
17	0.87	1.15	1.15	1.99	1.49	0.92	0.87	0.87	0.75	1.77	2.1	1.32
18	0.98	0.98	1.09	1.71	1.49	0.87	0.87	0.87	0.75	1.77	2.49	1.21
19	1.04	0.92	1.32	1.71	1.43	0.87	0.87	0.87	0.75	1.71	2.82	2.55
20	1.21	0.92	1.32	1.43	1.43	0.87	0.87	0.87	0.75	0.92	3.16	1.88
21	0.98	0.87	1.32	1.43	1.43	0.87	0.87	0.87	0.75	1.38	2.1	1.43
22	0.92	0.92	1.32	1.43	1.38	0.92	0.87	0.87	0.75	1.26	1.49	1.26
23	1.38	0.92	1.15	1.43	1.32	0.92	0.87	0.87	0.7	1.77	1.77	1.38
24	1.77	0.87	1.71	1.28	1.32	0.92	0.81	0.81	0.75	1.77	1.71	1.54
25	1.49	0.87	1.62	1.32	1.43	0.92	0.81	0.81	0.75	1.71	1.43	1.6
26	1.49	1.21	2.27	1.38	1.32	0.92	0.81	0.81	0.81	1.49	1.71	1.88
27	1.49	1.71	1.71	1.21	1.32	0.92	0.75	0.75	0.87	1.94	2.27	1.77
28	1.54	1.71	2.27	1.43	1.32	0.92	0.75	0.75	0.92	1.43	2.05	1.43
29	2.16	1.43	1.99	1.32	1.32	0.98	0.75	0.75	0.92	1.38	1.71	1.21
30	1.71		2.6	1.32		0.98	0.75	0.75	1.09	1.38	1.26	0.98
31	1.71		2.27				0.75	0.75		1.32		0.92
MEAN	**1.15**	**1.25**	**1.92**	**1.83**	**1.68**	**1.36**	**0.87**	**0.87**	**0.80**	**1.22**	**1.56**	**1.50**
mm	***36.87***	***40.1***	***61.71***	***58.62***	***54.02***	***43.61***	***27.89***	***27.89***	***25.58***	***39.16***	***50.11***	***48.28***

YEAR:1981

date	J	F	M	A	M	J	J	A	S	O	N	D
1	1.43	0.92	0.87	1.71	1.38	1.6	0.98	0.87	1.28	1.21	1.49	1.04
2	1.38	0.92	0.98	1.43	1.21	1.49	0.98	0.87	1.38	1.15	0.98	0.98
3	1.49	0.92	0.92	1.38	2.38	2.32	0.98	0.87	1.38	0.81	0.81	0.92
4	1.21	0.87	1.15	1.38	2.16	1.99	0.98	0.87	1.28	0.87	0.81	0.87
5	0.92	0.92	0.98	1.49	2.1	1.43	0.98	0.87	1.32	0.87	0.81	0.87
6	1.68	0.87	0.98	1.15	2.21	1.38	0.98	0.87	1.32	0.81	0.75	0.98
7	1.54	0.98	1.6	1.21	2.38	1.38	0.98	0.87	1.21	0.81	0.75	1.09
8	1.09	0.98	1.43	1.04	2.71	1.38	0.87	0.87	1.26	0.75	0.75	1.09
9	1.32	0.98	1.54	0.92	2.66	1.32	0.87	0.87	1.38	0.81	1.38	1.21
10	1.09	1.28	1.43	1.88	2.32	1.21	0.87	0.75	2.27	0.81	1.38	1.21
11	0.92	1.21	1.71	2.05	2.55	1.15	0.87	0.75	1.38	0.75	0.98	1.09
12	1.04	0.92	1.38	3.49	3.27	1.15	0.87	0.75	1.38	0.75	0.92	1.04
13	1.43	0.87	1.21	3.1	3.32	1.15	0.87	0.75	1.38	0.81	1.26	0.98
14	1.54	0.87	1.94	2.05	3.38	1.15	0.87	0.75	1.38	0.81	1.43	0.92
15	1.43	0.92	2.05	5.9	2.88	1.15	0.87	0.75	1.49	0.81	1.38	0.92
16	1.28	1.09	1.77	6.88	3.65	1.15	0.87	0.87	1.32	0.75	1.04	1.09
17	1.09	1.38	1.88	5.08	4.15	1.15	0.87	1.15	1.21	0.75	0.87	1.49
18	0.98	1.09	1.43	3.54	3.38	1.09	0.92	1.54	1.15	0.81	0.81	1.49
19	0.92	1.21	1.43	2.27	2.49	1.04	0.92	1.15	1.09	0.81	0.87	1.6
20	1.26	1.04	1.66	2.32	2.21	1.04	0.87	0.75	1.09	0.81	0.81	1.54
21	1.49	0.87	1.77	2.1	1.94	1.04	0.87	0.75	1.09	0.87	0.75	1.54
22	1.38	0.87	1.99	2.05	1.94	1.04	0.87	0.75	0.98	0.87	0.75	1.43
23	1.43	0.81	2.27	1.94	1.88	0.98	0.87	0.81	0.87	0.81	0.87	1.38
24	1.49	0.87	3.1	1.99	1.88	0.98	0.87	0.87	0.81	0.87	0.81	0.98
25	1.43	0.92	2.49	1.99	1.6	0.98	0.87	0.81	0.75	0.98	0.87	0.92
26	1.6	0.87	1.94	2.16	1.49	0.98	0.87	0.81	0.75	0.98	0.81	1.21
27	1.32	0.81	1.15	2.1	1.49	0.98	0.87	0.75	0.92	1.32	1.26	1.38
28	1.09	0.87	1.71	2.1	1.54	0.98	0.87	0.81	0.87	1.88	1.82	1.38
29	1.09		2.27	1.6	1.6	0.98	0.87	0.87	0.87	1.99	1.71	1.38
30	1.04		1.77	1.43	1.77	0.98	0.87	0.87	0.92	1.99	1.09	1.43
31	0.92		1.49		1.66		0.87	0.92		1.99		1.49
mean	**1.27**	**0.97**	**1.62**	**2.32**	**2.31**	**1.22**	**0.90**	**0.86**	**1.19**	**1.01**	**1.03**	**1.19**
mm	***40.74***	***31.12***	***52.11***	***74.66***	***74.16***	***39.23***	***28.84***	***27.78***	***38.31***	***32.44***	***33.21***	***38.27***

YEAR:1982

date	J	F	M	A	M	J	J	A	S	O	N	D
1	1.49	0.98	0.92	3.6	2.55	1.6	0.98	0.87	0.75	0.75	1.54	2.71
2	1.28	0.98	0.92	5.24	2.44	1.77	0.98	0.87	0.75	0.75	1.28	2.93
3	1.82	0.92	1.26	5.79	2.55	1.77	0.92	0.81	0.75	0.75	1.38	3.82
4	1.54	0.87	1.62	3.71	2.21	1.66	0.92	0.81	0.81	0.81	1.49	3.93
5	1.21	0.92	1.66	3.16	2.6	1.54	0.92	0.81	0.81	0.81	1.77	2.82
6	1.04	0.98	1.99	2.44	3.1	1.49	0.92	0.87	0.75	0.75	1.43	1.99
7	1.09	0.92	1.99	1.99	2.99	1.43	0.92	0.87	0.75	0.75	1.43	1.38
8	1.04	0.92	1.99	1.99	2.38	1.38	0.92	0.87	0.75	0.92	1.04	1.43
9	0.98	0.87	1.54	1.88	2.05	1.32	0.92	0.87	0.75	0.92	1.21	1.38
10	0.87	0.98	1.82	1.49	2.88	1.15	0.92	0.87	0.75	0.92	1.09	1.09
11	0.98	0.92	1.04	1.43	3.54	1.09	0.92	0.81	0.75	1.38	1.94	1.28
12	1.32	0.98	0.92	1.54	3.05	0.98	0.92	0.81	0.75	1.32	2.49	2.27
13	1.71	1.04	0.87	1.49	2.1	0.98	0.92	0.81	0.75	0.98	2.05	2.49
14	1.71	1.26	0.92	1.49	2.05	0.98	0.87	0.81	0.75	1.09	1.43	2.1
15	1.43	1.38	1.15	1.99	1.82	0.98	0.87	0.81	0.75	1.09	1.43	1.8
16	1.54	1.38	1.15	2.16	1.77	0.98	0.87	0.81	0.75	1.21	1.43	1.43
17	1.21	1.43	1.04	2.05	1.71	0.98	0.87	0.81	0.75	1.09	1.43	1.09
18	0.83	1.38	0.92	2.05	1.54	0.98	0.87	0.81	1.09	1.32	1.54	0.92
19	0.92	1.04	0.87	2.71	1.82	0.98	0.87	0.81	0.98	1.43	1.88	1.26
20	1.04	0.87	1.32	2.21	1.71	0.98	0.87	0.81	0.92	1.26	1.43	1.6
21	2.49	0.87	1.6	3.54	1.82	0.92	0.87	0.81	0.92	1.38	1.15	1.49
22	1.6	0.92	1.54	4.97	1.82	0.92	0.87	0.81	0.92	1.43	0.93	2.05
23	1.04	0.92	1.43	2.88	1.82	0.92	0.87	0.81	0.87	1.49	1.66	2.21
24	1.04	0.87	1.26	2.71	1.66	0.92	0.87	0.81	0.87	1.38	1.54	2.21
25	0.98	0.87	0.98	2.71	1.54	0.92	0.87	0.81	0.87	1.62	1.71	2.38
26	0.92	0.87	0.92	2.66	1.54	0.92	0.87	0.81	0.81	1.77	1.99	2.21
27	0.92	0.87	0.92	2.06	1.71	0.92	0.87	0.81	0.87	1.49	2.38	1.54
28	1.04	0.92	1.38	2.55	1.99	0.92	0.87	0.75	0.87	1.77	3.21	1.38
29	0.92		1.94	2.55	1.94	0.92	0.87	0.75	0.81	1.54	3.49	1.6
30	1.04		1.26	2.55	1.88	0.92	0.87	0.75	0.75	1.94	3.1	1.66
31	0.92		1.99		1.6		0.87	0.75		1.66		1.77
mean	**1.22**	**1.00**	**1.33**	**2.65**	**2.13**	**1.14**	**0.89**	**0.82**	**0.81**	**1.22**	**1.73**	**1.94**
mm	***39.33***	***32.27***	***42.61***	***85.21***	***68.57***	***36.64***	***28.74***	***26.2***	***26.14***	***39.13***	***55.53***	***62.39***

YEAR:1983

date	J	F	M	A	M	J	J	A	S	O	N	D
1	1.6	0.98	1.32	1.8	4.64	1.43	1.99	1.94	1.88	2.27	2.55	2.2
2	2.0	0.98	1.88	1.9	4.91	1.26	1.94	1.94	1.88	2.44	2.55	2.3
3	1.6	1.04	1.82	1.7	5.52	1.26	1.99	1.94	1.88	2.27	2.55	2.2
4	1.4	0.98	1.43	1.6	5.73	1.21	1.99	1.94	1.99	2.27	2.6	2.2
5	1.4	1.26	1.38	4.1	4.04	1.08	2.05	1.88	2.1	2.27	2.6	2.2
6	1.7	1.15	2.77	2.8	1.04	1.99	1.88	2.1	2.38	2.38	2.71	2.7
7	1.6	1.32	1.26	1.4	2.27	1.04	1.99	1.88	2.1	2.44	2.88	2.4
8	1.4	1.21	1.38	1.3	1.71	1.04	1.99	1.99	1.99	2.49	2.77	2.5
9	1.3	1.09	1.38	1.2	2.05	1.15	1.94	2.44	1.94	3.32	2.82	2.4
10	1.0	1.21	1.21	1.0	2.1	1.77	1.94	2.71	1.94	5.41	2.66	2.4
11	0.9	1.49	2.1	0.9	2.16	1.82	1.94	2.27	1.88	5.84	2.77	2.3
12	0.8	1.66	3.38	1.0	2.32	1.43	1.94	2.1	4.2	5.13	2.71	2.2
13	0.8	1.66	2.1	1.4	2.16	1.32	1.94	2.1	3.1	5.02	2.82	2.0
14	0.9	1.71	1.77	2.0	2.1	1.32	1.94	2.05	2.16	3.54	2.66	2.3
15	0.9	1.88	1.6	1.9	1.99	1.32	1.94	2.05	2.1	2.99	2.88	2.8
16	1.0	1.71	1.54	2.0	1.99	1.32	1.94	2.05	1.99	3.21	3.05	3.0
17	1.0	1.49	1.77	1.9	1.99	1.32	1.94	1.99	1.94	4.09	3.16	2.9
18	1.0	1.43	1.66	1.6	1.82	1.32	1.94	2.05	1.88	4.53	3.16	2.9
19	1.0	1.54	1.94	1.4	1.71	1.26	1.94	2.05	1.88	4.64	3.1	2.9
20	0.9	1.94	4.59	1.6	1.6	1.26	1.94	2.16	1.82	4.64	2.99	2.8
21	0.9	1.77	4.15	2.1	1.54	1.32	1.94	2.1	1.82	4.59	2.88	2.6
22	0.9	1.66	2.32	3.6	1.54	1.43	1.94	2.1	1.77	4.2	2.77	
23	0.9	1.54	1.82	3.4	1.49	1.38	1.94	2.1	1.71	4.48	2.26	
24	0.9	1.43	1.38	3.3	1.54	1.32	1.94	1.99	1.82	4.53	2.6	
25	0.9	1.38	1.38	3.7	1.71	1.32	1.94	1.94	2.6	4.15	2.71	
26	0.9	1.32	1.32	4.3	1.71	1.26	1.94	1.94	2.66	4.26	2.71	
27	0.9	1.09	1.21	4.7	1.6	1.26	1.94	1.94	2.44	4.37	2.66	
28	1.0	0.98	1.21	5.2	1.54	1.26	1.94	1.88	2.32	4.15	2.66	
29	1.2		2.1	5.6	1.54	1.21	1.88	1.88	2.21	3.93	2.77	
30	1.0		1.82	5.0	1.49	1.66	1.88	1.88	2.1	3.43	2.66	
31	0.9		1.66		1.43		1.88	1.88		2.93		
Mea	**1.1**	**1.39**	**1.89**	**2.5**	**2.29**	**1.34**	**1.94**	**2.04**	**2.15**	**3.75**	**2.76**	**2.5**
mm	***37.***	***44.6***	***60.7***	***82.***	***73.5***	***43.1***	***62.4***	***65.5***	***69.0***	***120.***	***88.5***	***81.***

Appendix F: Temperatures at Rwegura station (degree siliceous)

1. Mean maximum monthly temperatures

	JAN	FEV	MAR	AVR	MAI	JUIN	JUIL	AOUT	SEPT	OCT	NOV	DEC	An.
1969	20.1	19.5	19.8	19.9	19.0	19.5	19.8	21.4	21.5	21.2	19.3	20.6	**20.1**
1970	19.6	20.6	19.9	19.3	18.5	19.4	19.5	19.9	21.3	21.2	20.5	19.6	**19.9**
1971	20.2	19.9	20.1	18.9	18.2	18.7	17.8	20.0	20.0	20.0	19.4	18.8	**19.3**
1972	20.0	19.5	19.9	19.1	18.2	18.5	19.3	20.2	20.7	20.5	19.5	20.6	**19.6**
1973	21.4	22.0	20.5	19.0	18.8	19.4	19.9	20.8	20.8	20.3	19.8	19.5	**20.2**
1974	20.1	20.5	19.8	19.3	18.5	18.4	17.1	20.5	20.3	20.7	20.1	19.8	**19.6**
1975	20.0	20.1	19.4	19.4	18.9	18.6	18.7	19.6	18.7	19.1	19.9	19.5	**19.3**
1976	20.4	19.4	20.5	19.6	18.7	18.7	19.0	19.2	20.2	21.0	20.1	20.3	**19.7**
1977	19.8	20.4	19.9	19.2	19.2	19.1	19.5	19.9	20.6	21.2	19.3	20.3	**19.9**
1978	20.6	20.5	19.7	19.3	19.0	18.8	19.5	20.5	21.2	20.4	19.4	19.6	**19.9**
1979	20.1	20.6	21.3	19.6	19.0	18.9	-	21.4	22.7	21.9	20.3	20.3	**20.5**
1980	21.1	21.3	20.7	20.5	19.1	19.9	20.0	20.6	21.2	21.1	19.8	20.2	**20.4**
1981	20.8	20.8	20.0	19.9	19.3	19.9	19.8	20.4	20.6	20.6	20.8	20.8	**20.3**
1982	20.9	20.7	20.6	19.6	18.8	19.3	19.6	-	20.8	19.0	19.9	20.5	**20.0**
1983	21.7	21.9	21.4	19.8	20.2	20.4	20.0	20.3	21.4	22.5	21.0	20.1	**20.9**
1984	19.2	20.9	21.0	19.8	20.1	19.7	19.1	20.7	21.8	20.4	18.9	20.3	**20.1**
1985	20.4	19.5	22.7	19.2	18.9	18.8	19.7	20.3	19.9	20.5	20.3	20.1	**20.0**
1986	20.7	21.2	20.4	19.3	19.4	19.6	19.9	22.3	21.5	21.8	20.3	20.4	**20.6**
1987	20.9	22.7	21.8	21.4	19.8	19.8	21.2	21.1	21.7	21.5	19.9	21.9	**21.1**
1988	20.1	21.4	20.5	20.0	19.5	19.6	19.4	19.6	20.2	20.0	19.9	19.1	**19.9**
1989	19.3	19.8	20.0	18.9	18.4	18.3	18.8	20.1	20.3	19.8	20.5	20.0	**19.5**
1990	20.9	20.6	20.4	20.9	20.4	20.7	20.5	21.2	11.1	21.1	20.4	20.1	**19.9**
1991	21.1	22.0	21.6	20.5	19.3	20.3	18.8	21.1	21.7	19.7	19.9	20.0	**20.5**
1992	20.8	20.5	20.9	20.2	19.3	19.3	19.7	21.4	21.8	20.9	20.1	19.6	**20.4**
1993	20.1	20.4	20.3	20.5	19.9	19.5	20.4	20.9	23.4	23.6	22.4	24.0	**21.3**
1994	20.9	20.7	20.9	20.5	19.3	-	-	-	22.6	20.5	19.8	20.6	**20.6**
1995	21.0	21.0	20.9	20.1	19.5	20.4	20.6	22.3	22.6	21.2	21.1	21.1	**21.0**
1996	20.8	20.9	20.8	20.2	20.0	18.9	19.8	21.2	21.5	21.2	20.3	20.8	**20.5**
1997	20.5	21.0	21.1	19.7	19.7	20.1	20.2	22.5	24.4	21.5	20.0	19.9	**20.9**
1998	21.1	21.8	22.1	21.0	20.6	20.7		21.4	22.7	20.8	21.4	21.1	**21.3**
1999	20.2	22.1	20.3	19.7	19.8	20.2	20.4	19.5	20.7	20.8	19.7	20.1	**20.3**
2000	21.1	23.6	20.0	20.3	20.9	19.8	20.7	21.9	23.5	21.6	20.3	20.6	**21.2**
2001	19.4	20.9	20.3	20.5	19.4	19.6	19.5	21.4	21.8	20.9	20.5	20.8	**20.1**
2002	20.5	20.9	20.6	19.8	19.3	19.5	19.6	20.7	21.0	20.8	20.2	20.3	**20.3**
2003	20.5	20.9	20.6	19.9	19.4	19.5	19.6	20.8	21.0	20.8	20.2	20.3	**20.3**
2004	20.5	20.9	20.7	19.9	19.4	19.5	19.7	20.8	21.1	20.9	20.2	20.4	**20.3**
2005	20.5	21.0	20.7	19.9	19.4	19.5	19.7	20.8	21.1	20.9	20.2	20.4	**20.3**
2006	20.5	21.0	20.7	19.9	19.4	19.5	19.7	20.8	21.1	20.9	20.2	20.4	**20.3**
Av.	**20.5**	**20.9**	**20.6**	**19.8**	**19.3**	**19.5**	**19.6**	**20.8**	**21.1**	**20.9**	**20.1**	**20.3**	**20.3**

2. Mean minimum monthly temperatures at Rwegura station

year	JAN	FEV	MAR	AVR	MAI	JUIN	JUIL	AOUT	SEPT	OCT	NOV	DEC	An.
1969	11.5	12.0	12.3	12.4	12.3	11.1	10.8	11.5	12.4	11.7	11.7	11.8	**11.8**
1970	11.6	12.4	12.0	12.2	11.7	11.2	11.0	11.8	11.6	10.0	11.5	10.9	**11.5**
1971	10.8	11.0	11.5	11.2	11.4	10.4	10.8	11.0	11.5	11.8	11.3	11.0	**11.1**
1972	11.2	11.2	11.6	11.8	11.7	11.3	12.9	11.5	11.9	12.0	11.7	12.0	**11.7**
1973	12.1	12.6	12.4	12.2	11.9	11.2	10.9	11.7	11.7	12.2	11.5	11.0	**11.8**
1974	10.8	11.8	11.9	11.5	11.6	11.4	10.6	10.6	10.6	11.0	10.9	10.8	**11.1**
1975	10.9	10.9	10.6	10.1	10.9	10.5	10.0	10.1	10.0	11.2	11.3	11.0	**10.6**
1976	11.2	10.9	11.4	11.3	11.8	10.7	10.5	11.3	11.1	12.0	11.5	11.4	**11.2**
1977	11.5	11.8	11.9	11.9	11.6	11.0	10.6	11.0	12.0	12.6	11.4	11.7	**11.6**
1978	11.9	12.1	11.7	11.9	11.3	10.9	10.1	11.5	11.7	11.7	11.1	11.4	**11.4**
1979	11.5	11.2	11.6	11.4	11.2	10.5	-	11.9	12.0	12.2	11.3	10.9	**11.4**
1980	11.4	11.5	11.2	11.7	11.7	10.6	10.2	11.0	11.9	11.6	11.4	11.0	**11.3**
1981	11.4	11.1	11.2	11.1	10.5	9.8	9.9	10.5	10.3	11.3	10.4	10.8	**10.7**
1982	10.6	10.9	11.1	10.4	9.8	10.5	-	-	11.3	10.2	11.1	11.6	**10.8**
1983	11.7	12.3	12.3	11.9	12.3	11.5	11.2	11.3	11.4	11.6	12.2	11.1	**11.7**
1984	11.4	11.4	12.0	12.0	11.8	10.6	10.8	11.4	11.4	11.8	11.2	11.6	**11.4**
1985	11.7	11.5	11.9	11.7	11.5	11.0	10.1	11.1	11.6	12.1	11.6	11.4	**11.4**
1986	11.7	11.6	11.3	12.0	11.7	10.0	10.1	11.6	11.5	11.4	11.8	11.9	**11.4**
1987	12.1	12.3	12.4	12.7	14.5	11.6	11.6	12.1	12.4	12.5	12.1	12.3	**12.4**
1988	12.1	12.4	12.3	12.6	12.3	11.1	11.4	11.8	11.9	12.2	11.7	11.3	**11.9**
1989	11.7	11.5	11.4	11.9	11.6	10.3	10.2	11.2	11.6	11.8	11.9	11.7	**11.4**
1990	11.6	12.0	12.0	12.5	11.9	11.1	10.2	11.5	11.7	11.8	11.9	11.6	**11.6**
1991	11.9	11.9	12.2	12.1	12.5	11.7	10.7	11.7	12.0	11.1	11.7	11.9	**11.8**
1992	12.2	11.9	12.4	12.5	12.2	11.6	10.3	10.9	11.9	11.9	11.5	11.5	**11.7**
1993	11.8	11.7	11.3	12.2	12.0	11.4	10.6	11.4	12.6	12.8	12.4	12.4	**11.9**
1994	12.0	11.8	11.6	12.2	12.3	-	-	-	12.5	12.0	11.9	12.0	**12.0**
1995	11.8	12.0	12.0	12.3	12.1	11.9	10.9	11.8	12.2	11.6	12.2	11.6	**11.9**
1996	11.5	11.6	11.8	12.1	12.0	10.8	10.7	10.9	11.7	11.9	11.9	11.8	**11.6**
1997	12.0	12.0	12.3	11.9	11.6	11.2	10.9	11.8	12.8	12.4	12.4	12.0	**11.5**
1998	13.0	13.2	13.2	13.6	13.0	11.4	11.4	11.9	12.4	12.6	12.6	12.2	**11.5**
1999	12.2	12.3	11.8	12.1	11.7	10.8	10.4	11.5	12.0	12.1	11.9	11.8	**11.5**
2000	12.1	11.7	11.8	12.2	12.4	11.7	11.1	11.8	12.2	12.0	12.0	12.0	**11.5**
2001	11.8	12.2	11.9	12.7	12.4	11.1	11.1	11.7	12	12.3	12.3	12.3	**11.5**
2002	12.1	12.3	12.4	12.7	14.5	11.6	11.6	12.1	12.4	12.5	12.1	12.3	**12.4**
2003	12.1	12.4	12.3	12.6	12.3	11.1	11.4	11.8	11.9	12.2	11.7	11.3	**11.9**
2004	11.7	11.5	11.4	11.9	11.6	10.3	10.2	11.2	11.6	11.8	11.9	11.7	**11.4**
2005	11.6	12.0	12.0	12.5	11.9	11.1	10.2	11.5	11.7	11.8	11.9	11.6	**11.6**
2006	11.9	11.9	12.2	12.1	12.5	11.7	10.7	11.7	12.0	11.1	11.7	11.9	**11.8**
Av.	**11.7**	**11.8**	**11.9**	**12.0**	**11.9**	**11.0**	**10.7**	**11.4**	**11.8**	**11.8**	**11.7**	**11.6**	**11.5**

3. Mean monthly temperatures at Rwegura station

year	J	F	M	A	M	J	J	A	S	O	N	D	AN.
1969	15.8	15.7	16.1	16.2	15.6	15.3	15.3	16.5	16.9	16.4	15.5	16.2	**16.0**
1970	15.6	16.5	16.0	15.7	15.1	15.3	15.3	15.9	16.5	15.6	16.0	15.2	**15.7**
1971	15.5	15.5	15.8	15.0	14.8	14.5	14.3	15.5	15.7	15.9	15.3	14.9	**15.2**
1972	15.6	15.3	15.8	15.4	14.9	14.9	16.1	15.8	16.3	16.2	15.6	16.3	**15.7**
1973	16.8	17.3	16.5	15.6	15.4	15.3	15.4	16.2	16.2	16.2	15.6	15.2	**16.0**
1974	15.5	16.1	15.9	15.4	15.1	14.9	13.9	15.5	15.5	15.8	15.5	15.3	**15.4**
1975	15.4	15.5	15.0	14.7	14.9	14.6	14.4	14.9	14.3	15.1	15.6	15.3	**15.0**
1976	15.8	15.1	16.0	15.5	15.2	14.7	14.8	15.3	15.6	16.5	15.8	15.8	**15.5**
1977	15.7	16.1	15.9	15.5	15.4	15.1	15.1	15.5	16.3	16.9	15.4	16.0	**15.7**
1978	16.3	16.3	15.7	15.6	15.1	14.9	14.8	16.0	16.5	16.1	15.3	15.5	**15.7**
1979	15.8	15.9	16.5	15.5	15.1	14.7	15.8	16.7	17.3	17.0	15.8	15.6	**16.0**
1980	16.3	16.4	15.9	16.1	15.4	15.3	15.1	15.8	16.5	16.3	15.6	15.6	**15.9**
1981	16.1	15.9	15.6	15.5	14.9	14.8	14.9	15.4	15.4	15.9	15.6	15.8	**15.5**
1982	15.7	15.8	15.9	15.0	14.3	14.9	15.3	15.8	16.1	14.6	15.5	16.1	**15.4**
1983	16.7	17.1	16.9	15.8	16.2	16.0	15.6	15.8	16.4	17.0	16.6	15.6	**16.3**
1984	15.3	16.1	16.5	15.9	15.9	15.1	14.9	16.0	16.6	16.1	15.1	16.0	**15.8**
1985	16.1	15.5	17.3	15.5	15.2	14.9	14.9	15.7	15.8	16.3	16.0	15.8	**15.7**
1986	16.2	16.4	15.9	15.7	15.5	14.8	15.0	17.0	16.5	16.6	16.0	16.1	**16.0**
1987	16.5	17.5	17.1	17.0	17.2	15.7	16.4	16.6	17.0	17.0	16.0	17.1	**16.8**
1988	16.1	16.9	16.4	16.3	15.9	15.3	15.4	15.7	16.0	16.1	15.8	15.2	**15.9**
1989	15.5	15.6	15.7	15.4	15.0	14.3	14.5	15.6	15.9	15.8	16.2	15.8	**15.5**
1990	16.2	16.3	16.2	16.7	16.2	15.9	15.4	16.3	11.4	16.4	16.1	15.8	**15.8**
1991	16.5	16.9	16.9	16.3	15.9	16.0	14.7	16.4	16.8	15.4	15.8	15.9	**16.1**
1992	16.5	16.2	16.6	16.4	15.8	15.5	15.0	16.2	16.9	16.4	15.8	15.6	**16.1**
1993	15.9	16.1	15.8	16.3	16.0	15.4	15.5	16.2	18.0	18.2	17.4	18.2	**16.6**
1994	16.4	16.3	16.2	16.4	15.8	15.3	15.4	16.2	17.6	16.2	15.9	16.3	**16.2**
1995	16.4	16.5	16.5	16.2	15.8	16.1	15.7	17.1	17.4	16.4	16.6	16.4	**16.4**
1996	16.1	16.3	16.3	16.2	16.0	14.8	15.3	16.1	16.6	16.6	16.1	16.3	**16.1**
1997	16.3	16.5	16.7	15.8	15.7	15.7	15.6	17.2	18.6	17.0	16.2	16.0	**16.4**
1998	17.1	17.5	17.7	17.3	16.8	16.1	16.4	16.7	17.6	16.7	17.0	16.7	**16.9**
1999	16.2	17.2	16.1	15.9	15.8	15.5	15.4	15.5	16.4	16.5	15.8	16.0	**16.0**
2000	16.6	17.7	15.9	16.3	16.7	15.8	15.9	16.9	17.9	16.8	16.2	16.3	**16.6**
2001	15.6	16.6	16.1	16.6	15.9	15.4	15.3	16.6	16.9	16.6	16.4	16.6	**16.2**
2003	16.4	16.3	16.2	16.4	15.8	15.3	15.7	16.0	16.8	16.2	15.9	16.2	**16.1**
2004	16.5	16.4	16.5	16.1	15.8	16.1	15.7	17.1	17.4	16.3	16.6	16.4	**16.4**
2005	16.1	16.3	16.8	16.5	16.7	15.8	15.7	16.3	16.7	17.1	16.8	16.5	**16.4**
2006	15.9	16.1	15.8	16.3	16.0	15.4	15.5	16.2	18.0	18.2	17.4	18.1	**17.0**
mean	**16.1**	**16.3**	**16.2**	**15.9**	**15.6**	**15.3**	**15.3**	**16.1**	**16.5**	**16.4**	**16.0**	**16.0**	**16.0**

Appendix G: Relative humidity at Rwegura station (%)

1. Maximum relative humidity

year	J	F	M	A	M	J	J	A	S	O	N	D	an.me
199	95	97	9	99	96	93	87	78	71	9	98	98	**91.6**
199	98	96	9	98	98	93	91	83	89	9	91	89	**92.8**
199	91	85	9	98	94	88	82	89	88	8	97	95	**90.8**
200	94	94	9	93	87	79	75	74	76	8	94	96	**86.8**
200	94	94	9	93	92	86	84	79	87	9	93	93	**89.9**
mea	**94.**	**93.**	**9**	**96.**	**93.**	**87.**	**83.**	**80.**	**82.**	**8**	**94.**	**94.**	**90.4**

2. Minimum relative humidity

year	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**An.**
1997	66	64	71	76	72	65	57	46	4	6	7	7	**64.7**
1998	74	71	72	77	76	64	63	55	5	6	6	6	**66.9**
1999	69	60	72	75	72	63	57	65	6	6	7	7	**66.9**
2000	67	69	74	72	65	62	54	49	4	6	7	7	**63.3**
2001	73	69	74	73	77	68	67	56	6	6	7	6	**68.7**
mea	**69.**	**66.**	**72.**	**74.**	**72.**	**64.**	**59.**	**54.**	**5**	**6**	**7**	**7**	**66.1**

Appendix H: Mean monthly wind speed at Rwegura station (m/s)

year	Jan	Fe	Marc	Apri	Ma	Jun	Jul	Au	Sep	Oct	No	De
1982	0.8	1.1	1.2	1.1	1.1	1.5						
1983	0.9	0.9	0.9	1	1.2	1.1						
1984	1.3	1.3	1.3	1.5	1.7	1.7						
1985	0.9	1.2	1.2	1.1	1.9	1.9						
1986	1.2			1.1								
1987	0.6	0.7	0.5	0.8	0.9	0.7						
1988			0.2		0.9	0.9						
1989	0.2	0.3	1.1									
1990	1.4	1.3	0.4	1.5	1.5	1.7						
1991	0.4	0.3	0.4	1.2	1.7	1.5						
1992	0.4	0.2	0.5	0.3	1.3	1.4						
1993	0.6	0.4		1	0.6	0.5						
1994											1.2	
1995												
1996								0.3	0.2		0.2	0.2
1997					0.4							
1998	0.4	0.5										
1999		0.8	0.64	1								
2000	0.5	0.6	0.8			0.7						
2001												
2002	0.9	0.5	0.4	0.7	0.8	0.7						
2003	1.2	1.5	1.3	1.4	1.5	1.5	1.6	1.5	1.3	1.4	1.6	1.3
2004	1.5											
mea	**0.8**	**0.7**	**0.77**	**1.05**	**1.2**	**1.22**	**1.6**	**0.9**	**0.7**	**1.4**	**1.0**	**0.7**

Appendix I: Computed Evaporation using aerodynamic method (1999-2006)

		J	F	M	A	M	J	J	A	S	O	N	D	ann.
1999	Temp	16.2	17.2	16.1	15.9	15.8	15.5	15.4	15.5	16.4	16.5	15.8	16.0	
	es(mmHg)	13.8	14.7	13.7	13.5	13.4	13.2	13.1	13.2	13.9	14.0	13.5	13.6	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.3	11.8	11.5	11.6	11.1	10.0	9.4	8.9	9.4	10.8	11.1	11.2	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	37.0	43.5	32.5	31.9	38.9	53.8	70.9	66.1	65.7	58.4	36.8	35.4	571.0
2000	Temp	16.6	17.7	15.9	16.3	16.7	15.8	15.9	16.9	17.9	16.8	16.2	16.3	
	es(mmHg)	14.2	15.1	13.5	13.8	14.2	13.4	13.5	14.4	15.3	14.3	13.8	13.9	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.6	12.1	11.3	11.8	11.8	10.2	9.7	9.7	10.4	11.0	11.4	11.4	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	38.0	44.8	32.2	32.7	41.2	54.7	73.2	72.0	72.3	59.7	37.6	36.2	594.5
2001	Temp	15.6	16.6	16.1	16.6	15.9	15.4	15.3	16.6	16.9	16.6	16.4	16.6	
	es(mmHg)	13.3	14.1	13.7	14.2	13.5	13.1	13.0	14.1	14.4	14.2	14.0	14.1	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	10.9	11.3	11.5	12.1	11.2	9.9	9.3	9.5	9.8	10.9	11.6	11.6	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	35.6	41.8	32.6	33.4	39.3	53.3	70.4	70.7	68.1	59.0	38.2	36.8	579.1
2002	Temp	16.5	17.3	16.6	16.4	15.8	15.3	15.4	16.2	17.6	16.2	15.9	16.3	
	es(mmHg)	14.1	14.8	14.1	13.9	13.4	13.0	13.1	13.8	15.0	13.8	13.5	13.9	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.6	11.8	11.8	11.9	11.1	9.9	9.4	9.3	10.2	10.6	11.2	11.4	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	37.7	43.8	33.5	32.9	39.0	53.2	70.8	69.3	71.0	57.6	36.9	36.2	581.8
2003	Temp	16.4	16.3	16.2	16.4	15.8	15.3	15.7	16.0	16.8	16.2	15.9	16.2	
	es(mmHg)	14.0	13.9	13.8	14.0	13.5	13.0	13.4	13.6	14.3	13.8	13.5	13.8	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.5	11.1	11.6	11.9	11.2	9.9	9.6	9.2	9.7	10.6	11.2	11.3	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	37.5	41.1	32.8	33.0	39.0	53.2	72.2	68.2	67.6	57.5	37.0	36.0	575.1
2004	Temp	16.5	16.4	16.5	16.1	15.8	16.1	15.7	17.1	17.4	16.3	16.6	16.4	
	es(mmHg)	14.1	14.0	14.1	13.7	13.5	13.7	13.4	14.6	14.9	13.9	14.2	14.0	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.6	11.2	11.8	11.7	11.2	10.4	9.6	9.9	10.1	10.7	11.7	11.5	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	37.7	41.4	33.4	32.4	39.0	55.9	72.2	73.2	70.3	57.8	38.7	36.4	588.5

(Cnt)

		J	F	M	A	M	J	J	A	S	O	N	D	ann.
2005	Temp	16.1	16.3	16.8	16.5	16.7	15.8	15.7	16.3	16.7	17.1	16.8	16.5	
	es(mmHg)	13.7	13.9	14.3	14.1	14.2	13.5	13.4	13.9	14.2	14.6	14.3	14.1	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.3	11.1	12.0	12.0	11.8	10.2	9.6	9.4	9.6	11.2	11.9	11.6	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.5	0.5	0.6	0.5	0.5	
	EV(mm)	36.8	41.1	34.1	33.2	41.3	54.9	72.2	69.6	67.2	60.8	39.2	36.7	587.1
2006	Temp	15.9	16.1	15.8	16.3	16.0	15.4	15.5	16.2	18.0	18.2	17.4	18.1	
	es(mmHg)	13.5	13.7	13.5	13.9	13.6	13.1	13.2	13.8	15.5	15.7	14.9	15.6	
	RH	82.1	79.9	83.8	85.4	82.9	76.1	71.7	67.4	67.6	76.9	82.8	82.1	
	e	11.1	11.0	11.3	11.9	11.3	10.0	9.5	9.3	10.5	12.0	12.3	12.8	
	uz	0.8	0.8	0.8	1.1	1.2	1.2	1.6	0.9	0.8	1.4	1.0	0.8	
	u(km/h)	2.5	2.4	2.3	3.2	3.6	3.7	4.8	2.7	2.3	4.2	3.0	2.3	
	k	0.5	0.5	0.5	0.5	0.6	0.6	*0.6*	*0.5*	*0.5*	*0.6*	*0.5*	*0.5*	
	EV(mm)	36.3	40.6	32.0	32.8	39.5	53.5	71.3	69.1	73.0	65.2	40.7	40.6	594.5

Appendix J: Computed monthly flows

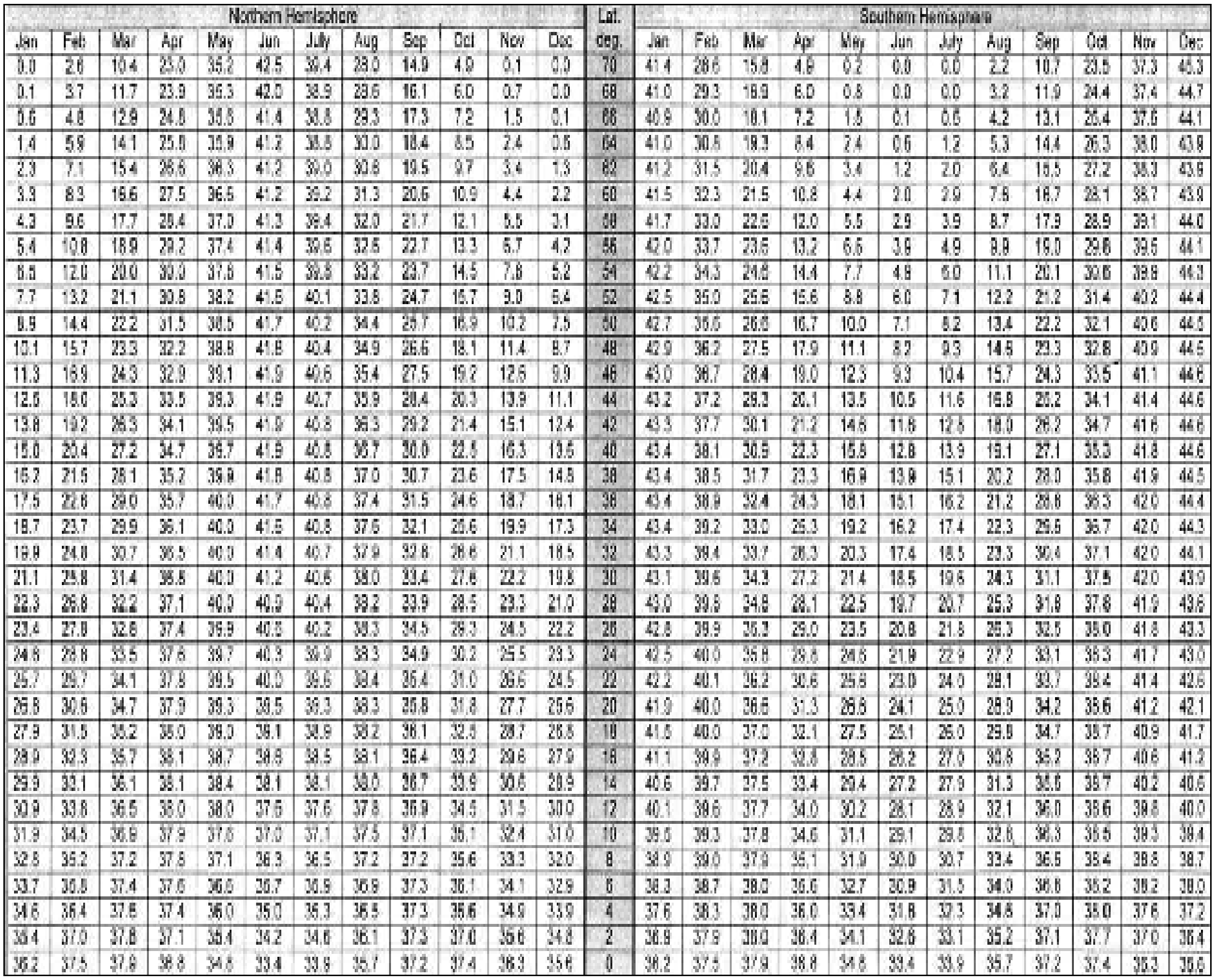
		J	F	M	A	M	J	J	A	S	O	N	D
1986	prec.mm	153.8	253.6	165.7	337.4	160.0	41.8	0.0	1.6	122.4	285.5	233.7	116.5
	Run.mm	53.2	88.0	56.5	134.4	54.9	30.2	24.5	24.7	45.4	103.4	79.6	44.1
	Q(m3/s)	**1.7**	**2.7**	**1.8**	**4.2**	**1.7**	**0.9**	**0.8**	**0.8**	**1.4**	**3.2**	**2.5**	**1.4**
1987	prec.mm	189.7	121.4	155.9	225.6	193.3	9.3	3.2	72.1	201.6	88.9	300.6	178.9
	Run.mm	63.8	45.2	53.8	76.4	64.9	25.7	24.9	35.2	67.7	38.4	111.6	60.4
	Q(m3/s)	**2.0**	**1.4**	**1.7**	**2.4**	**2.0**	**0.8**	**0.8**	**1.1**	**2.1**	**1.2**	**3.5**	**1.9**
1988	prec.mm	244.9	204.6	244.1	387.3	38.9	0.0	0.0	90.6	79.0	194.6	168.6	240.3
	Run.mm	84.3	68.8	83.9	172.8	29.8	24.5	24.5	38.7	36.5	65.4	57.3	82.3
	Q(m3/s)	**2.6**	**2.1**	**2.6**	**5.4**	**0.9**	**0.8**	**0.8**	**1.2**	**1.1**	**2.0**	**1.8**	**2.6**
1989	prec.mm	220.4	169.9	281.4	204.6	143.0	94.9	47.0	33.2	78.6	205.0	219.5	194.9
	Run.mm	74.5	57.7	101.3	68.8	50.4	39.5	31.0	29.0	36.4	68.9	74.1	65.5
	Q(m3/s)	**2.3**	**1.8**	**3.2**	**2.1**	**1.6**	**1.2**	**1.0**	**0.9**	**1.1**	**2.1**	**2.3**	**2.0**
1990	prec.mm	62.6	233.3	213.7	269.7	75.5	2.6	0.0	28.9	174.8	161.7	200.9	221.3
	Run.mm	33.6	79.5	72.0	95.5	35.8	24.8	24.5	28.3	59.2	55.4	67.5	74.8
	Q(m3/s)	**1.0**	**2.5**	**2.2**	**3.0**	**1.1**	**0.8**	**0.8**	**0.9**	**1.8**	**1.7**	**2.1**	**2.3**
1991	prec.mm	178.3	173.7	169.3	335.0	266.6	39.1	1.8	4.4	75.3	226.0	113.3	151.6
	Run.mm	60.2	58.8	57.5	132.8	94.0	29.8	24.7	25.0	35.8	76.6	43.4	52.6
	Q(m3/s)	**1.9**	**1.8**	**1.8**	**4.1**	**2.9**	**0.9**	**0.8**	**0.8**	**1.1**	**2.4**	**1.4**	**1.6**
1992	prec.mm	144.8	179.6	234.2	236.1	154.2	30.4	0.0	0.0	66.4	245.8	207.7	235.6
	Run.mm	50.8	60.6	79.8	80.6	53.3	28.6	24.5	24.5	34.2	84.6	69.8	80.4
	Q(m3/s)	**1.6**	**1.9**	**2.5**	**2.5**	**1.7**	**0.9**	**0.8**	**0.8**	**1.1**	**2.6**	**2.2**	**2.5**
1993	prec.mm	152.5	224.6	208.3	130.4	164.4	13.3	7.0	42.1	8.3	29.9	144.7	124.7
	Run.mm	52.9	76.1	70.1	47.3	56.1	26.2	25.4	30.3	25.5	28.5	50.8	45.9
	Q(m3/s)	**1.6**	**2.4**	**2.2**	**1.5**	**1.7**	**0.8**	**0.8**	**0.9**	**0.8**	**0.9**	**1.6**	**1.4**
1994	prec.mm	110.0	149.3	239.4	185.5	126.3	0.8	0.0	2.4	48.0	184.9	284.5	213.4
	Run.mm	42.7	52.0	82.0	62.4	46.3	24.6	24.5	24.8	31.2	62.3	102.9	71.9
	Q(m3/s)	**1.3**	**1.6**	**2.6**	**1.9**	**1.4**	**0.8**	**0.8**	**0.8**	**1.0**	**1.9**	**3.2**	**2.2**
1995	prec.mm	169.3	112.6	206.5	196.4	199.3	73.9	0.8	0.0	88.8	292.5	172.6	99.9
	Run.mm	57.5	43.2	69.4	66.0	66.9	35.6	24.6	24.5	38.3	107.1	58.5	40.5
	Q(m3/s)	**1.8**	**1.3**	**2.2**	**2.1**	**2.1**	**1.1**	**0.8**	**0.8**	**1.2**	**3.3**	**1.8**	**1.3**
1996	prec.mm	110.2	222.3	260.9	189.9	35.2	8.0	2.2	45.0	149.4	126.9	171.8	180.1
	Run.mm	42.7	75.2	91.3	63.8	29.3	25.5	24.8	30.7	52.0	46.5	58.3	60.8
	Q(m3/s)	**1.3**	**2.3**	**2.8**	**2.0**	**0.9**	**0.8**	**0.8**	**1.0**	**1.6**	**1.4**	**1.8**	**1.9**
1997	prec.mm	162.9	128.5	119.4	366.0	213.7	10.7	2.4	37.6	21.8	243.2	187.4	357.9
	Run.mm	55.7	46.8	44.7	155.2	72.0	25.8	24.8	29.6	27.3	83.5	63.0	149.0
	Q(m3/s)	**1.7**	**1.5**	**1.4**	**4.8**	**2.2**	**0.8**	**0.8**	**0.9**	**0.9**	**2.6**	**2.0**	**4.6**
1998	prec.mm	219.4	252.9	275.0	244.6	148.3	23.0	16.0	2.4	133.8	136.1	104.2	123.1
	Run.mm	74.1	87.7	98.1	84.1	51.8	27.5	26.5	24.8	48.1	48.7	41.4	45.6
	Q(m3/s)	**2.3**	**2.7**	**3.1**	**2.6**	**1.6**	**0.9**	**0.8**	**0.8**	**1.5**	**1.5**	**1.3**	**1.4**

		J	F	M	A	M	J	J	A	S	O	N	D
1999	prec.mm	*197.2*	*139.0*	*289.4*	*200.2*	*53.4*	*9.3*	*0.3*	*163.5*	*95.1*	*64.8*	*319.6*	*204.9*
	Run.mm	66.2	49.4	105.5	67.2	32.1	25.7	24.5	55.9	39.6	34.0	122.8	68.9
	Q(m3/s)	**2.1**	**1.5**	**3.3**	**2.1**	**1.0**	**0.8**	**0.8**	**1.7**	**1.2**	**1.1**	**3.8**	**2.1**
2000	prec.mm	*143.5*	*156.5*	*208.3*	*118.6*	*90.2*	*0.6*	*0.2*	*6.4*	*41.2*	*181.5*	*306.0*	*316.7*
	Run.mm	*50.5*	*53.9*	*70.1*	*44.6*	*38.6*	*24.6*	*24.5*	*25.3*	*30.1*	*61.2*	*114.7*	*121.0*
	Q(m3/s)	**1.6**	**1.7**	**2.2**	**1.4**	**1.2**	**0.8**	**0.8**	**0.8**	**0.9**	**1.9**	**3.6**	**3.8**
2001	prec.mm	*218.8*	*125.4*	*190.8*	*156.5*	*178.2*	*33.1*	*37.1*	*69.8*	*263.8*	*189.5*	*189.5*	*302.7*
	Run.mm	*73.9*	*46.1*	*64.1*	*53.9*	*60.2*	*28.9*	*29.5*	*34.8*	*92.7*	*63.7*	*63.7*	*112.8*
	Q(m3/s)	**2.3**	**1.4**	**2.0**	**1.7**	**1.9**	**0.9**	**0.9**	**1.1**	**2.9**	**2.0**	**2.0**	**3.5**
2002	prec.mm	*307.8*	*128.8*	*156.2*	*248.1*	*97.2*	*0.0*	*0.0*	*0.0*	*59.6*	*105.7*	*175.4*	*176.5*
	Run.mm	*115.7*	*46.9*	*53.9*	*85.6*	*40.0*	*24.5*	*24.5*	*24.5*	*33.1*	*41.7*	*59.3*	*59.7*
	Q(m3/s)	**3.6**	**1.5**	**1.7**	**2.7**	**1.2**	**0.8**	**0.8**	**0.8**	**1.0**	**1.3**	**1.8**	**1.9**
2003	prec.mm	*157.8*	*129.5*	*206.5*	*228.7*	*145.3*	*8.6*	*0.2*	*0.0*	*178.0*	*167.0*	*172.0*	*156.0*
	Run.mm	*54.3*	*47.1*	*69.4*	*77.6*	*51.0*	*25.6*	*24.5*	*24.5*	*60.1*	*56.9*	*58.3*	*53.8*
	Q(m3/s)	**1.7**	**1.5**	**2.2**	**2.4**	**1.6**	**0.8**	**0.8**	**0.8**	**1.9**	**1.8**	**1.8**	**1.7**
2004	prec.mm	*126.6*	*139.2*	*218.0*	*226.0*	*0.4*	*0.0*	*19.4*	*18.4*	*199.6*	*101.8*	*171.5*	*270.4*
	Run.mm	*46.4*	*49.4*	*73.6*	*76.6*	*24.5*	*24.5*	*27.0*	*26.9*	*67.0*	*40.9*	*58.2*	*95.8*
	Q(m3/s)	**1.4**	**1.5**	**2.3**	**2.4**	**0.8**	**0.8**	**0.8**	**0.8**	**2.1**	**1.3**	**1.8**	**3.0**
2005	prec.mm	*255.9*	*42.3*	*226.4*	*129.4*	*135.6*	*9.1*	*11.2*	*23.2*	*158.3*	*187.5*	*204.2*	*274.8*
	Run.mm	*89.1*	*30.3*	*76.8*	*47.0*	*48.5*	*25.6*	*25.9*	*27.5*	*54.4*	*63.1*	*68.6*	*98.0*
	Q(m3/s)	**2.8**	**0.9**	**2.4**	**1.5**	**1.5**	**0.8**	**0.8**	**0.9**	**1.7**	**2.0**	**2.1**	**3.1**
2006	prec.mm	*61.3*	*154.8*	*137.0*	*147.6*	*203.8*	*13.0*	*8.1*	*7.9*	*35.2*	*80.1*	*247.0*	*203.8*
	Run.mm	33.4	53.5	48.9	51.6	68.5	26.2	25.5	25.5	29.3	36.7	85.2	68.5
	Q(m3/s)	**1.0**	**1.7**	**1.5**	**1.6**	**2.1**	**0.8**	**0.8**	**0.8**	**0.9**	**1.1**	**2.7**	**2.1**
	Q.av(m3/s)	**2.06**	**1.47**	**2.19**	**1.96**	**1.41**	**0.80**	**0.80**	**0.95**	**1.58**	**1.55**	**2.46**	**2.64**

Appendix K: Recorded power at Rwegura power plant

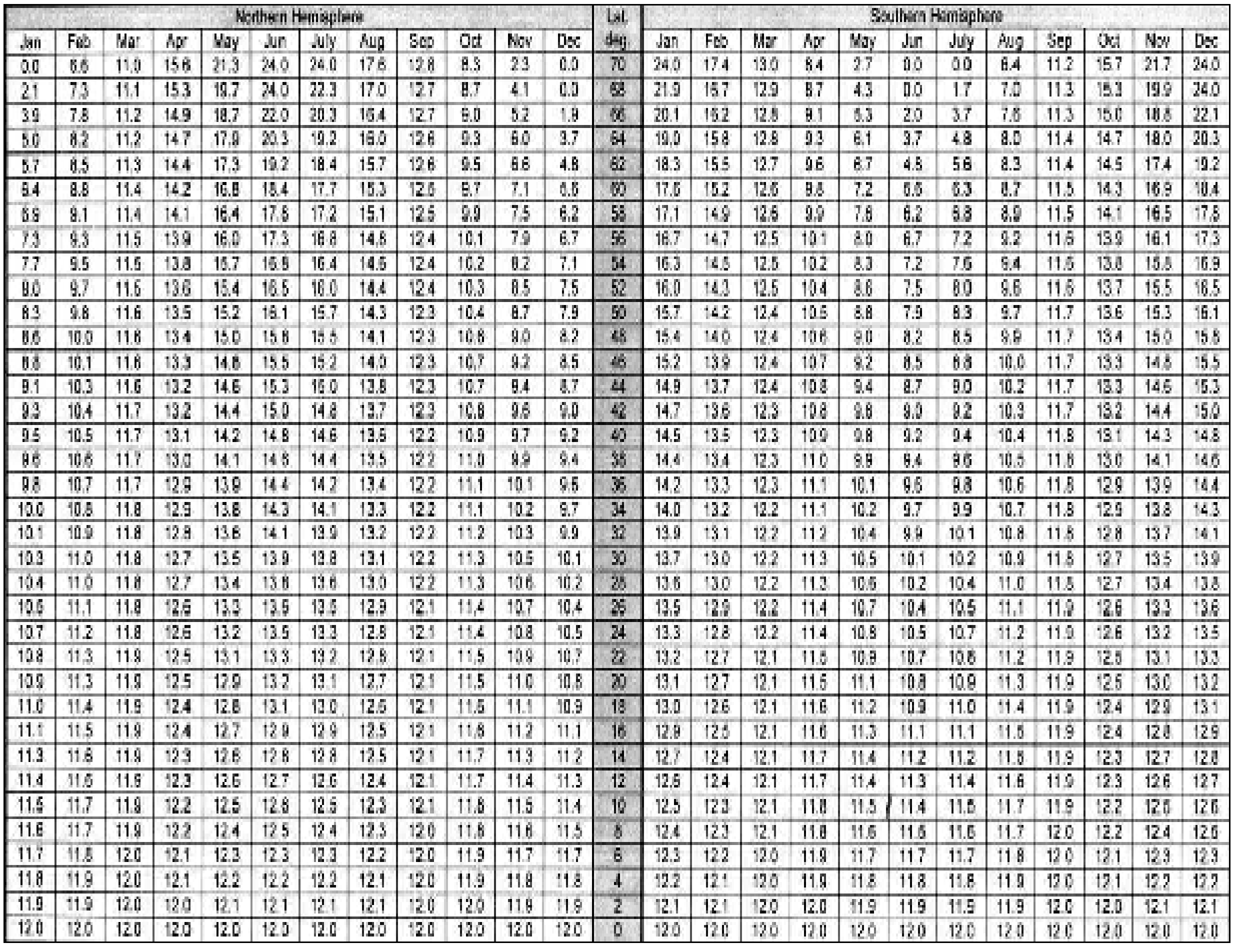
	JAN	FEB	MAR	APR	MAY	JUN	JULY	AUG	SEPT	OCT	NOV	DEC	An.
1986								2943.2	4135.6	4377.0	4292.2	3949.9	**19697.9**
1987	4039.3	4065.1	4414.3	4163.1	5024.4	5349.9	4176.9	5186.5	4460.0	4784.1	4015.5	4248.3	**53927.5**
1988	3674.6	4221.2	5098.8	4382.3	4441.7	4528.3	4908.3	4023.6	4952.6	4796.7	4833.8	5410.0	**55271.8**
1989	5151.0	5277.4	6243.3	5200.9	5401.0	3495.3	3073.0	3462.4	4884.8	5075.4	4826.6	4804.5	**56895.6**
1990	5100.7	5043.7	6035.2	4405.6	4766.7	4811.1	5011.3	5167.6	4640.3	3596.1	3578.8	4958.5	**57115.5**
1991	3806.0	3704.2	4635.3	5756.7	5414.5	5304.6	6194.3	7916.9	5642.6	4918.1	3911.5	3123.2	**60327.9**
1992	3286.5	2915.1	3275.1	3470.6	6844.8	5381.0	4727.8	5292.6	5587.8	5190.4	4482.0	4358.1	**54811.8**
1993	4719.8	4448.5	4715.3	4027.3	3804.4	4539.2	5283.0	5192.4	5853.3	4842.1	2967.3	3851.0	**54243.6**
1994	3025.4	5459.7	2394.3	2103.0	2289.1	2174.7	2310.1	2375.7	3278.0	3029.8	2975.5	3094.2	**34509.4**
1995	2923.8	3810.9	5241.4	3671.1	6561.4	4069.1	4811.4	5179.4	2619.2	5685.6	1405.6	4243.9	**50222.7**
1996	2068.8	6755.6	6634.5	6285.8	2809.9	5425.7	7529.5	3765.3	2189.5	5102.2	4274.9	3459.5	**56301.3**
1997	3665.2	2047.9	1091.9	4034.1	6001.6	6096.5	3620.9	3498.5	3484.6	3491.3	3326.7	3409.0	**43768.1**
1998	3117.2	3118.3	3756.3	3754.5	2773.8	3040.0	4959.6	5335.9	5137.3	5388.1	4744.4	5065.2	**50190.5**
1999	3062.5	3088.9	3526.0	3535.5	3113.1	3391.4	3698.4	4032.0	3689.6	3559.0	3167.9	3515.7	**41380.0**
2000	3509.7	3269.9	4692.6	4957.3	5260.0	4279.0	4574.2	4494.3	4801.6	3621.4	3500.0	3006.9	**49966.9**
2001	4030.9	4683.3	3781.6	5644.1	6877.4	5036.5	5691.7	5059.9	4692.8	4511.9	4190.7	4345.4	**58546.2**
2002	8451.9	6082.1	4101.6	7003.1	8123.4	5827.8	5691.7	5059.9	4692.8	4511.9	4190.7	4345.4	**68082.3**
2003	4328.9	3940.5	4431.1	3828.3	3166.2	3749.5	5185.8	4342.3	4239.7	4213.4	3842.6	3442.5	**48710.8**
2004	3713.6	3576.9	3589.3	3660.5	3920.1	3500.2	4269.1	4292.6	3689.9	3337.3	3128.7	3196.5	**43874.7**
2005	3198.3	4070.9	4266.0	4022.9	4252.9	4796.9	4750.1	4391.9	4128.7	4223.6	3971.6	3196.5	**49270.3**
2006	2456.0	2359.6	3059.4	2421.4	2453.3	2432.5	2997.5	3171.0	3520.0	3560.2	3471.9	3920.3	**35823.1**
Av.	**3866.5**	**4097.0**	**4249.2**	**4316.4**	**4665.0**	**4361.5**	**4673.2**	**4562.0**	**4309.3**	**4371.9**	**3740.3**	**3949.7**	**51162.0**

Appendix L: Coefficient Ra: Average daily extraterrestrial radiation in mm/day



Northern Hemisphere												Lat. deg.	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
0.0	2.6	10.4	23.0	35.2	42.5	39.4	28.0	14.9	4.9	0.1	0.0	70	41.4	28.6	15.8	4.9	0.2	0.0	0.0	2.2	10.7	23.5	37.3	45.3
0.1	3.7	11.7	23.9	35.3	42.0	38.9	28.6	16.1	6.0	0.7	0.0	68	41.0	29.3	16.9	6.0	0.8	0.0	0.0	3.2	11.9	24.4	37.4	44.7
0.6	4.8	12.9	24.8	35.6	41.4	38.8	29.3	17.3	7.2	1.5	0.1	66	40.9	30.0	18.1	7.2	1.5	0.1	0.5	4.2	13.1	25.4	37.6	44.1
1.4	5.9	14.1	25.8	35.9	41.2	38.8	30.0	18.4	8.5	2.4	0.6	64	41.0	30.8	19.3	8.4	2.4	0.6	1.2	5.3	14.4	26.3	38.0	43.9
2.3	7.1	15.4	26.6	36.3	41.2	39.0	30.6	19.5	9.7	3.4	1.3	62	41.2	31.5	20.4	9.6	3.4	1.2	2.0	6.4	15.5	27.2	38.3	43.9
3.3	8.3	16.6	27.5	36.6	41.2	39.2	31.3	20.6	10.9	4.4	2.2	60	41.5	32.3	21.5	10.8	4.4	2.0	2.9	7.6	16.7	28.1	38.7	43.9
4.3	9.6	17.7	28.4	37.0	41.3	39.4	32.0	21.7	12.1	5.5	3.1	58	41.7	33.0	22.6	12.0	5.5	2.9	3.9	8.7	17.9	28.9	39.1	44.0
5.4	10.8	18.9	29.2	37.4	41.4	39.6	32.6	22.7	13.3	6.7	4.2	56	42.0	33.7	23.6	13.2	6.6	3.9	4.9	9.9	19.0	29.8	39.5	44.1
6.5	12.0	20.0	30.0	37.8	41.5	39.8	33.2	23.7	14.5	7.8	5.2	54	42.2	34.3	24.6	14.4	7.7	4.9	6.0	11.1	20.1	30.6	39.8	44.3
7.7	13.2	21.1	30.8	38.2	41.6	40.1	33.8	24.7	15.7	9.0	6.4	52	42.5	35.0	25.6	15.6	8.8	6.0	7.1	12.2	21.2	31.4	40.2	44.4
8.9	14.4	22.2	31.5	38.5	41.7	40.2	34.4	25.7	16.9	10.2	7.5	50	42.7	35.6	26.6	16.7	10.0	7.1	8.2	13.4	22.2	32.1	40.6	44.5
10.1	15.7	23.3	32.2	38.8	41.8	40.4	34.9	26.6	18.1	11.4	8.7	48	42.9	36.2	27.5	17.9	11.1	8.2	9.3	14.6	23.3	32.8	40.9	44.6
11.3	16.9	24.3	32.9	39.1	41.9	40.6	35.4	27.5	19.2	12.6	9.9	46	43.0	36.7	28.4	19.0	12.3	9.3	10.4	15.7	24.3	33.5	41.1	44.6
12.5	18.0	25.3	33.5	39.3	41.9	40.7	35.9	28.4	20.3	13.9	11.1	44	43.2	37.2	29.3	20.1	13.5	10.5	11.6	16.8	25.2	34.1	41.4	44.6
13.8	19.2	26.3	34.1	39.5	41.9	40.8	36.3	29.2	21.4	15.1	12.4	42	43.3	37.7	30.1	21.2	14.6	11.6	12.8	18.0	26.2	34.7	41.6	44.6
15.0	20.4	27.2	34.7	39.7	41.9	40.8	36.7	30.0	22.5	16.3	13.6	40	43.4	38.1	30.9	22.3	15.8	12.8	13.9	19.1	27.1	35.3	41.8	44.6
16.2	21.5	28.1	35.2	39.9	41.8	40.8	37.0	30.7	23.6	17.5	14.8	38	43.4	38.5	31.7	23.3	16.9	13.9	15.1	20.2	28.0	35.8	41.9	44.5
17.5	22.6	29.0	35.7	40.0	41.7	40.8	37.4	31.5	24.6	18.7	16.1	36	43.4	38.9	32.4	24.3	18.1	15.1	16.2	21.2	28.8	36.3	42.0	44.4
18.7	23.7	29.9	36.1	40.0	41.6	40.8	37.6	32.1	25.6	19.9	17.3	34	43.4	39.2	33.0	25.3	19.2	16.2	17.4	22.3	29.6	36.7	42.0	44.3
19.9	24.8	30.7	36.5	40.0	41.4	40.7	37.9	32.8	26.6	21.1	18.5	32	43.3	39.4	33.7	26.3	20.3	17.4	18.5	23.3	30.4	37.1	42.0	44.1
21.1	25.8	31.4	36.8	40.0	41.2	40.6	38.0	33.4	27.6	22.2	19.8	30	43.1	39.6	34.3	27.2	21.4	18.5	19.6	24.3	31.1	37.5	42.0	43.9
22.3	26.8	32.2	37.1	40.0	40.9	40.4	38.2	33.9	28.5	23.3	21.0	28	43.0	39.8	34.8	28.1	22.5	19.7	20.7	25.3	31.8	37.8	41.9	43.6
23.4	27.8	32.8	37.4	39.9	40.6	40.2	38.3	34.5	29.3	24.5	22.2	26	42.8	39.9	35.3	29.0	23.5	20.8	21.8	26.3	32.5	38.0	41.8	43.3
24.6	28.8	33.5	37.6	39.7	40.3	39.9	38.3	34.9	30.2	25.5	23.3	24	42.5	40.0	35.8	29.8	24.6	21.9	22.9	27.2	33.1	38.3	41.7	43.0
25.7	29.7	34.1	37.8	39.5	40.0	39.6	38.4	35.4	31.0	26.6	24.5	22	42.2	40.1	36.2	30.6	25.6	23.0	24.0	28.1	33.7	38.4	41.4	42.6
26.8	30.6	34.7	37.9	39.3	39.5	39.3	38.3	35.8	31.8	27.7	25.6	20	41.9	40.0	36.6	31.3	26.6	24.1	25.0	28.9	34.2	38.6	41.2	42.1
27.9	31.5	35.2	38.0	39.0	39.1	38.9	38.2	36.1	32.5	28.7	26.6	18	41.5	40.0	37.0	32.1	27.5	25.1	26.0	29.8	34.7	38.7	40.9	41.7
28.9	32.3	35.7	38.1	38.7	38.6	38.5	38.1	36.4	33.2	29.6	27.9	16	41.1	39.9	37.2	32.8	28.5	26.2	27.0	30.6	35.2	38.7	40.6	41.2
29.9	33.1	36.1	38.1	38.4	38.1	38.1	38.0	36.7	33.9	30.6	28.9	14	40.6	39.7	37.5	33.4	29.4	27.2	27.9	31.3	35.6	38.7	40.2	40.6
30.9	33.8	36.5	38.0	38.0	37.6	37.6	37.8	36.9	34.5	31.5	30.0	12	40.1	39.6	37.7	34.0	30.2	28.1	28.9	32.1	36.0	38.6	39.8	40.0
31.9	34.5	36.9	37.9	37.6	37.0	37.1	37.5	37.1	35.1	32.4	31.0	10	39.5	39.3	37.8	34.6	31.1	29.1	29.8	32.8	36.3	38.5	39.3	39.4
32.8	35.2	37.2	37.8	37.1	36.3	36.5	37.2	37.2	35.6	33.3	32.0	8	38.9	39.0	37.9	35.1	31.9	30.0	30.7	33.4	36.6	38.4	38.8	38.7
33.7	35.8	37.4	37.6	36.6	35.7	35.9	36.9	37.3	36.1	34.1	32.9	6	38.3	38.7	38.0	35.6	32.7	30.9	31.5	34.0	36.8	38.2	38.2	38.0
34.6	36.4	37.6	37.4	36.0	35.0	35.3	36.5	37.3	36.6	34.9	33.9	4	37.6	38.3	38.0	36.0	33.4	31.8	32.3	34.6	37.0	38.0	37.6	37.2
35.4	37.0	37.8	37.1	35.4	34.2	34.6	36.1	37.3	37.0	35.6	34.8	2	36.9	37.9	38.0	36.4	34.1	32.6	33.1	35.2	37.1	37.7	37.0	36.4
36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6	0	36.2	37.5	37.9	36.8	34.8	33.4	33.9	35.7	37.2	37.4	36.3	35.6

Appendix M: Daily maximum sunshine hours (coefficient N)



Northern Hemisphere												Lat. deg.	Southern Hemisphere											
Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
0.0	6.6	11.0	15.6	21.3	24.0	24.0	17.6	12.8	8.3	2.3	0.0	70	24.0	17.4	13.0	8.4	2.7	0.0	0.0	6.4	11.2	15.7	21.7	24.0
2.1	7.3	11.1	15.3	19.7	24.0	22.3	17.0	12.7	8.7	4.1	0.0	68	21.9	16.7	12.9	8.7	4.3	0.0	1.7	7.0	11.3	15.3	19.9	24.0
3.9	7.8	11.2	14.9	18.7	22.0	20.3	16.4	12.7	9.0	5.2	1.9	66	20.1	16.2	12.8	9.1	5.3	2.0	3.7	7.6	11.3	15.0	18.8	22.1
5.0	8.2	11.2	14.7	17.9	20.3	19.2	16.0	12.6	9.3	6.0	3.7	64	19.0	15.8	12.8	9.3	6.1	3.7	4.8	8.0	11.4	14.7	18.0	20.3
5.7	8.5	11.3	14.4	17.3	19.2	18.4	15.7	12.6	9.5	6.6	4.8	62	18.3	15.5	12.7	9.6	6.7	4.8	5.6	8.3	11.4	14.5	17.4	19.2
6.4	8.8	11.4	14.2	16.8	18.4	17.7	15.3	12.6	9.7	7.1	5.6	60	17.6	15.2	12.6	9.8	7.2	5.6	6.3	8.7	11.5	14.3	16.9	18.4
6.9	9.1	11.4	14.1	16.4	17.8	17.2	15.1	12.5	9.9	7.5	6.2	58	17.1	14.9	12.6	9.9	7.6	6.2	6.8	8.9	11.5	14.1	16.5	17.8
7.3	9.3	11.5	13.9	16.0	17.3	16.8	14.8	12.4	10.1	7.9	6.7	56	16.7	14.7	12.5	10.1	8.0	6.7	7.2	9.2	11.6	13.9	16.1	17.3
7.7	9.5	11.5	13.8	15.7	16.9	16.4	14.6	12.4	10.2	8.2	7.1	54	16.3	14.5	12.5	10.2	8.3	7.2	7.6	9.4	11.6	13.8	15.8	16.9
8.0	9.7	11.5	13.6	15.4	16.5	16.0	14.4	12.4	10.3	8.5	7.5	52	16.0	14.3	12.5	10.4	8.6	7.5	8.0	9.6	11.6	13.7	15.5	16.5
8.3	9.8	11.6	13.5	15.2	16.1	15.7	14.3	12.3	10.4	8.7	7.9	50	15.7	14.2	12.4	10.5	8.8	7.9	8.3	9.7	11.7	13.6	15.3	16.1
8.6	10.0	11.6	13.4	15.0	15.8	15.5	14.1	12.3	10.6	9.0	8.2	48	15.4	14.0	12.4	10.6	9.0	8.2	8.5	9.9	11.7	13.4	15.0	15.8
8.8	10.1	11.6	13.3	14.8	15.5	15.2	14.0	12.3	10.7	9.2	8.5	46	15.2	13.9	12.4	10.7	9.2	8.5	8.8	10.0	11.7	13.3	14.8	15.5
9.1	10.3	11.6	13.2	14.6	15.3	15.0	13.8	12.3	10.7	9.4	8.7	44	14.9	13.7	12.4	10.8	9.4	8.7	9.0	10.2	11.7	13.3	14.6	15.3
9.3	10.4	11.7	13.2	14.4	15.0	14.8	13.7	12.3	10.8	9.6	9.0	42	14.7	13.6	12.3	10.8	9.6	9.0	9.2	10.3	11.7	13.2	14.4	15.0
9.5	10.5	11.7	13.1	14.2	14.8	14.6	13.5	12.2	10.9	9.7	9.2	40	14.5	13.5	12.3	10.9	9.8	9.2	9.4	10.4	11.8	13.1	14.3	14.8
9.6	10.6	11.7	13.0	14.1	14.6	14.4	13.5	12.2	11.0	9.9	9.4	38	14.4	13.4	12.3	11.0	9.9	9.4	9.6	10.5	11.8	13.0	14.1	14.6
9.8	10.7	11.7	12.9	13.9	14.4	14.2	13.4	12.2	11.1	10.1	9.6	36	14.2	13.3	12.3	11.1	10.1	9.6	9.8	10.6	11.8	12.9	13.9	14.4
10.0	10.8	11.8	12.9	13.8	14.3	14.1	13.3	12.2	11.1	10.2	9.7	34	14.0	13.2	12.2	11.1	10.2	9.7	9.9	10.7	11.8	12.9	13.8	14.3
10.1	10.9	11.8	12.8	13.6	14.1	13.9	13.2	12.2	11.2	10.3	9.9	32	13.9	13.1	12.2	11.2	10.4	9.9	10.1	10.8	11.8	12.8	13.7	14.1
10.3	11.0	11.8	12.7	13.5	13.9	13.8	13.1	12.2	11.3	10.5	10.1	30	13.7	13.0	12.2	11.3	10.5	10.1	10.2	10.9	11.8	12.7	13.5	13.9
10.4	11.0	11.8	12.7	13.4	13.8	13.6	13.0	12.2	11.3	10.6	10.2	28	13.6	13.0	12.2	11.3	10.6	10.2	10.4	11.0	11.8	12.7	13.4	13.8
10.6	11.1	11.8	12.6	13.3	13.6	13.5	12.9	12.1	11.4	10.7	10.4	26	13.5	12.9	12.2	11.4	10.7	10.4	10.5	11.1	11.9	12.6	13.3	13.6
10.7	11.2	11.8	12.6	13.2	13.5	13.3	12.8	12.1	11.4	10.8	10.5	24	13.3	12.8	12.2	11.4	10.8	10.5	10.7	11.2	11.9	12.6	13.2	13.5
10.8	11.3	11.9	12.5	13.1	13.3	13.2	12.8	12.1	11.5	10.9	10.7	22	13.2	12.7	12.1	11.5	10.9	10.7	10.8	11.2	11.9	12.5	13.1	13.3
10.9	11.3	11.9	12.5	12.9	13.2	13.1	12.7	12.1	11.5	11.0	10.8	20	13.1	12.7	12.1	11.5	11.1	10.8	10.9	11.3	11.9	12.5	13.0	13.2
11.0	11.4	11.9	12.4	12.8	13.1	13.0	12.6	12.1	11.6	11.1	10.9	18	13.0	12.6	12.1	11.6	11.2	10.9	11.0	11.4	11.9	12.4	12.9	13.1
11.1	11.5	11.9	12.4	12.7	12.9	12.9	12.5	12.1	11.6	11.2	11.1	16	12.9	12.5	12.1	11.6	11.3	11.1	11.1	11.5	11.9	12.4	12.8	12.9
11.3	11.6	11.9	12.3	12.6	12.8	12.8	12.5	12.1	11.7	11.3	11.2	14	12.7	12.4	12.1	11.7	11.4	11.2	11.2	11.5	11.9	12.3	12.7	12.8
11.4	11.6	11.9	12.3	12.6	12.7	12.6	12.4	12.1	11.7	11.4	11.3	12	12.6	12.4	12.1	11.7	11.4	11.3	11.4	11.6	11.9	12.3	12.6	12.7
11.5	11.7	11.9	12.2	12.5	12.6	12.5	12.3	12.1	11.8	11.5	11.4	10	12.5	12.3	12.1	11.8	11.5	11.4	11.5	11.7	11.9	12.2	12.6	12.6
11.6	11.7	11.9	12.2	12.4	12.5	12.4	12.3	12.0	11.8	11.6	11.5	8	12.4	12.3	12.1	11.8	11.6	11.5	11.6	11.7	12.0	12.2	12.4	12.5
11.7	11.8	12.0	12.1	12.3	12.3	12.3	12.2	12.0	11.9	11.7	11.7	6	12.3	12.2	12.0	11.9	11.7	11.7	11.7	11.8	12.0	12.1	12.3	12.3
11.8	11.9	12.0	12.1	12.2	12.2	12.2	12.1	12.0	11.9	11.8	11.8	4	12.2	12.1	12.0	11.9	11.8	11.8	11.8	11.9	12.0	12.1	12.2	12.7
11.9	11.9	12.0	12.0	12.1	12.1	12.1	12.1	12.0	12.0	11.9	11.9	2	12.1	12.1	12.0	12.0	11.9	11.9	11.9	11.9	12.0	12.0	12.1	12.1
12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0	12.0

Appendix N: Rwegura station sunshine hours

	JAN	FEB	MARC	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1991	171.4	178.2	191.1	129.8	97.3	214						134.2
1992	174.2	147.6	182.5	137.3	164.3	157.7	245.1	272	190.6	157.6	154.2	140.7
1993	147.2	135.2	178.8	151.2	167.2	184.3	303.9	215.5	242.6	161.1		
1994	125	136.1	183.8	135.5	146.1				182.9	157.4	131.6	
1995		152.8	178.2	132.6	140.9	191.1	210.4	146.5	143.3			
Mean	**154.5**	**150**	**182.9**	**137.3**	**143.2**	**186.8**	**253.1**	**211.3**	**189.9**	**158.7**	**142.9**	**137.5**
Daily mean n	**5.0**	**5.4**	**5.9**	**4.6**	**4.6**	**6.2**	**8.2**	**6.8**	**6.3**	**5.1**	**4.8**	**4.4**