PREFEASIBILITY STUDIES FOR MINI HYDRO POWER GENERATION ON KINTAMPO FALLS

By

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A thesis submitted to the Graduate School,

Kwame Nkrumah University of Science and Technology

In partial fulfillment of the requirement for the degree of

Master of Science Renewable Energy Technologies

Department of Mechanical Engineering

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June 2013

DECLARATION

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ACKNOWLEDGEMENT

To Jehovah God be the glory for the great things he has done and helping me to accomplish this task. My special thanks go to my supervisor Dr. Gabriel Takyi for the guidance, time and support he gave me throughout this study. I wish to acknowledge the help from Messer's Daniel Duah and Obed Sowah for helping me carry out measurements at the project site. I also thank the staff of Metrological Service Department (MSD), Sunyani for their immense help in getting information for this study. Last but not the least to my Parents, Siblings and Wife for investing in my education and giving me the support I cannot measure. I wish them all well.

DEDICATION

This study is dedicated to my wife Mrs. Rita Adu Boahen and my entire family for their support and inspiration throughout these years.

ABSTRACT

Energy demand is increasing worldwide amid rising fuel cost and environmental pollution. Small Hydro Power has emerged as alternative source of energy that can be easily harnessed with minimal environmental impact. Since 1980, several studies have been conducted in Ghana on potential sites for Small hydro power schemes. This thesis assesses the prospects of developing Randal Falls or Kintampo Falls into a mini hydropower scheme for power generation. Randal Falls has the potential for producing electricity by using hydro turbo – generator. Area rainfall method using rainfall and temperature data of the catchment area was used to estimate the flow rate and the available head measured using a GPS receiver. The results of the work reported here indicate that the proposed site has a gross head of 50.93 m and a designed flow of 0.32 m^3/s which is available 95% throughout the year. Crossflow turbine was selected as the preferred turbine with specific speed of 62, runner diameter of 380 mm and runner length of 140 mm. An 8 poles induction motor was selected as the generator with estimated size of 134 KVA and rotational speed of 750 rpm. The estimated power produced was 114 KW. RETScreen module was used to analyze the financial viability of the project. Annual energy production estimated from the module was 880 MWh and the anticipated revenue to be generated is $90,830.The initial cost of the project estimated by RETScreen was $395,000. From the module, the simple payback of the project was 4.9 years.

TABLE OF CONTENT

DECLARATION ii
ACKNOWLEDGEMENT iii
DEDICATION iv
ABSTRACT v
TABLE OF CONTENT vi
LIST OF TABLES ix
LIST OF FIGURES xi
ABBREVIATIONS AND SYMBOLS xii
CHAPTER ONE 1
INTRODUCTION 1
1.1 General Introduction 1
1.2 Background 2
1.3 Objectives 4
1.4 Methodology 4
CHAPTER TWO 6
LITERATURE REVIEW 6
2.1 Sustainable Development 6
2.2 Renewable Energy 6
2.3 Small Hydro Power 7
2.4 Hydropower and energy 9
2.5 Small hydro power component 11
2.5.1 Diversion Weir and Intake 12
2.5.2 Settling Basin 13
2.5.3 Headrace Canal 14
2.5.4 Forebay 15
2.5.5 Penstock 16
2.5.6 Tailrace 18
2.6 Turbines 18
2.6.1 Impulse turbines. 19
2.6.1.1 Pelton Turbine. 19
2.6.1.2 Turgo Turbine 21

2.6.1.3 Crossflow Turbine. 22
2.6.2 Reaction Turbines. 25
2.6.2.1 Francis Turbine. 25
2.6.2.2 Propeller. 26
2.6.2.3 Kaplan. 28
2.6.3 Turbine Efficiency. 29
2.7 Governors. 30
2.8 Generators. 31
2.9 Capacity Factor 32
2.10 Design Flow 32
CHAPTER THREE 33
METHODOLOGY 33
3.1 Reconnaissance Survey 33
3.2 Primary and Secondary data 33
3.3 Stream Flow Measurement 33
3.4 Stream Flow Estimation 37
3.4.1 Area –Rainfall Method 37
3.7 Measurement of Head 43
CHAPTER FOUR 44
RESULT AND DATA ANALYSIS 44
4.1 Flow-duration curve for catchment area 45
4.2 Compensational Flow 48
4.3 Power potential 48
4.3 Design of Civil structures 49
4.3.1 Height of flood barrier walls 49
4.3.2 Intake dimension 50
4.3.4 Headrace slope and width (normal flow condition) 52
4.3.5 De-silting Basin (normal flow condition) 53
4.3.7 Forebay Design 55
4.3.8 Penstock Design 57
4.4 Design of Mechanical equipments 59
4.4.1Determination of specific speed of turbine n (rpm) 59
4.4.2 Cross flow runner diameter 60

4.4.3 Cross flow runner length 60
4.5 Sizing of Electrical equipments 61
4.5.1 Speed and number of poles... 61
4.6 Economic Appraisal 64
4.6.1 Project Costing.. 65
4.6.2 Retscreen – Energy Model and Power Project General Entries 67
CHAPTER FIVE... 70
CONCLUSIONS AND RECOMMENDATIONS 70
5.1 Conclusions 70
5.2 Recommendations 72
REFERENCES... 73
APPENDICES 77
APPENDIX A. Monthly rainfall (mm) from year 1992 to 2012 77
APPENDIX B. Monthly average temperature (^oC) from year 1992 to 2012................ 78
APPENDIX C. Estimated monthly discharge (m^3/s) of Pumpum River from year 1992 to 2012 79
APPENDIX D. RETScreen Formula costing method Empirical formulas 85
APPENDIX E. Monthly rate of annual sunshine (Northern Hemisphere) (%) 87
APPENDIX F. Roughness Coefficients for Different Canals..................................... 88
APPENDIX G. RETScreen modeling of project 89

LIST OF TABLES

Table 2.1: Electricity generation by each renewable energy.................................... 8

Table 2.2: Installed SHP capacity by world region in 2004……………………......... 9

Table 2.3: Turbine classification…………………………………....................... 18

Table 2.4: Design flow in relation to capacity factor…………………................... 32

Table 3.1: Measuring stream flow using float method.. 36

Table 3.2: World water balance model………..…………………………………...40

Table 3.3: Calculation of possible evaporation and real evaporation....................... 42

Table 3.4: Calculation of mean stream discharge……………………….............. 43

Table 4.1: Monthly mean discharge of Pumpum river from 1992 to 2012............ 44

Table 4.2: Monthly mean discharge and percentage probability............................ 46

Table 4.3: Vertical velocities of particles……………………………………......... 53

Table 4.4: Summary of project technical specifications……………………......... 64

Table 4.5: Hydro formula costing method……………………………………........66

Table 4.6: Cost categorization of project…………………………………………...67

Table 4.7: Financial summary of project………………………….......................... 69

LIST OF FIGURES

Fig. 2.1: Available head for mini hydro power…... 10

Fig. 2.2: Components of mini hydro power scheme……………………............ 12

Fig. 2.3: Diversion Weir……………….. 13

Fig. 2.4: Trash Rack.. 13

Fig. 2.5: Settling Basin………………………………............................ 14

Fig. 2.6: Head Race Canal………………………………………........................... 15

Fig. 2.7: Forebay………………………….. 16

Fig. 2.8: Penstock……………………….. 17

Fig. 2.9: Impulse Turbine……………………………………………………..............19

Fig. 2.10: Pelton turbine nozzle……….. 20

Fig. 2.11: Pelton turbine bucket split into two halves... 20

Fig. 2.12: Two Pelton wheels place side by side……… 21

Fig. 2.13: Turgo turbine runner…………………………………........................ 22

Fig. 2.14: Crossflow turbine runner…………………….. 23

Fig. 2.15: Efficiency of Crossflow turbine at different loads…………………… 24

Fig. 2.16: Reaction Turbine…………………………….. 25

Fig. 2.17: Francis Turbine Assembly…………………………............................ 26

Fig. 2.18: Propeller Turbine…………………………... 27

Fig. 2.19: Propeller Turbine Assembly……………………................................. 28

Fig. 2.20: Kaplan Turbine Assembly……………………………………............... 29

Fig. 2.21: Kaplan Turbine components……………….. 29

Fig. 2.22: Turbine efficiency curve………………………………………............. 30

Fig. 3.1: Measuring stream flow using float method……...................................... 34

Fig. 3.2: Measuring Stream width….. 34

Fig. 3.3: Measuring Stream width.. 35

Fig. 3.4: Measuring Stream flow rate... 35

Fig. 3.5: Catchment area of an MHP…………………………………………....... 37

Fig. 3.6: Water balance of drainage area…………………………....................... 39

Fig. 3.7: Pattern figure of amount of rainfall and evaporation……………........... 39

Fig. 3.8: Pattern figure of runoff……………………………………….............. 40

Fig. 4.1: Monthly hydrograph of Pumpum river……………………….................. 45

Fig. 4.2: Flow duration curve for Pumpum river……………………................... 57

Fig. 4.3: Intake barrier wall………………………………………...................... 49

Fig. 4.4: Side Intake …………………………………………............................. 51

Fig. 4.5: Dimension of head canal... 52

Fig. 4.6: Schematic of sedimentation basin... 54

Fig. 4.7: Forebay dimension…….. 57

Fig. 4.8: Turbine Selection Chart…….. 59

Fig. 4.9: Layout of the main components on project site.. 63

Fig. 4.10: Cumulative cash flow graph……………….. 69

ABBREVIATIONS AND SYMBOLS

Abbreviations/Symbol	Description
BHA	British Hydropower Association
ESHA	European Small Hydropower Association
FDC	Flow Duration Curve
GHG	Green House Gas
GPS	Global Position System
GTOE	Giga Ton Oil Equivalent
HDPE	High Density Polythene
IEA	International Energy Agency
IHA	International Hydropower Association
KW	Kilowatt
KWh	Kilowatt –hour
KWh/yr	Kilowatt –hour per year
MDG	Millennium Development Goals
Q_{mean}	Mean Flow (m/s)
PVC	Poly Vinyl Chloride
RPM	Revolution per minute
SHP	Small Hydro Power

CHAPTER ONE

INTRODUCTION

1.1 General Introduction

The demand for energy is increasing day by day with the growing of industry and living standard of people. To overcome this demand, new sources of energy have to be exploited. Dependence on fossil fuels to generate electricity results in a high greenhouse gas emission which is leading to global warming with it associated consequence coupled with climate change.

The total amount of fossil fuel reserves in the world is around 785 GTOE. Coal that has been formed 300 million years ago accounts for 500 GTOE which represents 65 % of the fossil fuel reserves. Oil also formed hundreds of million years ago and account for 150 GTOE which represents 18 %. Gas which is another hydrocarbon like oil accounts for 135 GTOE and represent 17 % of the fossil fuel reserves. At the rate of the present fossil fuel consumption i.e. 10 GTOE per year, in less than 100 years there will be no oil, no coal, and no Gas left on the planet.

This may be the biggest energy challenge the world will have to face. Moreover, considering the fast economic growth of developing countries like China, India or Brazil the average consumption is assumed to be around 20 GTOE/year in 2015.

An effort has to be made to bring down this consumption level to 15 GTOE/year at least by 2015. Otherwise a catastrophe is to be feared.

Moreover, the cost of electricity is getting higher due to the high cost of fossil fuels. Fluctuation in pricing also makes planning and forecasting of energy cost very difficult.

Studies have indicated a strong correlation between energy consumption and economic growth. Access to modern energy services directly contributes to economic growth and poverty reduction through the creation of income generating activities. Contributions to poverty reduction may come from freeing up time for other productive activities.

The Millennium Development Goals (MDGs) are the international community's commitment to halving poverty in the world's poorest countries by the year 2015. Whilst some of these countries have seen tremendous success in poverty reduction over the past decade, others, especially in the Sub-Saharan African region, are lagging behind. Electricity is essential for the provision of basic social services, including education and health, and also for powering machines that support income generating activities which tends to reduce poverty. Harnessing hydropower to generate electricity has the potential for ensuring energy security which can be an effective way of reducing poverty in Africa.

Ghana has been plagued with inadequate energy supply for the past decades leading to two energy crisis within the last decade due to shortfall in water supply in the Volta basin which is a major source of power for this country. It is therefore imperative for governmental and private institutions to find other sustainable energy sources to argument the country's energy supply. The country has small hydro power (SHP) potential of about 795 MW which can be harnessed to increase energy supply and Kintampo falls is one of the potential locations for sitting a grid connected mini hydro plant.

1.2 Background

Energy demand is increasing worldwide. Rising fuel costs and concerns over atmospheric pollution have spurred interest in energy from renewable sources. Many forward thinking communities are taking a closer look at their renewable natural resources to determine which, if any, are suitable for development. Thanks to a variety of technological advancements, energy sources that were once discounted impractical are now finding their way into the mainstream.

In this respect, small hydro power has emerged as an energy source which is accepted as renewable, easily developed, inexpensive and harmless to the environment. These features have increased small hydropower development in value giving rise to a new trend in renewable energy generation. (Adigüzel et al., 2002) Moreover, because of the considerable amount of financial requirements and insufficient financial sources of the national budget, together with the strong opposition of environmentalist, civil organizations, large scale hydropower projects cannot be completed in the planned construction period generally, which leads to use of SHP in developing countries with its low investment cost, short construction period, and environmentally friendly nature.

Comprising these features, small hydropower has been getting the attention in both developed and developing countries. Europe and North America have already exploited most of their hydropower potentials. On the other hand, Africa, Asia and South America have still substantial unused potentials of hydropower (Altinbilek, 2005). Small hydro can be the remedy of the insufficient energy in developing countries, as China did with 43,000 small schemes and 265 GW of total installed capacity. (IHA, 2003).

Since the beginning of the 1980s various studies have been carried out analyzing the small hydro potential of the country and evaluating several sites. In the year 2000, the Hydro Department (Ministry of Works and Housing) prepared an overview of potentially interesting small hydro sites in Ghana, containing about 70 locations. One of these sites is the Randall falls also known as Kintampo falls. It is located on the Pumpum River a few kilometers north of Kintampo Township.

1.3 Objectives

The general objective of this study is to analyze the technical viability of grid connected mini hydro power scheme on Kintampo falls.

The specific objectives are to:

1. Assess the stream flow rate, available head and other preliminary data for mini hydro power generation on Kintampo falls.
2. Estimate the energy output of a mini hydro power scheme at the site
3. Conduct preliminary design of the mini hydro plant
4. Conduct financial appraisal of the hydro power scheme using RET Screen software

1.4 Methodology

The flow-rate of a river can either be estimated using analytical techniques, such as the area-rainfall method, or measured directly. In either case, a hydrology study should be based on many years of daily records (Harvey, 2006). Typically, for short duration studies like this one, the area-rainfall method is preferable because historic precipitation data can be obtained.

In this study, flow-rates will be estimated as follows:

1. 20-years worth of daily rainfall data for the catchment area would be obtained from the Metrological Service Division (MSD).
2. A hydrograph of the river will be plotted. This curve statistically relates rainfall quantities to the number of days of occurrence.
3. Catchment areas would be calculated from drainage basin maps obtained from Survey Department or Google earth maps.

4. Evapotranspiration of the catchment area will be estimated using Blaney-Criddle method and Runoff quantities calculated using the area-rainfall method.
5. Site Specific flow rate measurement using the velocity area method to confirm the appropriateness of the estimated flow rate.
6. Site-specific flow-duration curves would be constructed to calculate the power potentials of the sites.
7. Sizing of components of the project based on flow rate and available head.

Head determination of the site will be measured using GPS receiver to determine the available head for the Mini hydro power scheme

Financial and economic appraisal of the site would be analyzed with RETSceen software to determine the project financial viability.

CHAPTER TWO

LITERATURE REVIEW

2.1 Sustainable Development

The term sustainable development is defined as development that meets the needs of the present without compromising the ability of future generations to meet their own needs. It must be legally sound, politically advantageous, socially accepted, environmentally sustainable, economically viable and technical feasible.

In the energy sector it means using the energy resources in a way that some of it is left for the future generation. Energy poses serious environmental problems leading to the assumption that its current use is not sustainable.

Energy sources are limited to:

1. Fossil energy (Coal, oil and natural gas)
2. Nuclear energy.
3. Renewable energy (solar, hydropower, geothermal, wind power, biomass energy and marine energy)

Only the last group is renewable. This means that the two first groups are not sustainable energy sources especially fossil energy sources. It has been emphasized by several experts that fossil fuels depletion is so crucial that in a hundred years time, they will disappeared from the earth.

2.2 Renewable Energy

Renewable energy is from energy source that is replaced by a natural process at a rate that is equal to or faster than the rate at which the resource is being consumed. Renewable energy can come from variety of sources such as sunlight, wind, rain, tides, waves and geothermal heat.

2.3 Small Hydro Power

Hydroelectric power is electricity produced by the movement of fresh water from rivers and lakes. At higher ground, water has stored gravitational energy that can be extracted by turbines as the water flows downstream. Gravity causes water to flow downwards and this downward motion of water contains kinetic energy that can be converted into mechanical energy, and then from mechanical energy into electrical energy via hydroelectric power stations

Small hydropower is a sustainable resource. Lins et al. (2004) states that "SHP meets the needs of the present without compromising the ability of future generations to meet their own needs."

Small hydropower plants are among the cheapest systems to generate electricity. It is a well known technology open to new technological developments. SHP has a high untapped potential especially in developing countries (ESHA, 2005). The main characteristics of small hydropower plants are their flexibility and reliable operation. Moreover, depending on the rapid demand changes, its fast start up and shutdown response is an important advantage (Dragu et al., 2001). Small hydropower plants uses water to generate electricity therefore the electricity generation is independent from the changes in fuel costs (Dragu et al., 2001). Without any harm or decrease to its resource it can satisfy the energy demand (Lins et al., 2004). Moreover, SHP schemes recovers the waste that flows with the river flow with its trash racks, thus it helps the maintenance of river basins (Pelikan et al., 2006).

Small hydropower is a clean energy source, thus it is environmentally friendly. It does not pollute the environment and does not generate greenhouse gases. Pelikan et al. (2006) states that "one GWh of electricity produced by small hydropower means a reduction of

480 tonnes of emitted carbon dioxide". Moreover, small hydropower schemes have long life span and very limited maintenance is required (Paish, 2002).

Small hydropower has an important share in the world's renewable energy budget. Table 2.1 shows global electricity generation by each renewable energy source.

Table 2.1: Electricity Generation by each renewable energy

Large hydro (>10 MW)	86 %
Small hydro (<10 MW)	8.3 %
Wind and solar	0.6 %
Geothermal	1.6 %
Biomass	3.5 %

Source (Dragu et al., 2001)

In 2004, the total installed capacity of small hydropower (<10 MW) was about 48 GW worldwide as shown in Table 2.2. In 2005, China has reached a SHP capacity of 31,200 MW which is more than half of the worlds SHP capacity (Taylor et al., 2006). Canada uses small hydropower to replace expensive diesel generation in remote off-grid regions. Moreover, countries in South America, Africa and former Soviet Union also have great untapped potentials (Lins et al., 2005).

Table 2.2: Installed SHP (<10 MW) Capacity by World Region in 2004

Region	Capacity (MW)	Percentage (%)
Asia	32,641	68.0
Europe	10,723	22.3
North America	2,929	6.1
South America	1,280	2.7
Africa	228	0.5
Australasia	198	0.4

Source (Taylor et al., 2006)

2.4 Hydropower and energy

Hydro power can be obtained where a flow of water falls from a higher plane to a lower plane. This could be in a stream running down a hillside, a river over a waterfall, a weir or from a reservoir discharge back in to a main outlet.

The amount of power available from a hydro scheme depends on the 'head' and the ‘flow’ rate of the water. The head is the height difference between the inlet to the hydro turbine and its outlet as shown in Figure 2.1

The gross head is the maximum vertical drop available to the water from the top of the fall to the water level below. The actual head seen by a turbine is slightly less than gross head due to losses while transferring the water into and away from the turbine, and is therefore called the net head.

The flow rate (Q) in the water source is the volume of water passing per second.

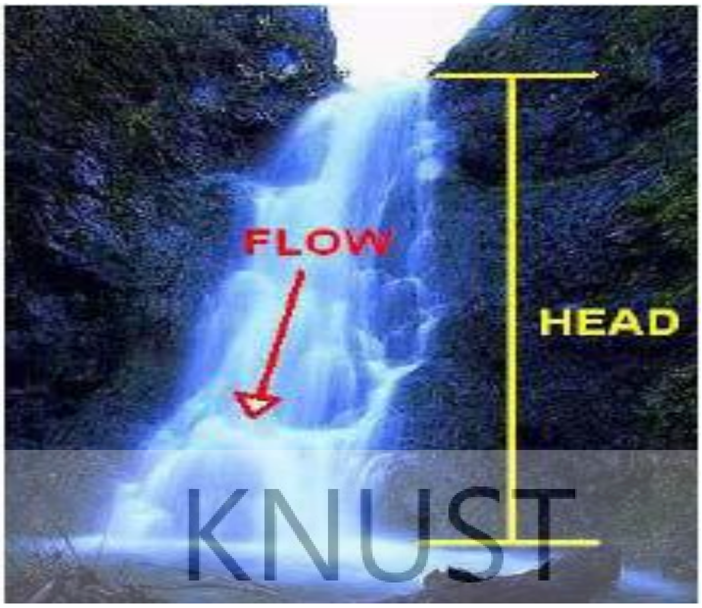


Figure 2.1: **Available head for Mini hydro power**

This can be shown by equation 2.1.

Energy released = m g H ………….. 2.1

Where:

m = mass of water

g = gravity

H = gross head or vertical distance

The mass of the water is its density (*p*) multiplied by its volume (V) so that the equation changes to:

Energy released = V ρ ***g*** **H** ……………. 2.2

The water enters the turbine at a rate Q value in cubic meters per second m^3/s, and can be expressed in terms of power. The S.I. unit for power is Watt.

Therefore:

Gross Power = ρ **Q g H Watts ………… 2.3**

Where:

ρ = 1000 kg/m³

g = 9.81 m/sec²

Q = volumetric flow rate m³/sec

H = gross head in meters

However the power produced by the turbine cannot equal the gross power because of losses such as friction in pipe work and conversion machinery i.e. turbines and generators.

A hydro turbine can have between 80% to over 90% hydraulic efficiency, although this will reduce with size. A typical micro hydro system (<100kW) will tend to be 60% to 80% efficient.

Therefore:

$$\textbf{Net Power} = \eta \rho Q g H \textbf{ Watts} \quad \ldots\ldots\ldots\ldots\ 2.4$$

Where:

η = hydraulic efficiency of turbine

ρ = 1000 kg/m³

Q = volumetric flow rate m³/sec

g = 9.81 m/sec²

H = gross head in meters

2.5 Small hydro power component

A typical small hydro power is arranged as depicted in figure 2.2.

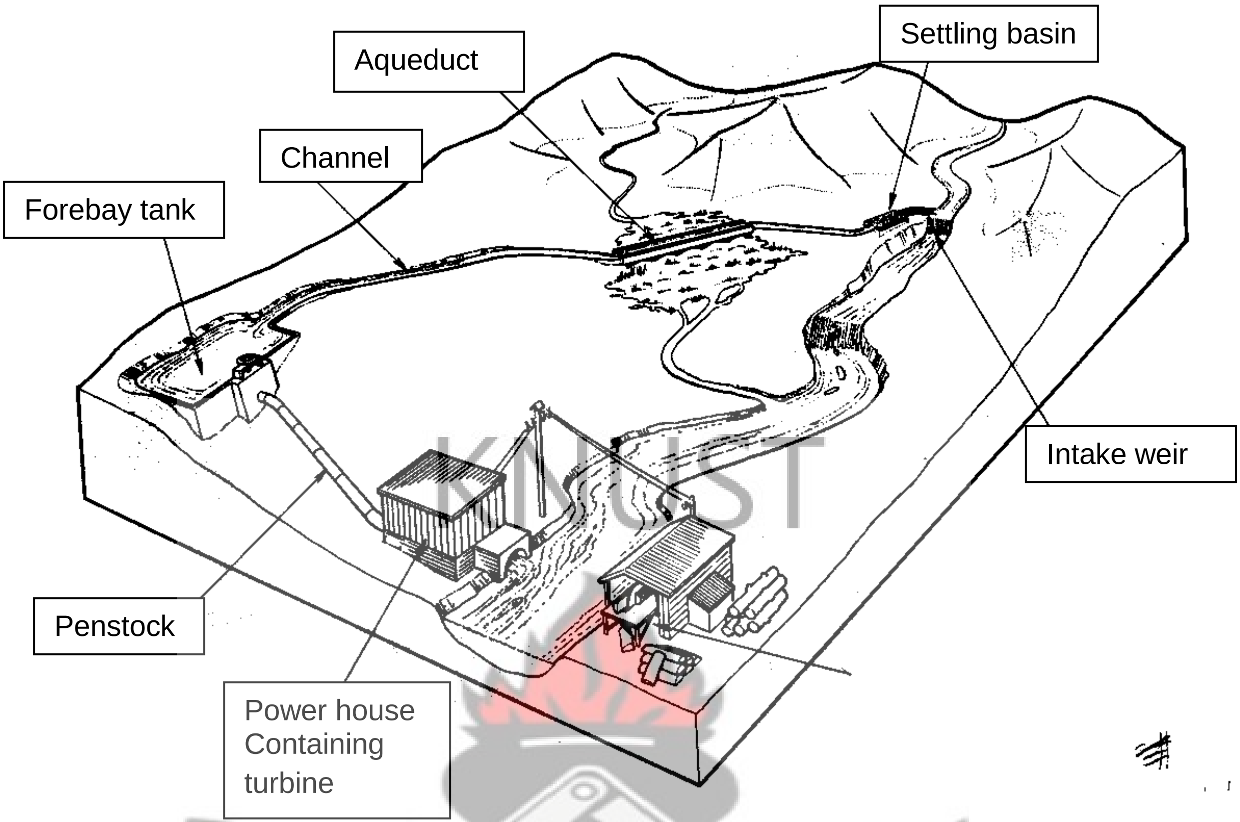


Figure 2.2: Components of Mini hydro power scheme

The principal components that are used in the MHS (Mini Hydropower System) could be further classified into civil components, powerhouse components and transmission and distribution networks.

2.5.1 Diversion Weir and Intake

The diversion weir depicted in figure 2.3 is a barrier built across the river and used to divert water through an opening in the riverside (the 'Intake' opening) into a settling basin. Intake is the primary means of conveyance of water from the source of water in required quantity towards the waterways of Hydro Power Project. Intake could be of side intake type or the bottom intake type. Usually, trash racks as shown in figure 2.4 have to be placed at the intake which acts as the filter to prevent large water borne objects to enter the waterway of the MHP (Mini Hydro Project) (Harper, December 2011).

Figure 2.3: **Diversion weir**

Figure 2.4: **Trash rack**

2.5.2 Settling Basin

Rivers generally carry high amount of sediments due to erosion activities in hills and mountains. In order to reduce the sediments density, which have negative impact to components of the hydropower system; de-sanding basins are used to capture sediments by letting the particles settle by reducing the speed of the water and clearing them out before they enter the canal. Therefore, they are usually built at the head of the canal. They are equipped with gate valves for flushing the settled undesirable sediments. De sanding basin is capable of settling particles above 0.2-0.3 mm of size (Harvey, Mini Hydro Design Manual, 1993). Figure 2.5 shows a typical de-sanding basin.

Figure 2.5: Settling basin

2.5.3 Headrace Canal

Once the water enters through the intake, the headrace canal conveys the water to the forebay. Sometimes, pipes can also be used in place of the canals. The materials to be used in constructing the canal depends upon the geographical condition of the site and other obvious factors such as the availability of labor and materials. Most usual types of canal as shown in figure 2.6 are built from combination of cement and mortar, only soil, mixture of stone and mud, mixture of stone masonry with cement and other different types of possible combinations (Pandey V., 2011). When pipes are used, they are generally of HDPE (High Density Polythene) types. The length of the headrace canal can be anywhere from few meters to over a kilometer long. The most important thing to consider while constructing head race canal is to make the slope of the canal only slightly elevated because higher slope can lead to higher velocity of water which can then cause erosion in the headrace canal surface.

Figure 2.6: **Head race canal**

2.5.4 Forebay

Pond at the top of a penstock or pipeline serves as final settling basin, provides submergence of penstock inlet and accommodation of trash rack and overflow/spillway arrangement.

Forebay tank is basically a pool at the end of headrace canal from which the penstock pipe draws the water. The main purpose of the forebay is to reduce entry of air into the penstock pipe, which in turn could cause cavitations (explosion of the trapped air bubbles under high pressure) of both penstock pipes and the turbine (Masters, 2004). It is also necessary to determine the water level at the forebay because operational head of the mini hydro power plant is determined through this factor. A forebay again requires two sets of additional construction. As the water speed is lowered at the forebay, it can cause sedimentation of particles, which requires the construction of spillway as mentioned before. Similarly, installation of trash racks to filter the fine sediments might be required before the water from the forebay gets inside. Figure 2.7 illustrates a typical forebay tank.

Figure 2.7: Forebay

2.5.5 Penstock

Penstock pipes are basically close conduit pipes that help to convey the water from the forebay tank to the turbine under pressure. The pipeline itself must be able to tolerate sudden changes in water pressures, and to resist adequately internal and external forces, such as the changing weather conditions for the sited area. The materials used in penstock are usually steel, HDPE (High Density Polythene) and increasingly PVC (Poly Vinyl Chloride).

PVC is widely used in micro-hydro because it is relatively cheap and is widely available in a variety of sizes from 25mm to 500mm in diameter. It is suitable for high-pressure use, has good friction loss characteristics and is corrosion resistant, but suffers from being fragile in the respect to damage from falling rocks or trees. Mild steel is used for its cheapness and is easily available in a wide range of diameters and pipe wall thicknesses. It is resistant to external damage from falling rocks and trees, but when buried, it suffers from long term corrosion and needs to be protected by painting or some other form of anticorrosion coating to give an expected life of 15 years plus. Mild steel piping is heavy but can come in convenient lengths, easier for movement and is jointed either by welding or bolted flanges.

Penstock is one of the most important components of the MHS (Mini Hydro-power System) because it is at this point that the potential energy of the water is converted into kinetic energy. Due to the risk of contraction and expansion of penstock pipes due to fluctuation in seasonal temperature, sliding type of expansion joints are placed between two consecutive pipe lengths. Anchor block, which is basically a mass of concrete fixed into the ground, is used to restrain the penstock from movement in undesirable directions. Figure 2.8 depicts a mild steel penstock secured to the ground by anchor blocks.

Figure 2.8: Mild Steel Penstock

2.5.6 Tailrace

Tailrace is very similar to headrace canal described previously in this section. The only difference with that of the headrace canal is that it is situated at the end of the civil components and is used to convey the water back to the source after use in the Mini hydro plant.

2.6 Turbines

The purpose of a turbine is to convert energy in the form of falling water into rotating shaft power. The selection of the best turbine for any particular hydro site depends on the site characteristics, the dominant ones being the head and flow available. Selection also depends on the desired running speed of the generator or other device loading the turbine. Other considerations such as whether the turbine is expected to produce power under part-flow conditions also play an important role in the selection. All turbines have power-speed design characteristics, as they will tend to run more efficiently at a particular speed, head and flow combination. Turbines can be classified as high head, medium head or low head machines.

Turbines are grouped under the following two headings: impulse turbines and reaction turbines, as shown in the table 2.3.

Table 2.3: Turbine classification

	High Head	Medium Head	Low Head
Impulse Turbines	Pelton Turgo Multi-Jet Pelton	Cross-Flow/ Banki Multi-Jet Pelton Turgo	Cross-Flow/ Banki
Reaction Turbines		Francis	Propeller Kaplan

2.6.1 Impulse turbines.

Impulse turbines derive their power from a jet stream striking a series of blades or buckets as illustrated in figure 2.9. A distinct feature of an impulse turbine runner is that it operates in air. The momentum of a high-speed water jet turns impulse turbines.

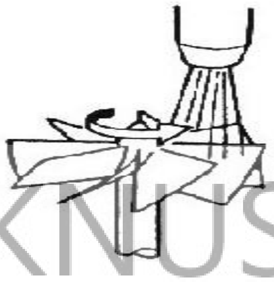


Figure 2.9: **Impulse turbine**

2.6.1.1 Pelton Turbine.

The Pelton wheel is probably the best known of the tangential flow impulse turbines. Invented by a Californian mining engineer, it has changed little in the last hundred years. It is efficient over a very wide range of flows but at lower heads the speed is a bit too low for convenient belt drives. The Pelton wheel is used where a small flow of water is available with a 'large head'. It resembles the waterwheels used at water mills in the past. The Pelton wheel has small 'buckets' all around its rim (Figure 2.10). Water from the dam is discharged from one or more nozzles very high speed hitting the buckets, pushing the wheel around (Figure 2.10).

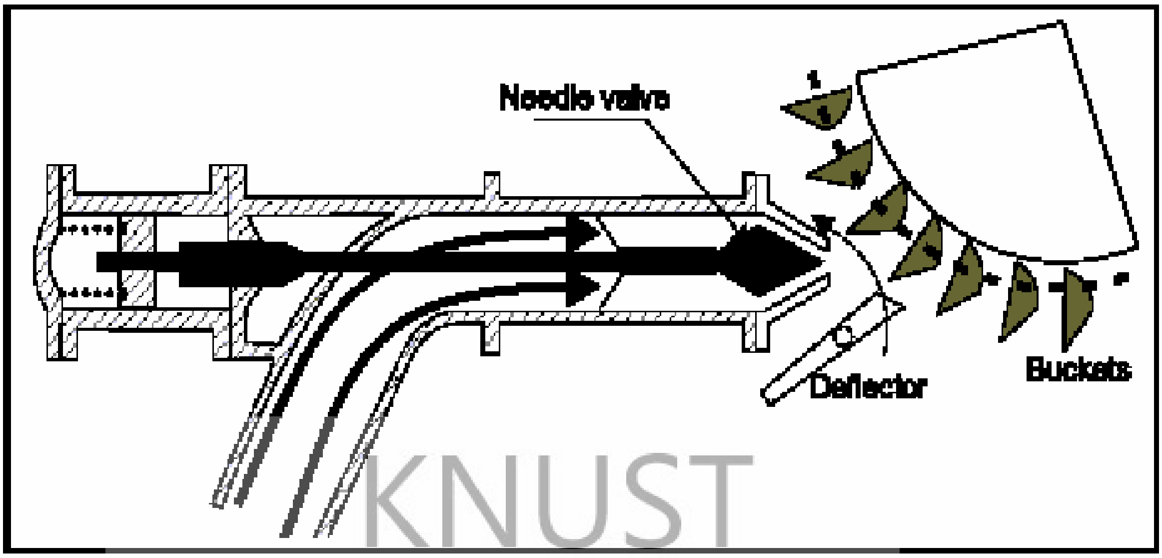


Figure 2.10: Pelton Turbine nozzle

The buckets are split into two halves so that the central area does not act as a dead spot incapable of deflecting water away from the oncoming jet (Figure 2.11).

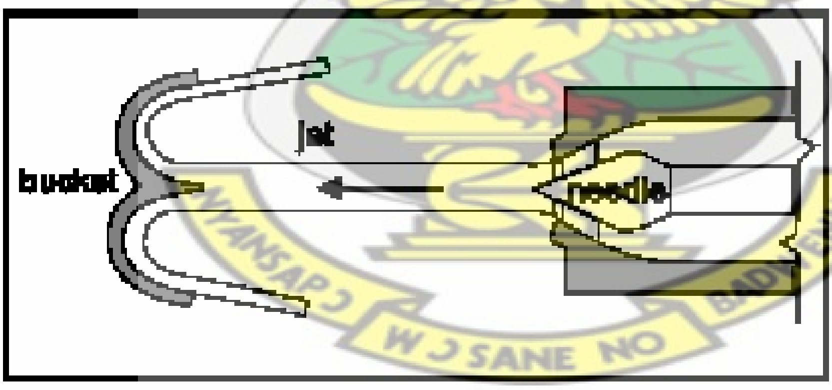


Figure 2.11: Pelton Turbine bucket split into two halves

Having two or more jets enables a smaller runner to be used for a given flow and increases the rotational speed. The required power can still be attained and the part-flow efficiency is especially good because the wheel can be run on a reduced number of jets with each jet in use still receiving the optimum flow.

Two Pelton Wheels can be placed on the same shaft either side by side or on opposite sides of the generator (figure 2.12). This configuration is unusual and would only be used if the number of jets per runner had already been maximized, but it allows the use of smaller diameter and hence faster rotating runners.

Figure 2.12: Two Pelton wheels placed side by side

2.6.1.2 Turgo Turbine.

Eric Crewdson invented the Turgo impulse in 1920; it is used for heads of 12 meters or more. The Turgo Impulse design allows a large water jet to be directed at an angled runner blade, usually approximately 20°, giving the turbine a higher specific speed, and therefore a smaller physical size (Figure2.13).The rugged design is particularly suited to schemes having abrasive solids in suspension.

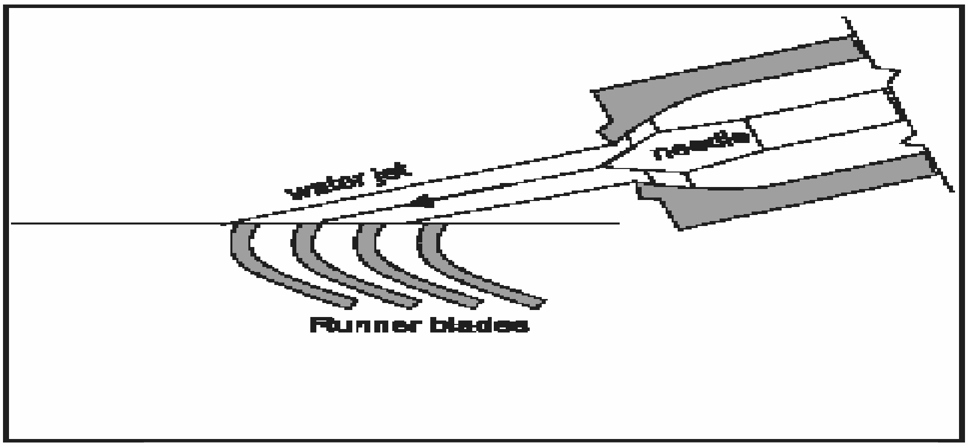


Figure 2.13: Turgo Turbine runner

Because power output from the turbine can be regulated using rapid acting deflectors without affecting the water flow, the Turgo Impulse Turbine has been applied on many irrigation and water treatment schemes where continuity of water flow is essential. It has several disadvantages. Firstly it is difficult to fabricate since the buckets or vanes are more complex in shape and overlap, it also experiences axial loading on the runner that has to be quelled by a suitable bearing on the shaft, usually a roller bearing.

2.6.1.3 Crossflow Turbine.

In the crossflow turbine, the water in the form of a sheet is directed into the blades tangentially at about mid way on one side. The flow of water "crosses" through the empty centre of the turbine and exits just below the centre on the opposite side (figure 2.14). Thus the water strikes blades on both sides of the runner.

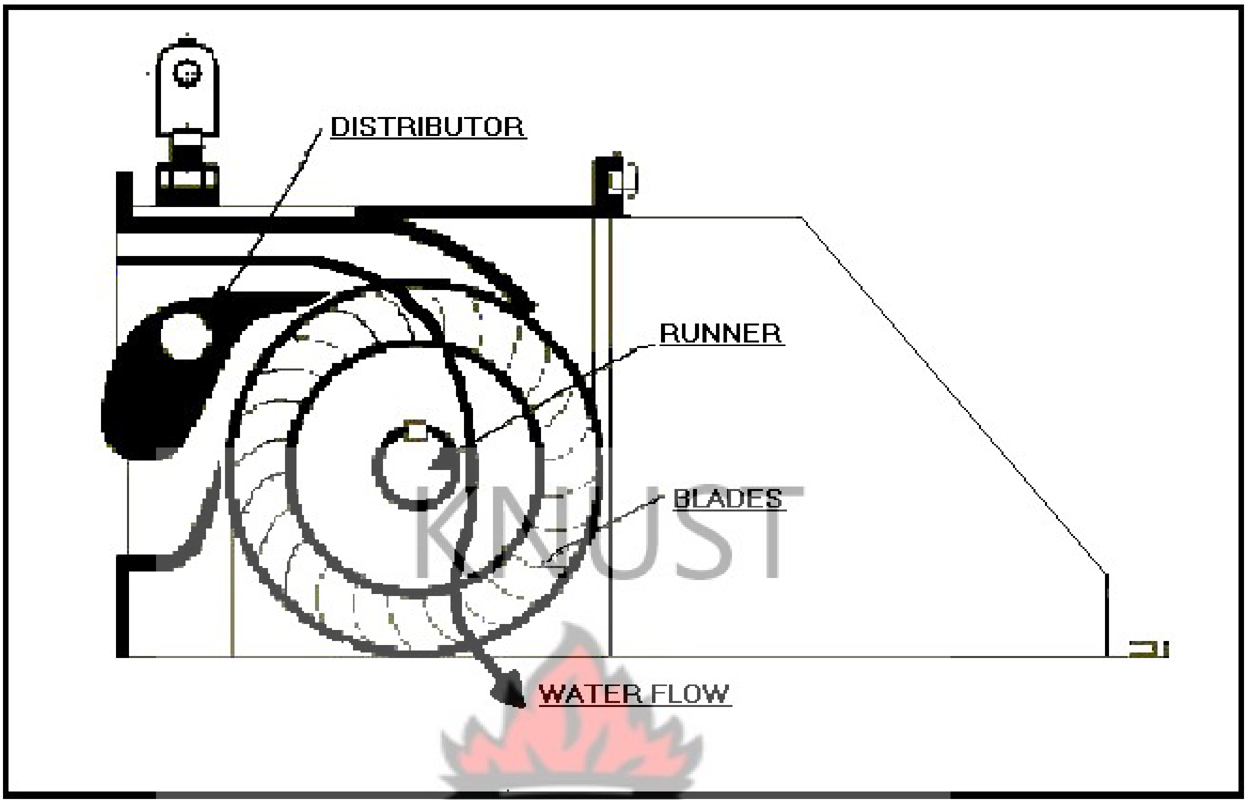


Figure 2.14: Crossflow Turbine runner

It is claimed that the entry side contributes about 75% of the power extracted from the sheet of water and that the exit side contributes the remainder. The main characteristic of the cross-flow turbine is that it uses a broad rectangular jet of water that travels through the turbine only once but travels across each runner blade twice, once in each direction. This machine is therefore a turbine with two velocity stages, the water filling only part of the runner at any one time. As far as energy utilization is concerned, the use of two velocity stages provides no immediate advantages. The arrangement represents, however, a very skilful design, which removes the water in a simple manner, after it has passed through the runner without producing any backpressure. The addition of a draft tube to the cross-flow turbine represents an idea implemented by Ossberger to enhance the turbine's performance. Ossberger uses an air valve in the draft tube to help regulate the head by introducing air in the draft tube.

Furthermore, this flow mechanism makes the turbine self-cleaning. During the first strike, suspensions and impurities, which reach the turbine, are pressed against the blanket of the runner. During the second strike, after a half rotation these would then be washed out. This mechanism contributes to the long functioning period and reliability of the turbine.

They are generally built as multi-cell turbines, where the runner can be sectioned off to allow the smaller cell to utilize small water flows and the larger cell to use medium water flow and when both cells are opened together they utilize the full flow of the water. (Figure 2.15)

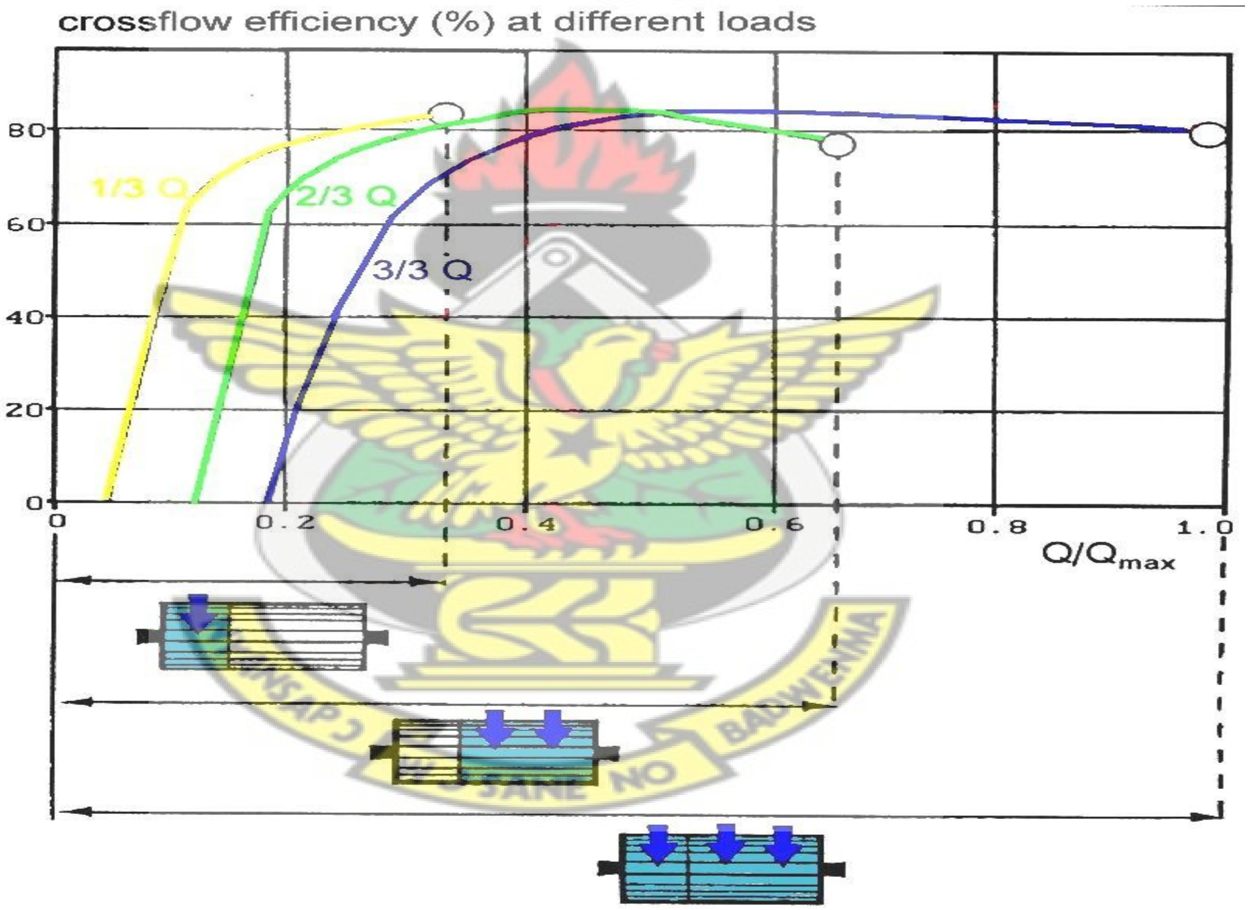


Figure 2.15: Efficiency of Crossflow turbine at different loads

2.6.2 Reaction Turbines.

Reaction turbines use both velocity and pressure forces to produce power. Consequently, large surfaces over which these forces can act are needed. Also, flow direction as the water enters the turbine is important. They are distinguished from impulse type turbines by having a runner that always functions within a completely water filled casing (figure 2.16). Hydrodynamic lift forces acting on the runner blades turn reaction turbines.

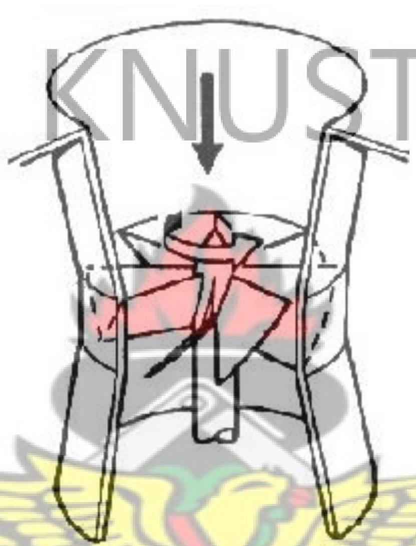


Figure 2.16: Reaction Turbine

2.6.2.1 Francis Turbine.

The Francis turbine is used where a large flow and a high or medium head of water is involved. The Francis turbine is also similar to a waterwheel in that it looks like a spinning wheel with fixed blades in between two rims. This wheel is called a 'runner'. A circle of guide vanes surrounds the runner and controls the amount of water driving it. Water is fed to the runner from all sides by these vanes causing it to spin. Francis turbines are radial flow reaction turbines, with fixed runner blades and adjustable guide vanes, used for medium heads. Francis turbines include a complex vane arrangement surrounding the turbine itself (also called the runner) which can be seen in Figures 2.17.

Water is introduced around the runner through these vanes and then falls through the runner, causing it to spin. Velocity force is applied through the vanes by causing the water to strike the blades of the runner at an angle. Pressure forces are much more subtle and difficult to explain, and in general, the flowing water causes pressure forces. As the water flows across the blades, it causes a pressure drop on the back of the blades; this in turn induces a force on the front, and along with velocity forces, causes torque.

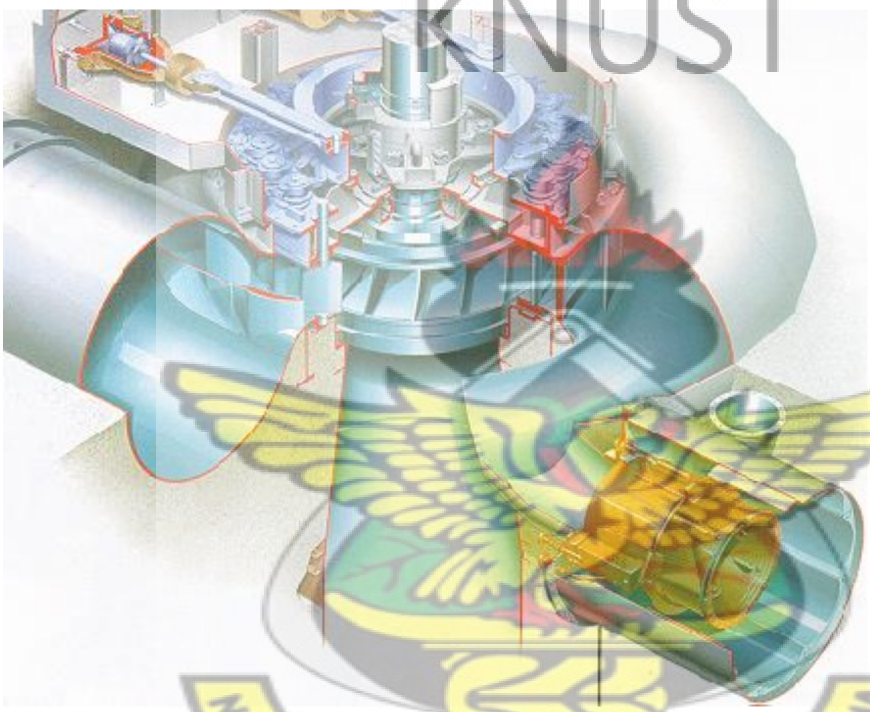


Figure 2.17: Francis turbine assembly

Francis turbines are usually designed specifically for their intended installation; with the complicated vane system, they are generally not used for Micro hydropower applications. Because of their specialized design, Francis turbines are very efficient yet very costly.

2.6.2.2 Propeller.

Propeller type turbines are designed to operate where a small head of water is involved. These turbines resemble ship's propellers (Figure 2.18). The basic propeller turbine consists of a propeller, similar to a ship's propeller, fitted inside a continuation of the penstock tube. The turbine shaft passes out of the tube at the point where the tube changes direction. The propeller usually has three to six blades, three in the case of very low head units and the water flow is regulated by static blades or swivel gates ("wicket gates") just upstream of the propeller.

This kind of propeller turbine is known as a fixed blade axial flow turbine because the pitch angle of the rotor blades cannot be changed. The part-flow efficiency of fixed-blade propeller turbines tends to be very poor. However, with some of these the angle (pitch) of the blades can be altered to suit the water flow.

The Propeller turbine in its simplest form is like a ship's propeller running in a tube. As the water flows through the propeller rotates. Special coatings are used for increased corrosion and abrasion resistance. For lowland and old mill sites the propeller turbine is ideally suited since it is compact and fast running even on low heads.

Figure 2.18: Propeller Turbine

The angle of the bend can be between 30 and 90 degrees but standard layouts are either 45 or 90 degrees (Figure 2.19). A penstock can be used for higher heads up to 15 meters and the turbine runner 'setting' can be lowered to avoid cavitations by inserting a length of parallel tube between the bend and the turbine casting. Existing civil works associated with old mills, navigation locks or irrigation structures often lend themselves to the installation of this type of turbine. The Siphon layout is used for small turbines and axial-flow pumps, where the unit is installed 'Over a Wall'.

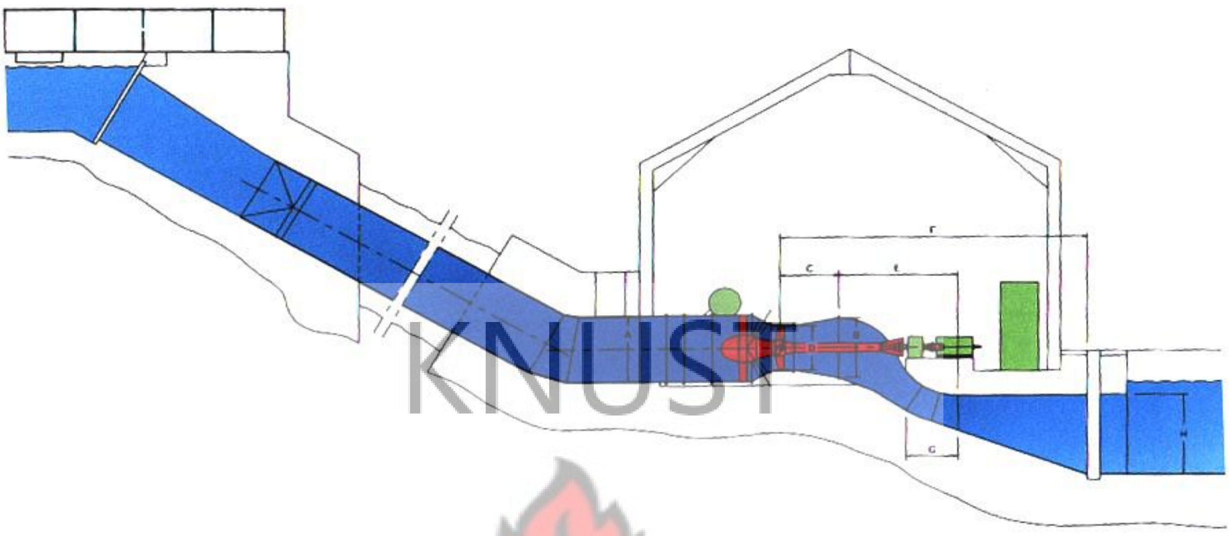


Figure 2.19: Propeller turbine assembly

2.6.2.3 Kaplan.

Large-scale hydro sites make use of more sophisticated versions of the propeller turbines (Figures 2.20). Varying the pitch of the propeller blades together with wicket gate adjustment enables reasonable efficiency to be maintained under part flow conditions. For good efficiency water needs to be given some swirl before entering the turbine runner, where the swirl is absorbed by the runner and the water that emerges flows straight into the draft tube. Methods for adding inlet swirl include the use of a set of guide vanes mounted upstream of the runner with water spiraling into the runner through them. Another method is to form a ‘snail shell’ (Figure 2.21) housing for the runner in which the water enters tangentially and is forced to spiral into the runner. Such turbines are known as variable pitch or Kaplan turbines. Water flows into the turbine casing and passes the runner blades through to the draft tube then to the tailrace .Various configurations of Kaplan turbines exist and can be mounted horizontally, vertically or angled in the same way as propeller turbines. This type of turbine has a high efficiency over a wide range of heads and outputs and has a high specific speed.

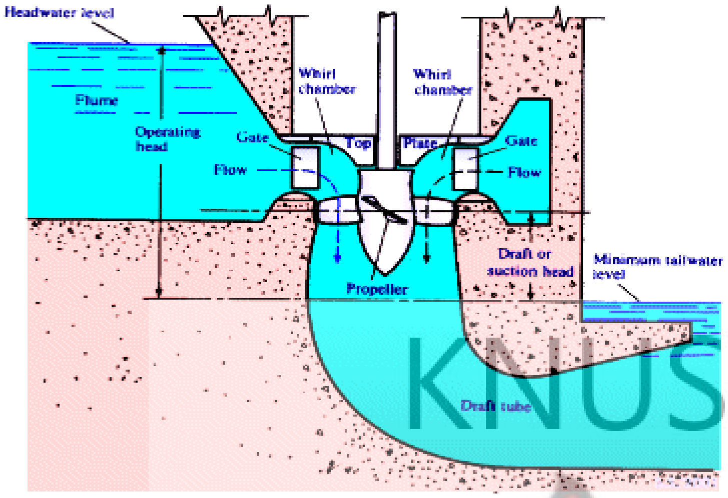


Figure 2.20: Kaplan Turbine assembly

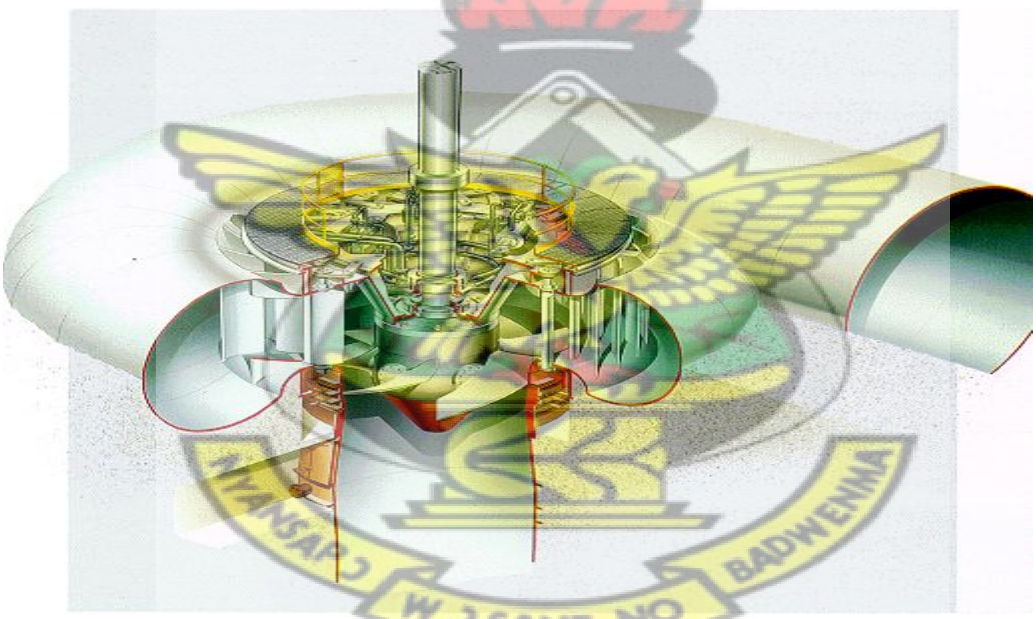


Figure 2.21: Kaplan Turbine components

2.6.3 Turbine Efficiency.

A significant factor in the comparison of the various turbine types is their relative efficiencies both at their design and at reduced flows. Typical efficiency curves are shown in Figure 2.22.

An important note is that the Pelton and Kaplan turbines retain very high efficiencies when running below design flow; in contrast the efficiency of the Francis turbine falls away more sharply if run below half their normal flow, as does the Crossflow turbine, but the multi-celled Crossflow turbine retains a high efficiency but with a reduced output. Most fixed pitch propeller turbines perform poorly except above 80% of full flow.

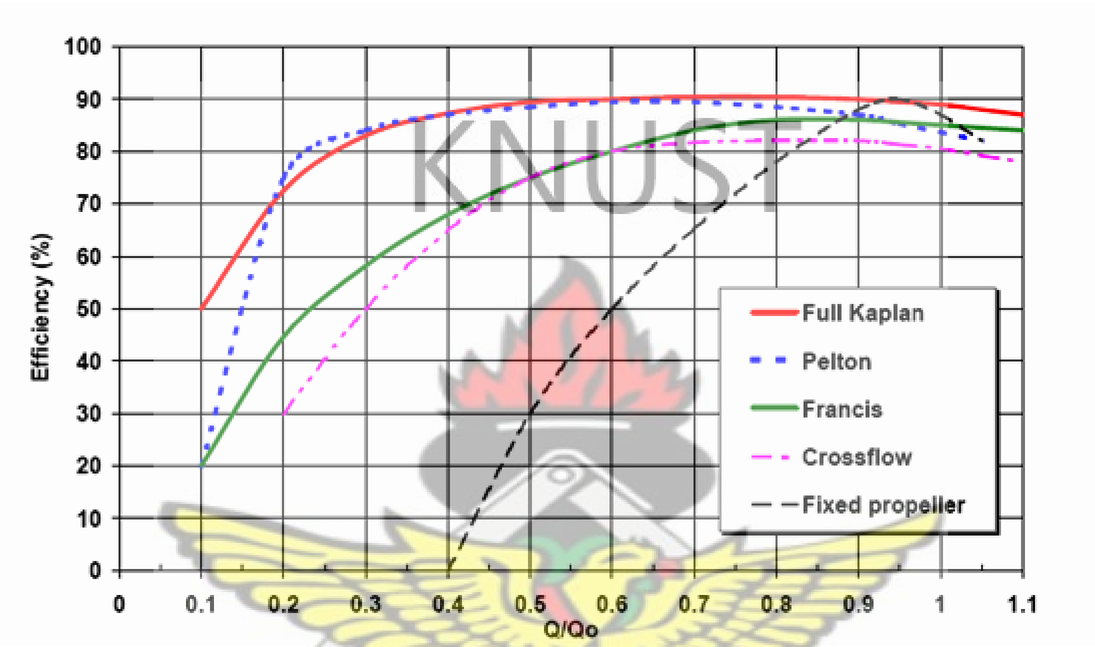


Figure 2.22: Turbine efficiency curve

2.7 Governors.

The turbine usually drives the generator through either a gearbox, through a pulley and belt system, or directly using shock-absorbing brushes. The governor modulates the generator speed in order to control the electrical frequency of generation. The governor does this by detecting the change in the electrical load output of the generator, and then altering the flow of water into the turbine using valves. They can be linked to a level switch situated in the storage reservoir so that the flow through the turbine is also dependent on the level, and hence the water flows. Governors can either be mechanical or electrically operated.

2.8 Generators.

Generators can be either of a **Synchronous** or **Asynchronous** type. In a synchronous generator the frequency of the electricity produced is directly related (i.e. synchronous) with the rotational speed of the shaft. Therefore at 50 Hz generation, the shaft rotates at a fixed sub multiple of 50Hz, depending on the gearing ratio. This type of generator must be designed to withstand the high runaway speeds that can sometimes occur during hydroelectric turbine system faults. They often have to be specially designed, thus increasing their cost considerably. These generators come in single phase (for small systems) and three phase (for larger outputs), and the single phase type is more commonly known as an alternator. Within induction generation or asynchronous generation a motor is used as a generator. This type of generator is simple in construction containing fewer parts, making it cheaper and more reliable than synchronous generators. It can withstand 200% runaway speeds without harm, and has no brushes or other parts to require maintenance. In this type of generator power enters the grid when the speed of rotation has a frequency greater than that of the grid. This is called slip. Usually systems are designed for maximum power to be entering the grid at a slip of about 10%. Power is actually drawn from the grid to provide the magnetic field until running speed is achieved, when power is then produced. When operating in conjunction with a large power grid, a standard single or three-phase motor may be used as a generator. Hydro power plants designed as asynchronous installations are usually more economical than synchronous generating sets. In the past, asynchronous plants were equipped with minimal equipment.

2.9 Capacity Factor

Capacity factor is a ratio summarizing how hard a turbine is working. This is expressed as

$$Capacity\ factor\ (\%) = \frac{Energy\ generated\ per\ year(Kwh/yr)}{Installed\ Capacity(kw)\ x\ 8760\ (hours/yr)} \ldots\ldots\ldots\ldots\ldots\ldots 2.5$$

Capacity factor varies with design flows as shown in table 2.4.

Table 2.4: Design flow in relation to capacity factor

Design flow Qo	Capacity Factor
Q_{mean}	40%
0.75 Q_{mean}	50%
0.5 Q_{mean}	60%
0.33 Q_{mean}	70%

2.10 Design Flow

It is not promising to have a scheme that uses significantly more than the mean river flow since it will not be economically feasible. Therefore turbine design flow for run of the river scheme operating with no appreciable water storage will not normally be greater than $Q_{mean.}$ The greater the chosen value of the design flow, the smaller proportion of the year that the system will be operating on full power meaning low capacity factor. Operating at full power or high capacity factor means design flow should be less than $Q_{mean.}$

CHAPTER THREE

METHODOLOGY

The methodology used in this study entails the following activities: reconnaissance of the study area, data collection of both primary and secondary data and data analysis and preliminary design of the Mini hydro system.

3.1 Reconnaissance Survey

The purpose of the site reconnaissance was to gain understanding of the site characteristics, site topography, flow regimes, geology of the area, access roads to the place and nearness of transmission line. From this observation, identification of possible location for weirs, head canal, de-silting tank, forebay and switch yard were obtained.

3.2 Primary and Secondary data

Both primary and secondary data were gathered. Primary data was collected from the field and these were hydrological data, topographical data and geological data. Secondary data was collected on rainfall, temperature, relative humidity and wind speed from meteorological agency and from report and document to supplement field data.

3.3 Stream Flow Measurement

Stream velocity was measured using the float method. Measurement was taken at a place where the axis of the streambed is straight and has fairly constant cross sectional area. A cork was tossed from upstream of the river of known length and the time taken to traverse that distance was noted. This sequence was repeated several times at four different locations from the edge of the river and average time was obtained hence average velocity. Figure 3.1 – 3.4 shows how this was done.

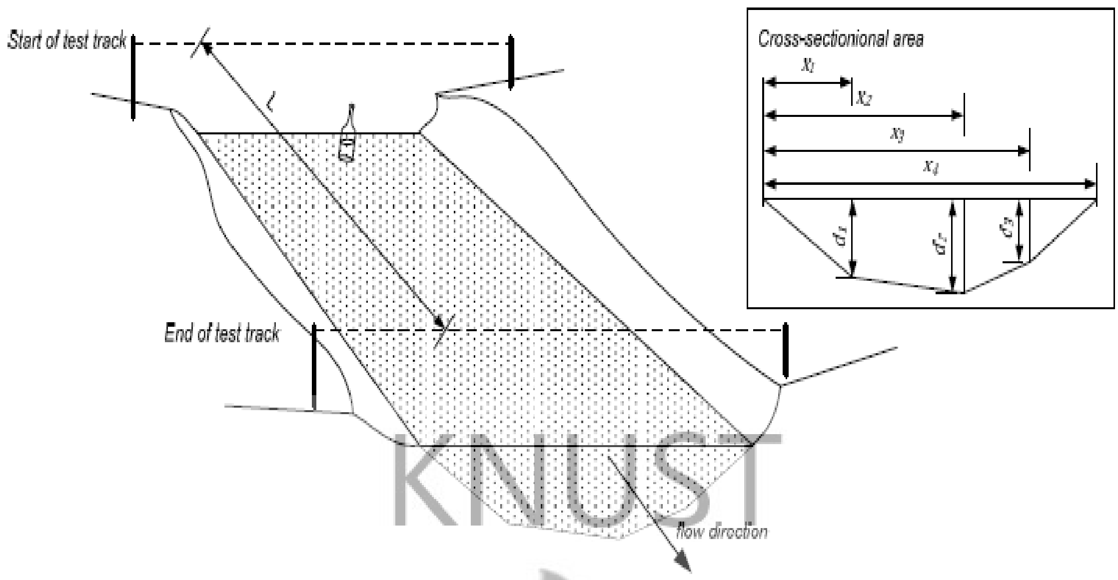


Figure 3.1: **measuring stream flow using float method**

Figure 3.2: measuring stream width.

Figure 3.3: **measuring stream width.**

Figure 3.4: measuring stream flow rate.

Table 3.1: Measuring stream flow using float method

Location from edge (m)	Depth (m)	Length (m)	Time (s)	Velocity (m/s)
0.91	0.3	5	10	0.50
1.83	0.48	5	6	0.83
1.74	0.85	5	6	0.83
3.66	0.3	5	11	0.45
Mean				0.65

Measurement of cross sectional area was made at a place where the axis of the streambed is straight and the cross section of the river is almost uniform. The width of the river was measured with a tape and was 5.03 meters. The depth of the river was measured at an interval along it width and average depth calculated as shown in table 3.1. The cross sectional area was determined by multiplying stream width by average depth of the river.

$$S = B(\frac{\sum h}{n}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where:

B – Stream width

h- Depth of stream

S-Cross sectional area

$$S = 5.03(\frac{0.3 + 0.48 + 0.85 + 0.3}{4})$$

$$S = 2.427m^2$$

Stream flow was calculated using the formula

Stream discharge (m^3/s) = Average Depth x Width x Average velocity

Stream discharge (m^3/s) = Cross sectional area x Average velocity

Stream discharge (m^3/s) = $2.427m^2 \times 0.65m/s$

$= 1.58m^3/s$

3.4 Stream Flow Estimation

Since river Pumpum is not gauged, there is no discharge data that can be used for planning Mini hydro power project. Since only rainfall data is available, the stream flow was estimated using Area –Rainfall method.

Figure 3.5: **Catchment area of an MHP**

3.4.1 Area –Rainfall Method

The relation of rainfall, runoff (direct runoff, base runoff), and evaporation is indicated by the viewpoint of annual water balance as shown in equation 3.2. In this case, pooling of drainage area and inflow and runoff from/to other drainage area are not necessary.

An estimated average discharge at the considered intake point can be made from existing precipitation records at a nearby meteorological station or a preinstalled rain gauge. Precipitation is usually measured in mm. The total volume of rain passing through the control point (Figure 3.5) each month is calculated by equation 3.4.

$$P = R + E_t \quad \text{.......... 3.2}$$

$$R = P - E_t \quad \text{.......... 3.3}$$

$$Q = \frac{A_{catchment}\,(R)}{T} \quad \text{.......... 3.4}$$

Where,

P: Annual rainfall (mm)

R: Annual runoff (mm)

Q: Flow rate (m^3/s)

Et: Annual evaporation (mm)

$A_{catchment}$: Catchment Area (Km^2)

T: Time

Consider that some of the rain does not pass through the control point, because it seeps into the underground and drains as sub surface flow (Figure 3.6). A much larger amount evaporates in dry and windy areas. The losses caused by seepage and evaporation are difficult to quantify and therefore it is useful to make assumptions to be on the safe side. Evaporation losses depend on water surfaces, irrigated surfaces and transpiring plants. The potential evaporation losses per day from water surfaces can be calculated using the Blaney Criddle Formula.

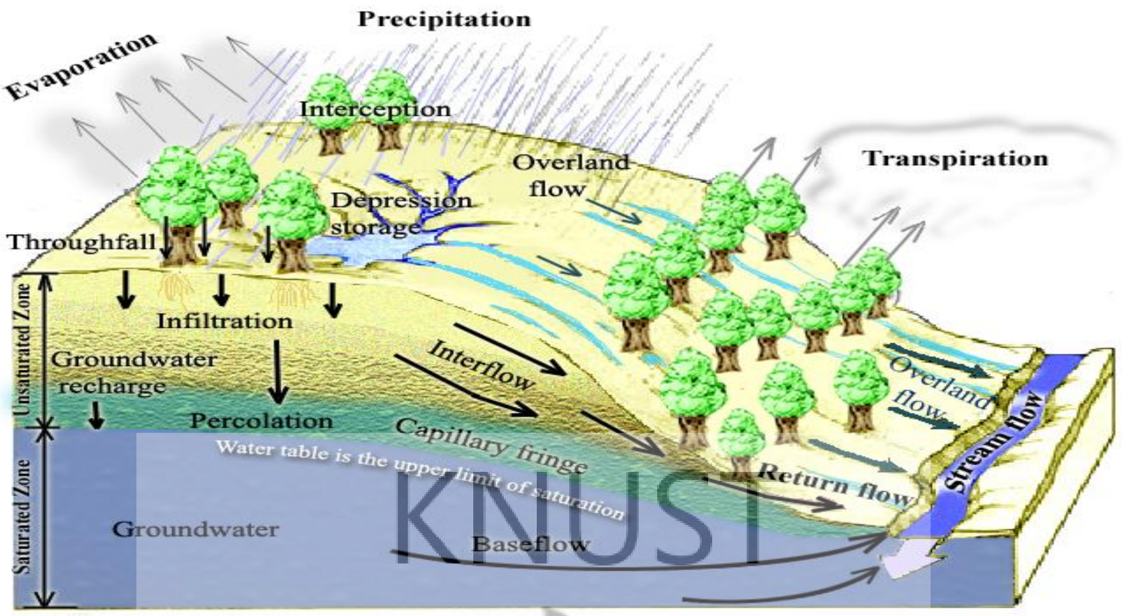


Figure 3.6: Water balance of drainage area

Runoff (R) is obtained from calculated evaporation (Et) by the presumption formula and observed rainfall (P).

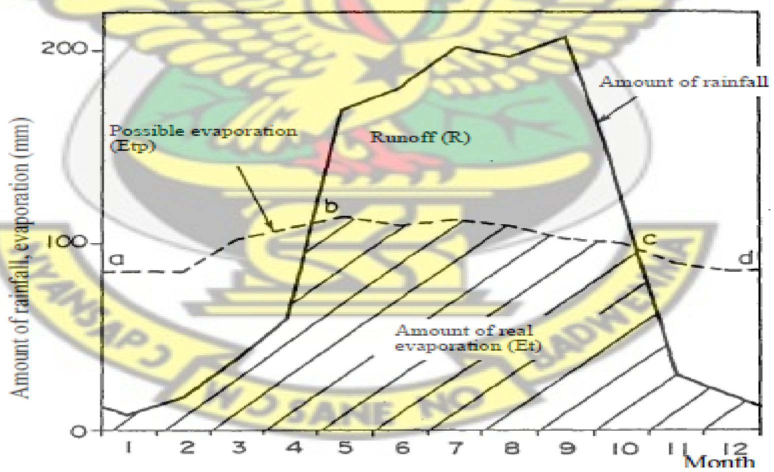


Figure 3.7: Pattern figure of amount of rainfall and evaporation

A pattern figure of the relation of rainfall (R), possible evaporation (Etp), and real evaporation (Et) is shown Figure 3.7. Indicated as diagonal line is real evaporation, and area above line b-c is river runoff including sub-surface water. Possible evaporation (a-b-c-d) is obtained by presumption formula.

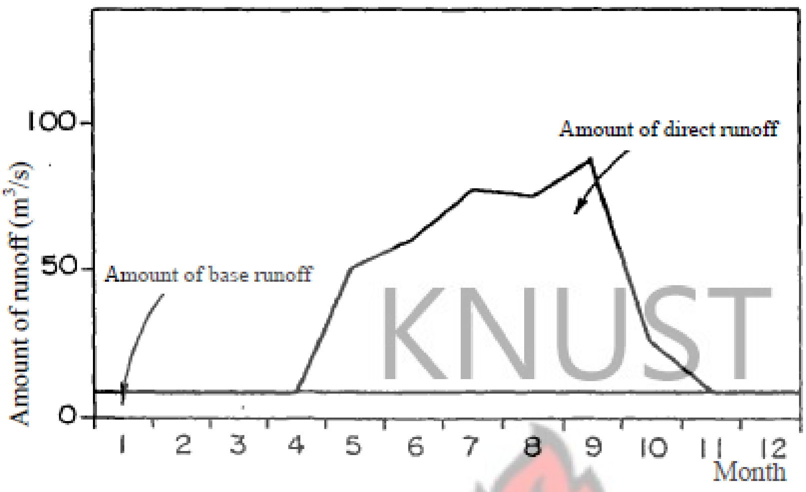


Figure 3.8: Pattern figure of runoff

(2) Direct runoff and base runoff

A pattern of annual runoff is shown Figure 3.8. The runoff is provided from sub-surface water, and it contained base runoff with less seasonal fluctuation and direct runoff wherein the rainfall immediately becomes the runoff. The ratio of sub-surface water to annual runoff (R) is shown in Table 3.2. Where, Rb is sub surface water,

For Africa, Rb / R = 0.35 constant, and the base runoff is taken as constant.

Table 3.2: World Water balance model

Area	Asia	Africa	North America	South America	Europe	Australia	Japan
Rainfall (P)	726	686	670	1648	734	736	1788
Runoff (R)	293	139	287	583	319	226	1197
Direct runoff (Rd)	217	91	203	373	210	172	–
Subsoil water	76	48	84	210	109	54	–
Evaporation (Et)	433	547	383	1065	415	510	597
Rg / R	26	35	32	36	34	24	–

Source: Lvovich 1973

Data of Japan from Ministry of Land, Infrastructure and Transport

(3) Calculation of possible evaporation

The calculation formulas are Blaney-Criddle formula, Penman formula, and Thornthwaite formula etc. Herein, Blaney-Criddle formula was used which is the simplest method using the longitude and temperature of the project site.

Blaney-Criddle formula is given by equation 3.5.

$$U = K.P.\frac{(45.7t+813)}{100} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad 3.5$$

Where,

U: Monthly evaporation (mm)

K: Monthly coefficient of vegetation

P: Monthly rate of annual sunshine (%)

t: Monthly average temperature (^{o}C)

Monthly average temperature (t) was obtained from measured temperatures at the catchment area.

Monthly rate of annual sunshine (P) was obtained by taking the latitude of the propose dam site (Lat. 8° N) and selecting the appropriate P from a table in appendix E corresponding to the selected latitude.

K value depends on the vegetation condition. Herein, a constant of 0.6 was used.

(4) Calculation of evaporation

As shown in Table 3.3; the monthly evaporations are obtained by lower value of rainfall or possible evaporation.

(5) Computation of monthly runoff data

Derivation of the monthly mean discharge data at the dam site is by using equation 3.6.

$$Q(i) = \frac{Monthly\ runoff(mm)}{1000}\ x\ CA\ x10^6\ x\ \frac{1}{86{,}400\ x\ n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.6$$

Where

Q (i): Monthly mean discharge at dam site in ‘i (month)’ (m^3/s)

CA: Drainage area (km^2)

n: Number of days in the month

The catchment area or the drainage area is 87 km^2 (Ofosu-Ahenkora, 2002).

In addition, the ratio of the base runoff to the total runoff (35%) and the monthly distribution of base runoff (constant) can be analyzed with regards to the characteristic of runoff at the area.

Tables 3.3 and 3.4 illustrate the estimation of monthly mean discharge of Pumpum River from the monthly mean temperature, rainfall and rate of annual sunshine

Table 3.3: Calculation of possible evaporation and real evaporation

Month	(1) Temperature (°C)	(2) Rate Of Annual Sunshine P (%)	(3) Possible Evaporation (Blaney-Criddle)(mm)	(4) Rainfall (mm)	(5) Real Evaporation(mm) (small value of (3) and (4))
Jan	26.36	8.21	99.38	10.11	10.11
Feb	28.19	7.51	94.68	41.06	41.06
Mar	28.37	8.45	106.96	86.17	86.17
Apr	27.51	8.34	103.59	163.36	103.59
May	26.95	8.74	107.23	150.11	107.23
Jun	25.85	8.53	102.08	194.48	102.08
Jul	24.93	8.78	102.85	86.73	86.73
Aug	24.60	8.66	100.66	60.49	60.49
Sep	25.25	8.25	97.37	161.04	97.37
Oct	25.87	8.37	100.21	174.23	100.21
Nov	26.44	7.98	96.77	55.49	55.49
Dec	25.93	8.18	98.07	11.52	11.52

Table 3.4: Calculation of mean stream discharge

Month	(6) Runoff(mm) ((4) -(5))	(7) Direct Runoff(mm) ((2) x 0.65)	(8) Base Runoff(mm)	(9) Monthly Runoff(mm) ((7)+ (8))	(10) Monthly mean discharge(m^3/s)
Jan	0.00	0.00	9.89	9.89	0.32
Feb	0.00	0.00	8.93	8.93	0.32
Mar	0.00	0.00	9.89	9.89	0.32
Apr	59.77	38.85	9.57	48.42	1.63
May	42.88	27.88	9.89	37.77	1.23
Jun	92.40	60.06	9.57	69.63	2.34
Jul	0.00	0.00	9.89	9.89	0.32
Aug	0.00	0.00	9.89	9.89	0.32
Sep	63.67	41.39	9.57	50.96	1.71
Oct	74.02	48.11	9.89	58.00	1.88
Nov	0.00	0.00	9.57	9.57	0.32
Dec	0.00	0.00	9.89	9.89	0.32
	332.75	216.29	116.46	332.75	0.92

(Note) (8) Base runoff: distribute uniformity 332.75 ×0.35 = 116.4625 mm to each month

3.7 Measurement of Head

The head between the intake point and the power house was measured .While a surveying level can be used for the purpose of measuring, a more simple head measuring method using GPS device was used to determine the head. The Altitude of the intake point was taken with the GPS receiver and noted down. Next the elevation at downstream end where the proposed power house will be located was also taken. The measured head was calculated by the difference in elevation of intake point and the elevation of power house.

Elevation of intake point - 292.93m

Elevation of power house point – 242m

Head = Elevation of intake point – Elevation of power house point

= 292.93m – 242m

50.93m

CHAPTER FOUR

RESULT AND DATA ANALYSIS

Data was collected on rainfall and temperature from the year 1992 to 2012 and was used to estimate stream flow for the period. Table 4.1 shows the mean flow rate of Pumpum River from the year 1992 to 2012.

Table 4.1: Monthly mean discharge of Pumpum River from 1992 to 2012

	Months												
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
1992	0.39	0.39	0.39	2.25	1.46	1.39	0.39	0.39	2.73	1.20	0.39	0.39	0.98
1993	0.39	0.39	0.39	0.58	3.30	1.52	0.39	0.39	2.33	1.45	0.39	0.39	0.99
1994	0.39	0.39	0.39	0.39	0.59	1.22	0.39	0.39	2.40	3.01	0.39	0.39	0.86
1995	0.39	0.39	1.18	3.99	1.40	1.56	0.49	0.41	2.64	1.46	0.39	0.39	1.22
1996	0.39	1.94	0.39	1.09	0.52	3.07	0.93	0.91	0.39	2.23	0.39	0.39	1.05
1997	0.39	0.39	0.39	0.39	0.89	2.96	0.39	0.39	0.39	1.73	0.39	0.39	0.76
1998	0.39	0.39	0.39	1.07	0.39	2.40	0.39	0.39	1.86	3.40	0.39	0.39	0.99
1999	0.39	0.39	1.37	1.21	1.58	0.98	0.39	0.39	1.71	1.20	0.39	0.39	0.87
2000	0.39	0.39	0.39	3.45	0.39	0.89	0.39	0.79	0.39	0.39	0.49	0.39	0.73
2001	0.39	0.39	0.95	6.86	0.39	4.96	0.39	0.39	0.76	0.39	0.39	0.39	1.39
2002	0.39	0.39	0.39	3.86	1.92	1.93	0.39	0.39	0.39	1.50	0.39	0.39	1.03
2003	0.39	0.39	0.39	2.60	1.17	3.26	0.39	0.39	3.23	2.70	0.39	0.39	1.31
2004	0.39	0.39	0.39	1.16	1.88	0.39	0.39	1.03	4.40	3.62	0.39	0.39	1.24
2005	0.39	0.39	0.39	0.81	0.53	0.62	0.39	0.39	1.38	3.23	0.39	0.39	0.78
2006	0.39	0.39	0.42	0.39	2.02	3.58	0.39	0.39	0.57	3.91	0.39	0.39	1.10
2007	0.39	0.39	0.56	1.66	1.04	2.91	1.30	0.39	5.48	1.25	0.39	0.39	1.35
2008	0.39	0.39	0.39	2.62	0.94	1.97	0.39	1.51	3.05	2.26	0.39	0.39	1.23
2009	0.39	0.39	1.59	1.54	1.33	2.30	1.88	0.39	0.39	0.68	2.75	0.39	1.17
2010	0.39	0.39	0.59	2.56	1.11	4.57	1.59	0.39	1.59	1.23	0.39	0.39	1.27
2011	0.39	0.48	0.39	0.39	1.26	5.29	0.39	0.39	3.15	2.55	0.39	0.39	1.29
2012	0.39	0.39	0.39	0.39	4.92	3.78	0.39	0.39	0.61	3.17	0.39	0.39	1.30
Mean	0.39	0.47	0.58	1.87	1.38	2.45	0.59	0.52	1.90	2.03	0.51	0.39	1.09

Figure 4.1 depicts the monthly average discharge or hydrograph for the past 20 years. It shows the months with the least and highest flow rates.

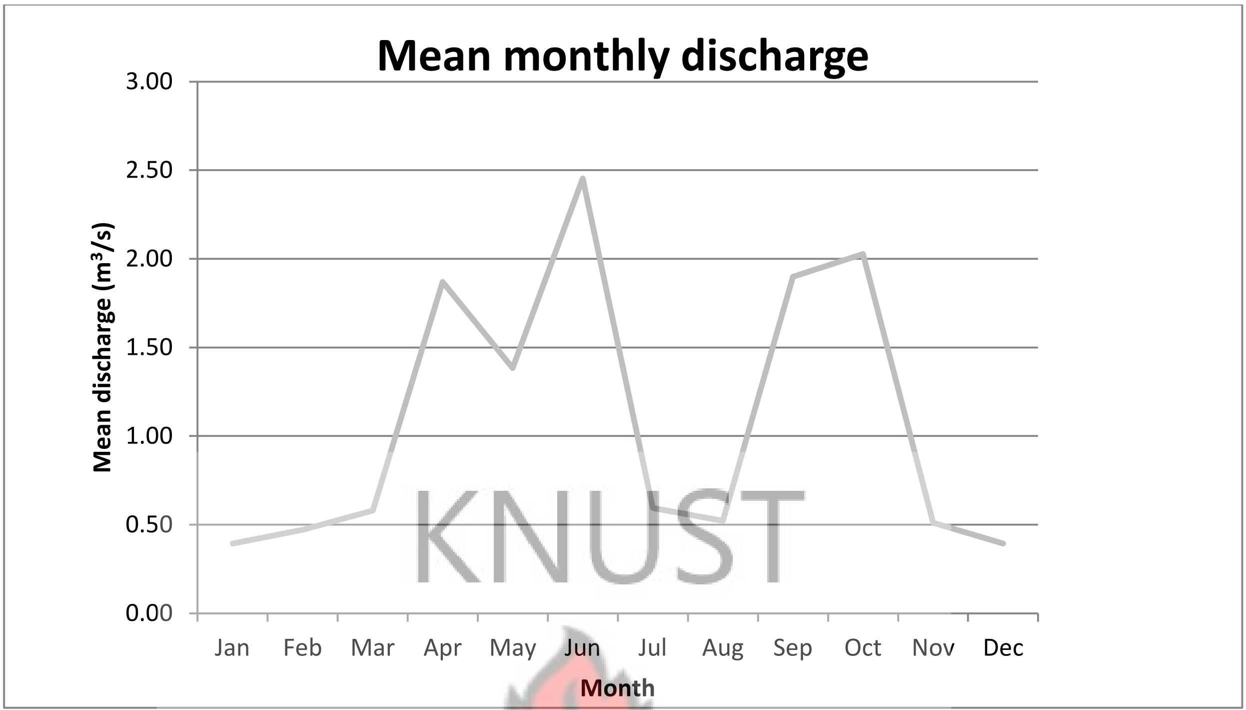


Figure 4.1: **Monthly hydrograph of Pumpum River**

4.1 Flow-duration curve for catchment area

Flow –duration curve of a stream is a graphical plot of stream discharge against the corresponding percentage of time that the stream discharge was equaled or exceeded. In preparing the flow duration curve, stream flow data was arranged in descending order of stream discharges. As the numbers of discharges are very large, a range of values as class intervals was established from the monthly mean flow data from 1992 to 2012 (Table 4.2).The percentage of probability, Pp of any flow magnitude, Q being equaled or exceeded is given as

$Pp = \left(\frac{M}{N+1}\right) x\ 100\ (\%)$……………………………………………………..4.1

Where:

M – The order number of discharge (or class interval)

N – The number of data points in the list

Table 4.2: Monthly mean discharge and percentage probability

By using table 4.2 data points, a flow duration curve was drawn for Pumpum River in figure 4.2

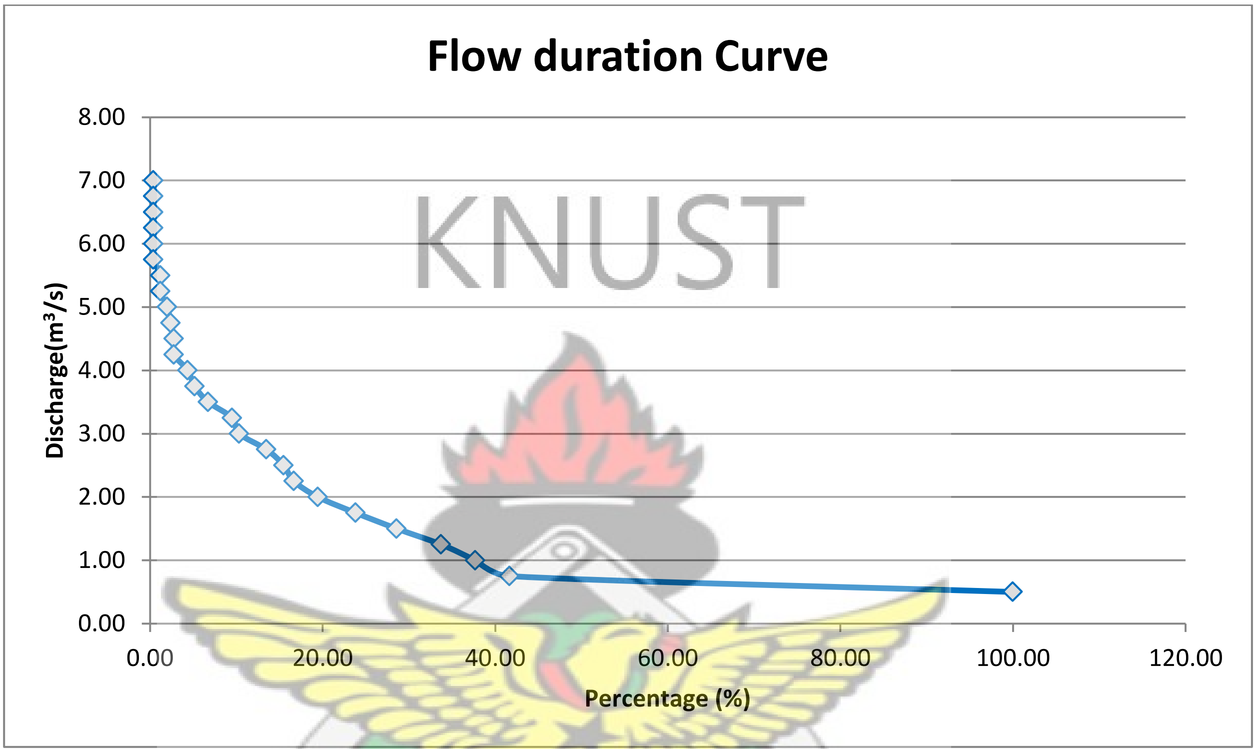


Figure 4.2: **Flow duration curve for Pumpum River.**

From the graph;

The Minimum flow of water is 0.39m^3/s

Discharge at 5% percentage is 3.51m^3/s

Discharge at 20% percentage is 1.70m^3/s

Discharge at 40% percentage is 0.58m^3/s

Discharge at 95% percentage is 0.39m^3/s

4.2 Compensational Flow

Some volume of water is allowed to flow all the time so as to sustain aquatic organisms in the stream.70 liters or 0.07m^3/s is allowed for this purpose leaving 0.32m^3/s of flow available for power generation.

4.3 Power potential

Power potential of the site is obtained from equation 4.1. The design flow obtained is 0.32m^3/s which is available 95% throughout the year from the flow duration curve.

$P(KW) = k\ x\ Q(m^3/s) x\ H(m)$ ………………………………………………………….. 4.2

The best turbine can have hydraulic efficiencies in the range of 80% to over 90% although this will reduce with size. If we take 70 % (as typical water to wire efficiency for the whole system (BHA, 2005) then the above equation simplifies to

$P(KW) = 7x\ Q(m^3/s) x\ H(m)$………………………………………………………….4.3

$$P(KW) = 7x\ 0.32m^3/s\ x\ 50.93(m)$$

$$P(KW) = 114.1$$

Energy = 114.1KW x Capacity Factor x 8760hr

= 114.1KW x 0.95 x 8760hr

= 949,540.2 KWh

4.3 Design of Civil structures

Based on the survey results, the preliminary design was accomplished at prefeasibility level to determine the main specifications of the facilities and equipment.

4.3.1 Height of flood barrier walls

Height of intake barrier walls H_b is the height to which water is likely to rise in the worst flood condition as shown in figure 4.3.

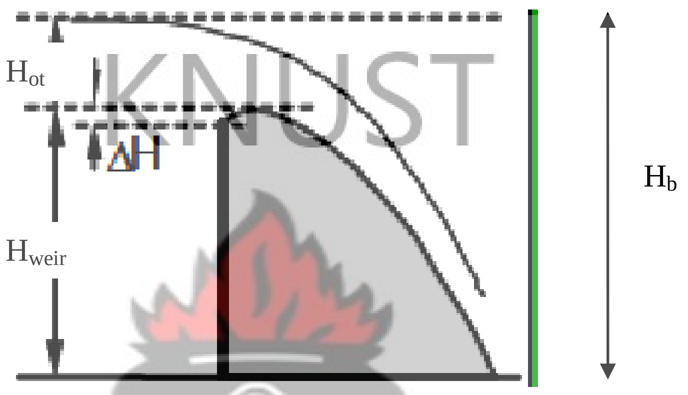


Figure 4.3: Intake barrier wall.

The characteristic discharge of a weir is given by the equation

$$Q_r = C_d \ x \ L_w \ x \ H^{\frac{3}{2}} \quad \text{.......} \quad 4.4$$

Where:

Qr =River discharge (m^3/s)

C_d - Coefficient of discharge for the weir

H_{ot} – Head over top of weir (m)

L_w – Length of weir (m)

Length of weir (L_w) is the same as the width of the river = 5.03m.Mean discharge of the stream is 1.09m3/s and the coefficient of discharge of the weir C_d = 0.6.subsituting this in the equation the head over top of the weir is given by

$H_{ot} = \left[\frac{Q_r}{C_d \ x \ L_w}\right]^{\frac{2}{3}}$ …………………………………………………………………….. 4.5

$$H_{ot} = \left[\frac{1.09}{0.6 \ x \ 5.03}\right]^{\frac{2}{3}}$$

= 0.507m

Height of the weir is assume to be 1m so the height of the flood barrier wall will be given by

$H_b = H_{ot} + H_{weir}$ = 1m + 0.5077m = 1.5077m

4.3.2 Intake dimension

The intake behaves according to discharge equation given by

$Q = AV = AC_d\sqrt{2g(Hr - Hh)}$……………………………………………………4.6

Where:

Q - Discharge through intake (m3/s)

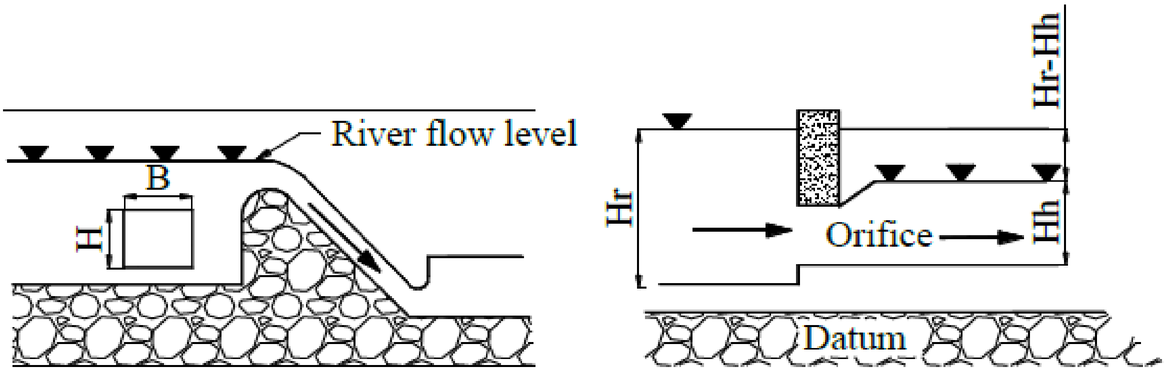
V – Velocity of water passing through intake m/s

C_d – coefficient of discharge of intake orifice (0.6<Cd<0.8)

A – Cross sectional area of intake.

H_r – Depth of water in river channel

H_h – Depth of water in head canal



A section through weir

A section through submerged orifice

Figure 4.4: **Side intake.**

The intake dimensions are determined under two conditions; normal condition when there is no flood and flood condition.

Normal condition

Under this condition H_h = d the depth of intake opening H_r is computed from equation.

H_{weir} is assumed and set to 1m during normal conditions $H_{ot} = 0$

H_r (normal) = $H_{weir} + H_{ot}$ = 1.0m

$$V_i = C_d\sqrt{2g(H_r - H_h)}$$

The velocity is assumed to be $2<V_i<4$ m/s. Assuming a velocity of 2m/s and coefficient of discharge of an intake of 0.6 (assuming masonry orifice) substituting into equation 4.6, height of intake H_h is obtained.

$$2 = 0.6\sqrt{2x9.81(1 - H_h)}$$

$$\left(\frac{2}{0.6}\right)^2 = 2x9.81(1 - H_h)$$

$$\frac{11.11}{2x9.81} = (1 - H_h)$$

H_h = 0.434m

From

$$Q_d = AiVi = HxBxVi$$

Where: Q_d – Design flow = 0.32m^3/s

H – Intake depth = 0.434

V -velocity of intake = 2m/s

$$B = \frac{Qd}{dxVi}$$

B = 0.32/0.434x2 = 0.37m

Therefore the dimension of the side intake is 0.43m x 0.37m

4.3.4 Headrace slope and width (normal flow condition)

Velocity of V_h = 2m/s is considered good practice and chosen as first assumption. This is the maximum allowable velocity for concrete beyond which channel erosion will occur. The head race must be such that this velocity is maintained. Water depth H_h is assumed to be equal to d of intake canal.

$$W = \frac{Q_d}{dxVi}$$

W = 0.32/0.434x2 = 0.37m

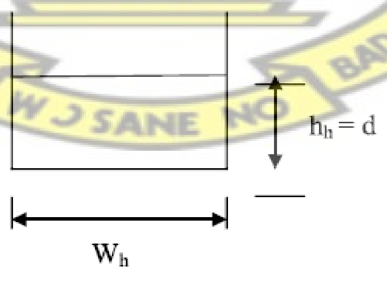


Figure 4.5: Dimension of head canal

Slope of the headrace is found using Manning's equation

$S = \left[\frac{n\ x\ Vh}{R^{0.667}}\right]^2$ ……………………………………………………………………..4.7

Where:

S = slope of the headrace

R = Wetted perimeter

n = roughness value for the material of the headrace

$$R = \frac{A}{P} = \left[\frac{W_h x\ H_h}{W_h + 2H_h}\right]$$

R = (0.37 x 0.434) / (0.37 + 2*0.434) = 0.13

$$S = \left[\frac{0.015\ x\ 2}{0.13^{0.667}}\right]^2$$

S = 0.0137

4.3.5 De-silting Basin (normal flow condition)

De-silting tanks are often provided in the head race of the canals and other water conducting systems to trap as much as possible sediment in the water and thereafter produce sediment free water. A basin for mini-hydropower scheme is often designed to remove particles with diameter greater than 0.3mm with corresponding settling velocity of about 0.03 m/s (Table 4.3).

Table 4.3: Vertical velocities of particles

Particle size mm	Vertical m/s
0.1	0.02
0.3	0.03
0.5	0.1
1.0	0.4

For the construction of the settling basin (figure 4.6), the first step is to choose a suitable width of the basin (W). Rule of the thumb dictates that the width of the settling basin should be two to five times larger than that of the headrace canal trying to make it as bigger as possible depending upon the available width in the MHP location (Pandey B., 2006).

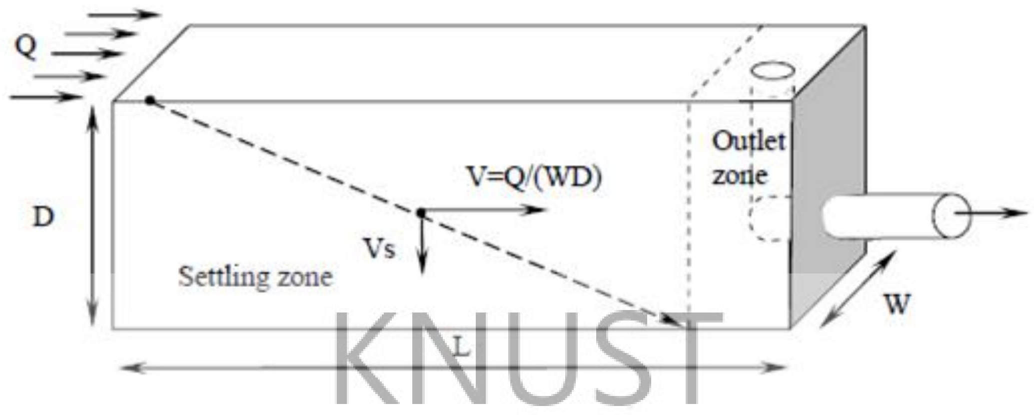


Figure 4.6: **Schematic sedimentation basin**

After determination of the width, the next process is to calculate the length of settling basin ($L_{settling}$) by using equation 4.8.

$$L_{settling} = \frac{2Q}{WV_{vertical}} \quad \ldots\ldots 4.8$$

Where,

Q = design flow (m^3/s)

$V_{vertical}$ = fall velocity (For the settling particles of 0.3 mm diameter the fall velocity is taken as 0.03 m/s).

By this equation the length of the settling basin is determined, but it is very important to check at this time that the length of the settling basin is around four to ten times its width.

The width of the head race canal = 0.37m

The width of the settling basin (W) was chosen as 1.85 m which is about Five times the width of the headrace canal and is therefore allowed.

$$L_{settling} = \frac{2x0.32}{1.85x0.03}$$

L = 11.53m

Here the L/W which is 11.53/1.85 = 6.85 = 6.23 which is about 6 times the width and therefore the width is within the range of 4-10 times the length.

4.3.7 Forebay Design

Forebay is usually designed for a live storage of 2 minutes. Stored water is utilized while starting the turbines. The transition canal is provided for lowering the velocity gradually. Forebay is constructed immediately before the penstock pipe and at the end of the head race (figure 4.7). The most important element to be calculated in the design of the forebay tank is the submergence head. The submergence head or the depth of water above penstock pipe, should fulfill the criteria (Submergence head) hs ≥1.5 V2/2g

Where, V refers to the velocity of water in the penstock, which in this case is 2.5 m/s;

$$hs = \frac{1.5\ xV^2}{2xg} \quad \text{......} 4.9$$

$$hs = \frac{1.5\ x2.5^2}{2x9.81}$$

hs = 0.5m

The covering water depth at the penstock inlet must be above the following value to prevent the occurrence of inflow turbulence.

D≤ 1.0m -> h ≥ 1.0d
D> 1.0m -> h ≥ 1.0d^2

Where,
h: water depth from the centre of the inlet to the lowest water level of the head tank = covering water depth (m)
d: inner diameter of the penstock (m) which is 0.41m

According to design guidelines, the value should not be less than one times the penstock diameter hence we assumed increase by 2 times

Hs = 2 x 0.5m = 1m

Total depth = submergence head + diameter of penstock + freeboard

= 1m + 0.43m + 0.5m = 1.93m

Storage period T = 30s (minimum 15s)

Size of forebay

$Volume(V) = Q \: x \: T$ ………………………………………………………………… 4.10

$$Volume(V) = 0.32 \: x \: 30$$

Volume = 8.4m^3

Area of forebay

$A = \frac{V}{h_s}$……………………………………………………………………… 4.11

$$A = \frac{9.6m^3}{1m}$$

Area = 9.6m^2

Assume a width (W) of 2m

Length (L)

$$L = \frac{9.6m^2}{2m}$$

Length (L) = 4.8m

Transition length:

We assume the transition angle to be 35^o

$$L_{transition} = \frac{2 - 0.37}{2 \: x \: tan35}$$

Transition length = 1.16m

Total length of forebay = 4.8m + 1.16m = 5.96m

Spillway in forebay is given by equation 4.12

$$Q_{spillway} = C_w x L_{spillway} x H_{overtop}^{\frac{3}{2}} \quad \text{..} 4.12$$

(ENTEC AG, March 2001) agrees that for a MHP, broad round edged profile where C_w = 1.6 is easy and reliable to construct. Therefore, the value of C_w taken while designing spillway for the project is also 1.6

$H_{overtop}$ = 500mm = 0.5m

$$L_{spillway} = \frac{Q_{spillway}}{C_w x H_{overtop}^{\frac{3}{2}}}$$

$$L_{spillway} = \frac{0.32}{1.6x0.5^{1.5}}$$

Spillway length = 0.57m

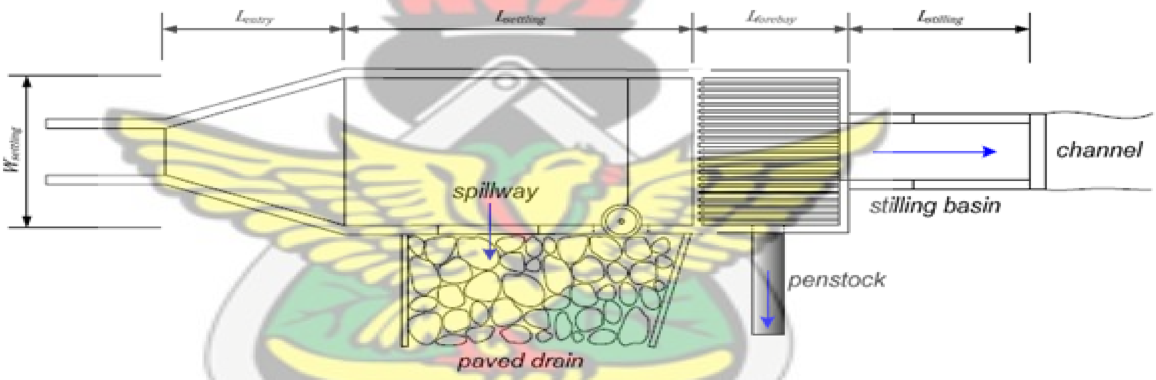


Figure 4.7: Forebay dimension

4.3.8 Penstock Design

In designing the penstock, it length (L) was determined from topographic map. In this project, the length of the penstock was 200m.Restricting head loss to 5% is considered to be a good practice. Head loss in penstock is given by equation 4.13

$$\frac{h}{1} = \frac{10.3 \, x \, n^2 x \, Q^2 x \, L}{D^{5.33}} \quad \text{..} \, 4.13$$

Where:

D = Penstock diameter

h = Head loss

n = surface roughness of penstock

If we limit hf at 4H/100, D can be computed knowing Q, n and L, by equation 4.14.

$$D = 2.69\left(\frac{n^2 x\, Q^2 x\, L}{H}\right)^{0.1875} \quad \text{……………………………………………………….... 4.14}$$

$$D = 2.69\left(\frac{0.012^2 x\ 0.32^2 x\ 200}{50.93}\right)^{0.1875}$$

D = 0.43m

Pipe Thickness

The pipe thickness t for a pipe of internal diameter D and internal pressure P is given by

$$t = \frac{PxD}{S} + e_s \quad \text{………………………………………………………………………… 4.15}$$

Where e_s – Extra thickness to allow for corrosion

P – Hydrostatic pressure in pipe (KN/m^2)

D – Internal pipe diameter (mm)

S – Allowable tensile strength (KN/m^2)

Pressure of water = Pa + pgh ………………………………………………………………. 4.16

Where Pa – Atmospheric pressure at water surface

P – Water density

h- Head of water

g – Acceleration due to gravity

P = 1.103 x 10^5 + 1000 x 9.81 x 50.93

P = 110300 + 499623.3 = 609923.3 N/m

Material selected for this penstock is welded steel with ultimate tensile strength of $400\ x\ 10^6\ N/m^2$ (ESHA, 2004) with a safety factor of 2.

$$t = \frac{609923.3x0.43x2}{400\ x\ 10^6} + e_s$$

T = 0.001311m + 0.001m = 0.002311m = 2.3mm

4.4 Design of Mechanical equipments

Turbine selection is based on the output of turbine and available head for the site. From figure 4.8, the suitable turbine for this plant is Cross flow turbine.

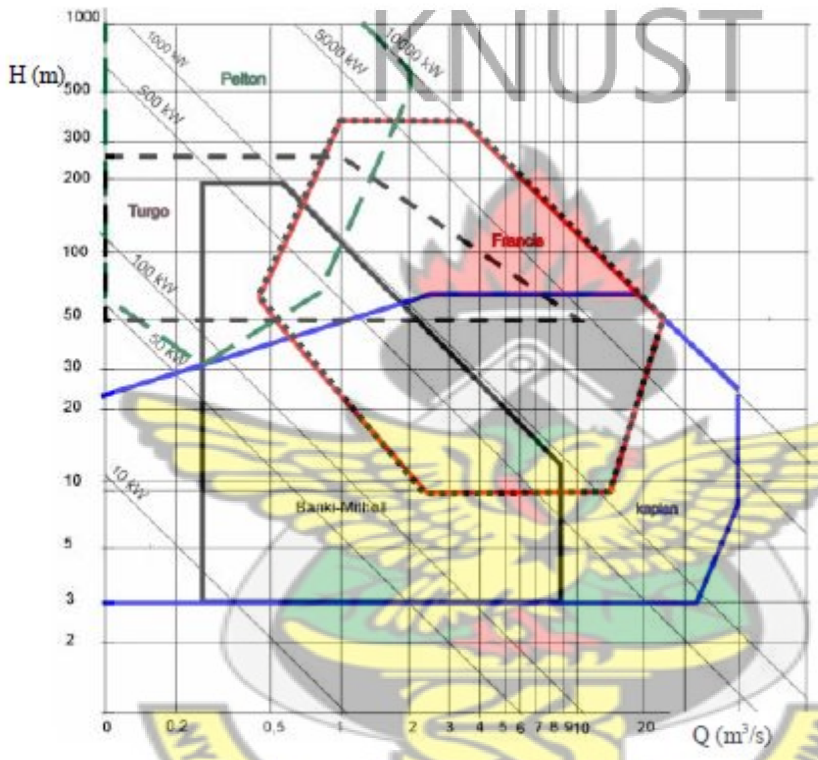


Figure 4.8: **Turbine Selection Graph**

4.4.1Determination of specific speed of turbine n (rpm)

Rotational speed of the turbine is given by equation 4.18

$N_s = \frac{N\sqrt{P}}{H^{1.25}}$ …………………………………………………………………… 4.18

Net head = Gross head – Head loss

Net head = Gross head – 4% (Gross Head)

= 50.93m – (0.04x50.93) = 48.89m

Rotational speed of turbine = 750 rpm

$$N_s = \frac{750\sqrt{114}}{48.89^{1.25}}$$

Ns = 62

This is within the specific speed range of a cross flow turbine given as 40 $\leq$ Ns $\leq$ 200. (MHP-1, 2009)

4.4.2 Cross flow runner diameter

Runner diameter of cross flow turbine is given by equation 4.19.

$$D_{runner} = \frac{41\sqrt{H_{Net}}}{Crossflow\ RPM} \quad \text{………………………………………………………….. 4.19}$$

$$D_{runner} = \frac{41\sqrt{48.89}}{750}$$

D = 0.38 m

4.4.3 Cross flow runner length

The jet thickness is usually between one tenth and one fifth of runner diameter. Having estimated t_{jet}, the approximate runner length L_{runner} can be found from the orifice discharge equation

$$Q = A_{nozzle}\sqrt{2gH_{net}}$$

$$Q = t_{jet}\ x\ jet\ width\ x\ \sqrt{2gH_{net}}$$

$$Q = t_{jet}\ x\ L_{runner}\ \ x\ \sqrt{2gH_{net}}$$

$$L_{runner} = \frac{0.23Q}{t_{jet}\sqrt{H_{net}}} \quad \text{…………………………………………………………….. 4.20}$$

t_{jet} = 1/5 x D = 0.2 x 0.38 = 0.0758

$$L_{runner} = \frac{0.23x0.32}{0.076\sqrt{48.89}}$$

L = 0.139m

4.5 Sizing of Electrical equipments

The output of generator in KVA is calculated from the following equation

$$P(KVA) = \frac{9.81\ x\ H\ x\ Q\ x\ n}{pf} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4.21$$

Where H – net head

Q – Rated discharge

n – Combined efficiency of turbine, transmitter and generator

pf –power factor usually 80%

Power factor (pf) is based on the type of load in the system. However, 80% is usually applied for convenient purpose.

$$P(KVA) = \frac{9.81\ x\ 48.89x\ 0.32\ x\ 0.7}{0.8}$$

P (KVA) = 134

4.5.1 Speed and number of poles

The rated rotational speed is specified according to the frequency (50 or 60 Hz) of power network and the number of poles as shown in equation 4.22 for induction generator selected for this project.

$$N(rpm) = \frac{120f}{P}(1+s) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ 4.22$$

Where P – number of poles of generator

F – Frequency of the system (Hz)

S – Slip of generator

Slip is given by the equation

$$s = \frac{N_s - N_r}{N_s} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots$$

4.23

Where Ns – is the synchronous speed

Nr - is the rated rotor speed of the induction motor and Nr always exceeds Ns while acting as a generator.

$$Ns = \frac{120f}{P}$$

The speed desired for the generator is 750 rpm and therefore the number of poles is

$$P = \frac{120f}{Ns}$$

$$P = \frac{120x50}{750}$$

P = 8 pole generator

Rotational speed of induction generator

$$N(rpm) = \frac{120f}{P}(1 + s)$$

S is normally given as 0.02

$$N(rpm) = 750(1 + 0.02)$$

= 765

Gearing ratio (G)

$$G = \frac{alternator\ rpm}{turbine\ rpm}$$

$$G = \frac{765}{750}$$

1.02

Figure 4.9 illustrates the layout of the main components of the project on the landscape.

Table 4.4 depicts the summary of the project specifications.

Figure 4.9: Layout of the main components on site

Table 4.4: Summary of project technical specifications

Components	Dimension/Size
Drainage Area (km^2)	87
Gross head (m)	50.93
Design Discharge (m3/s)	0.32
Orifice for side intake	Area – 0.37m x 0.43m
	Delivery discharge – 0.32m^3/s
Headrace canal	Area – 0.37m x 0.43m
	Wetted perimeter – 0.13m
	Velocity – 2m/s
	Canal bed slope – 0.0137 (1:73m)
Settling Basin	Length – 11.53m
	Width – 1.85m
Forebay	Length -5.96m
	Width -2m
	Depth - 1.93m
Penstock	Diameter - 0.43m
	Thickness - 2.3mm
	Length -250m
Turbine	Crossflow -(114KW)
	Specific Speed - 62
	Runner diameter - 0.38m
	Runner length - 0.14m
Generator	Size - 134 KVA
	rotational speed -750 rpm
	number of poles - 8

4.6 Economic Appraisal

The economic analysis is a comparison of cost and benefits that enables the investor(s) to make informed choice whether to develop the project or abandon it. Small hydro cost can be split into three segments which are: Machinery, Civil works and external costs. Payback method was used to validate the viability of the project. The payback method determines the number of years required for the invested capital to be offset by resulting benefits. The required number of years is termed the payback, recovery, or break-even period. The economic analysis was done using the software program RETScreen4, a clean energy project analysis software which is provided free of charge by Natural Resources Canada.

4.6.1 Project Costing

The Small Hydro Project Model of RETScreen software offers two methods for project costing; the detailed costing method and the formula costing method. The costing method is selected from the drop-down list in the beginning of *Cost Analysis* worksheet. The detailed costing method will not be used in this study. The formula costing method is based on empirical formulae that have been developed to relate project costs to key project parameters. After selecting formula costing method for calculation of project costs, project country should be entered (Table 4.5). The formula method uses Canadian projects as a baseline and then allows the user to adjust the results for local conditions. The cost of projects outside Canada compared to the cost of projects in Canada will depend, to a great extent, on the relative cost of equipment, fuel, labour and equipment manufacturing, and the currency of the country. For projects outside Canada, costs are adjusted based on the relative costs of these items and the exchange rate. The ratio of the costs of fuel and labour between Ghana and Canada for the year 2013 are examined and the following values were found:

Canadian average diesel fuel cost was 5.1 US$/gallon and Ghana average diesel fuel cost 5.0US$/gallon. Therefore Ghana versus Canadian fuel cost ratio is calculated as 1:1.

Canadian versus Ghana labor cost was calculated based on the minimum wage per month. Canada’s minimum wage is 16,710$/Month and Ghana minimum wage is 689$/Month (Wikipedia.com) and as such Ghana versus Canada labor cost is calculated as 0.04:1

Ghana versus Canadian equipment manufacture cost ratio is also estimated as unity since the manufacturing sector for hydropower does not exist in Ghana and significant percentage of the equipment needed is generally imported. The average exchange rate between USD and CAD for the year 2013 is found as 0.98 (Bank of Canada, 2013).

The selection of project classification is an important parameter for the correct evaluation of project costing because the costs of certain components, particularly the civil works, are affected by this selection. This is due to larger projects requiring more conservative designs with higher associated risks.

Table 4.5: Hydro formula costing method.

Country	Ghana		
Local vs. Canadian equipment cost ratio		1.00	
Local vs. Canadian fuel cost ratio		1.00	
Local vs. Canadian labour cost ratio		0.04	
Equipment manufacture cost coefficient		1.00	
Exchange rate	\$/CAD	0.98	
Cold climate	yes/no	No	
Design flow	m³/s	0.32	0.32
Gross head	m	50.93	50.93
Number of turbines	turbine	1	1
Type		Cross-flow	Cross-flow
Flow per turbine	m³/s	0.32	
Turbine runner diameter per unit	m	0.29	
Facility type		Mini	Micro
Existing dam	yes/no	No	
New dam crest length	m	1	
Rock at dam site	yes/no	Yes	
Maximum hydraulic losses	%	4.0%	4.0%
Miscellaneous losses	%	2.0%	

Based on the hydro costing method, the initial cost of the project was estimated as $395,000 breaks down as follows (Table 4.6).

Table 4.6: Cost categorization of project.

Initial costs (credits)	**Amount $**	**Adjustment factor**	**Amount $**	**Relative costs**
Feasibility study	12,000	1.00	12,000	3.0%
Development	15,000	1.00	15,000	3.8%
Engineering	75,000	1.00	75,000	19.0%
Power system				
Hydro turbine	118,000	1.00	118,000	29.9%
Road construction	0	1.00	0	0.0%
Transmission line	4,000	1.00	4,000	1.0%
Substation	4,000	1.00	4,000	1.0%
Balance of system & miscellaneous				
Penstock	104,000	1.00	104,000	26.3%
Canal	2,000	1.00	2,000	0.5%
Tunnel	0	1.00	0	0.0%
Other	61,000	1.00	61,000	15.4%
Sub-total:	167,000		167,000	
Total initial costs	**395,000**		**395,000**	**100.0%**

4.6.2 Retscreen – Energy Model and Power Project General Entries

RETScreen project information entries are list below. Items in **bold** refer to RETScreen field name, and items in normal font were entered by the user. Note that descriptions of some of the more obscure fields are given below it.

Analysis Type: Method 1

Proposed Project: Run-of -river

Gross Head: 50.93 (m)

Maximum Tail water Effect: 0.00 (m)

Residual Flow: 0.070 (m3/s)

Percent Time Firm Flow Available: 95 (%)

Design Flow: 0.32 (m^3/s)

Turbine Type: Cross-flow

Turbine Efficiency: Standard

Number of Turbines: 1

Efficiency Adjustment: 0.0 (%)

Flow Values (m3/s) for the Flow Duration Curve (FDC): 1992-2012 estimated average Flow Data (m3/s) were used

Maximum Hydraulic Losses: 4 (%)

Miscellaneous Losses: 2 (%)

Generator Efficiency: 89 (%)

Availability: 95 (%)

(This represents about 18 days of equivalent down time per year.)

Electricity Export Rate: 0.1 Dollars ($) per kilowatt hour (kWh), or 100 dollars per megawatt hour ($/MWh)

Total Initial Cost: 395,000 ($)

O&M Parts and Labour: 10,000 ($)

Fuel Cost Escalation Rate: 0 (%)

Inflation Rate: 9.0 (%) (Bank of Ghana, 2010)

Project Life: 25 (yrs)

Debt Ratio: 70 (%)

(This is the amount of money borrowed compared with the money used).

Debt Interest Rate: 20 (%)

Debt Term: 15 (yrs)

(This is the length of time that debt is being paid on the project).

Table 4.7: Financial summary of project.

Financial viability		
Pre-tax IRR - equity	%	43.4%
Pre-tax IRR - assets	%	21.3%
Simple payback	yr	4.9
Equity payback	yr	3.2

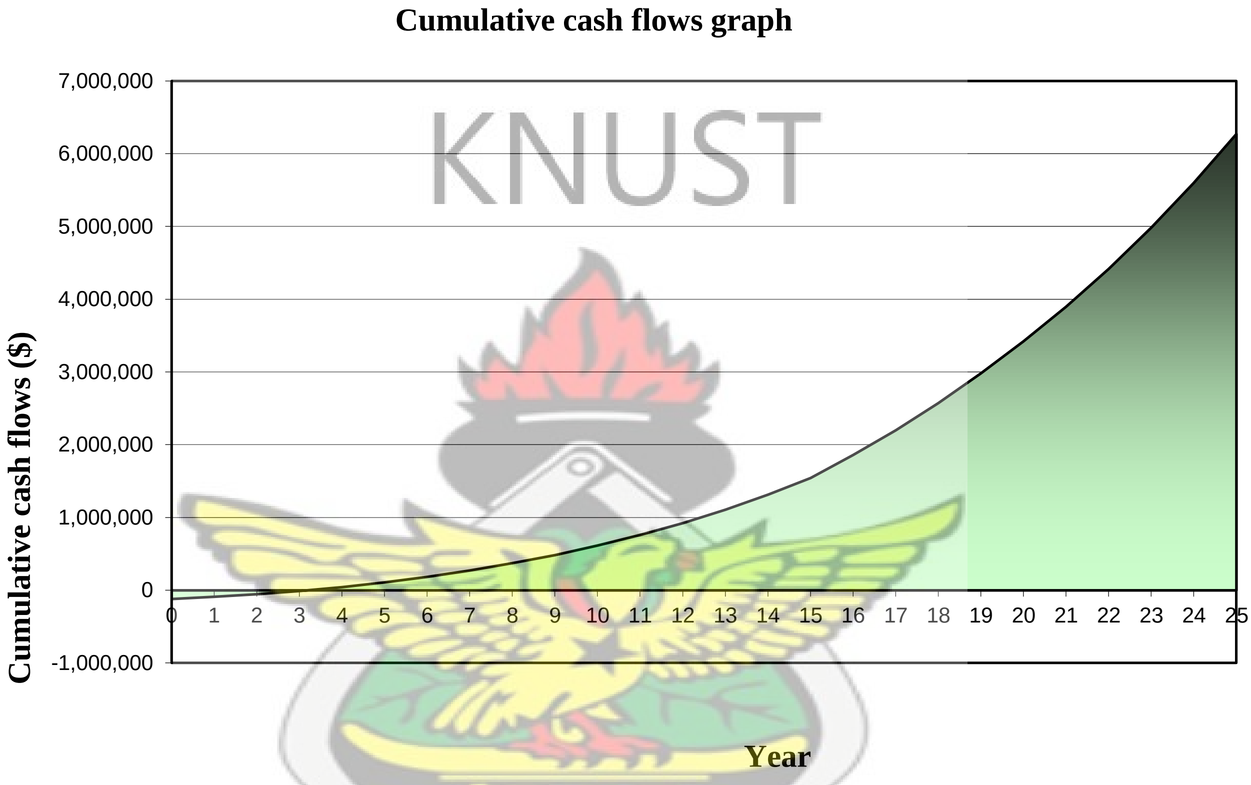


Figure 4.10: Cumulative cash flow graph

The project is feasible according to RETScreen-Small Hydro Model as the net present value and internal rate of return are positive and the benefit cost ratio is above 1 which is shown in Figure 4.10. The simple payback is after 4.9 years.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The summary of the main findings based on the analysis undertaken in chapters is presented in this section followed by key recommendations.

- Stream flow rate and head of Pumpum river

  Adequate head and flow are necessary requirements for hydropower generation (ESHA, 2004). Pumpum River has a potential for producing electricity. The available head measured was 50.93m. Pumpum River is perennial as it has some flow at all times of the year. There is a guarantee flow rate of 0.32m^3/s throughout the year. The designed flow obtained in this work is 0.32m^3/s which is available 95 percentage of the time and gives a power of 114 KW.

- Preliminary design of small hydro power plant.

  Preliminary design of the hydropower plant was carried out. Cross flow turbine was selected since it meets both head and power requirements which can be produced by the plant and also maintains appreciable efficiency at low flow rate. The turbine was sized to produce power output of 114kW with a runner diameter of 380mm and a runner length of 140mm.An 8 poles Induction motor was used as the preferred generator with a rated power of 134KVA and a rotational speed of 750rpm.

  The following civil work components were designed: Weir and intake, headrace, spillway, de-silting tank, forebay tank and penstock. The dimension of the side intake is 0.37m x 0.43m allowing a delivery of 0.32m^3/s discharge into the headrace canal. Headrace canal have a size of 0.37m x 0.43m with a bed slope of 0.0137.Settling basin has the following dimensions: Length -11.53m, Width-1.85m.Forebay has the following dimensions: Length – 5.96m, Width -2m, Depth – 1.93m.The penstock material selected is welded steel with the following dimensions: Diameter -430mm,thickness -2.3mm and length of 250m

- Economical Appraisals of Kintampo mini hydropower plant

  RETScreen module was used to analyze the economic viability of the hydropower project. From the module, the simple payback of 4.9 years was obtained. Initial cost of the project was $ 395,000 and estimated annual revenue of $ 90,830.

- Modeling of RETScreen module

  RETScreen module was used to analyze the viability of the project. The outputs calculated from this module were: Maximum hydraulic losses (4%), power capacity (106 KW), Capacity factor (95%) and electricity exported to grid (880MWh).The result of the experiment compares favorably with the result of RETScreen. Whiles 114 KW was obtained from the experiment as the power produced, 106 KW was estimated by the RETScreen Software. This means the software value is 93% of the experimental value. For the annual energy delivered to the grid, experimental result gave 950MWh whiles RETScreen gave annual energy delivered to the grid as 880 MWh. This value is 93% of the experimental result. The proposed project will bring benefits such as no atmospheric pollutants and minimal green house gases emission; enhance air quality, minimized depleting non-renewable fuel resources and slowing down climate change. Proposed small hydropower plant will be sustainable and can be implemented.

5.2 Recommendations.

The project is found to be technically attractive, financially sound and environmentally friendly. The key recommendations can be summarized as follows:

i. The in- situ and laboratory test of rock and soil type at project site is recommended to get further geo-technical properties of rock and soil in details.

ii. It is recommended to carry out detail investigation of flood hazards around proposed project site.

iii. The catchment area needs to be estimated using GIS software such as ArcGIS.

iv. It is recommended that the river be gauged for at least a year for accurate discharge information before any serious hydropower development.

REFERENCES

Anderson, T. D (1999), *Rural Energy Services, A handbook for stainable energy development, Intermediate Technology Development Group (ITDG)*, London

BHA (2005), *A guide to UK mini-hydro developments*. British Hydropower Association.

Boustani, F (2009), *An Assessment of the Small Hydropower Potential of Sisakht Region of Yasuj*, World Academy of Science, Engineering and Technology 57 2009

Christian Arduser, Leif Karcheter (2009), *Civil Works for micro hydro power units*, Institute of civil engineering, University of Applied sciences, Northwestern Switzerland.

ESHA (2004), Guide on how to develop a small hydro plant

D. Bashir (2009), *Hydrological Studies for small Hydropower planning*. National Water Resources Institute, Kaduna

Eri A. Boye (2011), *A feasibility and economic study into the use of micro hydro power applications to generate electricity from the Victoria Capital Regional District's municipal water facility, Victoria, British Columbia, Canada*. Msc Thesis, University of Iceland

Emmanuel Mwangomo (2010), *Proposing sustainable small hydro power for rural setting*, Msc thesis University of Dar es Salaam.

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

Gordon, N. D, McMahon TA, Finlayson B.L, Gippel G.J, Nathan R.J,(2004). *Stream Hydrology - An introduction for ecologists*. 2nd Edition, Wiley

Google Earth, *www.google earth*

Hauer, F.R and Lambert', G. (1996), *Methods **in** stream ecology*. Academic Press.

Jayanta, K. G (2009), *Geospatial Technology - its applications in small Hydro Power Project*, A paper presented at international training course on small hydro

JICA (2003), MHP-*1 Manual for Design, Implementation and Management for Micro-hydropower volume 1*.

Karekezi, S and Kimarii J (2005), "The potential contribution of non-electrified renewable energy technologies for poverty reduction in east Africa"

Klaus Jorde (2009), *Good and Bad of Mini Hydro Power*, the ASEAN Center of Energy (ACE)

Mohibullah, M. A. (2004), Basic *Design Aspects of Micro Hydro Power Plant and Its*

Potential Development in Malaysia, National Power & Energy Conference (PECon) 2004 Proceedings, KualaLumpur, Malaysia.

Ministerial conference on water for Agriculture and energy in Africa (2008). *Hydro Power Resource Assessment of Africa.*

Orzan Korkmaz (2007), A case study of feasibility assessment of small hydropower scheme, Middle East Technical University.

Pushpa Chitrakar (2005), Micro – Hydropower Design Aids Manual, Version 2005.10, Small Hydropower promotion project GTZ.

Ramos H (2000), *Guidelines for design of small hydropower plants-*, Department of Economic Development, Belfast, North Ireland.

Robert Bass (2009). *Hydroelectric Feasibility Study. An assessment of the feasibility of generating power using storm water in Oregon City.*

RET Screen International (2010), *Clean Energy Project Analysis Software.* Natural Resources Canada Ottawa.

Sarkar, S and Gundekar, H. G (2007), *Geomorphologic Parameters: Are they Indicators for Installation of a Hydropower Site*, International Conference on Small Hydropower - Hydro Sri Lanka, 22-24 October 2007.

Standards/Manuals/guidelines for small hydro development (2008), *Ministry of New and*

Renewable Energy, Government of India

Sven Dernedde, A.K. Ofosu-Ahenkorah (2002). *Mini Hydro Power in Ghana Prospects and Challenges.* Energy Foundation, Ghana.

TEA (2004), *World Energy Outlook*-, International Energy Agency, Paris,

France.Wamukonya,N (2001), *Renewable Energy Technologies in Africa, UNEP Collaborating Centre on Energy and Environment.*

Wazed, M.A and Ahmed, S (2008), Micro *Hydro Energy Resources in Bangladesh*, A *Review*. Australian Journal of Basic and Applied Sciences. 2(4):1209-1222, 2008 TSSN 1991-8178 ·0 2008, ENSTnei Publication.

Younis A. G (1996), *Use of a GIS in reconnaissance studies for small-scale hydro power development in a developing country: a case study of Tanzania*-. Proceedings of the Vienna conference, April 1996. TAHS Publ. no. 235, 1996

APPENDICES

APPENDIX A. Monthly rainfall (mm) from year 1992 to 2012

	Month											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1992	0	10.3	17.7	188.5	157.4	147	83.8	1.5	203.6	138.5	54.3	0.5
1993	0	61	79	112.7	245.7	154	19.8	18	186.2	151.1	44.3	8.3
1994	14.2	24.6	71.5	100.8	116.6	139.9	16.2	17	190.2	223.9	47.8	0
1995	0	32	144	268.7	155.5	156.3	108.7	103.3	201.1	150.6	39.5	41.9
1996	0	159.8	96.1	135.1	113.4	224.5	128.6	125.6	62.1	186.2	14.8	11.6
1997	24.5	0	57.8	59.2	130.2	219.1	94.9	53.7	83.2	165.1	17.6	18.6
1998	5.6	4.9	34.6	137	58.6	195.4	57.1	45.1	165.7	243.2	6.5	23.7
1999	20.5	74.1	152.4	140.1	163	129.8	34.7	83.7	156.8	136.7	86.5	0
2000	27.4	0	62.3	243.1	104.8	124.5	101.6	118.5	75	59.3	101.1	0
2001	0	10.1	134.2	398.6	76.3	311.3	56.4	31.5	112.3	70.7	26.1	10.7
2002	30.1	30.2	102.9	262.4	179.1	172.3	97.4	44.7	67.7	152.6	77.2	7
2003	22.5	63.9	56.1	204.6	144.9	232.8	32	50.7	228.7	211	78.6	0
2004	14.6	56.9	48.2	137.9	177.2	58.9	94.4	131	281.2	253.8	52.9	0
2005	1.1	47	78	123.7	114	112.5	73.6	40.7	142.6	233.7	56.9	29.4
2006	47.6	6.3	106.7	65.5	183.3	249.1	85.4	15.3	106.9	267.6	15	7.6
2007	0.6	19	116.2	161.2	137.7	217.7	146.8	100.5	330.4	140.5	81.8	0
2008	0	41.4	49.8	204.9	132.9	174	81.5	154.4	219.5	188.7	40.1	39.3
2009	0	53.8	161.3	154.3	151.1	189.4	172.1	8.5	86.4	112.9	203	14
2010	0	28.5	115.8	203.5	141.7	293.4	158.8	91.5	151.4	139.2	64.9	20
2011	2.6	96	36.6	32	148.2	325.5	88.2	27.5	222.9	201.6	12.4	0
2012	1	42.5	80.1	96.8	320.7	256.7	89.4	7.5	108	232	43.9	9.4
Mean	10.11	41.06	85.78	163.36	150.11	194.48	86.73	60.49	161.04	174.23	55.49	11.52

APPENDIX B. Monthly average temperature (^oC) from year 1992 to 2012

	Months											
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1992	25.35	28.4	28.8	27.45	26.8	25.45	23.9	23.8	24.85	25.9	25.4	25.7
1993	25.3	28.7	27.3	27.85	27.35	26.05	24.9	24.65	25.35	26.25	26.8	25.45
1994	26.5	28.6	28.85	27.95	27	25.9	25.35	25.15	25.55	25.7	25.85	25.1
1995	25.7	28.65	28.35	27.7	27.2	26.2	25.4	25.4	25.55	25.9	26.35	25.45
1996	26.9	27.7	27.65	27.3	27.1	25.8	25.05	24.9	25.05	25.45	26.7	25.9
1997	26.55	27.8	29.15	27.55	26.75	25.6	24.75	24.6	25.55	26.55	27	26.7
1998	26.95	28.95	30.85	28.55	27.75	26.35	25.3	25.05	25.65	26.1	27.45	26.55
1999	27.5	27.45	27.95	27.05	26.85	26.2	25.4	24.8	24.8	25.05	26	25.45
2000	27	26.75	29.25	27.25	27	25.65	24.55	24.2	24.95	25.8	26.45	25.7
2001	26.65	28.25	28.7	26.85	26.8	25.9	25.15	24.2	24.5	25.95	26.8	27.25
2002	25.9	28.6	28	27.5	26.7	25.7	25.3	24.35	24.95	25.9	26.35	25.35
2003	26.65	28.8	28.95	27.5	27.35	25.65	25.05	24.9	25.75	26.45	26.45	25.7
2004	26.8	28.25	28.3	27.2	26.7	25.75	24.85	24.65	25.35	26.15	26.6	26.85
2005	25.35	29.05	27.9	27.9	27	25.9	24.7	24.1	25.3	25.55	26.5	25.6
2006	27.15	28.1	27.65	27.85	26.65	26.35	25.5	25.15	25.8	26.3	26.4	25.95
2007	26.1	28.8	29	27.35	26.85	25.9	25.3	24.6	25.25	25.7	26.3	25.9
2008	24.5	29.15	28.2	27.15	26.95	25.8	25.1	24.9	25.5	25.95	26.4	25.9
2009	28.3	26.45	27.3	26.75	26.7	25.8	24.55	24.5	25.2	25.45	25.7	26.15
2010	27.1	28.5	28.15	27.75	27.15	25.8	24.65	24.45	25	25.55	25.95	26.15
2011	25.15	27	27.35	27.75	26.85	25.5	24.2	23.9	24.9	25.65	26.9	25.75
2012	26.1	28.05	28.2	27.45	26.5	25.7	24.6	24.35	25.5	26.05	26.8	26.05

APPENDIX C. Estimated monthly discharge (m^3/s) of Pumpum River from year 1992 to 2012

Year	Rainfall	Temperature	Annual Sunshine	Possible Evaporation (Blaney-Criddle)	Real Evaporation	Runoff	Direct Runoff	Base Runoff	Monthly Runoff	Monthly mean discharge
Jan-92	0	25.35	8.21	97.12	0.00	0.00	0.00	12.12	12.12	0.39
Feb-92	10.3	28.4	7.51	95.12	10.30	0.00	0.00	10.95	10.95	0.39
Mar-92	17.7	28.8	8.45	107.95	17.70	0.00	0.00	12.12	12.12	0.39
Apr-92	188.5	27.45	8.34	103.46	103.46	85.04	55.28	11.73	67.01	2.25
May-92	157.4	26.8	8.74	106.86	106.86	50.54	32.85	12.12	44.97	1.46
Jun-92	147	25.45	8.53	101.14	101.14	45.86	29.81	11.73	41.54	1.39
Jul-92	83.8	23.9	8.78	100.37	83.80	0.00	0.00	12.12	12.12	0.39
Aug-92	1.5	23.8	8.66	98.76	1.50	0.00	0.00	12.12	12.12	0.39
Sep-92	203.6	24.85	8.25	96.46	96.46	107.14	69.64	11.73	81.37	2.73
Oct-92	138.5	25.9	8.37	100.27	100.27	38.23	24.85	12.12	36.97	1.20
Nov-92	54.3	25.4	7.98	94.50	54.30	0.00	0.00	11.73	11.73	0.39
Dec-92	0.5	25.7	8.18	97.55	0.50	0.00	0.00	12.12	12.12	0.39
Jan-93	0	25.3	8.21	97.00	0.00	0.00	0.00	12.12	12.12	0.39
Feb-93	61	28.7	7.51	95.73	61.00	0.00	0.00	10.95	10.95	0.39
Mar-93	79	27.3	8.45	104.47	79.00	0.00	0.00	12.12	12.12	0.39
Apr-93	112.7	27.85	8.34	104.37	104.37	8.33	5.41	11.73	17.15	0.58
May-93	245.7	27.35	8.74	108.18	108.18	137.52	89.39	12.12	101.51	3.30
Jun-93	154	26.05	8.53	102.54	102.54	51.46	33.45	11.73	45.18	1.52
Jul-93	19.8	24.9	8.78	102.77	19.80	0.00	0.00	12.12	12.12	0.39
Aug-93	18	24.65	8.66	100.78	18.00	0.00	0.00	12.12	12.12	0.39
Sep-93	186.2	25.35	8.25	97.59	97.59	88.61	57.60	11.73	69.33	2.33
Oct-93	151.1	26.25	8.37	101.07	101.07	50.03	32.52	12.12	44.64	1.45
Nov-93	44.3	26.8	7.98	97.57	44.30	0.00	0.00	11.73	11.73	0.39
Dec-93	8.3	25.45	8.18	96.99	8.30	0.00	0.00	12.12	12.12	0.39
Jan-94	14.2	26.5	8.21	99.70	14.20	0.00	0.00	12.12	12.12	0.39
Feb-94	24.6	28.6	7.51	95.53	24.60	0.00	0.00	10.95	10.95	0.39
Mar-94	71.5	28.85	8.45	108.06	71.50	0.00	0.00	12.12	12.12	0.39
Apr-94	100.8	27.95	8.34	104.60	100.80	0.00	0.00	11.73	11.73	0.39
May-94	116.6	27	8.74	107.34	107.34	9.26	6.02	12.12	18.14	0.59
Jun-94	139.9	25.9	8.53	102.19	102.19	37.71	24.51	11.73	36.25	1.22
Jul-94	16.2	25.35	8.78	103.86	16.20	0.00	0.00	12.12	12.12	0.39
Aug-94	17	25.15	8.66	101.96	17.00	0.00	0.00	12.12	12.12	0.39
Sep-94	190.2	25.55	8.25	98.04	98.04	92.16	59.90	11.73	71.63	2.40
Oct-94	223.9	25.7	8.37	99.81	99.81	124.09	80.66	12.12	92.78	3.01
Nov-94	47.8	25.85	7.98	95.49	47.80	0.00	0.00	11.73	11.73	0.39
Dec-94	0	25.1	8.18	96.20	0.00	0.00	0.00	12.12	12.12	0.39
Jan-95	0	25.7	8.21	97.90	0.00	0.00	0.00	12.12	12.12	0.39
Feb-95	32	28.65	7.51	95.63	32.00	0.00	0.00	10.95	10.95	0.39
Mar-95	144	28.35	8.45	106.91	106.91	37.09	24.11	12.12	36.23	1.18

Apr-95	268.7	27.7	8.34	104.03	104.03	164.67	107.04	11.73	118.77	3.99
May-95	155.5	27.2	8.74	107.82	107.82	47.68	30.99	12.12	43.12	1.40
Jun-95	156.3	26.2	8.53	102.89	102.89	53.41	34.72	11.73	46.45	1.56
Jul-95	108.7	25.4	8.78	103.98	103.98	4.72	3.07	12.12	15.19	0.49
Aug-95	103.3	25.4	8.66	102.56	102.56	0.74	0.48	12.12	12.61	0.41
Sep-95	201.1	25.55	8.25	98.04	98.04	103.06	66.99	11.73	78.72	2.64
Oct-95	150.6	25.9	8.37	100.27	100.27	50.33	32.71	12.12	44.84	1.46
Nov-95	39.5	26.35	7.98	96.58	39.50	0.00	0.00	11.73	11.73	0.39
Dec-95	41.9	25.45	8.18	96.99	41.90	0.00	0.00	12.12	12.12	0.39
Jan-96	0	26.9	8.21	100.61	0.00	0.00	0.00	12.12	12.12	0.39
Feb-96	159.8	27.7	7.51	93.67	93.67	66.13	42.98	10.95	53.93	1.94
Mar-96	96.1	27.65	8.45	105.28	96.10	0.00	0.00	12.12	12.12	0.39
Apr-96	135.1	27.3	8.34	103.11	103.11	31.99	20.79	11.73	32.52	1.09
May-96	113.4	27.1	8.74	107.58	107.58	5.82	3.78	12.12	15.91	0.52
Jun-96	224.5	25.8	8.53	101.95	101.95	122.55	79.66	11.73	91.39	3.07
Jul-96	128.6	25.05	8.78	103.14	103.14	25.46	16.55	12.12	28.67	0.93
Aug-96	125.6	24.9	8.66	101.37	101.37	24.23	15.75	12.12	27.87	0.91
Sep-96	62.1	25.05	8.25	96.91	62.10	0.00	0.00	11.73	11.73	0.39
Oct-96	186.2	25.45	8.37	99.24	99.24	86.96	56.53	12.12	68.65	2.23
Nov-96	14.8	26.7	7.98	97.35	14.80	0.00	0.00	11.73	11.73	0.39
Dec-96	11.6	25.9	8.18	97.99	11.60	0.00	0.00	12.12	12.12	0.39
Jan-97	24.5	26.55	8.21	99.82	24.50	0.00	0.00	12.12	12.12	0.39
Feb-97	0	27.8	7.51	93.88	0.00	0.00	0.00	10.95	10.95	0.39
Mar-97	57.8	29.15	8.45	108.76	57.80	0.00	0.00	12.12	12.12	0.39
Apr-97	59.2	27.55	8.34	103.68	59.20	0.00	0.00	11.73	11.73	0.39
May-97	130.2	26.75	8.74	106.74	106.74	23.46	15.25	12.12	27.37	0.89
Jun-97	219.1	25.6	8.53	101.49	101.49	117.61	76.45	11.73	88.18	2.96
Jul-97	94.9	24.75	8.78	102.41	94.90	0.00	0.00	12.12	12.12	0.39
Aug-97	53.7	24.6	8.66	100.66	53.70	0.00	0.00	12.12	12.12	0.39
Sep-97	83.2	25.55	8.25	98.04	83.20	0.00	0.00	11.73	11.73	0.39
Oct-97	165.1	26.55	8.37	101.76	101.76	63.34	41.17	12.12	53.29	1.73
Nov-97	17.6	27	7.98	98.01	17.60	0.00	0.00	11.73	11.73	0.39
Dec-97	18.6	26.7	8.18	99.79	18.60	0.00	0.00	12.12	12.12	0.39
Jan-98	5.6	26.95	8.21	100.72	5.60	0.00	0.00	12.12	12.12	0.39
Feb-98	4.9	28.95	7.51	96.25	4.90	0.00	0.00	10.95	10.95	0.39
Mar-98	34.6	30.85	8.45	112.70	34.60	0.00	0.00	12.12	12.12	0.39
Apr-98	137	28.55	8.34	105.97	105.97	31.03	20.17	11.73	31.90	1.07
May-98	58.6	27.75	8.74	109.14	58.60	0.00	0.00	12.12	12.12	0.39
Jun-98	195.4	26.35	8.53	103.24	103.24	92.16	59.90	11.73	71.64	2.40
Jul-98	57.1	25.3	8.78	103.74	57.10	0.00	0.00	12.12	12.12	0.39
Aug-98	45.1	25.05	8.66	101.73	45.10	0.00	0.00	12.12	12.12	0.39
Sep-98	165.7	25.65	8.25	98.27	98.27	67.43	43.83	11.73	55.56	1.86
Oct-98	243.2	26.1	8.37	100.73	100.73	142.47	92.61	12.12	104.73	3.40
Nov-98	6.5	27.45	7.98	98.99	6.50	0.00	0.00	11.73	11.73	0.39
Dec-98	23.7	26.55	8.18	99.45	23.70	0.00	0.00	12.12	12.12	0.39

Jan-99	20.5	27.5	8.21	101.96	20.50	0.00	0.00	12.12	12.12	0.39
Feb-99	74.1	27.45	7.51	93.16	74.10	0.00	0.00	10.95	10.95	0.39
Mar-99	152.4	27.95	8.45	105.98	105.98	46.42	30.17	12.12	42.30	1.37
Apr-99	140.1	27.05	8.34	102.54	102.54	37.56	24.41	11.73	36.15	1.21
May-99	163	26.85	8.74	106.98	106.98	56.02	36.41	12.12	48.54	1.58
Jun-99	129.8	26.2	8.53	102.89	102.89	26.91	17.49	11.73	29.22	0.98
Jul-99	34.7	25.4	8.78	103.98	34.70	0.00	0.00	12.12	12.12	0.39
Aug-99	83.7	24.8	8.66	101.13	83.70	0.00	0.00	12.12	12.12	0.39
Sep-99	156.8	24.8	8.25	96.34	96.34	60.46	39.30	11.73	51.03	1.71
Oct-99	136.7	25.05	8.37	98.32	98.32	38.38	24.95	12.12	37.07	1.20
Nov-99	86.5	26	7.98	95.82	86.50	0.00	0.00	11.73	11.73	0.39
Dec-99	0	25.45	8.18	96.99	0.00	0.00	0.00	12.12	12.12	0.39
Jan-00	27.4	27	8.21	100.83	27.40	0.00	0.00	12.12	12.12	0.39
Feb-00	0	26.75	7.51	91.72	0.00	0.00	0.00	10.95	10.95	0.39
Mar-00	62.3	29.25	8.45	108.99	62.30	0.00	0.00	12.12	12.12	0.39
Apr-00	243.1	27.25	8.34	103.00	103.00	140.10	91.07	11.73	102.80	3.45
May-00	104.8	27	8.74	107.34	104.80	0.00	0.00	12.12	12.12	0.39
Jun-00	124.5	25.65	8.53	101.60	101.60	22.90	14.88	11.73	26.62	0.89
Jul-00	101.6	24.55	8.78	101.93	101.60	0.00	0.00	12.12	12.12	0.39
Aug-00	118.5	24.2	8.66	99.71	99.71	18.79	12.21	12.12	24.34	0.79
Sep-00	75	24.95	8.25	96.68	75.00	0.00	0.00	11.73	11.73	0.39
Oct-00	59.3	25.8	8.37	100.04	59.30	0.00	0.00	12.12	12.12	0.39
Nov-00	101.1	26.45	7.98	96.80	96.80	4.30	2.79	11.73	14.53	0.49
Dec-00	0	25.7	8.18	97.55	0.00	0.00	0.00	12.12	12.12	0.39
Jan-01	0	26.65	8.21	100.04	0.00	0.00	0.00	12.12	12.12	0.39
Feb-01	10.1	28.25	7.51	94.81	10.10	0.00	0.00	10.95	10.95	0.39
Mar-01	134.2	28.7	8.45	107.72	107.72	26.48	17.21	12.12	29.34	0.95
Apr-01	398.6	26.85	8.34	102.08	102.08	296.52	192.74	11.73	204.47	6.86
May-01	76.3	26.8	8.74	106.86	76.30	0.00	0.00	12.12	12.12	0.39
Jun-01	311.3	25.9	8.53	102.19	102.19	209.11	135.92	11.73	147.66	4.96
Jul-01	56.4	25.15	8.78	103.38	56.40	0.00	0.00	12.12	12.12	0.39
Aug-01	31.5	24.2	8.66	99.71	31.50	0.00	0.00	12.12	12.12	0.39
Sep-01	112.3	24.5	8.25	95.67	95.67	16.63	10.81	11.73	22.54	0.76
Oct-01	70.7	25.95	8.37	100.39	70.70	0.00	0.00	12.12	12.12	0.39
Nov-01	26.1	26.8	7.98	97.57	26.10	0.00	0.00	11.73	11.73	0.39
Dec-01	10.7	27.25	8.18	101.02	10.70	0.00	0.00	12.12	12.12	0.39
Jan-02	30.1	25.9	8.21	98.35	30.10	0.00	0.00	12.12	12.12	0.39
Feb-02	30.2	28.6	7.51	95.53	30.20	0.00	0.00	10.95	10.95	0.39
Mar-02	102.9	28	8.45	106.09	102.90	0.00	0.00	12.12	12.12	0.39
Apr-02	262.4	27.5	8.34	103.57	103.57	158.83	103.24	11.73	114.97	3.86
May-02	179.1	26.7	8.74	106.62	106.62	72.48	47.11	12.12	59.23	1.92
Jun-02	172.3	25.7	8.53	101.72	101.72	70.58	45.88	11.73	57.61	1.93
Jul-02	97.4	25.3	8.78	103.74	97.40	0.00	0.00	12.12	12.12	0.39
Aug-02	44.7	24.35	8.66	100.06	44.70	0.00	0.00	12.12	12.12	0.39
Sep-02	67.7	24.95	8.25	96.68	67.70	0.00	0.00	11.73	11.73	0.39

Oct-02	152.6	25.9	8.37	100.27	100.27	52.33	34.01	12.12	46.14	1.50
Nov-02	77.2	26.35	7.98	96.58	77.20	0.00	0.00	11.73	11.73	0.39
Dec-02	7	25.35	8.18	96.76	7.00	0.00	0.00	12.12	12.12	0.39
Jan-03	22.5	26.65	8.21	100.04	22.50	0.00	0.00	12.12	12.12	0.39
Feb-03	63.9	28.8	7.51	95.94	63.90	0.00	0.00	10.95	10.95	0.39
Mar-03	56.1	28.95	8.45	108.30	56.10	0.00	0.00	12.12	12.12	0.39
Apr-03	204.6	27.5	8.34	103.57	103.57	101.03	65.67	11.73	77.40	2.60
May-03	144.9	27.35	8.74	108.18	108.18	36.72	23.87	12.12	35.99	1.17
Jun-03	232.8	25.65	8.53	101.60	101.60	131.20	85.28	11.73	97.01	3.26
Jul-03	32	25.05	8.78	103.14	32.00	0.00	0.00	12.12	12.12	0.39
Aug-03	50.7	24.9	8.66	101.37	50.70	0.00	0.00	12.12	12.12	0.39
Sep-03	228.7	25.75	8.25	98.49	98.49	130.21	84.63	11.73	96.37	3.23
Oct-03	211	26.45	8.37	101.53	101.53	109.47	71.15	12.12	83.28	2.70
Nov-03	78.6	26.45	7.98	96.80	78.60	0.00	0.00	11.73	11.73	0.39
Dec-03	0	25.7	8.18	97.55	0.00	0.00	0.00	12.12	12.12	0.39
Jan-04	14.6	26.8	8.21	100.38	14.60	0.00	0.00	12.12	12.12	0.39
Feb-04	56.9	28.25	7.51	94.81	56.90	0.00	0.00	10.95	10.95	0.39
Mar-04	48.2	28.3	8.45	106.79	48.20	0.00	0.00	12.12	12.12	0.39
Apr-04	137.9	27.2	8.34	102.88	102.88	35.02	22.76	11.73	34.49	1.16
May-04	177.2	26.7	8.74	106.62	106.62	70.58	45.88	12.12	58.00	1.88
Jun-04	58.9	25.75	8.53	101.84	58.90	0.00	0.00	11.73	11.73	0.39
Jul-04	94.4	24.85	8.78	102.65	94.40	0.00	0.00	12.12	12.12	0.39
Aug-04	131	24.65	8.66	100.78	100.78	30.22	19.65	12.12	31.77	1.03
Sep-04	281.2	25.35	8.25	97.59	97.59	183.61	119.35	11.73	131.08	4.40
Oct-04	253.8	26.15	8.37	100.84	100.84	152.96	99.42	12.12	111.54	3.62
Nov-04	52.9	26.6	7.98	97.13	52.90	0.00	0.00	11.73	11.73	0.39
Dec-04	0	26.85	8.18	100.13	0.00	0.00	0.00	12.12	12.12	0.39
Jan-05	1.1	25.35	8.21	97.12	1.10	0.00	0.00	12.12	12.12	0.39
Feb-05	47	29.05	7.51	96.45	47.00	0.00	0.00	10.95	10.95	0.39
Mar-05	78	27.9	8.45	105.86	78.00	0.00	0.00	12.12	12.12	0.39
Apr-05	123.7	27.9	8.34	104.49	104.49	19.21	12.49	11.73	24.22	0.81
May-05	114	27	8.74	107.34	107.34	6.66	4.33	12.12	16.45	0.53
Jun-05	112.5	25.9	8.53	102.19	102.19	10.31	6.70	11.73	18.44	0.62
Jul-05	73.6	24.7	8.78	102.29	73.60	0.00	0.00	12.12	12.12	0.39
Aug-05	40.7	24.1	8.66	99.47	40.70	0.00	0.00	12.12	12.12	0.39
Sep-05	142.6	25.3	8.25	97.48	97.48	45.12	29.33	11.73	41.06	1.38
Oct-05	233.7	25.55	8.37	99.47	99.47	134.23	87.25	12.12	99.37	3.23
Nov-05	56.9	26.5	7.98	96.91	56.90	0.00	0.00	11.73	11.73	0.39
Dec-05	29.4	25.6	8.18	97.32	29.40	0.00	0.00	12.12	12.12	0.39
Jan-06	47.6	27.15	8.21	101.17	47.60	0.00	0.00	12.12	12.12	0.39
Feb-06	6.3	28.1	7.51	94.50	6.30	0.00	0.00	10.95	10.95	0.39
Mar-06	106.7	27.65	8.45	105.28	105.28	1.42	0.92	12.12	13.04	0.42
Apr-06	65.5	27.85	8.34	104.37	65.50	0.00	0.00	11.73	11.73	0.39
May-06	183.3	26.65	8.74	106.50	106.50	76.80	49.92	12.12	62.04	2.02
Jun-06	249.1	26.35	8.53	103.24	103.24	145.86	94.81	11.73	106.54	3.58

Jul-06	85.4	25.5	8.78	104.22	85.40	0.00	0.00	12.12	12.12	0.39
Aug-06	15.3	25.15	8.66	101.96	15.30	0.00	0.00	12.12	12.12	0.39
Sep-06	106.9	25.8	8.25	98.61	98.61	8.29	5.39	11.73	17.12	0.57
Oct-06	267.6	26.3	8.37	101.19	101.19	166.41	108.17	12.12	120.29	3.91
Nov-06	15	26.4	7.98	96.69	15.00	0.00	0.00	11.73	11.73	0.39
Dec-06	7.6	25.95	8.18	98.11	7.60	0.00	0.00	12.12	12.12	0.39
Jan-07	0.6	26.1	8.21	98.80	0.60	0.00	0.00	12.12	12.12	0.39
Feb-07	19	28.8	7.51	95.94	19.00	0.00	0.00	10.95	10.95	0.39
Mar-07	116.2	29	8.45	108.41	108.41	7.79	5.06	12.12	17.19	0.56
Apr-07	161.2	27.35	8.34	103.23	103.23	57.97	37.68	11.73	49.41	1.66
May-07	137.7	26.85	8.74	106.98	106.98	30.72	19.97	12.12	32.09	1.04
Jun-07	217.7	25.9	8.53	102.19	102.19	115.51	75.08	11.73	86.82	2.91
Jul-07	146.8	25.3	8.78	103.74	103.74	43.06	27.99	12.12	40.11	1.30
Aug-07	100.5	24.6	8.66	100.66	100.50	0.00	0.00	12.12	12.12	0.39
Sep-07	330.4	25.25	8.25	97.36	97.36	233.04	151.47	11.73	163.21	5.48
Oct-07	140.5	25.7	8.37	99.81	99.81	40.69	26.45	12.12	38.57	1.25
Nov-07	81.8	26.3	7.98	96.47	81.80	0.00	0.00	11.73	11.73	0.39
Dec-07	0	25.9	8.18	97.99	0.00	0.00	0.00	12.12	12.12	0.39
Jan-08	0	24.5	8.21	95.20	0.00	0.00	0.00	12.12	12.12	0.39
Feb-08	41.4	29.15	7.51	96.66	41.40	0.00	0.00	10.95	10.95	0.39
Mar-08	49.8	28.2	8.45	106.56	49.80	0.00	0.00	12.12	12.12	0.39
Apr-08	204.9	27.15	8.34	102.77	102.77	102.13	66.38	11.73	78.12	2.62
May-08	132.9	26.95	8.74	107.22	107.22	25.68	16.69	12.12	28.82	0.94
Jun-08	174	25.8	8.53	101.95	101.95	72.05	46.83	11.73	58.56	1.97
Jul-08	81.5	25.1	8.78	103.26	81.50	0.00	0.00	12.12	12.12	0.39
Aug-08	154.4	24.9	8.66	101.37	101.37	53.03	34.47	12.12	46.59	1.51
Sep-08	219.5	25.5	8.25	97.93	97.93	121.57	79.02	11.73	90.75	3.05
Oct-08	188.7	25.95	8.37	100.39	100.39	88.31	57.40	12.12	69.53	2.26
Nov-08	40.1	26.4	7.98	96.69	40.10	0.00	0.00	11.73	11.73	0.39
Dec-08	39.3	25.9	8.18	97.99	39.30	0.00	0.00	12.12	12.12	0.39
Jan-09	0	28.3	8.21	103.76	0.00	0.00	0.00	12.12	12.12	0.39
Feb-09	53.8	26.45	7.51	91.10	53.80	0.00	0.00	10.95	10.95	0.39
Mar-09	161.3	27.3	8.45	104.47	104.47	56.83	36.94	12.12	49.06	1.59
Apr-09	154.3	26.75	8.34	101.86	101.86	52.44	34.09	11.73	45.82	1.54
May-09	151.1	26.7	8.74	106.62	106.62	44.48	28.91	12.12	41.03	1.33
Jun-09	189.4	25.8	8.53	101.95	101.95	87.45	56.84	11.73	68.57	2.30
Jul-09	172.1	24.55	8.78	101.93	101.93	70.17	45.61	12.12	57.73	1.88
Aug-09	8.5	24.5	8.66	100.42	8.50	0.00	0.00	12.12	12.12	0.39
Sep-09	86.4	25.2	8.25	97.25	86.40	0.00	0.00	11.73	11.73	0.39
Oct-09	112.9	25.45	8.37	99.24	99.24	13.66	8.88	12.12	21.00	0.68
Nov-09	203	25.7	7.98	95.16	95.16	107.84	70.10	11.73	81.83	2.75
Dec-09	14	26.15	8.18	98.56	14.00	0.00	0.00	12.12	12.12	0.39
Jan-10	0	27.1	8.21	101.06	0.00	0.00	0.00	12.12	12.12	0.39
Feb-10	28.5	28.5	7.51	95.32	28.50	0.00	0.00	10.95	10.95	0.39
Mar-10	115.8	28.15	8.45	106.44	106.44	9.36	6.08	12.12	18.21	0.59

Apr-10	203.5	27.75	8.34	104.14	104.14	99.36	64.58	11.73	76.31	2.56
May-10	141.7	27.15	8.74	107.70	107.70	34.00	22.10	12.12	34.22	1.11
Jun-10	293.4	25.8	8.53	101.95	101.95	191.45	124.44	11.73	136.17	4.57
Jul-10	158.8	24.65	8.78	102.17	102.17	56.63	36.81	12.12	48.93	1.59
Aug-10	91.5	24.45	8.66	100.30	91.50	0.00	0.00	12.12	12.12	0.39
Sep-10	151.4	25	8.25	96.80	96.80	54.60	35.49	11.73	47.22	1.59
Oct-10	139.2	25.55	8.37	99.47	99.47	39.73	25.83	12.12	37.95	1.23
Nov-10	64.9	25.95	7.98	95.71	64.90	0.00	0.00	11.73	11.73	0.39
Dec-10	20	26.15	8.18	98.56	20.00	0.00	0.00	12.12	12.12	0.39
Jan-11	2.6	25.15	8.21	96.67	2.60	0.00	0.00	12.12	12.12	0.39
Feb-11	96	27	7.51	92.23	92.23	3.77	2.45	10.95	13.40	0.48
Mar-11	36.6	27.35	8.45	104.59	36.60	0.00	0.00	12.12	12.12	0.39
Apr-11	32	27.75	8.34	104.14	32.00	0.00	0.00	11.73	11.73	0.39
May-11	148.2	26.85	8.74	106.98	106.98	41.22	26.79	12.12	38.92	1.26
Jun-11	325.5	25.5	8.53	101.25	101.25	224.25	145.76	11.73	157.49	5.29
Jul-11	88.2	24.2	8.78	101.09	88.20	0.00	0.00	12.12	12.12	0.39
Aug-11	27.5	23.9	8.66	99.00	27.50	0.00	0.00	12.12	12.12	0.39
Sep-11	222.9	24.9	8.25	96.57	96.57	126.33	82.11	11.73	93.85	3.15
Oct-11	201.6	25.65	8.37	99.70	99.70	101.90	66.24	12.12	78.36	2.55
Nov-11	12.4	26.9	7.98	97.79	12.40	0.00	0.00	11.73	11.73	0.39
Dec-11	0	25.75	8.18	97.66	0.00	0.00	0.00	12.12	12.12	0.39
Jan-12	1	26.1	8.21	98.80	1.00	0.00	0.00	12.12	12.12	0.39
Feb-12	42.5	28.05	7.51	94.40	42.50	0.00	0.00	10.95	10.95	0.39
Mar-12	80.1	28.2	8.45	106.56	80.10	0.00	0.00	12.12	12.12	0.39
Apr-12	96.8	27.45	8.34	103.46	96.80	0.00	0.00	11.73	11.73	0.39
May-12	320.7	26.5	8.74	106.14	106.14	214.56	139.46	12.12	151.59	4.92
Jun-12	256.7	25.7	8.53	101.72	101.72	154.98	100.74	11.73	112.47	3.78
Jul-12	89.4	24.6	8.78	102.05	89.40	0.00	0.00	12.12	12.12	0.39
Aug-12	7.5	24.35	8.66	100.06	7.50	0.00	0.00	12.12	12.12	0.39
Sep-12	108	25.5	8.25	97.93	97.93	10.07	6.55	11.73	18.28	0.61
Oct-12	232	26.05	8.37	100.62	100.62	131.38	85.40	12.12	97.52	3.17
Nov-12	43.9	26.8	7.98	97.57	43.90	0.00	0.00	11.73	11.73	0.39
Dec-12	9.4	26.05	8.18	98.33	9.40	0.00	0.00	12.12	12.12	0.39

APPENDIX D. RETScreen Formula costing method Empirical formulas

There are 15 categorized formulae in the RETScreen-Small Hydro Model Software to estimate the initial cost of a small hydropower project based on the input data.The items and the corresponding formulae are listed in Table 4.5 according to the

classification of the project.1

<table>
<tr><th>ITEM (NUMBER)</th><th colspan="2">SMALL</th><th>MINI</th><th>MICRO</th></tr>
<tr><td>Feasibility Study (1)</td><td colspan="3">$0.032\sum Eq(2 \text{ to } 15)$</td><td>$0.031\sum Eq(2 \text{ to } 15)$</td></tr>
<tr><td>Development (2)</td><td colspan="4">$0.04\sum Eq(3 \text{ to } 14)$</td></tr>
<tr><td>Engineering (3)</td><td colspan="3">$0.37n^{0.1}E(MW/H_g^{0.3})^{0.54}10^6$</td><td>$0.04E(MW/H_g^{0.3})^{0.54}10^6$</td></tr>
<tr><td rowspan="7">Energy Equipment (4)</td><td>Generator and Control:</td><td colspan="3">$0.82n^{0.96}C_g(MW/H_g^{0.28})^{0.9}10^6$</td></tr>
<tr><td>Kaplan turbine:</td><td colspan="3">$0.27n^{0.96}J_tK_td^{1.47}(1.17*H_g^{0.12}+2)10^6$</td></tr>
<tr><td>Francis turbine:</td><td colspan="3">$0.17n^{0.96}J_tK_td^{1.47}[(13+0.01H_g)^{0.3}+3]10^6$</td></tr>
<tr><td>Propeller turbine:</td><td colspan="3">$0.125n^{0.96}J_tK_td^{1.47}(1.17H_g^{0.12}+4)10^6$</td></tr>
<tr><td rowspan="2">Pelton&Turgo turbine:</td><td colspan="3">$3.47n^{0.96}(MW_u/H_g^{0.5})^{0.44}10^6$ *if* $(MW_u/H_g^{0.5})>0.4$</td></tr>
<tr><td colspan="3">$5.34n^{0.96}(MW_u/H_g^{0.5})^{0.91}10^6$ *if* $(MW_u/H_g^{0.5})<0.5$</td></tr>
<tr><td>Cross-flow turbine:</td><td colspan="3">(Cost of Pelton&Turgo) / 2</td></tr>
<tr><td>Installation of Energy Equipment (5)</td><td colspan="4">B[0.15Eq(4)]</td></tr>
<tr><td>Access road (6)</td><td colspan="4">$B[0.025TA^2l_a^{0.9}10^6]$</td></tr>
<tr><td>Transmission line (7)</td><td colspan="4">$B[0.0011DPl_t^{0.95}V10^6]$</td></tr>
</table>

Continued (RETScreen, 2004-a)

ITEM (NUMBER)	SMALL	MINI	MICRO
Substation - transformer (8)	$[0.0025n^{0.95}+0.02(n+0.1)](MW/0.95)^{0.9}V^{0.3}10^{6}$		
Substation - transformer installations (9)	$B[0.15Eq(8)]$		
Civil works (10)	$3.54n^{-0.04}BCR(MW/H_g^{0.3})^{0.82}$ $*(1+0.01l_b)(1+0.005l_d/H_g)10^{6}$	$1.97n^{-0.04}BCR(MW/H_g^{0.3})^{0.82}$ $*(1+0.01l_b)(1+0.005l_d/H_g)10^{6}$	
Penstock (11)	$20n_p^{0.95}W^{0.88}$		
Installation of Penstock (12)	$B[5W^{0.88}]$		
Canal (13)	$20B[(1.5+0.01S_s^{1.5})Q_d l_{cs}]^{0.9} + 100[(1.5+0.016S_r^{2})Q_d l_{cr}]^{0.9}$		
Tunnel (14)	$B[400R_v^{0.88} + 4000C_v^{0.88}]$		*N/A*
Miscellaneous (15)	$[(0.275iQ_d^{0.35})+0.1]\sum Eq(2 \text{ to } 14)$		$(0.187i+0.1)\sum Eq(2 \text{ to } 14)$
INITIAL COSTS (FORMULA METHOD)	**1+2+3+4+5+6+7+8+9+10+11+12+13+14+15**		

APPENDIX E. Monthly rate of annual sunshine (Northern Hemisphere) (%)

North Latitude	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
65	3.52	5.13	7.96	9.97	12.72	14.15	13.59	11.18	8.55	6.53	4.08	2.62
64	3.81	5.27	8.00	9.92	12.50	13.63	13.26	11.08	8.56	6.63	4.32	3.02
63	4.07	5.39	8.04	9.86	12.29	13.24	12.97	10.97	8.56	6.73	4.52	3.36
62	4.31	5.49	8.07	9.80	12.11	12.92	12.73	10.87	8.55	6.80	4.70	3.65
61	4.51	5.58	8.09	9.74	11.94	12.66	12.51	10.77	8.55	6.88	4.86	3.91
60	4.70	5.67	8.11	9.69	11.78	12.41	12.31	10.68	8.54	6.95	5.02	4.14
59	4.86	5.76	8.13	9.64	11.64	12.19	12.13	10.60	8.53	7.00	5.17	4.35
58	5.02	5.84	8.14	9.59	11.50	12.00	11.96	10.52	8.53	7.06	5.30	4.54
57	5.17	5.91	8.15	9.53	11.38	11.83	11.81	10.44	8.52	7.13	5.42	4.71
56	5.31	5.98	8.17	9.48	11.26	11.68	11.67	10.36	8.52	7.18	5.52	4.87
55	5.44	6.04	8.18	9.44	11.15	11.53	11.54	10.29	8.51	7.23	5.63	5.02
54	5.56	6.10	8.19	9.40	11.04	11.39	11.42	10.22	8.50	7.28	5.74	5.16
53	5.68	6.16	8.20	9.36	10.94	11.26	11.30	10.16	8.49	7.32	5.83	5.30
52	5.79	6.22	8.21	9.32	10.85	11.14	11.19	10.10	8.48	7.36	5.92	5.42
51	5.89	6.27	8.23	9.28	10.76	11.02	11.09	10.05	8.47	7.40	6.00	5.54
50	5.99	6.32	8.24	9.24	10.68	10.92	10.99	9.99	8.46	7.44	6.08	5.65
48	6.17	6.41	8.26	9.17	10.52	10.72	10.81	9.89	8.45	7.51	6.24	5.85
46	6.33	6.50	8.28	9.11	10.38	10.53	10.65	9.79	8.43	7.58	6.37	6.05
44	6.48	6.57	8.29	9.05	10.25	10.39	10.49	9.71	8.41	7.64	6.50	6.22
42	6.61	6.65	8.30	8.99	10.13	10.24	10.35	9.62	8.40	7.70	6.62	6.39
40	6.75	6.72	8.32	8.93	10.01	10.09	10.22	9.55	8.39	7.75	6.73	6.54
38	6.87	6.79	8.33	8.89	9.90	9.96	10.11	9.47	8.37	7.80	6.83	6.68
36	6.98	6.85	8.35	8.85	9.80	9.82	9.99	9.41	8.36	7.85	6.93	6.81
34	7.10	6.91	8.35	8.80	9.71	9.71	9.88	9.34	8.35	7.90	7.02	6.93
32	7.20	6.97	8.36	8.75	9.62	9.60	9.77	9.28	8.34	7.95	7.11	7.05
30	7.31	7.02	8.37	8.71	9.54	9.49	9.67	9.21	8.33	7.99	7.20	7.16
28	7.40	7.07	8.37	8.67	9.46	9.39	9.58	9.17	8.32	8.02	7.28	7.27
26	7.49	7.12	8.38	8.64	9.37	9.29	9.49	9.11	8.32	8.06	7.36	7.37
24	7.58	7.16	8.39	8.60	9.30	9.19	9.40	9.06	8.31	8.10	7.44	7.47
22	7.67	7.21	8.40	8.56	9.22	9.11	9.32	9.01	8.30	8.13	7.51	7.56
20	7.75	7.26	8.41	8.53	9.15	9.02	9.24	8.95	8.29	8.17	7.58	7.65
18	7.83	7.31	8.41	8.50	9.08	8.93	9.16	8.90	8.29	8.20	7.65	7.74
16	7.91	7.35	8.42	8.47	9.01	8.85	9.08	8.85	8.28	8.23	7.72	7.83
14	7.98	7.39	8.43	8.43	8.94	8.77	9.00	8.80	8.27	8.27	7.79	7.93
12	8.06	7.43	8.44	8.40	8.87	8.69	8.92	8.76	8.26	8.31	7.85	8.01
10	8.14	7.47	8.45	8.37	8.81	8.61	8.85	8.71	8.25	8.34	7.91	8.09
8	8.21	7.51	8.45	8.34	8.74	8.53	8.78	8.66	8.25	8.37	7.98	8.18
6	8.28	7.55	8.46	8.31	8.68	8.45	8.71	8.62	8.24	8.40	8.04	8.26
4	8.36	7.59	8.47	8.28	8.62	8.37	8.64	8.58	8.23	8.43	8.10	8.34
2	8.43	7.63	8.49	8.25	8.55	8.29	8.57	8.53	8.22	8.46	8.16	8.42
0	8.50	7.67	8.49	8.22	8.49	8.22	8.50	8.49	8.21	8.49	8.22	8.50

APPENDIX F. Roughness Coefficients for Different Canals

Canal type	Description	Roughness coefficient 'n'
Earthen canals	Clay, with stones and sand, after ageing	0.020
	Gravelly or sandy loam, maintained with minimum vegetation	0.030
	Lined with coarse stones, maintained with minimum vegetation	0.040
Rock canals	Medium coarse rock muck	0.037
	Rock muck from careful blasting	0.045
	Very coarse rock muck, large irregularities	0.059
	Rubble masonry with mud mortar	0.025
Masonry canals	Brickwork, bricks, and/or clinker with well-pointed cement mortar	0.015
	Normal masonry with cement mortar	0.017
	Coarse rubble masonry and coarsely hewn stones with cement mortar	0.020
Concrete canals	Smooth cement finish	0.010
	Concrete for which wood formwork was used, un-plastered	0.015
	Tamped concrete with smooth surface	0.016
	Coarse concrete lining	0.018
	Irregular concrete surface	0.020

APPENDIX G. RETScreen modeling of project

Project information	*See project database*
Project name	Mini Hydro power
Project location	Kintampo
Prepared for	Msc Thesis
Prepared by	Charles Ken Adu Boahen
Project type	Power
Technology	Hydro turbine
Grid type	Central-grid
Analysis type	Method 1
Heating value reference	Higher heating value (HHV)
Show settings	

Site reference conditions	*Select climate data location*
Climate data location	Kintampo
Show data	

Technology		Hydro turbine				
Analysis type	☐ ☐	Method 1 Method 2				
Resource assessment						
Proposed project		Run-of-river				
Hydrology method		User-defined				
Gross head	m	50.9				
Maximum tailwater effect	m	0.00				
Residual flow	m³/s	0.070				

Percent time firm flow available	%	95.0%				
Firm flow	m³/s	0.45				
Hydro turbine						
Design flow	m³/s	0.320				$ 395,000
Type		Cross-flow				
Turbine efficiency		Standard				
Number of turbines		1				
Manufacturer	Canyon Hydro					
Model	Cross-flow					
Efficiency adjustment	%	0.0%				
Turbine peak efficiency	%	0.0%				
Flow at peak efficiency	m³/s	0.0				
Turbine efficiency at design flow	%	79.0%				

	Flow		**Turbine efficiency**	**Number of turbines**	**Combined efficiency**
%	**m³/s**				
0%	5.56		0.00	0	0.00
5%	3.80		0.00	1	0.00
10%	3.10		0.34	1	0.34
15%	2.56		0.52	1	0.52
20%	1.97		0.61	1	0.61
25%	1.69		0.65	1	0.65
30%	1.43		0.68	1	0.68
35%	1.17		0.69	1	0.69
40%	0.86		0.70	1	0.70
45%	0.74		0.71	1	0.71
50%	0.71		0.71	1	0.71
55%	0.69		0.72	1	0.72
60%	0.67		0.73	1	0.73
65%	0.65		0.74	1	0.74
70%	0.63		0.74	1	0.74
75%	0.61		0.75	1	0.75
80%	0.59		0.76	1	0.76
85%	0.56		0.77	1	0.77
90%	0.54		0.77	1	0.77
95%	0.52		0.78	1	0.78
100%	0.50		0.79	1	0.79

	Maximum hydraulic losses	%	4.0%	
	Miscellaneous losses	%	2.0%	
	Generator efficiency	%	89.0%	
	Availability	%	95.0%	
	Summary			Firm
	Power capacity	kW	106	106
	Available flow adjustment factor		1.00	
	Capacity factor	%	95.0%	
	Electricity exported to grid	MWh	880	
	Electricity export rate	$/MWh	100.00	

Emission Analysis							
Base case electricity system (Baseline)		**GHG emission factor (excl. T&D)**	**T&D losses**	**GHG emission factor**			
Country - region	**Fuel type**	**tCO2/MWh**	**%**	**tCO2/MWh**			
Ghana	All types	0.275		0.275			
Electricity exported to grid	MWh	880	T&D losses	3.0%			
GHG emission							
Base case	tCO2	242.2					
Proposed case	tCO2	7.3					
Gross annual GHG emission reduction	tCO2	234.9					
GHG credits transaction fee	%						
Net annual GHG emission reduction	tCO2	234.9	is equivalent to	43.0	Cars & light trucks not used		
GHG reduction income							
GHG reduction credit rate	$/tCO2	12.00					
GHG reduction credit duration	yr	20					
GHG reduction credit escalation rate	%	3.0%					

Financial Analysis			
Financial parameters			
Inflation rate	%	9.0%	
Project life	yr	25	
Debt ratio	%	70%	
Debt interest rate	%	20.00%	
Debt term	yr	15	
Initial costs			
Power system	$	395,000	100.0%
Other	$		0.0%
Total initial costs	$	395,000	100.0%
Incentives and grants	$		0.0%
Annual costs and debt payments			
O&M (savings) costs	$	10,000	
Fuel cost - proposed case	$	0	
Debt payments - 15 yrs	$	59,138	
	$		
Total annual costs	$	69,138	
Annual savings and income			
Fuel cost - base case	$	0	
Electricity export income	$	88,011	
GHG reduction income - 20 yrs	$	2,819	
	$		
Total annual savings and income	$	90,830	
Financial viability			
Pre-tax IRR - equity	%	43.4%	
Pre-tax IRR - assets	%	21.3%	
Simple payback	yr	4.9	
Equity payback	yr	3.2	