ASSESSMENT OF A TYPICAL SMALL HYDROPOWER SITE FOR RURAL ELECTRIFICATION IN THE WESTERN REGION OF GHANA

BY

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DECLARATION

I hereby declare that this thesis is the result of my own original research work undertaken under the Supervision of the undersigned. All sources of materials used for this thesis have been duly acknowledged. I solemnly declare that this thesis is not submitted for the award of any academic degree in this University or elsewhere. A full list of the references employed is included.

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(Candidate)	Signature	Date

CERTIFICATION

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(Head of Department)	Signature	Date

DEDICATION

This thesis is dedicated to the Almighty God my family members,

And Managing Director of Northern Electricity Company of Ghana

Ing. John Nuworko

ACKNOWLEDGEMENT

As many people have contributed to this thesis, it is not possible to mention everyone. However, all of them deserve my gratitude. I am greatly indebted to my supervisor, Dr. Gabriel Takyi for his close friendship, professional assistance, genuine and valuable criticism all the way from the outset to the completion of the thesis. Besides, I wish to express my gratitude to Prof. Abeeku Brew Hammond of blessed memory for his constructive comments and advice at the proposal stage, which was the cornerstone of this study. I also grateful acknowledge Dr. Lawrence Darkwah for his valuable support and advice.

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ABSTRACT

Small hydropower is one of the promising renewable energy sources in Ghana. Despite the small hydropower potential, Ghana is yet to develop small hydropower plants to supplement her energy needs. The main focus of this research work is on the identification of potential small hydropower site for the generation of energy as an alternative source of rural electrification and reduction of poverty in the Western Region of Ghana. In this study, the capital cost of such a rural electrification project, unit cost of generation, and unit cost of electricity to the end user are analyzed. The results indicate that a typical 60 kW small-scale hydropower plant would serve about 365 household with an average of 5 persons per household. The 60 kW power was obtained from using the head of 24 m and a flow rate of 0.5 m^3/s . The total capital cost is GH¢ 283,935.53 (US$ 139,000). The specific construction cost per kW is GH¢4698.21 (US$ 2,300) and unit energy cost was found to be GH¢ 0.31(US$ 0.15). The project would deliver 525,600 kWh/year.

The RETScreen computer program which is commonly used in the North America is capable of evaluating the energy generation, investment and maintenance costs for small hydro-projects. The results also indicate that small-scale hydropower project would be favourable if government takes keen interest in its implementation. Small hydropower introduction in the rural community will enhance the quality of life for rural dwellers in numerous ways: improved lighting, more entertainment, communication options, replacement of paraffin lamps, supports rural enterprises, clinics etc.

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ABBREVIATIONS AND ACROYNYMS

BC	Before Christ
BCR	Benefit-to-Cost Ratio
CoG	Cost of Generation
EC	Energy Commission
ECG	Electricity Company of Ghana
ESHA	European Small Hydro Association
FDC	Flow Duration Curve
GH¢	Ghana Cedi's
GHG	Greenhouse Gases
GW	Gigawatt
GWh	Gigawatt hour
IEA	International Energy Agency
IPPs	Independent Power Producers
IRR	Internal Rate of Return
kW	Kilowatt
kWh	Kilowatt hour
kg/m^3	kilograms per cubic meter
m	Meters
MDGs	Millennium Development Goals
MoEn	Ministry of Energy
MW	Megawatt
MWh	Megawatt hour

NED	Northern Electricity Department
O&M	Operation and Maintenance
PM	Particulate Matter
RET	Renewable Energy Technology
RoR	Run-of-River
$	United States Dollars
SHEP	Self Help Electrification Project
SHP	Small Hydropower
SO_2	Sulphur Oxides
VAT	Value Added Tax
VRA	Volta River Authority

CHAPTER ONE

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

The western region of Ghana has many permanent rivers and streams providing excellent opportunities for small hydropower development. While large scale hydropower development is becoming a challenge due to environmental and socio-economic concerns and more recently its vulnerability to changing climates, small hydropower development continues to be an attractive resource, especially in remote parts of the region. It is a proven technology that can be connected to the national grid, isolated grid or as a stand-alone option, or combined with irrigation systems. Small hydropower can adequately contribute to the electricity needs of our country.

Small hydropower is typically highly customized for the size and the scale of the development, as schemes are typically greater than 1MW and less than 10MW. The most important aspect of the assessment is the quality of the data required for input and assessment. A subsequent broad – brush analysis of a site considers its location, catchment size, and flow and head parameters to perform a potential rated power output. The assessment refines the siting of the scheme, calculates the potential generation and determines the potential cost of the scheme. Small hydropower has proven itself as a major contributor to electrification in developing countries with China as an example where small hydro has been developed in large parts of the country.

The interest in small hydro on the African continent as emerged over the last couple of years has resulted in a number of projects that will pave the way. African government, international donors, development banks and the private sector in increasing energy assess in Africa will facilitate the uptake of this robust, environmentally friendly form of energy. The challenge upon us now is to ensure that the current interest will be translated into more small hydro power plants installed.

In general terms the environmental impacts of small hydropower plants are minimal through the use of “run-of –the –river” scheme in which no dam or reservoir storage is involved.

1.2 JUSTIFICATION

Access to electricity is one of the keys to development because it provides light, heat and power used in residential, commercial and industrial sectors. According to the World Bank, the world’s poor people spend more than 12% of their total income on energy and around 1.7 billion people do not have access to electricity (Laguna et. al., 2006).

Access to energy service is not directly included in the millennium development goals (MDGs) adopted by the world leaders in 2000 in the millennium summit (United States), as developments goals to achieve until 2015. However, it is considered by United Nation Development Programme (2005) to be “a prerequisite to the achievement of all eight MDGs". Infact, it's central to many aspect of poor people's everyday life and plays an important role in development.

Small hydropower (SHP) 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 (Adiguzel et. al., 2002).

Moreover, the considerable amount of financial requirements and insufficient financial sources of the national budget, together with the strong opposition from civil organizations, environmentalists etc. large-scale hydropower project cannot be completed in the planned construction period generally. Bui Power (400MW) is a typical example in this instance for Ghana. The use of SHP in developing countries has been getting the attention in both developed and developing countries.

Europe and North America has already exploited most of their hydropower potential. On the other hand Africa, Asia and South America have still substantial unused potential of hydropower (Altinbilek, 2005). China has developed most of her small hydro potential and most rural areas of that country.

1.3 OBJECTIVES

The main objective of this research work is on the identification of potential small hydropower site for the generation of energy as an alternative source of rural electrification in Ghana.

The specific objectives are listed below:

1. Assessment of the hydrology, geology and topography of the identified site(s).
2. Determine the head, flow rate and turbine type.
3. Calculate the specific construction cost per kW and unit energy cost.
4. Calculate the estimated power potential of the site.
5. Energy demand study and socio economic survey.

The study investigates the potential of SHP in improving the rural electrification levels in the western region of Ghana. The study is confined to the assessment of one potential site to meet energy needs of the communities surrounding the area. However, result of the study will be extrapolated to the other sites identified as potential hydro sites.

The RET Screen –small hydro software will be used to do this.

1.4 METHODOLOGY

In order to be abreast with what is happening in the field of SHP assessment, a review of relevant literature was carried out. Rural energy and development and rural electrification were also reviewed. Desktop concept, onsite measurement and a field survey formed the core of the methods used in the realization of the final thesis.

Both primary and secondary data sources were also used. Specific information for the selected site(s) was obtained from the following key government ministries, department and agencies: Ministry of Energy, Ministry of Water Resources and Housing, Energy Commission, Metrological Services Department, Statistical Services Department, Geological Services and Hydrological Survey Department. The major information that was collected from the above sources includes but not limited to;

1. Topographical and geological data
2. Metrological data (rainfall , sunshine, temperature, evaporation and wind)
3. Demographic data (population)
4. Government policy on rural electrification.

Again an informal household energy questionnaire was developed to gather data on household energy use, and other socio-economic characteristics of the selected site(s).

A Canadian organization, RETScreen has developed a software for performing pre-feasibility study of a small hydro project recently which can be used internationally. This user friendly software gives a general idea about the feasibility of a SHP project. It can also be used for performing sensitivity analysis or for monitoring the feasibility studies which have already been completed. This software was used to perform quick assessment on the selected site(s).

1.5 RESEARCH PROBLEM

In order to achieve the MDGs in the year 2015, access to electricity has been identified as one of the key factors. However, poverty in Ghana is widespread and mostly predominates among the rural folks.

The overwhelming majority of the rural people are characterized by low literacy level, poor health status and lack of descent employment. These facts are, largely, the result of relatively low consumption of commercial energy.

Most of Ghana's natural resources can be found is the Western Region but this does not translate into the standard of living among the majority of people living in the rural areas of the region. Most people living in the rural areas depend on wood-based fuels for cooking and heating. However, collection of these fuels is difficult and its availability is becoming increasing scarce. Continued use of wood fuels is contributing to an alarming deforestation and environmental degradation. As a result of deforestation, forest cover for the region is reducing at an unprecedented rate. Minimized use of wood fuel in rural areas of the western region where the majority of the people's life will invariably reduce the emissions of carbon dioxide and other greenhouse gases into the local environment. This study also explores the contribution of small-scale hydropower based rural electrification in the Western Region of Ghana.

Again, the present level of electrification (40.4%; MoEn) in rural areas of the region is undesirable. Although government through Self Help Electrification Project (SHEP) has provided electricity to most rural households, it appears it will not be feasible to connect the majority in the short and medium term. The commercialization of the two distribution companies namely; ECG and VRA/NED means that the utility is now governed by purely economic consideration. This clearly indicates that access to electricity will remain a major constraint in improving the living conditions of rural people.

Diesel generating units can also be used to provide electricity to the rural folks in the region which have a low investment cost when compared to other sources of energy. However, the recent rise in fuel costs has made the operation of diesel plants more expensive and less attractive. Besides, diesel engines emit smog-forming pollutants and their impact on public health is undesirable. Nitrous Oxides (NO and NO_2), Sulphur Oxides (SO_2) and other particulate matter (PM) emitted by diesel engines contribute to greenhouse gas effect (Silveria, 2007; 524-535).

Research questions

The study is designed to answer the following research question "what is the potential of utilizing small-scale hydropower to increase rural electrification in the western Region of Ghana and reduce greenhouse gas emissions".

The following subsets of questions have been posed to seek answers to address the above objectives:

a) How much small-scale hydropower potential exists in the Western region and which category can make the best contribution to rural electrification

b) What are the energy demands and how much of these can be met by small-scale hydropower?

c) To what extent can small-scale hydropower contribute to the reduction of environmental degradation and poverty among the rural folks.

d) At what price should electricity be sold so that rural households can afford connection cost?

1.6 STUDY HYPOTHESIS

The study is based on the following hypotheses:

1. Small-scale hydro scheme in areas with hydro potential could play a significant role in meeting energy needs of rural areas.
2. Small-scale hydro schemes can contributes to reduction of GHG and environmental degradation.
3. Rural electrification levels in the Western region of Ghana can be improved.
4. Effective policies and measures lead to successful rural electrification programmes.

1.7 SCOPE OF WORK

The study investigates the potential of small-scale hydropower in improving the rural electrification levels of the people of the Western region of Ghana. The study is confined to the assessment of one potential site to meet energy needs of the Community surrounding the area. However, results of this study will be extrapolated to other site identified as potential hydro sites. The following future work is beyond the scope of this study but is needed before implementation of the project.

- Establish a stream gauging station and monitor discharge flows for a period of not less them one year on identified sites.
- Conduct a strategic environmental assessment and environmental impact assessment of the sites.
- Conduct extensive assessment on Ankobra and Tano rivers in the western region of Ghana.

1.8 ASSUMPTIONS

The following assumptions were made in the research:

a. The project poses no negative impacts on the social and natural environment.
b. Water abstraction at the proposed site will be licensed.
c. The national utility company (i.e. ECG) will not electrify the identified area(s) at least for the next ten (10) years.

1.9 SIGNIFICANCE OF THE STUDY

Ghana is endowed with renewable energy resources such as wind, solar, biomass and small hydro. Demand for electricity is forecast to grow at an annual rate of 10% (MoEn 2012). The increase trend is due to the combined effects of expansion in the economy, growing population and higher disposable income, which provides a strong growth in energy demand. Increased utilization of renewable energy technologies such as small-scale hydropower will not only boost the energy supply use but also reduce advance environmental impacts of energy usage.

Again, investing in small-scale hydropower will invariably derive important benefits at the local level. The most important benefits would include among others:

1. Improved household food security through increased agricultural production.
2. Provision of electricity for small-scale industries and social services such as education and health care.
3. Electricity, will to some extent substitute the use of paraffin and diesel for cooking and heating.
4. It will also reduce the time spent on collecting wood fuel and this contributes to the reduction in drudgery. A study of this nature that promises to improve the quality of life among rural households cannot be overlooked.

1.10 LIMITATION OF THE STUDY

The major problems encounted in this study relate to data availability, time available for the research, and inadequate funding. This section will explore each of these in turn.

Data: The study is limited by the quality, consistency and extent of data available, Metrological data (rainfall, precipitation, evaporation, sunshine,) and topographical maps of sufficient detail of the area of interest were not available. The nearest gauging station located on Pra River was relocated 18km away. This makes river flow data inconsistent. Accessing accurate secondary data was a major challenge. As a result, the researcher used only primary data collected from the field.

Time and Funds: The limited funding and time frame in which to conduct this research has affected the amount of data, available to the research. The life span of this project was three months. In addition, insufficient funds were made available to this research.

Sample size: Study was conducted in one village (size). This is insufficient considering there are over ten major potential hydro sites in the region. This will negatively affect the outcome of any statistical inferences drawn from result of this study.

1.11 ORGANISATION OF THE THESIS

This thesis consists of five (5) chapters and is organized as follows:

Chapter 1 provides background information leading to the statement of this study. It defines the objectives, methodology, scope of work and limitations.

Chapter 2 reviews relevant literature on the history of hydropower, Energy conversion principles as well as small-scale hydro project development. Also presented in this chapter, is a brief discussion on the types of small-scale hydro configuration and associated electrical and mechanical equipment.

Chapter 3 looks at the theoretical aspect which must be considered when assessing the hydropower potential of a site, designing and costing of small-scale hydro project. Methods applied in carrying out the study are presented here.

Chapter 4 looks at financial analysis of small-scale hydropower projects.

Chapter 5 summarized the research findings, results, conclusions and recommendations for future work.

CHAPTER TWO

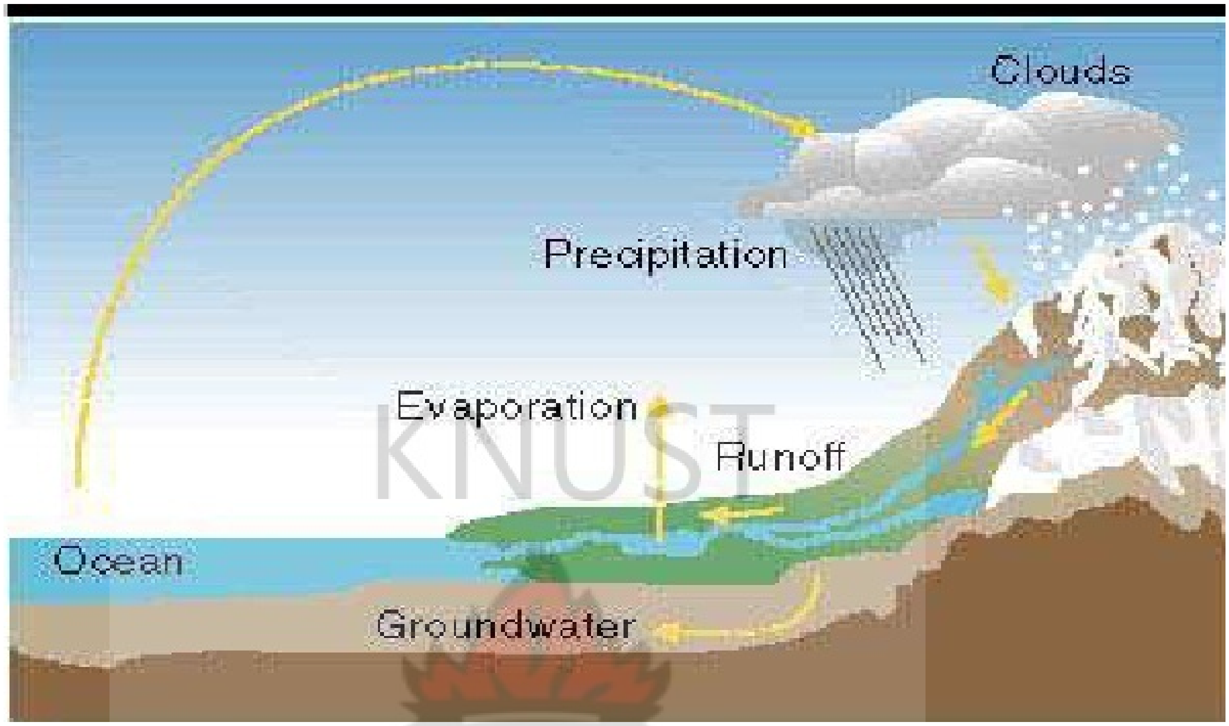
LITERATURE REVIEW

2.1 HISTORY OF HYDROPOWER

People have been benefiting from the power of water for more than two thousand years starting with wooden water wheel. Water wheels were used to grind wheat into flour as early as 100 B.C. and in many parts of Asia mostly for milling grain (Canadian Hydropower Association, 2007). Improved engineering skills during the 19th century, combined with the need to generate electricity, modern day turbines gradually replaced the water wheel and soil and rock dams built to control the flow of water and produce electricity. The golden age of hydropower started at the beginning of the 20th century before oil took the lead in energy generation. Europe and North America built large hydropower plants, equipment suppliers spread to supply this thriving business.

2.2 BASIC CONCEPT OF HYDROPOWER

Water constantly move through a vast global cycle, in which it evaporates (due to the activity of the sun) from oceans, seas and other water reservoirs, forms clouds, precipitates as rain or snow, then flow back to the ocean (*see* fig. 2.1). The energy of this cycle, which is driven by the sun's energy, is trapped as hydropower.



Source: http://www.eere.energy.gov/wind and hydro/hydro_how.html

Fig. 2.1: The hydrological cycle

2.2.1 Advantages of hydropower

- It is continuously renewable, non-polluting and efficient (Srinivasan, 1981).
- The technology is natural, reliable and offer flexible operations.
- Running costs are very low as compared to thermal or nuclear power stations.
- Hydraulic turbines can be switched on and off in a matter of minutes and gives very high efficiency over considerable range.
- Hydropower reservoirs can be used for fresh water for drinking or irrigation. This fresh water storage protects aquifers from depletion and reduces the possibility of droughts or floods.

- Hydropower is a clean source of electricity because it does not generate any toxic waste products, reduces air pollutions and contributes to the slow down of global warming.
- Hydropower facilities bring electricity, roads, industry, commerce and employment to rural areas, developing the regional economy and increasing the quality of life.
- Hydropower projects that are developed and operated in an economically viable, environmentally positive and socially responsible manner represents sustainable development (Kesharwani, 2006)
- Hydropower provides the most efficient energy, is capable of converting 90% of available energy into electricity, a level of efficiency higher than any other form of generation (Kesharwani, 2006)
- Hydropower provides national energy security which is a key issue for developing countries. Water used from rivers is a domestic resource that is not subject to fluctuations in fuel prices.
- Hydropower is an affordable power for today and tomorrow having an average life span of more than 50 years with very low operation and maintenance costs.

2.2.2 Disadvantages of hydropower

- Hydropower can only be used in areas where there is sufficient supply of water.
- The initial cost of hydropower projects is very high since construction of a dam and accompanying facilities are required.

- Dams containing huge amounts of water have the risk of failure which may cause catastrophic results such as flooding.
- The construction of a dam may have serious impact on the surrounding areas by changing the downstream environment, affecting both plant and animal life and creating problems such as relocation of people or historical artifact.

Generally, hydropower plants fall into two categories: conventional (large hydro) and non-conventional (small-scale hydro). This thesis is confined to the second type. Small-scale hydropower refers to hydraulic turbine system having capacities of less than 10MW (www.itdg.org).

The principles of operation, types of units, and the mathematical equations used in the selection of small-scale hydropower are essentially the same as for conventional hydropower. The global installed capacity is currently about 66GW (REN21, 2006).

2.2.3 Barriers to small scale hydro development

- Failure to realize how important full field data is for proper design.
- Failure of homemade equipment made with junked parts.
- Overestimating the amount and constancy of the stream flow.
- Penstocks that are too small to allow the plant to operate at full capacity.
- Failure to anticipate the expense of keeping trash racks clear and machinery in good repair.
- Failure to design and plan for winter ice buildup.

- Overestimation of a proposed plant's capacity. The average home has demand peaks varying from 4 to 12kW.

2.2.4 Environmental Impacts of small hydropower

The impacts of small-scale hydro schemes are likely to be small and localized, providing best practice and effective site planning are used. Nevertheless, SHP still has an impact on the environment whether large or small. The factors that harm a river habitat with large hydropower projects are also present with small projects: interrupted water flows, barriers to animal movement, water loss from evaporation, involuntary population displacement and loss of biodiversity from the sacrificed portion of river are some examples. The most obvious and difficult impacts to mitigate are those on fish and the river morphology with all its consequences in the flow, sedimentation, continuity, water quality and so on.

2.3 ENERGY CONVERSION PRINCIPLES

Hydropower captures the energy released from falling or moving water. Water falls due to gravity which causes the pressure and kinetic energy to be converted into mechanical energy then electrical energy. A water wheel or hydraulic turbine is used as a prime mover to transform the energy of water into mechanical energy (Twidell and Weir, 2000:183; Begamudre, 2000: 259). The potential energy lost by a volume of water falling down a slope in each second is given by the equation:

$$P_o = \rho QgH \qquad (2.1)$$

Hydroelectric power capacity of a plant is proportional to the product of gross head and discharge which can determined from

$$P_{net} = e\rho g Q H_g \quad (2.2)$$

Where

P is power (Watts)

e is the overall efficiency (%)

ρ is the density of water (1000kg/m^3)

g is the acceleration due to gravity (9.81m/s^2)

Q is the water discharge passing through the turbine (m^3/s)

Hg is the gross head (m)

The net power is often quickly estimated by taking "e" 50% (0.5) and rounding off:

$$P_{net}\,(\text{estimate}) = 0.5 * Q * 10 * H_{gross}\ \text{kW} \quad (2.3)$$

2.4 DEFINITION OF SMALL HYDROPOWER

There is no international consensus on the definition of the term "small hydro" which, depending on local definitions can range in size from a few kilowatts to 50 megawatts or more of related power output. Internationally, "small" hydro power plant capacities typically range in size from 5MW to 50MW. Projects in the 100kW to 5MW range are sometimes referred to as “mini” hydro. However, installed capacity is not enough to define the size of the project (RETScreen, 2004-a)

2.4.1 Small hydropower in the world

In the global small hydropower sector, China is the leader representing more than half of the world’s small hydro capacity with 31,200MW of installed capacity in 2005 (Laguna et.al., 2006).

Table 2.1 Installed SHP capacity (<10MW) by world region in 2004 (ibid)

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%
Australia	198	0.4%
TOTAL	**47,997**	**100%**

2.5 SMALL-SCALE HYDROPOWER SYSTEM COMPONENTS

The main components of a small-scale hydropower are: weir or dam, intake structures, penstocks, power house, tail race, fore bay tank and canal.

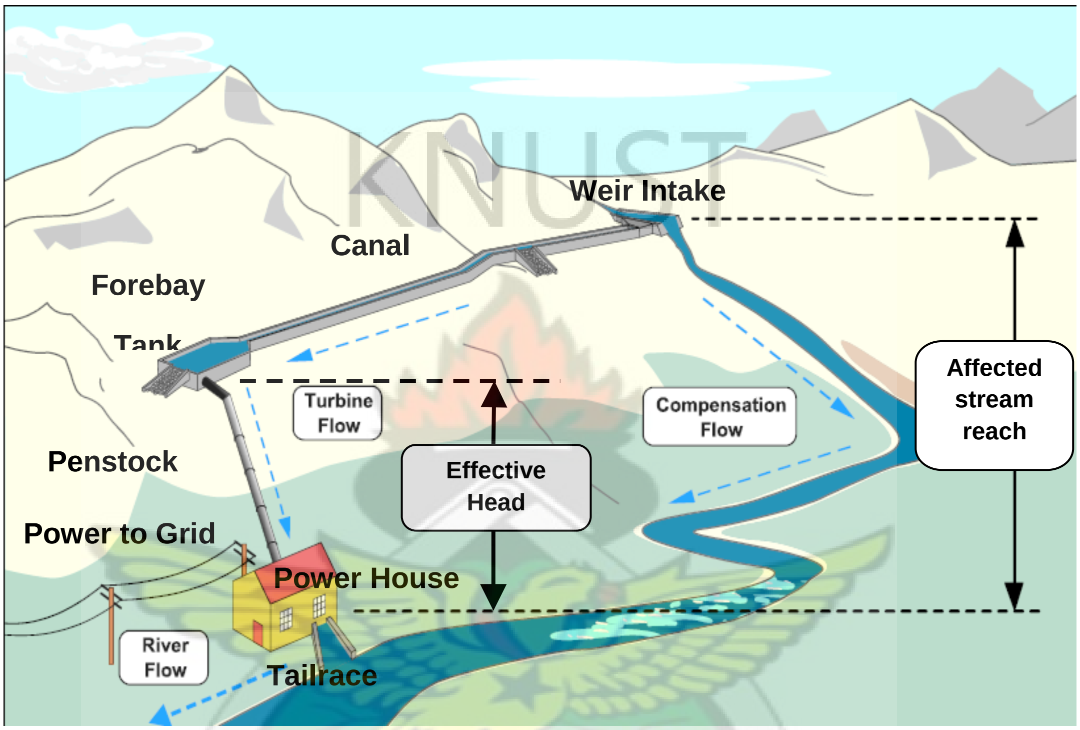


Figure 2.2: Overview of entire small-scale hydropower system

Source: www.british-hydro.org.uk

- **Dam or Weir**: This controls the flow of water and increases the elevation to create the head.
- **Power canal:** Coveys water from intake to the forebay, usually made of earth or concrete.

- **Forebay Tank:** The forebay tank purpose can be any combination of a surge volume, storage capacity, or sedimentation basin. Preventing sediments from entering the mechanical turbine from damage and shortened life.
- **Penstock:** Under full channel flow conditions the penstock transfers the collected water from the forebay tank to the mechanical works (figure 2.2). The purpose of the penstock is to provide the shortest path and largest elevation drop before the water enters the turbine. The change in elevation from the forebay head pressure in units of meters or feet. This head pressure provides the driving force to operate the turbine.
- **Power house:** Is the facility for converting the fluid energy into the electrical energy. It stores and protects all the power producing equipment and control devices.
- **Turbine:** Provides the mechanical energy from the water pushing against its blades to drive the generator.
- **Generator:** Converts the mechanical energy produced by the turbine into electrical energy.
- **Tailrace:** The used water enters the tailrace from the turbine and returns to the stream of origin. The tailrace is designed to minimize or prevent soil erosion by slowing the flow velocity before discharging to the stream. Reducing the velocity is often accomplished through the use of riprap commonly called rock slop protection (Hydraulic Energy Program, 2004)

2.6 SMALL HYDRO PROJECT DEVELOPMENT

The development of small hydro projects usually takes from 2 to 5 years to complete. After construction, small hydro plants require little maintenance over their useful life, which can be more than 50 years. Normally, one operator can easily handle operations and routine maintenance of a small hydro plant, while periodic maintenance of the large components requires more labor.

The technical and financial viability of each potential small hydro project are very site specific. The amount of energy that can be generated depends on the quantity of water available and the variability of flow throughout the year. The economics of a site depends on the energy that a project can produce, and the price paid for the energy. In an isolated area the value of electricity is generally significantly more than for systems that are connected to a central grid. However, isolated areas may not be able to use all the available energy from the small hydro plant because of seasonal variations in water flow and energy demand.

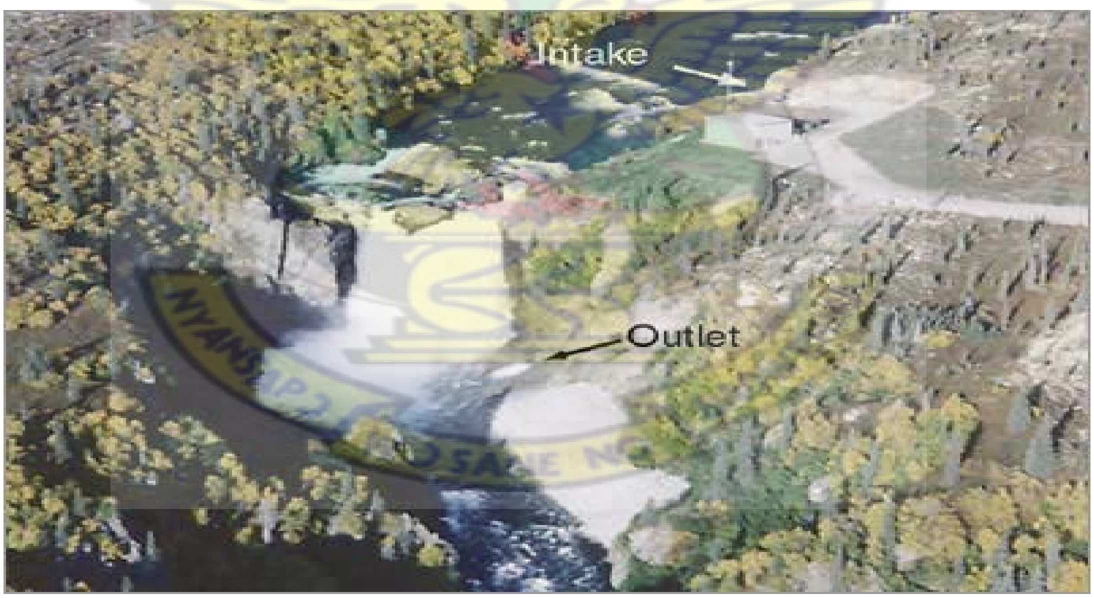
2.7 TYPES OF SMALL HYDRO CONFIGURATION

Generally three (3) main classifications can be identified namely:

2.7.1 Run-of river Scheme

This type of project allows generation of electricity without the impact of damming the water way. A portion of water flow from a river or stream is diverted through channel to forebay tank and then led via penstocks to drive hydraulic turbines after which, the water is redirected back to its original source (Dandekar and Shama 1979: 94-96). There is no water storage and the power fluctuates with the stream flow.

According to Sawyer (1986: 30-39), run-of-river plants (ROR) are employed where topography, environmental concern, or other factors prohibit reservoir construction and where natural river flows are reliable enough to justify the large capital costs that characterize hydropower. They are often suited to supply electrical needs of an isolated area or industry, if the minimum flow in the river or stream is sufficient to meet the load's peak power requirements (Dandekar and Shama, 1979: 94-96). Compared to other storage schemes, ROR have less environmental and social impacts (Schleicher, 2003). However, at times flows become too high or too low, for the utilities capacity and this necessitates shutdowns until flows return to within the acceptable range.



Source: http://www1.eere.energy.gov/windandhydro/hydro_plant_types.html

Figure 2.3 Run-of- River Scheme

2.6.2 Water storage (reservoir) scheme

For hydropower plant to provide power on demand, either to meet a fluctuating load or to provide peak power, water must be stored in a reservoir. Providing storage usually requires the construction of a dam and the creation of new lakes. This impacts the local environment in both negative and positive ways, although the scale of development after magnifies the negative impacts. This often presents a conflict as larger hydro projects are attractive because they can provide "stored" power during peak demand periods.

New dams for storage reservoirs for small hydro plants is generally not financially viable except at isolated locations where the value of energy is possibly very high.

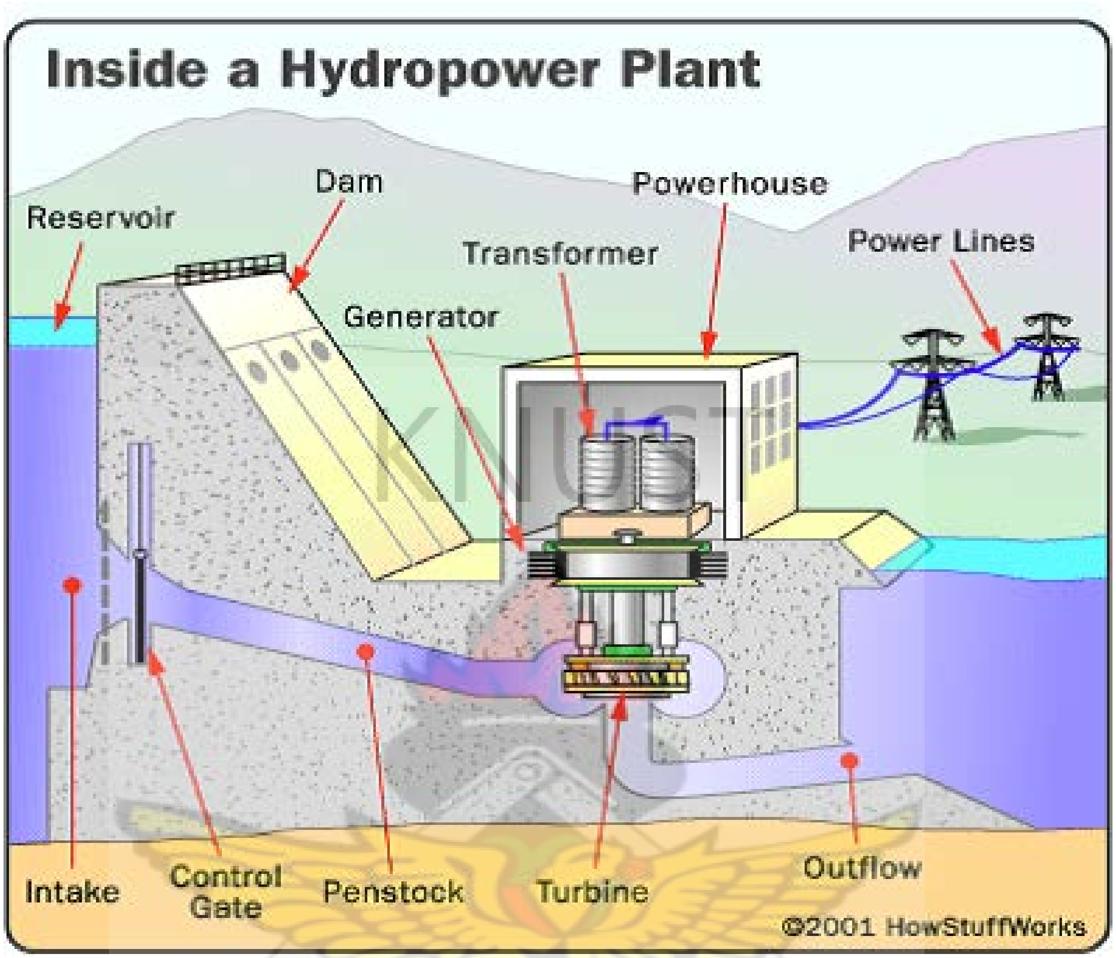


Figure 2.4 Reservoir Scheme

2.7.3 Developments using existing water networks

The use of water networks built for irrigation, drinking water and even waste water can be used for energy development. The advantage of using existing networks is that the initial cost is lower compared to other configurations.

In the case of irrigation or drinking water networks, the pressure caused by the strong slope between the reservoir and the consumers, has to be wasted in the surge tank. Instead of reducing the pressure it is often technically and financially possible to use a small pelton turbine which uses this pressure. Therefore, water generates energy before being consumed. There are two possible energy generation methods for existing waste water networks that the turbine can be set either before or after the treatment plant. In both cases optimal dimensioning of components is needed (MHylab, 2005).

Porsuk dam has the potential of being an example of the issue of electricity generation with small hydropower plants from irrigation dams after the article of Bakis and Bilgin is presented in International Symposium: Water for Development Worldwide (Bakis et. al., 2005).

Schemes are also classified according to the “Head”.

- High head : 100m and above
- Medium head : 30-100m
- Low head : 2-30m

2.8 COMPONENTS OF SMALL HYDROPOWER PLANTS

A small hydropower plant construction can be described under two main headings: Civil works, and electromechanical equipment.

2.8.1 Civil works (stream Diversion)

The basic design begins with partial stream diversion. There are a range of diversion designs from a simple pipe insertion into stream flow to a more complicated low weir that extends partially or completely across the stream (Figure 2.3). The inlet would also have a debris screen installed to prevent large objects such as rocks, leaves, or twigs from entering and damaging the system (New, 2004).

Figure 2.5: Full stream weir diversion

Source: www.whitman.edu/environmental_studies

2.8.2 Electrical and Mechanical Equipment

The primary electrical and mechanical components of a small hydro plant are the turbine(s), their governor(s) and generators.

Turbine

The turbine is the heart of a small hydropower plant because it determines the overall layout of the project (Canren, 2007). A number of different types of turbines have been designed to cover the broad range of hydropower site conditions found around the world. Turbine used for small hydro applications are scaled-down versions of turbine used in large hydro developments.

There are two types of hydro turbine, reaction turbines and impulse turbines. Turbines used for low to medium head applications are usually of the reaction type and a pressurized flow medium exists in a closed chamber in this case.

Reaction types include Francis turbines where flow is radially inward or mixed and Kaplan or Propeller turbines where flow is axial with fixed or adjustable blades respectively (Yanmax, 2006). Turbines used for high-head applications are generally referred to as impulse turbines.

Impulse turbines include Pelton, Turgo and Crossflow turbines. The runner of an impulse turbine spins in the air and is driven by a high-speed jet of water which remains at atmosphere pressure.

The main reasons for using different types of turbines at different heads is that electricity generation requires a short as close as possible to 1500 rpm to minimize the speed change between the turbine and the generator (Paish, 2002). The rotational speed of any given turbine, "n" is determined from:

$$n=\varphi\sqrt{2gHn} \tag{2.4}$$

Where φ is a dimensionless parameter and Hn is the net head (Yanmaz, 2006). Since turbine speed decreases in the proportion to the square root of the head, low head sites need turbines that are faster under a given operating conditions.

Small hydro turbines can attain efficiencies of about 90%. Care must be given to selecting the preferred turbine design for each application as some turbines only operate efficiently over a limited flow range. For most run-of-rivers small hydro sites where flows vary considerably, turbines that operate efficiently over a wide range are usually preferred (e.g. Kaplan, Pelton, Turgo and Crossflow designs). European small hydropower Association suggests the graph shown in figure. 2.4 to be used in the selection of the suitable turbine type.

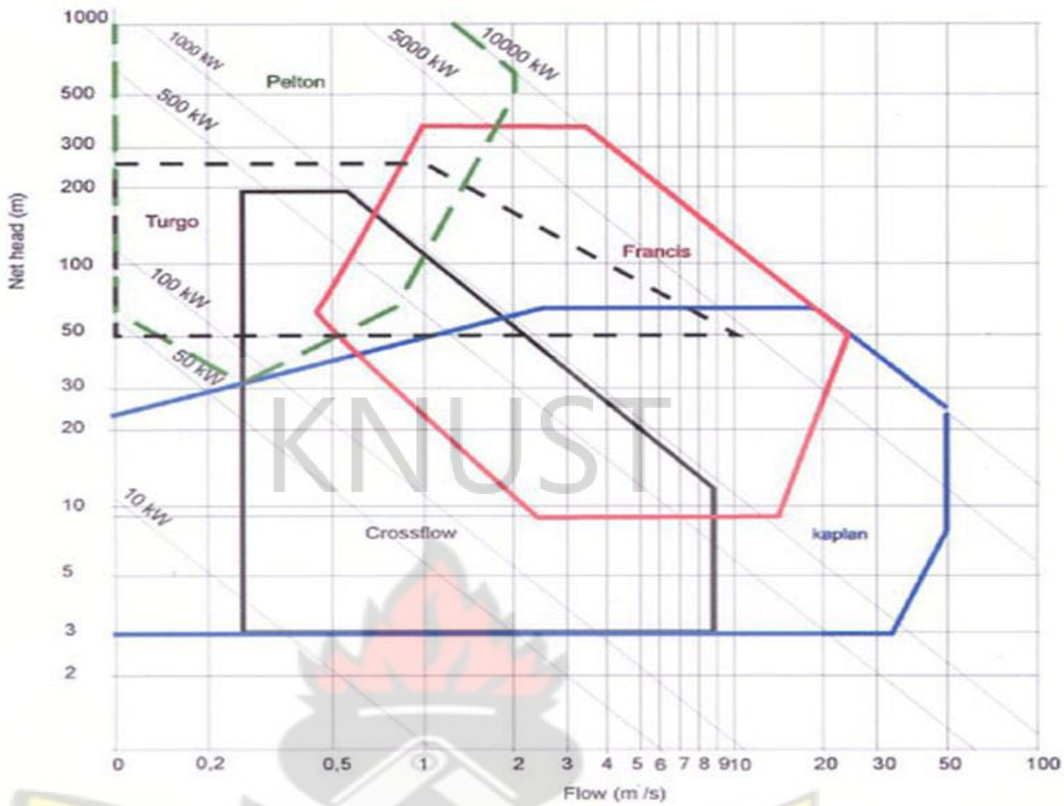


Figure 2.6: Turbine selection Graph (Canren, 2007)

In this graph, the horizontal axis represents the turbine design flow limited to $50m^3$/s and the vertical axis represents the net head limited to 1000m.

(i) Pelton Wheel

This is an example of an impulse turbine. Nozzles direct forceful streams of water against a series of spoon-shaped buckets mounted around the edge of a wheel. Each bucket reverses the flow of water and this impulse spins the turbine. The Pelton Wheel is suitable for high head, low flow sites. The quantity of water discharged by the nozzle can be controlled by controlling the nozzle's opening by means of needle placed in the tip of nozzle. (See figure 2.7 below)

(ii) Kaplan Turbine

The inlet is a scroll-shaped tube that wraps around the turbine's wicket gate. The Kaplan turbine is an example of reaction turbine. Water is directed tangentially, through the wicket gate, and spirals on to a propeller shaped runner causing it to spin. The output is a specially shaped draft tube that helps decelerate the water and recover kinetic energy. There are only 3 to 6 blades in Kaplan turbine which reduces frictional resistance. The Kaplan turbine is shown in figure 2.8 below.

(iii) Francis Turbine

The Francis turbine is also an example of a reaction turbine. It uses the total available head partly in the form of pressure energy and partly in the form of kinetic energy. This type of turbine is mostly used for medium heads; because in case of Pelton wheels as the head reduces for a given output the diameter of the rotor has to be increased at the same time the speed reduces. Thus the Pelton wheel becomes unsuitable and the choice goes for Francis turbine. See figure 2.9 below

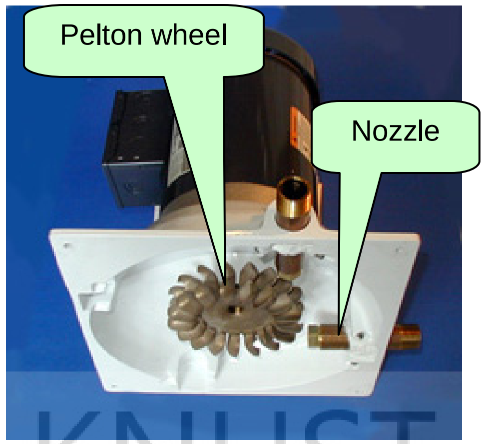


Figure 2.7: Pelton wheel and nozzle configuration

Source: www.hipowerhydro.com

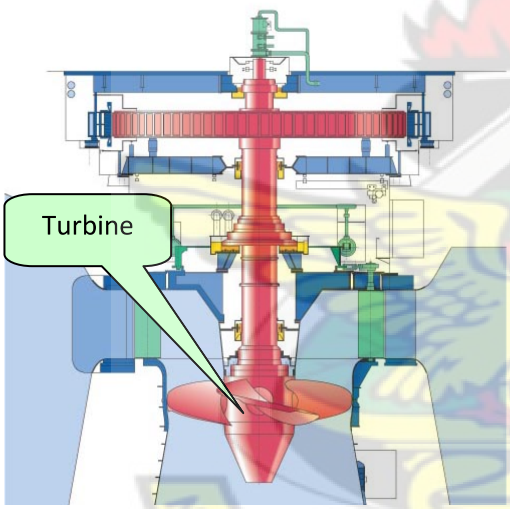


Figure 2.8: Kaplan turbine

Source: en.wikipedia.org/wiki/Kaplan turbine

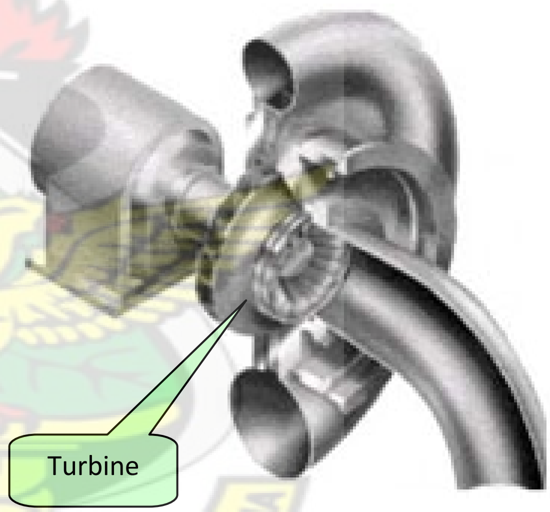


Figure 2.7: Francis turbine

Source: www.enerecosrl.com

Table 2.2 Turbine Type Head Classification

TURBINE TYPE	HEAD CLASSIFICATION		
Impulse	High (>50m)	Medium (10-50m)	Low (<10m)
	Pelton Turgo Multi jet Pelton	Cross flow Turgo Multi jet Pelton	Crossflow
Reaction		Francis (Special case)	Francis (Open flume) Propeller Kaplan

Governors

The rotational speed of turbines must be controlled within narrow limits to maintain the correct frequency.

This speed control is provided by a governor that adjusts the water flow by sensing changes in speed. The correct frequency is between 50 to 60 MHz (Paish, 2002).

Generators

There are two basic types of generator used in small hydro plants, synchronous and induction (asynchronous). A synchronous generator can be operated in isolation while an induction generator must normally be operated in conjunction with other generators. Synchronous generators are used as the primary source of power produced by utilities and for isolated diesel-grid and stand-alone small hydro applications. Induction generators with capacities less than about 500kW are generally best suited for small hydro plants providing energy to a large existing electricity grid (RETScreen, 2004-a).

2.8.3 Miscellaneous electromechanical equipment

Other mechanical and electrical components of a small hydro plant include:-

- Water shut-off valves(s) for the turbine(s);
- River by-pass gate and controls (if required);
- Hydraulic control system for the turbine(s) and valve(s);
- Electrical protection and control systems;
- Electrical switchgear;
- Transformers for station service and power transmission;
- Station service including lighting and heating and power to run control systems and switchgear;
- Water cooling and lubricating system (if required) ;
- Ventilation system
- Backup power supply
- Telecommunication system
- Fire and Security alarm system (if required); and
- Utility interconnection or transmission and distribution system (RETScreen, 2004-a)

CHAPTER THREE

MATERIALS AND METHODS

3.0 INTRODUCTION

This chapter present an overview of the area identified for the study. It discusses the research methods used in this study. These include desk studies, onsite measurement and a filed survey.

3.1 STUDY AREA

Daboase is a small town and is the capital of Mpohor/Wassa East District, a district in the Western Region of Ghana. It has about 170 communities. It occupies an area of 1,880 sq. kilometer out of (464,553ha), which 344 square km (85,000 ha) are used as cultivable land. The district capital Daboase is 6.7 km off Cape Coast -Takoradi main road.

3.1.1Climate

The district falls within the tropical climate zone. The mean annual rainfall is 1,500 mm and ranges from 1,300 to 2,000 mm, with an average annual temperature of 30^{o}C. The wet period in the district is between March and July while November to February are relatively dry months.

3.1.2 Relief and drainage

The district lies within the low - lying of the country with most parts below 150 meters above sea level. The landscape is generally undulating with an average height of above

70 meters. The highest elevation ranges between 150 and 200 meters above sea level. The drainage pattern is largely dendritic and there are medium and small rivers and streams distributed throughout the district.

The main rivers are the Pra, Subri, Butre, Brempong, Suhyen , Abetumaso, Hwini and Tipae. While most of them overflow their banks in the rainy season, majority virtually dry out in the dry season leaving behind series of dry valleys and rapid thus, reducing access to running water, which is the source of domestic water for most households.

3.1.3 Demographic characteristics

According to the 2010 population census, the population of the district was 123, 996 with an inter – censual growth rate of 3.2 percent which is the same as the regional growth rate. Males form 50.4 percent of the total population (62,470) as against 49.6 percent (61,526) for females due to the mining and agricultural activities in the district.

The following communities were identified at the catchment area of the study site and are without electricity; Kofi Ashia, Timtimhwe, Aboaboso and Mankesiasi. The total population of the identified communities was 1,825 with an average of 5 persons per household. **Appendix A** depicts a detailed feasibility studies and relevant information that is required to carry out assessment at a particular site.

3.2 Assessment Methods

This section describes the methods of study used to estimate the hydropower potential of the site, energy consumption of the identified village(s) and forecast demand. Generally three main assessment methods are used, namely:

(i) Desktop Concept/ Pre-Feasibility Study

(ii) Feasibility Study and

(iii) Implementation

3.2.1 Data collection methods

The data in this study was collected using the following approach

a) Desktop Concept

The first step of this research process was a review of the relevant literature on small-scale hydropower, rural energy and development. The study used both primary and secondary data sources. Most literature was obtained from online journals, conference proceedings, thesis, government policy documents, published books as well as project reports. Specific information for the area under study was obtained from the following key government ministries, departments and agencies. Ministry of Petroleum and Energy (MoEn), Ministry of Water Resources, Works and Housing, Geological and Hydrological Survey Departments, Metrological Services Departments and Ghana Statistical Services. Information collected from the above sources include:

i. Topographical and geological data
ii. Metrological data (rainfall, sunshine, temperature, evaporations and wind)
iii. Demographic data (population)
iv. Stream flow gauging data
v. Energy policy (SHEP Towns)

Appendix D shows the information gathered from the Metrological Services Department.

b) Site selection

A preliminary study of the sites listed in MoEn master plan for Rural Electrification popularly known as SHEP was carried out at ECG office at Sekondi. Due to funding constraints, only three (3) sites were visited. The sites visited were river Pra which runs through Central and Western regions. Two dams can be built on it. One at Awisam in the Central region and the other in Sekyere Heman in the Western region. River Tano is at Tanoso and River Ankobra is at Bunso both in the Western region of Ghana. The purpose of the visit was to

1. Assess the gross head and flow rate at each site
2. Consider access problems
3. Identify possible consumers of electricity within 1 kilometer radius, and
4. Consider the proportion of flow in the river that was likely to be available for power. River Pra met the above criteria and was selected for this study. In addition to the above factors, river Pra has the following features:

(a) Mountainous region mostly covered with forests.

(b) Relatively safe in terms of earthquakes.

3.2.2 Feasibility Study

Work would continue on the identified site with a major foundation investigation programme such as : delineation, estimation of diversion, design and probable maximum floods, determination of power potential for a range of dam heights and installed capacities for project optimization, determination of the design earthquake and the maximum credible earthquake, design of all structures in sufficient detail to obtain quantities for all items contributing more than 10 per cent to the cost of individual structures, determination of the dewatering sequence and project schedule, optimization of the project layout, water levels and components, production of detailed cost estimate, and finally, an economic and financial evaluation of the project including an assessment of the impact on the existing electrical grid along with comprehensive feasibility report with the following major headings:

- **Site Inspection**- Selection and location, Meet with developers, obtain more data
- **Hydrological Modeling**- Firm up hydrology, Sedimentation studies, Environmental flow assessment
- **Preliminary Costing**- Capital cost estimates, O & M assessment
- **Preliminary Design**- Preliminary drawings, Bill of quantities
- **Social and Environmental Assessment**- Planning legislation and policies, Construction impacts, Inundation and river barrier issues, operational impacts, Land acquisition and issues, Stakeholders assessment

- **Hydropower Assessment**- Run of river vs. storage, Net head, Available discharge, Sizing of generating set, Potential energy production
- **Field Investigation**- Geotechnical, survey

3.3 FILED SURVEY

This section outlines specific activities carried out during field surveys. Included are the socio-economic study and site stream flow measurements

3.3.1 *Socio Economic Study*

One of the hypothesis of this study was that small scale hydropower in areas with potential could play a significant role in meeting energy needs of rural areas in the Western Region of Ghana. It was therefore important to assess the energy requirements of the community and evaluate their ability to sustain the scheme. Determining the energy requirement for each household would be useful in matching the demand with exploitable potential available on site. It is also useful in formulating the rural household energy demand prediction model. Understanding their socio-economic status would direct the study to assess issues like affordability and sustainability of the project in the wake of abject and pervasive poverty existing in the rural areas of the Western Region. In order to elucidate this knowledge, available information at the district assemble were used. Also opinion leaders of the identified communities were contacted. **Appendix B** shows a detailed demand and capability question that are necessary for field survey.

3.3.2 *On-site measurements*

(a) Measuring head

The head between the intake point and the fore bay tank and between the fore bay tank and outlet position was measured. There are several methods for determining the available head at a particular site. Since most of the sophisticated instruments were not available, a simple level was used in measuring the head in this study. Figure 3.1 shows survey of weir and fore bay tank.

Procedure for the head measurement

A dummy level or a transparent water container (e.g. a glass jar) was used. With the glass jar approach, a rough idea of the level was made and this was used to measure the head.

(i) Started at the lowest point (where the hydro plant may be situated).

(ii) Viewed a point at an eye level (horizontal) on the ground ahead by viewing through the glass over the level surface of the water to a point that you can walk up.

(iii) Walk up to that point (and count the number of times you walk to the next point).

(iv) Place your feet at that point.

(v) Repeat ii, iii and iv until your eye level with the water source. (where the pipeline would begin)

(vi) Multiply the distance between your feet and your eyes by the number of times you walked up to the next point (including the final sighting). The head was found to be **24m** by this method.

Figure 3.1 Survey of river cross section at the proposed intake weir site

(b) Measuring discharge

The most important aspect of the field measurement was to determine the total flow rate of the river. The method used to measure the discharge is one of several described by Inversion (1986). This study used the grid point method, commonly known as velocity- area method.

To measure discharge, flow velocity and cross sectional area was required. A convenient position was selected along the river. Two river banks connected by a scaled tape were used. Using a graduated meter, depths were taken across the river and recorded. The section profile was scaled on paper and uniformly the grid points were located at uniformly latheral vertical points. A current meter was then lowered at different points across the river and the number of revolutions was recorded. A stop watch was used to time the number of revolutions. Elemental flow of each area was given by the equation: $\delta Q = V\delta A$. The total discharge was then calculated from the equation $Q = \sum \Delta Q = \sum V \Delta A$. The flow rate obtained in this work was 0.50 m^3/s.

Figure 3.2 below illustrates how river discharge measurements were conducted on site.

Figure 3.2 On -site discharge measurement

Table 3.1 Tabulated result of the determination of velocity at Y- section of river Pra

D(m) Length across a section of river Pra	Time (s)	d(m) travel distance	Depth (m)
10.4 meters	35	6	0.15
	33		0.23
	42		0.26
	32		0.28
	33		0.19

Average time, $T_{avg.} = \frac{35+33+42+32+33}{5}$

= 35seconds

But velocity, $V = \frac{Distance}{Time}$

$V = \frac{10.4}{35}$

= 0.295

Multiplying the answer by the velocity adjustment coefficient of 0.8, we obtain

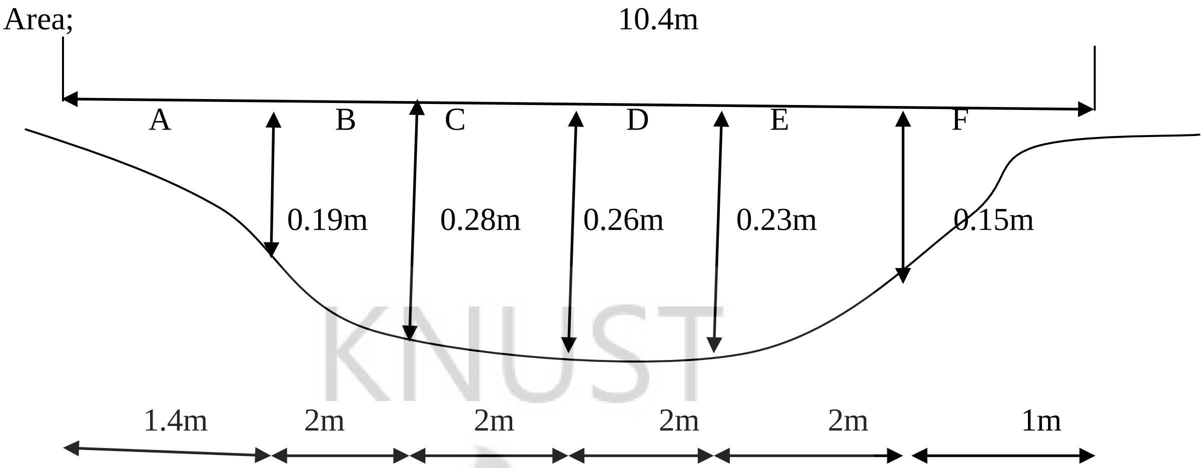
V= 0.295× 0.8

= 0.236

V= 0.24 m/s

Calculation of the Cross sectional Area (A) at Y- section of river Pra

For Area;



A and **F** are triangle, hence the formula for finding area of a triangle is used in the computation.

A = $\frac{1}{2}\boldsymbol{bh}$ (formula for finding the area of a triangle)

Where b = base, h = height

$= \frac{1}{2} \times 1.4 \times 0.19$

= ***0.133m***^{2}

B, C, D and **E** are trapezium; hence the formula for finding the area of a trapezium is used

B = $\left(\frac{a+b}{2}\right)\boldsymbol{h}$ (formula for finding the area of a trapezium)

Where **a** and **b** are opposite sides of the trapezium h is the distance between the parallel sides

$$B = \left(\frac{0.19+0.28}{2}\right)2$$

$= \boldsymbol{0.47m^2}$

$$C = \left(\frac{a+b}{2}\right)h$$

$$C = \left(\frac{0.28+0.26}{2}\right)2$$

$= \boldsymbol{0.54m^2}$

$$D = \left(\frac{a+b}{2}\right)h$$

$$= \left(\frac{0.26+0.23}{2}\right)2$$

$= \boldsymbol{0.49m^2}$

$$E = \left(\frac{a+b}{2}\right)h$$

$$= \left(\frac{0.23+0.15}{2}\right)2$$

$= \boldsymbol{0.38m^2}$

$$F = \frac{1}{2} \times 1 \times 0.15$$

$= \boldsymbol{0.075m^2}$

Therefore, total area = A+B+C+D+E+F

= (0.133+0.47+0.54+0.49+0.38+0.075) $\boldsymbol{m^2}$

Total area (A) = **2.088** $\boldsymbol{m^2}$

Q = AV

= 2.088×0.24

Q = **0.50** $\boldsymbol{m^3}$**/s**

2.9 CALCULATION OF ENERGY POTENTIAL AT A PARTICULAR SITE

Generally, three (3) main potentials can be derived at a particular site.

These are;

Theoretical – The maximum potential that exists.

Technical – It takes into account the cost involved in exploiting a source (including the environmental and engineering restrictions)

Economic – Calculated after detailed environmental, geological, and other economic constraints.

Using equation (2.3) and substituting the values obtained, i.e. H = 24m, Q = 0.50 m^3/s.

Pnet (estimate) = 0.5× 0.50×10× 24 kW

= **60 kW**

3.5 SOFTWARES FOR SMALL HYDRO PROJECT ASSESSMENT

Table 3.2 depicts the various softwares available for a quick assessment of hydro potential at a particular site.

Table 3.2 Small Hydropower Assessment Tools (IASH, 2007)

Assessment Tools		**Features**				
Software	Applicable Countries	**Hydrology**	**Power/ Energy**	**Costing**	**Economic Evaluation**	**Preliminary Design**
ASCE Small Hydro	USA	✓				
HES	USA	✓				
Hydra	Europe	✓	✓			
IMP	International	✓	✓		✓	
PEACH	France	✓		✓		✓
PROPHETE	France	✓	✓		✓	
Remote Small Hydro	Canada	✓	✓		✓	
RETScreen®	International	✓	✓	✓	✓	

The RETScreen was selected to manage this study because of it versatile nature.

3.5.1 RETScreen-Small Hydro Project Software

(a) General

The RETScreen International Clean Energy Decision support Centre is an organization seeking to help planners, designers, corporations and industry to implement renewable energy and invest in energy efficiency projects. This objective is achieved by developing decision-making software that reduces the cost and duration of pre-feasibility studies; help people make better and faster decisions; training people to better analyze the technical and financial viability of possible projects.

(b) RETScreen-Small Hydro Project Software

The RETScreen-small Hydro Project Software, which is written in visual Basic Code with iterative worksheets, provides a means to calculate the available energy at a potential small hydro site that could be provided to a central-grid or for isolated loads and the financial viability of the project by estimating project costs. The model addresses both run-of-river and reservoir developments and calculates efficiencies of a wide variety of hydro turbines.

The Small hydro model can be used to evaluate small hydro projects typically classified under the following three (3) categories:

- Small Hydro
- Mini Hydro
- Micro Hydro

The classification can be entered manually or selected by the model. If the selection is done by the model the classification is related with the design flow of the project and the runner diameter of the turbine. Project classification of RETScreen Software is shown in Table 3.3

Table 3.3 RETScreen's Project Classification (Source: RETScreen, 2004-a)

Project Classification	**SMALL**	**MINI**	**MICRO**
Design flow (m^3/s)	12.8	0.4 -12.8	0.4
Turbine Runner diameter (m)	0.8	0.3 – 0.8	0.3

The reason for this selection is that the turbine runner diameter value of 0.8 meter corresponds to the largest turbine that can be transported to a project site as one package loaded on a truck.

The small Hydro Project Model has been developed primarily to determine whether work on the small hydro project should proceed further or be dropped in favour of other alternatives (RETScreen, 2004-a).

Seven worksheets *Energy Model, Hydrology Analysis and Load Calculation (Hydrology* and *Load), Equipment Data, Costs Analysis, Greenhouse Gas Emission Reduction Analysis (GHG Analysis), Financial Summary and Sensitivity and Risk Analysis (Sensitivity)* are provided in the Small Hydro Project Workbook file (RETScreen, 2004-a).

RETScreen software suggests The *Energy Model*, *Hydrology* and *Load* and *Equipment Data* worksheets to be completed first. The *Cost Analysis* worksheet should than be completed, followed by the optional *GHG Analysis* worksheet. The *Financial Summary* worksheet and optional *Sensitivity* worksheet should be finally completed. The GHG

Analysis worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project. The Sensitivity worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. It is recommended that the user works from top-down for each of the worksheets although completing the *Hydrology* and *Load* and *Equipment Data* worksheets before the energy Model worksheet is recommended. The process can be repeated several times by the user in order to help optimize the design of the small hydro project from an energy use and cost standpoint (RETScreen, 2004-a). It should be noted that, the software itself does not make optimization.

The RETScreen-Small Hydro Project Model estimates the project costs with two different methods: the "Formula" and the "Detailed" costing methods. All the hydro cost equations used in the "Formula" costing methods are empirical. If used correctly, the "Formula" costing method will provide a baseline cost estimate for a proposed project.

The "Detailed" costing method allows the user to estimate costs based on estimated quantities and unit costs. The use of this costing method required that the user estimate the size and the layout of the required structures meaning that the project has to be pre-evaluated before the "Detailed" analysis can be used.

The small Hydro Project Model has been designed primarily to evaluate run-of-river small hydro projects. The evaluation of storage projects is also possible; however, variations in gross head due to changes in reservoir water level cannot be simulated. The model requires a single value for gross head. In the case of reservoir projects, an average value must be entered. The determination of the average head must be done outside of the model.

This user friendly manual software is presented in tabulated form with some examples in **Appendix C.**

3.5.2 Hydrology Data

In RETScreen, hydrological data are required to be specified as a flow-duration curve, which represents the flow conditions in the river being studied over a period of time. For storage projects, data must be entered manually by the user and should represent the regulated flow that results from operating a reservoir; the head variation with storage drawdown is not included in the model.

After flow-duration curve is entered or calculated and the residual flow that should be kept in the river is entered, the model calculates the firm flow that will be available for electricity production. However, it should be noted that, the calculation of flow-duration curve is performed using the database on basins located in Canada, therefore, the calculation is only available for Canadian projects. The user, however, is allowed to enter a basin information in the database and then perform the calculation. Calculation of flow-duration curve is the most difficult part of a pre-feasibility report and RETScreen software's calculation method is a time saver tool for the developers.

3.5.3 Flow-duration curve

A flow-duration curve is a graph of the historical flow at a site ordered from maximum to minimum flow. It is used to assess the availability of flow over time and the power and energy, at a site (RETScreen, 2004-a).

The flow-during curve is specified by twenty-one values $Q_{0,}Q_5, \ldots, Q_{100}$ representing the flow on the flow-duration curve in 5% increments. In other words, Q_n represents the flow that is equaled or exceeded n% of the time. An example of a flow-duration curve is shown in figure 3.3.

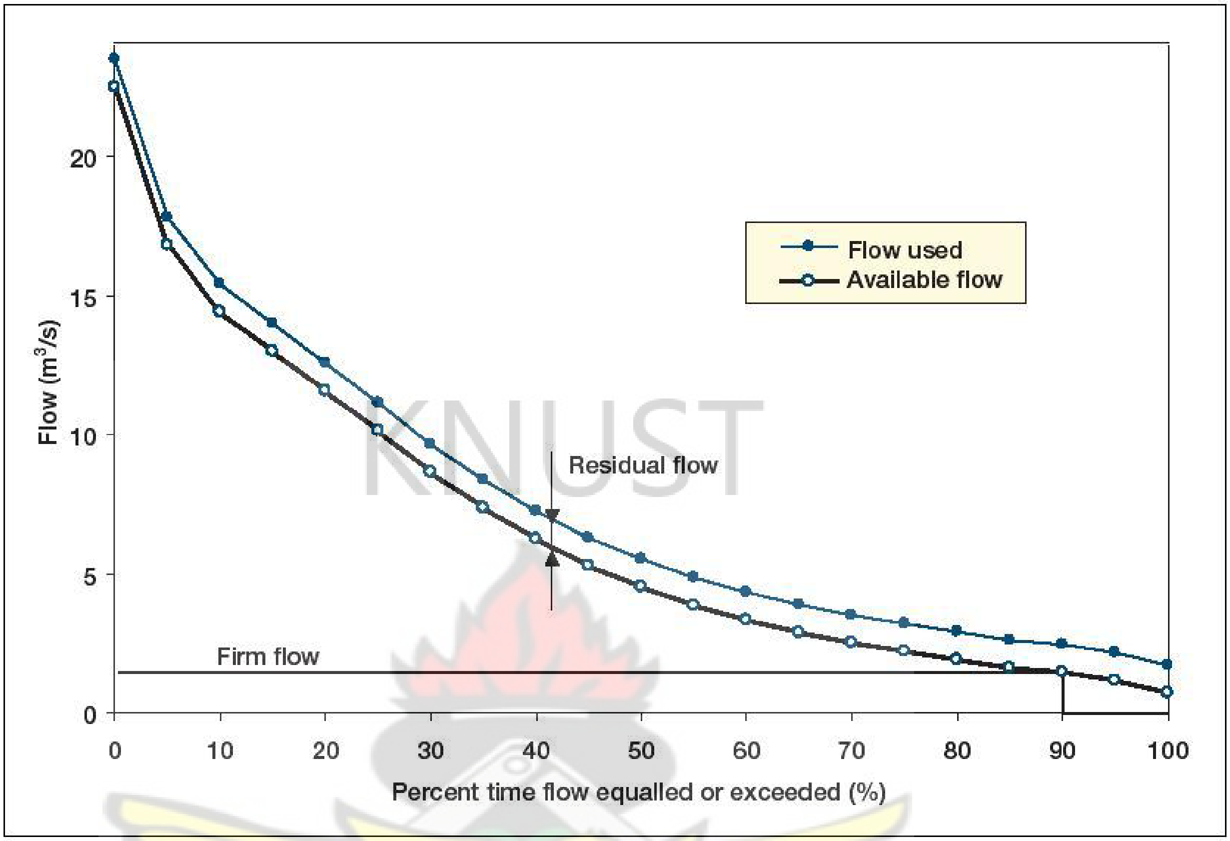


Figure 3.3 Example of Flow -Duration Curve (RETScreen 2004-a)

3.5.4 Residual flow

Residual flow, Q_r, is flow that must be left in the river throughout the year for environmental reasons. It is specified by the user and subtracted from all values of the flow-duration curve for the calculation of plant capacity, firm capacity and renewable energy available.

3.5.5 Firm flow

The firm flow is the flow being available p% of the time, where p is a percentage specified by the user and usually between 90% and 100%. The firm flow is calculated from the available flow-duration curve.

3.5.6 Design flow

The design flow is the maximum flow that can be used by the turbine. The selection of design flow depends on the available flow at the site. For run-of river projects, which are connected to a large grid, the optimum design flow is usually close to flow that is equaled or exceeded about 30% (Q_{30}) of the time (RETScreen, 2004-a).

3.5.7 Load Data

The load depends on the type of grid considered. If the small hydro power plant is connected to a central-grid, then it is assumed that the grid demands all the energy production. If on the other hand the system is off-grid or connected to an isolated-grid, then the portion of the energy that can be delivered depends on the load.

3.5.8 Energy Production

The RETScreen-Small Hydro Project Model calculates the estimated renewable energy delivered (MWh) based on the adjusted available flow (adjusted flow-duration curve), the design flow, the residual flow, the load (in case of isolated grid), the gross head and the efficiencies/losses.

3.5.9 Turbine efficiency curve

Small hydro efficiency data can be entered manually or can be calculated by RETScreen. Standard turbine efficiency curves have been developed for Kaplan, Francis, Propeller, Pelton, Turgo and Crossflow turbine types.

The type of turbine is entered by the user based on its suitability to the available head and flow conditions. The turbine efficiency curve calculation is based on rated head (design gross head less maximum hydraulic losses), runner diameter (calculated), turbine specific speed (calculated for reaction turbines) and the turbine manufacture/design coefficient. The efficiency equations were derived from a large number of manufacture efficiency curves for different turbine types and head and

flow conditions (RETScreen, 2004-a). It is a disadvantage that, the software does not include a feature that suggests the type of the turbine.

For multiple turbine applications it is assumed that all turbines are identical and that a single turbine will be used up to its maximum flow and then flow will be divided equally to the number of turbines. Therefore, unidentical turbines used in the small hydro project are assumed to be identical by the model. The turbine efficiency equations and the number of turbines are used to calculate plant turbine efficiency from 0% to 100% of design flow at 5% intervals. An example of turbine efficiency curve for 1 and 2 turbines, where the gross head and the design flow are 146 m and 1.90m^3/s respectively, is shown in figure 3.4. **Appendix E** shows the runner diameter calculations and other related parameters.

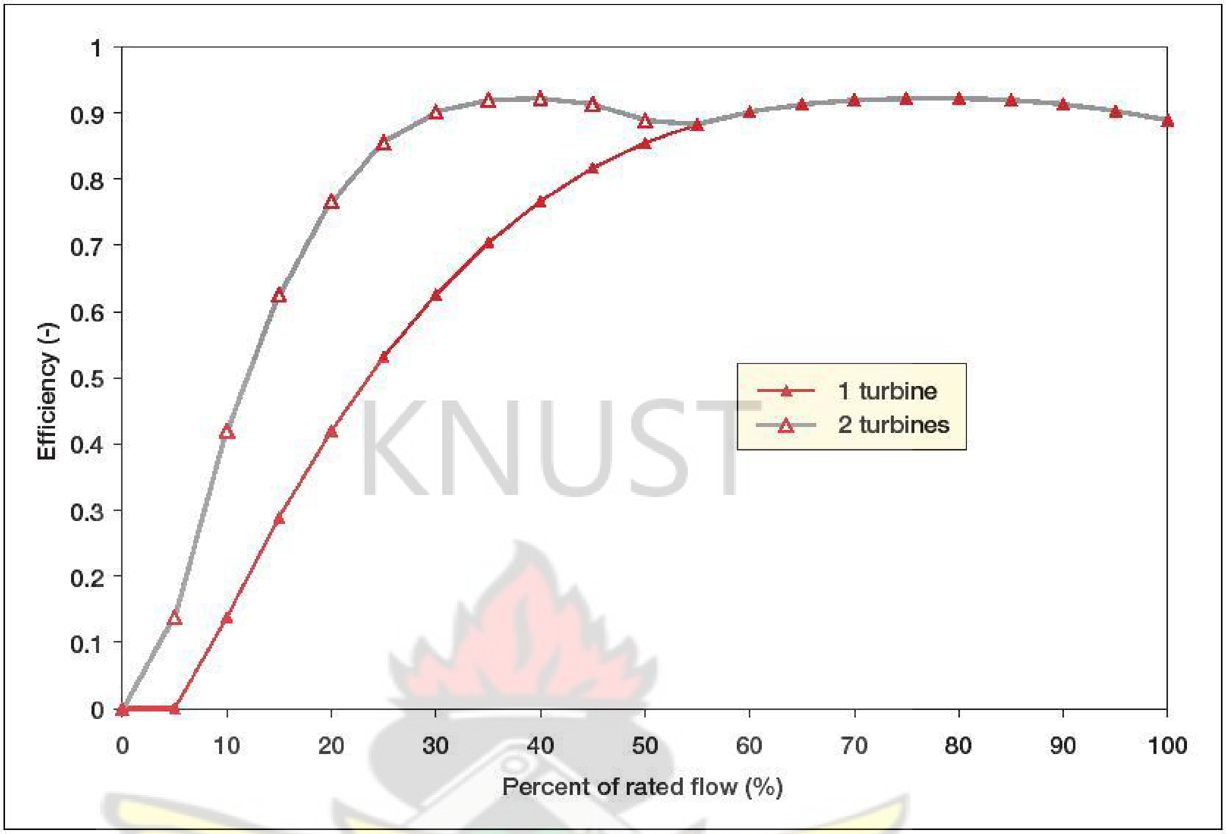


Figure 3.4 Example of a Turbine Efficiency Curve (RETScreen, 2004-a)

3.5.10 Power available as a function of flow

Actual power P available from the small hydro plant at any given flow value Q is given by Equation 3.1, in which the flow-dependent hydraulic losses and tailrace reduction are taken into account:

$$P= \rho gQ[H_g -(h_{hydr} +h_{tail})]e_t e_g(1-l_{trans})(1-l_{para}) \quad (3.1)$$

Where h_{hydr} and h_{tail} are respectively the hydraulic losses and tailrace effect associated with the flow; e_t is the turbine efficiency at flow Q; e_g is the generator efficiency, l_{trans} is the transformer losses, and l_{para} is the parasitic electricity losses (RETScreen 2004-a).

Hydraulic losses are adjusted over the range of available flow based on the following relationship:

$$h_{hydro} = H_g \, l_{hyra}, max \frac{Q\text{^}2}{Q_d\text{^}2} \quad (3.2)$$

Where l_{hyra}, max is the maximum hydraulic losses specified by the user, and Q_d is the design flow (RETScreen 2004-a).

The maximum tailrace effect is adjusted over the range of available flows with the following relationship:

$$h_{tail} = h_{tail}, \text{max} \frac{(Q - Q_{des})\text{^}2}{(Q_{max} - Q_{des})\text{^}2} \quad (3.3)$$

Where h_{tail}, max is the maximum tailwater effect which is the maximum reduction in available gross head that will occur times of high flow in the river. Q_{max} is the maximum river flow and equation (3.3) is applied only to river flows that are greater than the plant design flow (when Q>Q_{des}) (RETScreen, 2004-a).

3.5.11 Plant capacity

Plant capacity P_{des} is calculated by re-writing equation (3.1) at the design flowQ_{des}. The equation simplifies to:

$$P_{des =} \rho g Q_{des} H_g (1 - h_{hydr})] \; e_t, dese_g (1\text{-}l_{trans})(1\text{-}l_{para}) \quad (3.4)$$

Where P_{des} is the plant capacity and e_t, des the turbine efficiency at design flow, calculated from the turbine efficiency curve. The small hydro plant firm capacity is calculated again using equation 3.4, but this time using the firm flow and corresponding turbine efficiency and hydraulic losses at this flow (RETScreen, 2004-a).

CHAPTER FOUR

FINANCIAL ANALYSIS

4.1 TOOLS FOR FINANCIAL ANALYSIS

In order to make informed decisions about investing in small-scale hydropower development, potential investors need to know all relevant cost factors. These factors include plant data, such as its initial capital costs, operation and maintenance costs, predicted lifetime and load factor (Boyle, 2004:186). There is also the need to consider other external factors such as the discount rate, or the cost of borrowing money over a period. A number of criteria are used for evaluating projects from financial point of view. These include the net present value (NPV), internal rate of return (IRR) and net benefit cost ratio (Subroto et. al., 1981: 339-342). An example of the financial summary is shown in a tabulated form using the RETScreen software in **Appendix C.**

4.1.1 Present value

Present value is the value today of a benefit or cost that occurs in the future. It is measured using the discount rate. In mathematical terms, the present value of a sum of money received or spent in some future period is calculated using the formula below:

$$FV = PV\ (1+r)^n \tag{4.1}$$

Where PV is the present value

FV is the future value

r is the discount rate and

n is number of years.

The equation below is often referred to as the present worth factor and is used to calculate the present value $\frac{1}{(1+r)^n}$ (4.2)

4.1.2 Net present cost /Life cycle cost

The net present cost is the sum of the present values of all associated costs over the period of the project. Costs in any future year are discounted back to the based period using equation (4.1). In calculating the net present cost, the following assumptions are made.

a. Initial investment costs are lump sum (all occur at once) in period 0 ;

b. All recurrent costs begin to accumulate in period 1

c. Costs in any period are lumped together and assumed to occur at the end of that period; and

d. Salvage values are considered as negative costs.

4.1.3 Net present value

The net present value of the project is the sum of the present value of all benefits associated with the project, less the sum of the present values of all associated costs. It is calculated using the formula below:

$$NPV = \sum \frac{(TB - TC)}{(1+r)^n} \quad (4.3)$$

Where NPV = net present value

TC = total costs

TB = total benefits

r = is discount rate and

n = number of year

4.1.4 Internal rate of return

The internal rate of return (IRR) is the discount rate at which the cumulative net present value of the project is equal to zero. At this discount rate, the cumulative net present value of all project costs is exactly equal to the cumulative net present value of project benefits. As a general rule, *if the project being evaluated has an internal rate of return lower than the discount rate, the project should not be undertaken.* The IRR is found by solving the formula below through integration to find the discount rate (r) at which the NPV equal zero.

$$\sum PV = 0, \text{ thus} \sum \frac{FV}{(1+r)^n} = 0 \qquad (4.4)$$

4.1.5 Benefit – to – cost ratio (BCR)

The benefit to cost ration is equal to the NPV of associated benefits divided by the NPV of associated costs (net present cost).

$$BCR = \frac{NPVbenefits}{NPVcost} \qquad (4.5)$$

4.1.6 Cost of generation (Co G)

The cost of generation is equal to the net present cost of the energy system divided by the total kWh generated over the life of the system.

$$\text{Co G} = \frac{NPC}{TotalKW\ h} \tag{4.6}$$

4.2 COSTING

There are two categories of costs in small-scale hydropower development: investment and annual costs (Hosseini et.al., 2005:1945-1956). Investment cost includes civil costs, electromechanical equipment, power transmission line, and other indirect costs. Annual cost includes the depreciation of equipment, O & M, and replacement costs (Nouni et. al., 2006:1161-1174). The specific investment cost depends on the type and the size of the small hydropower project. Generally the smaller the hydropower scheme under consideration, the higher the specific costs, i.e. per KW installed, are likely to become.

The power generation cost $C_n = P_n \times C_\alpha$ (4.7)

Where $Pn = 9.81 \times QHeh$ is the power output of the site

$C\alpha = \frac{(C_{Lcc})}{(FdxD\ \ 365)}$ is the unit cost of power (US$ /KW)

Where Fd = discounted factor $= \frac{((1+r)^n - 1)}{i\ (1+r)^n}$, i = discounted rate on project cost escalation

n = number of years

D = systems daily demand kW = unit consumption x community size

C_{Lcc} = Life cycle cost (US$)

The cost of the equipment including the turbine, generator and transmission equipment constitute 20% to 40% of projects costs, site related civil costs generally vary between 50% and 70% of project costs, while 5% to 15% is devoted to engineering costs (Gordon and Noel, 1986). Given that site specificity of hydropower (hydrology, geology, topography) influence the investment cost, a formula that incorporates all site specifies conditions is more useful than its current form. Gordon and Penman (1983:30-37) proposes an empirical specific cost correlation based on the cost of previous projects as follows:

$$Cp = K.\ 10(h_t^x)^{\beta} \tag{4.8}$$

Where Cp = total initial project cost

P = is the plant capacity KW

ht = design head over turbine (m)

K is a constant (US$) and depends on installed capacity and head

α = exponent (α = 0.3) and

β = power component (β= 0.82)

As a basis for comparison, the standard plant is taken as a diesel plant (Subroto et. al., 1981:339-342) has a provided a formula for calculating the annual fuel cost as follows:

$$\text{Annual fuel cost} = C_{KWH} \times 8760 \times \alpha \times P \tag{4.9}$$

Where $C_{KWH} = 860 \times \frac{f}{\eta}$ = cost of fuel (US$/KWH), 860 = Conversion factor, α = annual utilization factor 97%, η =annual average operating efficiency (35%), and f = cost of fuel per K cal (US$/$10^3$ K cal)

Factors which influence the economic analysis for the small hydropower plant include service life, period of construction and financing expenditure schedules, interest rates and O & M costs (Subroto et. al ., 1981:339-342; Hosseini et. al., 2005: 1948 – 1956). The service life for SHP is 35 years and 40 years for diesel power plant and transmission and substations. These have to be taken in consideration.

4.3 TARRIF SETTING

In order to place a tariff on the Small-scale hydropower projects, four elements should be considered. The numbers, method and proposed rules are all subject to debate and discussion before such a system may be adopted and much of the proposal could be modified to take other considerations and policy into account. The four elements are:

(a.) **Energy Price**: This refers to international price of gas times a conversion rate or volume of gas used per kWh. The conversion rates imply reflects the efficiency of the plant.

(b.) **O & M Price**: A variable operation and maintenance cost of new gas plant which would be relatively small and consist of consumables, water or other similar items.

(c.) **Energy Security Incentive**: Some price recognition that domestic energy cannot be interrupted by others and has extra tariff because of it;

(d.) **Renewable Energy Incentive**: Some price recognition that renewable energy has some value to the SHP and provide extra tariff because of it.

Items (a) and (b) are clearly known. The price of gas (fuel) is negotiated annually and fixed for that period. The O & M price can be calculated. For many new plants in other parts of the world the amount might be 0.2 to 0.3 cents/kWh.

Items (c) and (d) are political decisions as they are not determined by technical or commercial conditions. Item (c) is of course difficult to determine but might be on the order of 0 to 3 cents/kWh. Item (d) may be more difficult to determine. It might even be neglected, with the developers/owners free to sell any carbon avoidance benefits to CDM or other markets (USAID, 2010).

4.3.1 Example of Tariff Calculation

An estimate of what the tariff might be and how it is calculated for the year 2014 is:

Conversion rate of gas generation units

- Estimated gas conversion = $0.22M^3$/kWh
- Estimated gas cost = \$230/TM^3 (including VAT)
- Estimated base tariff = $0.22\times 230 = 5.06$ cents/kWh

- Added to base

- Avoided O & M Component- Say 0.06 cents/kWh
- Any incentive foe Energy Security- Say 1 cents/kWh
- Any incentive for Renewable Energy – Say 0.4 cents/kWh

- Total Example Tariff = 5.06+0.06+1+0.4 = 7 cents/kWh, approximately

4.4 CONSUMPTION PATTERNS

Three aspects that are treated as important in as far as the determination of consumption patterns of a community is concerned are the penetration rate, peak factor, and load factors. According to Feibel (2003: 42), the penetration rate indicates the percentage of the population, commercial establishments and other consumers which are connected to the system. He observes that few people can afford a connection once electricity is introduced to the rural community. Therefore, the power supply system has to be designed with adequate consideration of the proportion of the population at a planning horizon in year x, when the total of the installed loads on the consumer side is expected to finally reach the plant capacity.

Clearly, this entails that the number and size of all installed loads and the consumer behavior in applying these loads must be known. He further observes the need to know at what time of the day and in what combination the applications are used (ibid).

The peak factor represents this degree of simultaneous use.

$$\text{Peak factor} = \frac{maximum \ \ of laod \ (really\ ) \ switched \ on \ sinultaneous \ \ ly \ (kW)}{avarage \ \ daily \ \ consumption \ \ \ 24h \ (kW)} \tag{4.10}$$

If the demands of the loads actually switched on is replaced by potential load (maximum possible), the result is the reciprocal of load factor. By definition the load factor is the ratio of energy actually consumed E_{act} (kW) to the potential demand for energy if power were consumed continually at peak levels E_{pot} (kW):

$$\text{Load factor} = \frac{Eact}{Epot} \,.\, 100 = \frac{load\ \ (Consumption\ \ \ time\ \ /day\ )}{maximum\ \ \ load\ installed\ \ .24h} \,.\, 100\ [\%] \qquad (4.11)$$

Feibel (2003:42) defines the load factor "*as the time aspect, according to the number of hours per day that the different loads one switched on*". In other words, if all loads installed in the system were continuously switched on 24 hours a day the factor would be 100%. The reference value is the total kW load installed on the consumer side and not the generation side since this would be the reference value for the so-called plant factor or plant utilization. The plant utilization is the ratio of energy used to energy available. It is affected by the load factor, the growth of population and the penetration rate.

4.5 LOAD FORECASTING

Generally, electricity from the SHP will be used by two main types of consumers: residential and commercial. The key forecast drivers for residential consumers are; historical number of accounts and account use, personal income, appliance saturation rates from residential end use survey etc.

The main determinant of the commercial electricity use forecast is the level of future economic activities in the locality. The stronger the economy, the more services are needed and the greater the electricity consumption of the commercial sector. Economic drivers such as retail sales, employment are good indicator of future electricity consumption.

Load forecasting develops from estimates of actual population, population growth and households' size, percentage of people connected and consumption per connection

(Feibel, 2003:45). Three types of electricity demand forecasting methods are covered in literature. These are trend analysis, end-use analysis and econometrics. A brief description for each method is presented below:

4.5.1Trend Analysis

Trend analysis uses historical consumption data and extends into the future by applying numerical analysis tools to identify trends, seasonal changes and other pattern (Feibel, 2003:46). It focused on past changes or movements in electricity and uses them to predict future changes in electricity demand. It is however, appropriate for short – term forecast and produced only one result – future electricity demand. But does not explain why the demand behaves the way it does nor provides the means to accurately measure how changes in energy prices or policies influence electricity demand.

4.5.2 End – Use Analysis

This method works based on the idea that demand for electricity depends on what it is used for. Historical data is studied to find how much electricity is used for individual electrical appliances in homes.

This appliance rating is multiplied by the projected number of appliances in each home. The results is further multiplied by the projected number of homes; an estimate of how much electricity will be needed to run all household appliances in geographical area during any particular year in the future can be determined. It identifies exactly where electricity goes, how much is used for each purpose.

One disadvantage of this method is that it assumed a constant relationship between electricity and end –use.

This mostly holds true over a few years, but over 10 years or so, it is highly likely that energy prices or technologies change and the relationship will not remain constant. The method also requires extensive data since all the relationship between electricity loads and many end – uses are calculated.

4.5.3 Econometric Methods

Econometric methods estimate the relationships between multiple variables. The basic assumption is that the behavior of a dependent variable such as electricity consumption is described as a function of several independent variables including population, gross domestic product and electricity price (Feibel, 2003):

Consumption = function (population, gross domestic product, electricity price …)

It aims to find the data series and the form of equation which best explain the historical data and this allow an optimized forecast. However, for rural areas with electrified, data is unavailable, so that it is impossible to find the relationship that provides a forecast. Based on the issues raised in the proceeding paragraphs, it appears end- use analysis is more appropriate and recommended for this study.

TABLE 4.1: Typical Hydro Scheme Cost Breakdown 60kW Plant

Capital cost (60 kW scheme)	Cost $	Proportion of total cost	Contribution to benefits
Planning/design Engineering, energy survey, hydrology study, pre-feasibility report, feasibility report, supervision fees, commissioning fees, training manuals	4000	3%	High
Management and finance Institution formation, funding procurement, legal & insurance training for management	2000	1%	High
Penstock	37000	27%	Medium
Other civil works Weir & intake, channel powerhouse, site preparation/access roads, other	35000	25%	Medium
Electro mechanical Turbine, generator, switchgear, other	36000	26%	
Distribution of electricity Transmission lines, domestic connections	12000	9%	
Appliances	3000	2%	

➢ **Contingency**	10000	7%	
Total capital costs	**139000**	**100%**	
Running costs			
1. **Fixed annual (O+M)costs** Labour for wages (O+M staff) Management committee (O+M) Specialist overhaul, maintenance, other	2000/year	6%	high
2. Variable running costs O+M staff recruitment, initial O+M training. 5-yearly O&M training refresher, spare parts, tools, materials, specialist advice, replacement equipment, other	Allow 1000/year	3%	High
3. Contingency	Allow 1000/year	3%	
Estimated total yearly running cost (O+M)	4000	12%	High
Capital cost expressed as	28000/year	88%	

annual cost **(C_{annual})**			
Total annual cost $= C_{annual\ +}{}^{(O+M)}$ = 28000+4000	32000	100%	
Plant factor	0.4		Very high
Unit energy cost Cost per KW installed	$\frac{C_{annual}\ +(O+M)}{P_{installed}\ \ x\ 8760\ x\ PF}$ $=$ $= \frac{139000}{60}$	$\frac{28000+4000}{60x8760x0.4}$ $= 2300\$/kW$	= 0.15$/kWh

Source: RET 558, Small Hydropower Technology, 2011

Appendix C.4 shows an example of cost analysis using the RETScreen.

CHAPTER –FIVE

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

The cost of generation of small hydro power is low compared to other renewable energy sources such as wind, solar PV, biomass etc. The operation and maintenance cost of small hydro project is very low. The payback period of these projects is usually between two to five years. These important facts, combined with the current industry trends (current oil prices), makes small hydro power projects a winning business proposition. Within the context of the objective of the proposed project, investments in small scale hydropower stations are justified bearing in mind the numerous socio economic benefits to be derived by the rural community. The major conclusions reported in this work can be discussed under the following headings:

- Technical
- Financial and
- Socio-economic

(a) ***Technical***

Power or energy generation calculation was made using the flow rate, net head and efficiency values on the power equation given in section 2.3. A suitable turbine was selected based on the head and discharge parameters. The following results were obtained from the study:

Head = 24m

Flow rate = $0.50 m^3/s$

Power = 60kW

Turbine type = Crossflow

(b) ***Financial Results***

The total capital cost is GH¢ 283,935.53 (US$ 139,000). The specific construction cost per kW is GH¢4698.21(US$ 2300) and unit energy cost was found to be GH¢ 0.31(US$ 0.15). The project would deliver 525,600 kWh/year.

(c) ***Socio-economic benefits***

Small hydropower is found to be suitable for enhancing the quality of life for rural dwellers in numerous ways. Firstly, it provides a wide range of services such as improved lighting, more entertainment, communication options and operations of a range of appliances.

Secondly, small hydropower reduces environmental pollution through replacement of paraffin lamps and other cooking fuels.

Thirdly, it supports rural enterprises, workshop, schools, clinics and production centers. These services are of great importance to the people in need of such services, and should therefore be given due consideration in energy planning.

Finally, minor environmental impacts will result through the use of run- of –river scheme.

5.2 RECOMMENDATIONS

This study has highlighted the need for the Western Region and Ghana as a whole to adopt rural electrification as a key policy of government as it improves the living standards of the people and reduce poverty by the creation of new income sources in rural areas. It is clear that the utilization of small-scale hydropower can provide a viable source of energy to increase the electrification levels in Ghana. However, small-scale hydropower will only be able to fulfill this role if certain policy and other issues are addressed before implementation of projects. As a result, this study has made a number of recommendations, a summary of which is provided below:

i. More hydrological data needs to be collected over a period of time. In order to achieve this goal, technical equipment such as a network of gauging stations is required along with human capacity building.
ii. Build or improve local manufacturing capacity to produce components such as low cost turbines for small hydropower plants.
iii. By further refining the energy price and specific construction costs a more accurate result can be determined.
iv. High initial cost need to be overcome with easier/improved access to finance for project developments. Awareness of small hydropower should be raised among local banking institutions or micro- finance institutions in order to improve risk assessment and provide attractive loan conditions.

v. Providing clear and agreed environmental compliance standards at licensing.

vi. With a well arrangement of system of power plant structures, new environmental impacts will not be introduced.

The following areas have been identified for further research and development which requires funding:

a) Carry out a more exhaustive feasibility studies to re-evaluate the previous studies and establish the available potential and cost to develop these sites.

b) Create a one-stop shop for small hydropower plants to streamline project implementation.

c) Design and manufacture of low cost turbines.

Last but not the least, there is the need to do more detailed hydrological, topographical and geological studies at each identified site. A more rigorous analysis of energy consumption and future demand would be useful.

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LIST OF APPENDICES

APPENDIX A: FEASIBILITY STUDY REPORT

1a. summary	Briefly present all the major conclusions reached in the report. Include requests for grants or subsidy. State whether or not the financial requirement is typical or exceptional and whether it belongs to a general policy for finance of schemes in the regions. Include economic comparison with other energy options.
1b. Key Illustrations	For instance a simple sketch map of village houses and transmissions, diagrams of layout of turbines and driven machinery, etc. include simple energy supply/demand graphs.
1c. Key data	Some of the key data can be presented on the diagrams/sketch maps. Ratings of turbine, generator, part flow arrangements, system efficiencies at part flow, table showing requirement for loans, connection charges, subsidy, and so on.
2. Energy demand	Summarize the results of your capability and demand study, concentrating on the daily and seasonal profile of energy demand. Include simple graphs. (Present the full results of your study as supporting document 1.) Also estimate future demand trends over forthcoming 10 years and illustrate.
3. Water demand	Summarize the requirement for water from the hydro catchment for irrigation. Include any other uses of water, such as domestic or industrial, which may compete with

	hydro. Comment on possible multiple use of water. Estimate future demand over forthcoming 10years. The full details should be in document 2 and some relevant data and sources in document 1.
4. Future demand trends	State whether the proposed scheme is intended to meet present or future demand for energy, and whether it allows for future growth in water use. Specify whether plans are for 5 years hence or 10 years hence, or as appropriate. Clearly specify whether conclusions of all sections below are projections into the future, and how growth in demand is accommodated.
5. Energy supply options	A brief survey and costing tables of various energy inputs including traditional fuels currently in use. Comment on future trends in supply of fuels, e.g. prospects for fuel wood replanting, kerosene price fluctuations. Comparative costing of energy sources which are alternatives to hydro (or could be used as auxiliary sources in combination with hydro) – e.g. solar photo-voltaic, solar thermal, wind, biogas, diesel; include hydro in comparative tables. Follow the same criteria as for hydro for socio-economic viability – life cycle cost, feasibility of management and maintenance, potential for accommodating growth in demand, welfare implications, convenience and sustainability, etc. Detailed information, source data references and calculations should be included in supporting document 8.
6. Management capability	Briefly summarize the results of the capability and demand study (supporting document 1) focusing this section on existing organizational arrangements, abilities and experience. Refer ahead to

	section 11 for proposed future management arrangements.
7. Hydro potential	This section contains 2 key elements of the feasibility study: a hydrograph and FDC. The hydrograph should have axes marked to show the conversion of flow to hydro power. In cases where variable flow turbines are considered, an extended graph showing varying system efficiency may be necessary. An exceedence table can be used to replace the FDC. All detailed information and hydrology data, sources, and site measurement data such as maps, should be placed in supporting document 3, a full hydrology study for the site in question.
8. Hydro design	This section sub-divides into civil works components, penstock, turbine and generator, application of power and distribution of power. For each part present a design philosophy, e.g. "the channel is constructed from local materials in order to facilitate maintenance". State sources of materials (names and locations of manufactures) and include sketches which present the dimensions and characteristics of each major component. Do not include calculations; these are in your full design Study, supporting document 4.
9. Plant factor: Matching of supply and demand	Comment on whether the power is available when it is needed, the effect of irrigation water demand. Calculate plant factor and discuss future trends in plant factor.
10a O+M structure	Summarize your plans for Operation and Maintenance of the installation and demonstrate that you are protecting against possible future difficulties: e.g. lack of motivation of operators. Present solutions such as bonus payments in return for

	continuous running of the hydro, exchange visits with neighboring installations, etc. summarize the operation schedules and arrangements for advance ordering of spare parts; full details to be in document 5.
10b O+M training	Describe requirements for training: translation of documents into local languages, visit by equipment manufactures, refresher courses, future training of newly recruited operators.
10c O+M costs	All aspects of O+M should be costed (e.g. spare parts, wages, training and translations) and allow a contingency sum of 50%. If experimental or newly designed and manufactured equipment is used (eg locally made turbine) allow a full replacement cost. If batteries are used as part of the installation (as in domestic trickle-charge distribution) then allow for complete replacement every 3 years (or as appropriate). Allow for rising prices of spare parts and transport. Include management costs here, as calculated in 12b below.
11 Integrated water use	Describe how management of the hydro will be integrated with management or irrigation and industrial and domestic users of the available water supply. Detail the extent of involvement of farmers and other water-users in the planning, implementation, and management of the hydro scheme.
12a Management structure	How are the O+M procedures above, and the integrated water use procedures, going to be implemented? Who pays the operations and recruits new operators? How the fund is for O+ M kept up, who

	kept the accounts and visit the bank? How are conflicting interest in hydro and irrigation going to be resolved during
	drought periods? These problems are simplified in cases of private ownership but must be elaborated very carefully in cases of collective responsibility
12b Management provisions	Refer this topic to an experienced specialist in rural development projects (e.g. water supply, agricultural assistance, and other hydro schemes in the area). State which management skills may be lacking and how training could help. Consider the benefits of delaying start of construction for a year. While a management committee is formed, and procedures such as accounts, double –checking, tariff structure, O+M training, contingency planning, are established. Ideally build these skills around a pilot project, such as a diesel generator or a much smaller hydro installation (which may be portable and usable elsewhere later) or a diesel engine drive to a device intended eventually for hydro power.
12c Management costs	However the management is arranged, it will require finance; for instance a pilot scheme, training costs a wage for a full time manager or a profit incentive for a private owner, on bonus schemes for the operator's managers and supervisory committee members. Include these costs in your financial analysis under O+M.
13. Schedule to operations	Provide a time chart (divided by months and year) starting with planning and design approval stages, through to

	commissioning. Include the first year of operation during which monitoring and O+M training procedures will still be required. Do not omit management provisions and pilot schemes which may take a year or two before construction starts. O+M training flow measurements (and rainfall measurements) can be shown on the chart.
14. Cost analysis	Provide a one-page cost sheet as in Table 4.1. Include running costs, contingency, plant factor, and unit energy cost (or other comparative economic indicators). More detailed breakdowns under each heading of the cost sheet can be provided on further sheets or in document 6 (Cost data).
15. Revenue	Comment on the various ways in which the hydro scheme will generate revenue, for instance, via sale of power to a mil-owner or other commercial enterprise, by offering of service for fee (battery charging, milling), by tariffs for fixed-wagged domestic electricity supplies. Specify how certain you are of this revenue in each case, and how this will change over time. Use supporting document 7 (Revenues) to record data on business and market studies for potential hydro-drive enterprises.
16. Welfare	Comment on the potential of the hydro scheme in increasing the economic security of the village as a whole; in introducing new jobs and in bringing benefits to the less wealthy members of the community. Also comment on possible dangers, (for instance some members of the community may receive electricity supply without payment of connection charge, due to lack of cash income, people due to lose jobs may be chosen for new jobs associated

	with the hydro installation).
17a. Tariff structure	In village electrification schemes it is often possible to present a comprehensive financial analysis in the form of a tariff proposal. The tariffs are prices paid by householders and entrepreneurs for use of electricity. The amounts paid are calculated from outgoings such as loan repayments, O+M costs, and welfare funds. A request for a grant or subsidy can be made on the basis of such a tariff calculation, which is based on a cash flow analysis. State in this section whether the tariff structure has been discussed with the villagers and whether agreement in principle exists. Will the tariff arrangement work in practice? – refer to experience elsewhere. Indicate how well matched it is to the findings of the capability and demand of all villagers to pay for the scheme? Does it include workable provisions for disadvantaged households and does it reflect the practical advice of most villages?
17b Financial analysis	This section presents the financial future of the scheme, for example by a cash flow analysis and by presenting economic indicators. It answers the question, is the scheme economically viable or not?
17c Sources of finance	This section states the recommended basis for financing of the scheme. For example, it may set out a request for a subsidy or grant which pays for professional inputs and 25% of the capital costs, and how a further 25% is covered by private investment by the users of the scheme (e.g. a connection charge or labour inputs) while the remaining 50% is covered by a loan at commercial lending rates. Note whether or not the recommendation

	matches existing policy on finance, and whether or not the same approach has been adopted elsewhere with success.
18. Socio-economic viability	Carefully draw together conclusions already made above on financial viability, management capability, O+M arrangements and comment on factors which may threaten sustainability.
19 Monitoring contingency plans	Describe how the proposed structures will be monitored and what alternative ownership, management and O+M provisions could be made should these structures prove not effective in forthcoming years.
20. Supporting documents	1. Capability and demand study 2. Water use and irrigation 3. Hydrology study 4. Technical design calculations 5. O+M arrangements 6. Cost data 7. Revenues 8. Energy supply options

Source**:** RET 558, Small Hydropower Technology. 2011

APPENDIX B: CAPABILITY AND DEMAND ASSEMENT

1. Types of people

Identify types of people and estimate their numbers.

A list like this is used to check that interviews have been held with every type of villager, to avoid bias.

- Men with farms, men without farms
- Women with no cash income, women with cash incomes
- Children, average per household
- Elderly people
- Disadvantaged people (disabled, chronically ill, lack of cash income, lack of work source of food)
- Members of religious community
- People living in village only of part the year, and visitors
- Professionals from outside (e.g. school teachers, government officers)
- People with jobs outside the village
- How will the distribution of types of people change over the next live or ten years?
- Are new people coming to live in the area? Or are people leaving?

2. Institutions

Make up a list to check that you are investigating all the possible institutions which may have a capability to manage a hydro scheme.

Note their activities and their membership.

- Private businesses
- Societies
- Local bank

- Government officers, extension workers
- Voluntary organizations
- Religious communities
- Local manufacture of machinery etc.
- For each of the above, note proficiency and experience in particular skills (e.g. welfare, accountability, maintenance of machinery)

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3. Energy Source	What types of fuel are used (wood, kerosene, dung, animals, etc.)? • Is the supply regular and easy, or are there shortages at times? • What does it cost in term of labour input (e.g. walking and carrying by hand), inconvenience (time spent), cash payments. • It were replaced by another fuel like electricity what inconvenience would this cause (e.g. collecting the fuel is also a useful opportunity to do other things, talking with neighbours, grazing animals, collecting medicine plants, etc. and using the fuel might have side-benefits e.g. wood smoke helps to clear insects) • What are the particular benefits of using this fuel (e.g. wood fires give high frying temperatures)
4. The future	Going back over these questions, will your answers be the same if you think five or ten years into the future? • What chance is there of a mains electricity grid connection, and how soon?

	• How much will the grid connection cost, and how will the village organize the finance?
Village organization	• Are there any organizations, for instance wider school activities, wider temple activities, a village welfare society, a childcare group, a farmers' association, a business, a government project? • Do villagers pay money into this or receive money from it? How are accounts kept? Are they open to inspection? • Could one of these organizations expand its activities to manage finance and waged labour for a village electrification scheme? Would the scheme be used to benefit everybody or only a few people? How would electricity tariffs be collected and how would accounts be kept? • How long has the most suitable organization been working? Have there been problems?
The future	• Is the organization likely to stop soon, or leave the area?
5. Households & individuals	• Size of household, number of occupants, ages, etc. • Cash incomes, home-grown food, non-cash income • Amount of farm land, cattle, tools • Desire for new energy source (e.g. electricity supply) • Do you already own electrical appliance? Which ones?

	• If not, do you know their cost? Would finding enough money to buy them cause problems? • Would you wait some years before buying appliances? • How much could you afford to pay per month for an electricity supply (say for enough to power a radio/TV and two lights). How would you spend that money otherwise? What is the maximum amount you could pay? • Would carrying a battery for recharging be as good, if it cost less than a connection to your house? • Would you move your house if it was the only way of getting electricity? Is there anywhere you would be allowed to build it nearer the generator? • Do the women think differently? Do the elderly think differently? If so, why? • Is the idea of electric lights and TV good for women? Will you get light for the kitchen?
The future	• Will these things be different in five years or ten years? (For instance, the children will want electricity much more than we do now; there will be more cash available to pay a higher tariff). • Will the new scheme cause divisions and conflicts in the village, if for instance not everyone is connected to an electricity supply? Or is this quite normal in other fields of activity, for instance irrigation provision? What methods could be used to avoid difficulties?
Entrepreneurs & officials	Consider past activities and present ones (e.g. a business or collective ownership of a

water supply system, a tractor or an irrigation system):

- Describe methods used to keep records of maintenance of machinery; and to keep records of finance.
- Are tariffs collected? Are there methods of including less wealthy people in the village? How are welfare benefits financed?
- What problems have been encountered? How have conflicts been resolved in the past?
- How would an electricity supply be organized here?

Who would employ the operators and arrange training?

Who would keep accounts, and ensure the spare parts stock was checked nod updated? How would tariffs be collected?

- Would an electricity supply be organized to ensure benefits for poorer villagers as well as successful farmers or professionals?

  How could this be done?

  Considering a business based on the hydro:
- What business activity is proposed? (For instance, grain-milling, wood turning, rubber mill)
- What is the market for the product, and how secure is it?

Would a bank lend start-up finance?

- How much energy (mechanical drive direct from the turbine, and/or electricity from the generator) would be needed, and how many hours each day, which seasons of the year?
- How much would the business pay for this energy supply

	• Would the business conflict with other interests? (For instance, some villagers would lose jobs, or a business in a neighbouring village would lose its market) • Would the business generate enough revenue for a hydro fund so that electricity tariffs could be reduced to levels easily affordable by the less well off? • What supervisory committee could be set up to ensure equitable access to the benefits of the hydro?
The future	Would the proposed arrangements hold good over time? • How would equitable access be monitored? • What corrective actions could be taken if conflicts occurred or the benefits of hydro became progressively less accessible to most villagers, or if maintenance and operation procedures did not work well? • Going back to all the questions above, how would your answers differ in five or ten years time?
Other villages and model schemes	• Identify similar schemes in neighboring villages. • Take note of studies made of demand and capability elsewhere • Find out how things have gone and whether there are lessons to be learned. Include this experience in the study.

Source**:** RET 558, Small Hydropower Technology. 2011.

APPENDIX C.1 – RETScreen Pre-feasibility Analysis Software, Hydro Version 99-Beta

Energy Model

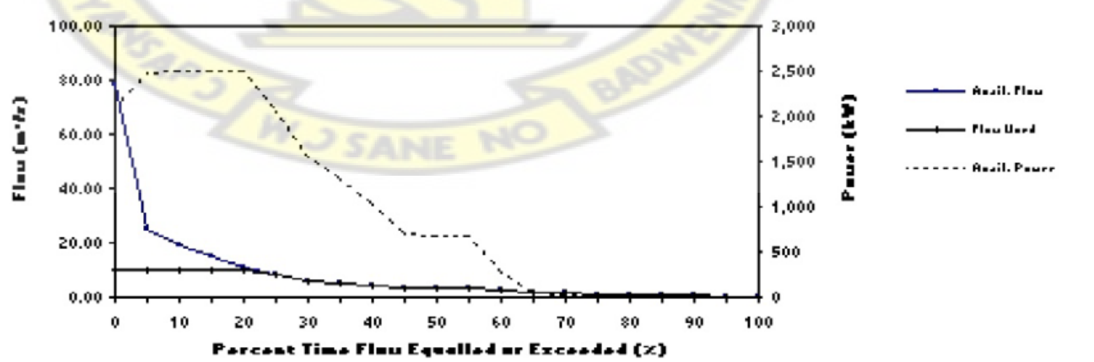
RETScreen™ Energy Model - Small Hydro Project

Site Conditions		Estimate	Notes/Range
Project name		Example	-
Project location		Alberta	-
Gross head	m	31.6	Measured value
Maximum tailwater effect	m	5	See manual
Residual flow	m³/s	1	*Complete Hydrology & Load sheet*
Firm flow	m³/s	1.40	See *Hydrology & Load* sheet
Peak load (electrical)	kW	**1,146**	See *Hydrology & Load* sheet
Energy demand (electrical)	MWh	**5,065**	See *Hydrology & Load* sheet

System Characteristics		Estimate	Notes/Range
Grid type	-	Isolated-grid	See *Hydrology & Load* sheet
Design flow	m³/s	10	Project specific
Turbine type	-	Francis	*Complete Equipment Data sheet*
Number of turbines	turbine	1	See *Equipment Data* sheet
Turbine efficiency at design flow	%	92.4%	See *Equipment Data* sheet
Maximum hydraulic losses	%	5%	See manual
Generator efficiency	%	95%	93% to 97%
Transformer losses	%	1%	1% to 2%
Parasitic electricity losses	%	2%	1% to 3%
Annual downtime losses	%	5%	2% to 7%

Annual Energy Production		Estimate	Notes/Range
Small hydro plant capacity	kW	2,507	Project specific
	MW	2.507	For user convenience
Small hydro plant firm capacity	kW	0	Project specific
Available flow adjustment factor	-	1.0	See manual
Small hydro plant capacity factor	%	37%	40% to 95%
Renewable energy available	MWh	8,091	Project specific
Renewable energy delivered	MWh	**2,845**	Project specific
	GJ	10240	For user convenience
Excess RE available	MWh	**5,246**	Project specific

Available Flow, Flow Used and Available Power



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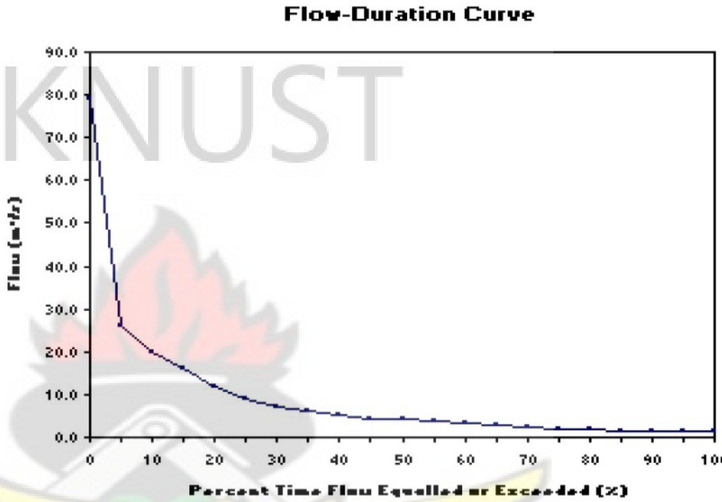
Appendix C.2 Hydrology & Load

RETScreen™ Hydrology Analysis and Load Calculation - Small Hydro Project

Hydrology Analysis		Estimate	Notes/Range
Project type		Run-of-river	
Hydrology method		User-defined	See manual
Hydrology Parameters			
Residual flow		1	Project specific
Percent time firm flow available	%	95%	90% to 100%
Firm flow	m³/s	1.40	-

Flow-Duration Curve Data

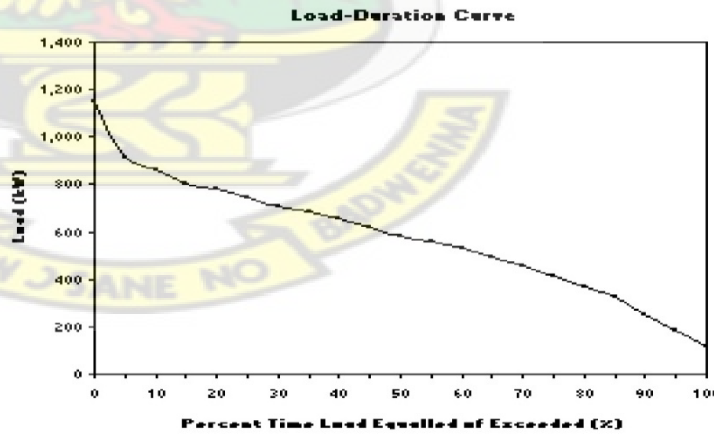
Time (%)	Flow (m³/s)
0%	79.00
5%	26.00
10%	20.00
15%	16.00
20%	12.00
25%	9.00
30%	7.00
35%	6.00
40%	5.00
45%	4.20
50%	4.10
55%	4.00
60%	3.20
65%	2.70
70%	2.50
75%	2.10
80%	1.80
85%	1.60
90%	1.50
95%	1.40
###	1.20



Load Characteristics		Estimate	Notes/Range
Grid type		Isolated-grid	See manual
Load Conditions			
Load duration curve		User-defined	See manual
Peak load (electrical)	kW	1,146	Project specific

Load-Duration Curve Data

Time (%)	Load (kW)
0%	1,146
5%	917
10%	860
15%	802
20%	779
25%	745
30%	711
35%	688
40%	653
45%	619
50%	584
55%	562
60%	527
65%	493
70%	458
75%	413
80%	367
85%	321
90%	252
95%	183
###	115



		Annual	Daily	
Energy demand (electrical)	MWh	5,065	13.9	Project specific
Average load factor	%	50%	50%	Project specific

Return to Energy Model sheet

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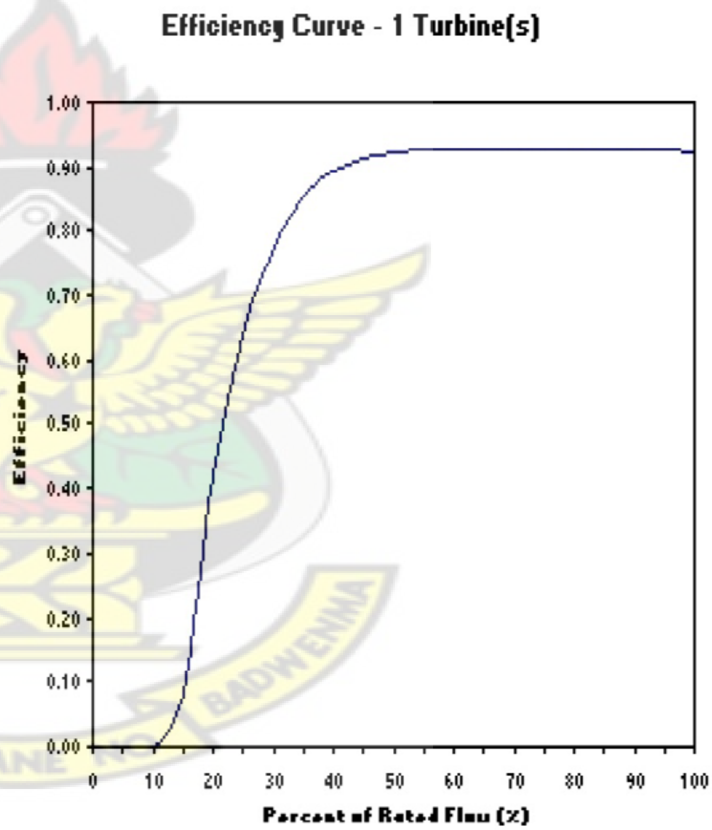
Appendix C.3 **Equipment Data**

RETScreen™ Equipment Data - Small Hydro Project

Small Hydro Turbine Characteristics		Estimate	Notes/Range
Design flow	m^3/s	10	See *Energy Model* sheet
Turbine type	-	Kaplan	See Product Database
Turbine efficiency curve data source	-	User-defined	See manual
Number of turbines	turbine	1	See manual
Small hydro turbine manufacture	-	AA	See product database
Small hydro turbine model	-	OO	See product database
Turbine manufacture/design coefficient	-	4.5	2.8 to 6.1; Default = 4.5
Efficiency adjustment	%	0%	Project specific

Turbine Efficiency Curve Data

Flow (%)	Turbine efficien	Turbines #	Combined efficiency
0%	0.00	0	0.00
5%	0.00	1	0.00
10%	0.00	1	0.00
15%	0.08	1	0.08
20%	0.42	1	0.42
25%	0.64	1	0.64
30%	0.78	1	0.78
35%	0.85	1	0.85
40%	0.90	1	0.90
45%	0.92	1	0.92
50%	0.92	1	0.92
55%	0.93	1	0.93
60%	0.93	1	0.93
65%	0.93	1	0.93
70%	0.93	1	0.93
75%	0.93	1	0.93
80%	0.93	1	0.93
85%	0.93	1	0.93
90%	0.93	1	0.93
95%	0.93	1	0.93
100%	0.92	1	0.92



Turbine efficiency at design flow	%	92.4%	Turbine type specific

Return to Energy Model sheet

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Appendix C.4 **Cost Analysis**

RETScreen™ Cost Analysis - Small Hydro Project

Costing method: Detailed

Initial Costs	Unit	Quantity	Unit Cost	Amount	:lative Costs	Quantity Rang	Unit Cost Rang
Feasibility Study							
Site investigation	p-d	60	$ 600	$ 36,000	0.40%	10 - 400	$400 - $600
Hydrologic assessment	p-d	25	$ 500	$ 12,500	0.14%	5 - 100	$500 - $700
Environmental assessment	p-d	60	$ 500	$ 30,000	0.33%	Project specific	$400 - $600
Preliminary design	p-d	25	$ 500	$ 12,500	0.14%	10 - 100	$500 - $700
Detailed cost estimate	p-d	20	$ 600	$ 12,000	0.13%	5 - 50	$500 - $700
Report preparation	p-d	10	$ 700	$ 7,000	0.08%	3 - 50	$500 - $700
Project management	p-d	10	$ 700	$ 7,000	0.08%	5 - 50	$500 - $700
Travel and accommodation	p-trip	4	$ 2,500	$ 10,000	0.11%	2 - 10	See manual
Other	-	0	$ -	$ -	0.00%	-	User defined
Credit	-	-1	$ -	$ -	0.00%	-	See manual
Subtotal:				$ 127,000	1.42%		
Development							
PPA negotiation	p-d	20	$ 1,000	$ 20,000	0.22%	5 - 200	$700 - $1,500
Permits and approvals	p-d	25	$ 700	$ 17,500	0.20%	5 - 100	$500 - $700
Land rights	site	0	$ -	$ -	0.00%	Project specific	See manual
Land survey	p-d	28	$ 500	$ 14,000	0.16%	20 - 200	$400 - $600
Project financing	p-d	30	$ 1,500	$ 45,000	0.50%	5 - 100	$500 - $1,500
Legal and accounting	p-d	25	$ 1,200	$ 30,000	0.33%	5 - 200	$500 - $1,500
Project management	p-yr	0.2	$ 130,000	$ 26,000	0.29%	0.2 - 2.0	$130K - $180K
Travel and accommodation	p-trip	10	$ 2,500	$ 25,000	0.28%	2 - 10	See manual
Other	-	0	$ -	$ -	0.00%	-	User defined
Credit	-	-1	$ -	$ -	0.00%	-	See manual
Subtotal:				$ 177,500	1.98%		
Engineering							
Design and tender documents	p-yr	0.7	$ 130,000	$ 91,000	1.01%	0.6 - 6.0	$130K - $180K
Contracting	p-d	50	$ 700	$ 35,000	0.39%	5 - 200	$500 - $1,500
Construction supervision	p-yr	0.5	$ 130,000	$ 65,000	0.72%	0.2 - 2.0	$130K - $180K
Other	-	0	$ -	$ -	0.00%	-	User defined
Credit	-	-1	$ -	$ -	0.00%	-	See manual
Subtotal:				$ 191,000	2.13%		
Renewable Energy (RE) Equipment							
Turbines/generators, controls	kW	2,507	$ 1,700	$ 4,262,197	47.50%	Project specific	$1,000 - $4,000
Equipment installation	%	10%	$ 4,262,197	$ 426,220	4.75%	5% - 45%	Project specific
Transportation	%	10%	$ 4,262,197	$ 426,220	4.75%	1% - 20%	Project specific
Other	-	0	$ -	$ -	0.00%	-	User defined
Credit	-	-1	$ -	$ -	0.00%	-	See manual
Subtotal:				$5,114,636	57.01%		

Cost Analysis (cont'd)

Balance of Plant							
Access Road	km	10.0	$ 20,000	$ 200,000	2.23%	Project specific	$20K - $500K
Concrete dam	m³	300	$ 800	$ 240,000	2.67%	Project specific	$400 - $1,600
Timber crib dam	m³	0	$ -	$ -	0.00%	Project specific	$100 - $500
Earthfill dam	m³	0	$ -	$ -	0.00%	Project specific	$30 - $90
Dewatering	%	10%	$ 240,000	$ 24,000	0.27%	5% - 15%	Project specific
Spillway	m³	0	$ -	$ -	0.00%	Project specific	$400 - $1,600
Canal	m³	0	$ 250	$ -	0.00%	Project specific	$20 - $400
Intake	m³	90	$ 1,200	$ 108,000	1.20%	See manual	$400 - $1,600
Tunnel	m³	0	$ -	$ -	0.00%	Project specific	$40 - $150
Pipeline/penstock	kg	10,000	$ 10	$ 100,000	1.11%	Project specific	$5 - $10
Powerhouse civil	m³	180	$ 1,200	$ 216,000	2.41%	Project specific	$400 - $1,600
Fishway	m lift	0.0	$ -	$ -	0.00%	See manual	$4K - $20K
Transmission line and substat	km	10.0	$ 75,000	$ 750,000	8.36%	Project specific	See manual
Transportation	%	8%	$ 1,638,000	$ 131,040	1.46%	See manual	Project specific
Other	-	0	$ -	$ -	0.00%	-	User defined
Credit	-	-1	$ -	$ -	0.00%	-	See manual
Subtotal:				**$1,769,040**	19.72%		
Miscellaneous							
Special equipment	project	0	$ -	$ -	0.00%	1	See manual
Contractor's overhead	%	10%	$ 1,769,040	$ 176,904	1.97%	10% - 100%	Project specific
Training	p-d	20	$ 700	$ 14,000	0.16%	5 - 100	$500 - $800
Interest during construction	%	4.0%	$ 7,379,176	$ 295,167	3.29%	3% - 15%	Project specific
Contingencies	%	15%	$ 7,379,176	$ 1,106,876	12.34%	10% - 40%	Project specific
Credit	-	-1	$ -	$ -	0.00%	-	See manual
Subtotal:				**$1,592,948**	17.75%		
Initial Costs - Total (Detailed Costing Method)				**$8,972,124**	100%		

Annual Costs	Unit	Quantity	Unit Cost	Amount	lative Costs	uantity Rang	nit Cost Rang
O&M							
Land lease	project	1	$ -	$ -	0.0%	Project specific	$0 - $2,000
Property taxes	%	0.0%	$ 8,972,124	$ -	0.0%	0% - 0.6%	Project specific
Water rental	kW	2,507	$ -	$ -	0.0%	Project specific	$0 - $20
Insurance premiums	%	0.40%	$ 8,972,124	$ 35,888	21.3%	0.25% - 1.0%	Project specific
Transmission line maintenanc	%	3.0%	$ 750,000	$ 22,500	13.4%	3% - 6%	Project specific
Spare parts	%	0.50%	$ 8,972,124	$ 44,861	26.6%	0.5% - 1%	Project specific
O&M labour	p-yr	0.75	$ 40,000	$ 30,000	17.8%	0.2 - 1.0	$40K - $80K
Travel and accommodation	p-trip	6	$ 1,000	$ 6,000	3.6%	2 - 10	$500 - $10,000
General and administrative	%	10%	$ 139,249	$ 13,925	8.3%	1% - 20%	Project specific
Other	-	0	$ -	$ -	0.0%	-	User defined
Contingencies	%	10%	$ 153,174	$ 15,317	9.1%	10% - 20%	Project specific
Annual Costs - Total				**$ 168,491**	**100%**		

Appendix C.5 Financial Summary

RETScreen™ Financial Summary - Small Hydro Project

Energy Balance

Project name		Example			
Renewable energy delivered	MWh	2,845	Peak load	kW	1,146
Excess RE available	MWh	5,246	Energy demand	MWh	5,065
Firm RE capacity	kW	-	Type of energy displaced	-	Electricity

Financial Parameters

Avoided cost of energy	$/MWh	200.0	Discount rate	%	10.5%
Avoided cost of excess ene	$/MWh	18.0	Debt ratio	%	90.0%
Avoided cost of capacity	$/kW-yr	110.0	Debt interest rate	%	7.5%
Inflation	%	2.5%	Debt term	yr	25
Energy cost escalation rate	%	4.0%	Project life	yr	35

Project Costs and Savings

			Annual Costs		
Initial Costs			O&M	$	168,491
Feasibility study	$	127,000	Fuel/Electricity	$	-
Development	$	177,500	Debt payments (25 years)	$	724,406
Engineering	$	191,000	**Annual Costs - Total**	**$**	**892,897**
RE equipment	$	5,114,636			
Balance of plant	$	1,769,040	Annual Savings (or Income)		
Miscellaneous	$	1,592,948	Energy savings (or income)	$	663,342
Initial Costs - Total	**$**	**8,972,124**	Capacity savings (or income)	$	-
			Annual Savings - Total	**$**	**663,342**

Financial Feasibility

Internal Rate of Return (IRR)	%	10.8%	Project equity	$	897,212
Simple Payback	yr	18.1	Project debt	$	8,074,912
Year-to-positive cash flow	yr	18.3	Debt payments	$/yr	724,406
Net Present Value (NPV)	$	110,839	Debt service coverage	-	0.7
PV of annual costs	$	(8,333,843)	Annual Life Cycle Savings	$	12,003
PV of energy savings	$	9,341,895			
PV of capacity savings	$	-			

Yearly Cash Flows

Year #	Net Flow $	Cumulative $
0	(897,212)	(897,212)
1	(207,233)	(1,104,446)
2	(183,956)	(1,288,402)
3	(159,683)	(1,448,084)
4	(134,372)	(1,582,456)
5	(107,981)	(1,690,437)
6	(80,464)	(1,770,902)
7	(51,776)	(1,822,678)
8	(21,866)	(1,844,544)
9	9,315	(1,835,229)
10	41,820	(1,793,410)
11	75,704	(1,717,706)
12	111,025	(1,606,681)
13	147,841	(1,458,840)
14	186,215	(1,272,626)
15	226,211	(1,046,415)
16	267,896	(778,519)
17	311,340	(467,180)
18	356,615	(110,565)
19	403,798	293,233
20	452,966	746,199
21	504,203	1,250,402
22	557,592	1,807,993
23	613,223	2,421,216
24	671,188	3,092,404
25	731,583	3,823,987
26	1,518,914	5,342,900
27	1,584,473	6,927,373
28	1,652,775	8,580,148
29	1,723,932	10,304,079
30	1,798,061	12,102,140
31	1,875,285	13,977,425
32	1,955,730	15,933,155
33	2,039,529	17,972,683
34	2,126,819	20,099,502
35	2,217,743	22,317,246

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APPENDIX D: METROLOGICAL DATA

Takoradi Monthly Rainfall Total (mm)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2000	27.2	27.2	68.0	145.1	195.1	296.3	296.3	34.1	33.3	42.1	30.2	15.22
2001	-	40.0	21.6	174.9	271.9	206.4	206.4	19.9	11.9	106.5	50.4	3.0
2002	13.7	35.8	17.3	181.9	181.5	307.6	247.6	5.2	5.2	88.8	67.2	6.8
2003	37.3	40.0	76.1	192.2	189.2	79.2	6.5	11.3	11.3	234.8	30.1	9.6
2004	59.3	77.2	96.2	14.0	189.4	132.3	98.9	135.8	135.8	251.2	24.5	13.2
2005	2.3	55.4	136.7	50.4	269.7	103.0	3.3	37.0	37.0	190.9	41.3	26.2
2006	4.3	6.8	11.2	22.6	360.4	228.4	132.2	23.9	23.9	85.4	22.8	4.6
2007	0.2	7.9	83.2	102.9	125.0	197.2	255.0	60.7	161.9	210.6	33.1	11.9
2008	28.7	1.6	41.9	104.0	220.1	352.0	107.7	34.9	54.8	58.6	102.9	52.3
2009	12.6	5.5	23.0	104.7	20.14	408.3	175.1	29.7	10.3	78.6	19.4	42.4
2010	27.6	-	44.1	169.7	296.8	320.1	44.1	-	-	-	-	-

Table D.1: Monthly Rainfall Total (mm)

Takoradi Mean Daily Maximum Temperature (^oC)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2000	30.5	31.7	31.7	31.1	31.1	29.0	27.9	27.3	27.9	29.7	31.2	30.7
2001	30.5	31.7	31.7	31.5	30.8	29.2	27.8	27.0	27.6	29.9	31.0	31.2
2002	31.4	32.1	31.7	31.6	31.5	29.2	27.6	27.4	28.2	29.7	31.1	31.7
2003	31.2	31.9	32.4	31.5	31.1	29.4	29.0	27.9	28.7	30.0	31.5	31.7
2004	31.2	31.8	32.3	31.4	30.6	28.5	27.7	27.2	28.5	29.8	31.0	31.2
2005	31.4	31.8	31.9	32.1	30.5	28.8	27.8	27.3	28.6	30.1	31.3	31.7
2006	31.2	31.9	32.0	32.7	30.7	29.9	28.9	27.8	28.6	29.8	31.1	31.6
2007	31.6	31.8	31.8	31.7	31.3	29.3	28.5	28.2	28.3	29.7	30.9	31.5
2008	31.3	32.1	32.1	31.8	31.4	30.1	29.3	28.6	29.0	30.5	31.2	31.8
2009	31.5	32.0	32.3	31.7	31.3	29.7	28.5	27.7	28.6	29.5	31.3	31.8
2010	32.2	-	32.8	32.5	32.4	29.7	28.8	-	-	-	-	-

Table D.2: Mean Daily Maximum Temperature (^oC)

Takoradi Mean Daily Minimum Temperature (^oC)

Year	Jan	Feb	March	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2000	23.4	23.3	24.8	24.0	23.7	23.4	21.9	22.9	22.4	22.9	23.6	23.5
2001	23.2	23.9	24.0	23.9	24.3	23.4	22.9	22.9	22.4	23.5	23.9	24.1
2002	23.5	24.4	24.8	24.6	24.6	23.5	22.9	22.9	22.6	23.5	23.5	22.7
2003	23.7	24.5	24.7	24.3	24.4	23.5	22.2	22.9	23.5	24.0	23.9	23.8
2004	24.0	24.5	24.8	25.0	24.3	23.4	22.5	22.9	23.4	23.7	24.1	24.3
2005	22.3	25.1	24.9	25.5	24.4	24.3	22.6	22.9	23.4	23.7	24.2	23.9
2006	24.2	24.7	24.3	24.7	241	23.5	22.7	22.9	23.2	22.6	23.9	23.8
2007	22.4	24.7	24.9	24.5	24.6	23.9	23.4	22.9	23.0	22.9	23.4	23.7
2008	22.4	24.3	24.3	24.5	24.1	23.8	23.1	22.9	23.1	30.5	24.0	24.0
2009	21.1	24.3	24.5	24.5	24.3	23.5	23.3	22.9	22.8	29.5	23.9	24.2
2010	22.5	-			25.1	24.7	23.3		-	-	-	-

Table D.3: Mean Daily Minimum Temperature (^oC)

APPENDIX E: CALULATION OF SHAPE NUMBER, RUNNER SPEED AND DIAMETER

Shape Number

The power output P_o from a turbine depends on head H, the angular velocity ω, the diameter of the turbine and the density of water ρ. Two useful dimensionless parameters that can be formed from the physical quantities are the power coefficient,

Kp=$\frac{P}{(W^3 D^5 p)}$ and the head coefficient

kh= $\frac{gH}{(W^2 D^2)}$

When the turbine is operating at maximum efficiency, $Kp\ and\ Kh$ can be used to predict the power and head in terms of diameter and the angular velocity. Estimating the dependence on diameter, a dimensionless ratio$is\ obtained$

$Kn = \frac{Kp½}{Kh\ 5/4} = \frac{WP½}{P½(gH\ )}5/4$ Substituting $P = pgHQ\eta$

From eqn 2.1 and assuming η=1,

The equation for shape number becomes

Shape number,$K_n = \frac{n\sqrt{Po/e}}{(gH\ )^{1.25}}$ where n is the rotational speed of the turbine (in rpm). The formula above can be written in a simple form:

$$K_{n=}5\left(\frac{r}{R}\right)\frac{VB}{VW}$$

Where $\frac{r}{R}$ is the ratio of diameter of the incoming flow or jet of water to the total diameter of the turbine. $\frac{VB}{VW}$ is the ratio of the blade speed to the speed of the water.

Runner Speed

A synchronous speed of the generation is used to determine the runner speed. For turbine speed, n, to be synchronous, the following equation is applied:

$$n = \frac{120(f)}{Np}$$

Where n is the rotational speed (rpm), f is electrical frequency (H_Z) and, Np is the number of poles for the generator.

Runner Diameter

Sadrul et. al., (2002: 216-219) provide an equation for approximating the runner diameter for the cross flow turbine as follows:

$$D = 40^{\frac{\sqrt{H}}{n}}$$

The jet thickness tj is generally between **one fifth and one tenth** of the diameter. The approximate runner length, in meter, is therefore given by

$$L = \frac{0.23Q}{tj\sqrt{H}}$$

DETERMINATION OF POWER OUTPUT, DESIGN FLOW AND PENSTOCK DIAMETER

The maximum amount of power available in theory from the flow is related to the speed of flow, and the head. The power output P is the product of the efficiency n, the potential energy per unit volume, ρgh and the volume of water flowing per second Q. This relationship is expressed by the formula (Harvey et. al., 1993: 4-5; Inversion, 1986: 48-49; ESHA, 1998: 75-77)

$$P = \rho gHQ\eta$$

Where P is net power output (KW), Q, is the flow through the turbine$\left(m\,{}^{3}/_{S}\right)$; H, is the net head of water $(m), \rho =$ density of water(Kg/m^3); g = acceleration due to gravity($=$ $9.81m/s^2$), and η = overall efficiency of the system.

Giesceke and Mosonyi (2003), cited in Maskey, (2004:56) give the following modified formula in order to determine the amount of electricity produced by a hydropower plant from water to wire.

$$\frac{p = \eta_{Tol}.\rho g.Qd.H.(1 - Ipel)}{1000}$$

With $\eta_{Tol} = \eta_T.\eta_{gen}.\eta_{tr},$ is overall system efficiency η_T is the turbine efficiency,η_{gen} = generator efficiency,η_{tr} = transmission efficiency, Qd being the design discharge and $Ipel$ parasitic electrical losses. The overall efficiency comprises efficiencies of penstock, turbine gearing, generator, transformed and losses in the transmission and distribution lines (Harvey et. al., 1993:4-5)

Inversion (1986: 96 – 102) presents an equation for head loss due to pipe friction derived from Manning equation: $hf = \frac{10.3n^2\,Q^2}{D^{5333}\,L}$

Where hf is the head loss due to friction (in meters), n is the roughness coefficient, Q is the flow (in cubic meters per second) D is the pipe diameter (in meter) and L is the pipe length (in meters). The gross head is the difference in elevation between the penstock inlet and the turbine. The net or usable head is the gross head minus head lost due to friction and is expressed as follows:

$$H = Hgross - hf$$

The head lost comprises the following partial losses

1. Intake losses, including trash rack loss (Screen loss)
2. Friction losses wrong the entire water way (canal, tunnel penstock); and
3. Local losses along the water way (bends, valves etc.). Power as a function of $Q.D, \eta, L, Hgross, and\ hf$

$$p = 9.81\eta Q\left(Hgross - \frac{10n^2\,Q^2}{D^{5.333}\,L}\right)$$

There are two conditions of interest for which to solve this equation. The first is to limit flow so that head loss due to friction is minimum. Second, is to find Q for which P is a minimum, bearing in mind that head decreases with increasing flow: Maximizing P as a function of Q

$\frac{dP}{dQ}$=9.81η_{gross} -9.81m $\frac{30n^2\,Q^2}{D^{5.333}\,L}$ = 0

Solving for Q, yields

Q=$\sqrt{\frac{D^{5.333\,Hgross}}{30n^2L}}$

It follows that: $\left(D = \frac{10.3n^2Q^2L}{hf}\right)^{0.1875}$

By limiting hf at $hf\ at\ 4H/100$ (so that power losses do not exceed 4%), D is computed using the following formula: $D = 2.69\left(\frac{10.3n^2Q^2L}{Hgross}\right)^{0.1875.}$