PRE-FEASIBILITY STUDIES OF HEMANG HYDROPOWER SITE

By

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DECLARATION

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

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DEDICATION

I dedicate this work to my parents,

Patrick and Ruth Dzobo

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This research work was mainly the inspiration of the late Prof. Abeeku Brew-Hammond (former director of KNUST Energy Center-TEC, 2006 - 2009) of Blessed memory.

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ABSTRACT

Ghana, though has a good number of small to medium hydro power potential sites, has still not exploited all of them. The focus of this thesis is a pre-feasibility study of the technical and financial viability of power generation from a medium hydropower potential site, the Hemang site, on the Pra River in the Western region of Ghana.

This study is carried out using recent flow data (1980 -2011) from the gauge station on the Pra River. The results are compared with previous studies carried out on the Hemang site by ACRES International in 1985. The power capacity, yearly energy output, greenhouse gas reduction and financial feasibility of the potential hydro site are studied in this work. The study also covers a preliminary sizing of some mechanical components (water passages) including turbine, draft tubes and penstocks for the Hemang site. RETScreen® project analysis software package was used in both the technical and financial analysis of the project. The sizing of water passages, however, was done using codes written in MATLAB®. Technical analyses of the power output capacity and yearly energy output of three (3) hydro-turbine types (Kaplan, Propeller, and Francis) operable at the same given head and design flow and also the possible reduction in greenhouse gas (CO_2) by the prospective project were performed.

The highest power capacity and annual energy output of the site is determined to be 70.524 MW and 225,346 MWh respectively with a Kaplan type turbine. The power capacities and annual energy output results of the Hemang site using the recent flow data on the Pra River is seen to have reduced as compared to the values stated by the Acres International's 1985 study with flow data from 1944-1984.

The financial analysis (using RETScreen® cost and financial analysis modules) was carried out on a range of electricity export rate (US$ 50/MWh - US$ 150/MWh). With a project life of 40 years and an electricity export rate of US$ 64.90/MWh, the project's net present value (positive) is found to be about 5 times the project's initial cost, which indicates the project is financially viable to only an extent. At the same electricity export rates, the project has an equity payback time of 13.4 years and an after-tax internal rate of return of 13.7%. This value of IRR, however, makes the project financially uncompetitive with similar project elsewhere in Africa.

A greenhouse gas (GHG) analysis on the project reveals that the project will annually cut GHG emission (CO_2) by 109,739 tonnes.

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BGC	Bulk generation cost
FDC	flow duration curve
GHG	Greenhouse gas
EPBT	Equity payback time
IRR	Internal Rate of Return
NEPAD	New Partnership for Africa Development
NPV	Net present value
p.f	power factor
PURC	Public Utilities Regulatory Commission
tCO_2	tonnes of Carbon dioxide
USD	United States Dollar
VRA	Volta River Authority

CHAPTER 1: INTRODUCTION

1.1 Background

This work explores the hydropower generation potential of the Hemang hydro site on the Pra River in the Western region of Ghana.

Until late 1997 and early 1998, virtually all of Ghana's electricity was produced from two hydro dams at Akosombo and Kpong, which have a combined installed capacity of 1,180 MW [1,2]. It is estimated that Ghana may have the potential for additional 2,000 MW of hydropower. About 1,205 MW of this total is expected to be produced from proven large hydro sources (≥500 MW) while the rest will come from medium (10 MW – 500 MW) to small hydro plants (≤10 MW) [3]. According to Edjakumhene et al [4], about 15 medium hydropower sites have been identified in Ghana [5] [6].

The site studied (Hemang) is one of the medium scale hydro power sites on the Pra river. The other hydro sites on the Pra River include: Awisam, Kojokrom and Abatumesu in the Ashanti and Central Regions of Ghana. *Table 1.1* presents the hydropower potential of all the sites on the Pra River according to the Acres, 1984 study.

Table 1.1: Hydroelectric power sites on the Pra River and their capacities

Site	Capacity (MW)
Awisam	50
Kojokrom	30
Abatumesu	50
Hemang	75

Source [7]

The site capacities shown in Table 1.1 above are a part of Acres International's[1] 1984 "Ghana Generation Planning Study" document, which is about the prospects of harnessing the hydroelectric potential of small rivers in Ghana. The prospects have been investigated in Ghana for over 20 years, leading to the identification of many potential mini hydro sites in the country. Since 1970, new surveys have been carried out systematically whilst information of existing reports have been updated. In spite of the existence of the numerous reports and an apparent interest in the development of the mini-hydro technology in the country, not a single small hydro plant has been constructed so far [8].

This thesis reports a pre-feasibility study conducted to assess the current capacity of the Hemang hydroelectric potential site using recent flow data (1980 - 2011) of the Pra river as compared to flow rates preceding the work by Acres International .

Figure 1.1 is a map showing all hydropower sites in Ghana (both potential and constructed).

[1] Acres International, founded in 1924 became Hatch-Acres International after it was purchased in 2004 by Hatch Corporation of Mississauga, Canada.

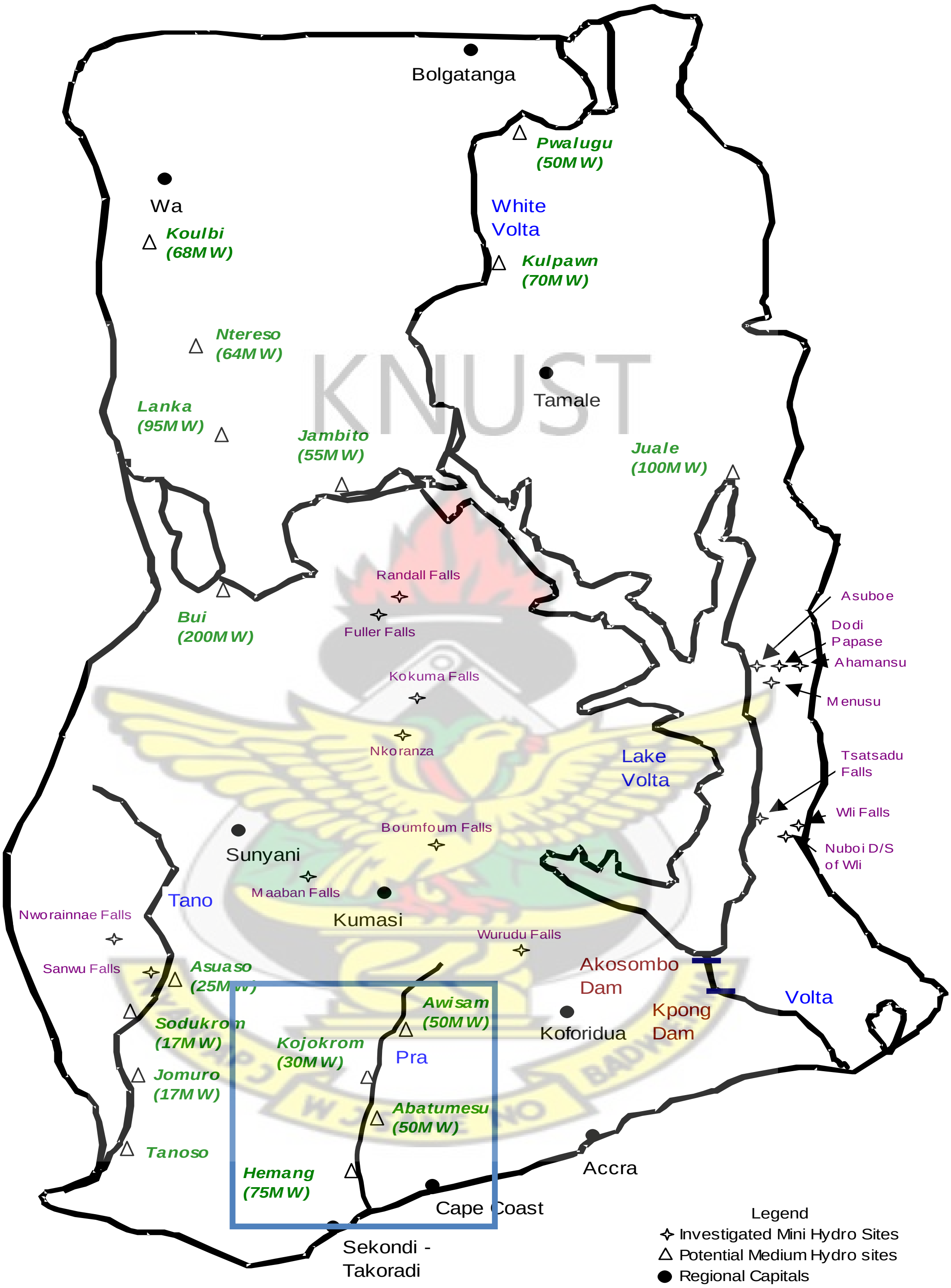

Figure 1.1: Map of Ghana showing hydropower sites.
SOURCE: [6]

From Figure 1.1, the locations with names in wine colourare large hydropower developments, the locations in green are medium-hydropower sites and the locations in violet are small hydropower sites. The sites on the Pra River are enclosed in the blue box.

1.2 Justification

One of the major areas of focus for NEPAD is energy infrastructure development. It is estimated that even though Africans constitute approximately 10% of the world's population, the total primary energy consumption of Africa is only about 3% of the total world primary energy consumption [6]. Africans therefore lack conventional and efficient sources of energy, which play a significant role in the development process.

The object of Ghana's renewable energy bill (RE Act 832, 2011) clearly is "To support the development, utilization and efficient management of renewable energy". This objective targets a total renewable energy penetration of 10% for Ghana by the year 2020 [9]. As of now, the total installed renewable energy technology in Ghana is under 1%. The Hemang site (which has a capacity below 100 MW, and therefore qualifies to be a renewable energy source) will contribute to realizing the goal of the renewable energy bill if it is explored and subsequently developed.

The Ghana Renewable Renewable Energy Bill also mentioned the fact that the government faces the challenge to increase the proportion of renewable energy of which hydropower is a part [10,9,11]. Realistically, the quite modest mini (<10 MW) hydropower potential in Ghana cannot make a considerable contribution to the national power requirement [8]. As such, medium scale hydro projects (10 MW – 500 MW - such as the Hemang site) need to be developed.

The document, 'Generation Master Plan Study for Ghana[1]' has projected that the Hemang site in addition to other sites like Pwalugu must be developed to add to the nation's power pool [2]. Ghana having another source of hydropower in addition to the currently operating three hydro installations (Akosombo, Kpong and Bui) will come a long way to support Ghana's energy generation capacity.

This study is also relevant because flow rates on the Pra river have changed considerably when compared to flow data used by the Acres International study (Ghana Generation planning study) of 1985.

[1] This is a documentation of study completed by Tracteble Engineering (an electrical engineering consultancy firm) in 2011 for the Grid Company of Ghana, GRIDCo.

1.3 Specific Objectives

The overall goal of this work is to assess the technical, financial and environmental feasibility of the Hemang hydro site on the Pra River using current flow data (1980 – 2011) and processed with RETScreen® software.

The specific objectives of this work are:

- To determine the power capacity of the selected site using recent flow data (1980 – 2011);
- To determine the appropriate hydro turbine suitable for power generation at the site and the size (characterizing dimensions) of the appropriate turbine and other water passages such as penstocks, scroll cases and draft tubes which will be parts of the plant;
- To determine the financial viability of the hydro power plant using Net Present Value (NPV), Equity Payback Time (EPT) and Internal Rate of Return (IRR) indicators;
- To determine the greenhouse gas emissions reduction associated with the hydropower plant.

1.4 Organization of thesis

Chapter 1 is the introduction to the thesis. It covers the background, justification, explanation of the objectives and the organization of this thesis.

Chapter 2 is literature review of the study. It covers hydropower and its development as a form of energy, some terminologies associated with hydropower as a renewable energy source, current medium hydropower schemes (10 MW – 500 MW) in Africa and Ghana in particular. The literature review also includes a review of some computer software used in analysis and development of hydropower and their features. The phases involved in hydro project engineering are also discussed in this Chapter.

Chapter 3 presents details of the methods and materials which were used to conduct the pre-feasibility study of the Hemang hydropower site. These details are divided into three, namely: technical analysis, financial analysis and an environmental assessment of the project (specifically GHG emissions which will be saved by the Hemang project).

Chapter 4 discusses the results obtained in this study. *Chapter 5* concludes the study and includes relevant recommendations by the study.

CHAPTER 2: LITERATURE REVIEW

2.1 Hydropower

Hydropower is the only renewable energy technology, which is presently used to generate the largest amount of energy across the world. It has four major advantages: it is renewable, it produces negligible amounts of greenhouse gases, it is the least costly way of storing large amounts of electricity, and it can easily adjust the amount of electricity produced to the amount demanded by consumers. Hydropower accounts for about 17 % of global generating capacity, and about 20 % of the energy produced each year [12,13].

2.1.1 History of hydropower

The power of water has been used by humans for thousands of years. The Greeks used water in wheels where they ground wheat into flour more than 2000 years ago. The 19th century was the turning point for the utilization of waterpower [14]. The improvement in technology and need for electricity replaced the waterwheels with modern day turbines. The development of hydroelectricity generation technology is summarized in *Table 2.1.*

Table 2.1: Developments in hydropower machinery

year	Developer	Development
Semi - axial or Francis Turbines		
1827	Fourneyron	Centrifugal reaction-turbine
1837	Howd	Centripetal reaction-turbine
1837	Henschel	Axial reaction turbine and draft tube
1855	Frink	Adjustable guide-vane

1873	Voith	Francis turbine with adjustable gate
Impulse Turbines		
1863	Girard	Axial tangential-action turbine
1880	Pelton	Bucket jet-action turbine
1890	Brener	Needle valve
1900	Abner Doble	Bucket cut-out
Axial Turbines		
1875	Escher Wyss	Straflo Turbine
1913	Kaplan	Adjustable runner vane
1936	Fischer and Escher Wyss	Bulb turbine
1942	Gibrat	Tidal-power turbine
Pumped Storage		
1930	Escher Wyss	Axial pump turbine
1934	Voith	Radial pump turbine
High-Voltage transmission		
1868	Oskar von Miller and Deprez	First initiative for high-voltage transmission
1891	Dolivo von Dobrovolsky	Industrial-scale system with an output voltage of 15 kV

source: [15]

2.1.2 Conversion of water power to electricity

Nearly a quarter of the energy from the Sun that reaches the Earth's surface causes water from the seas, lakes and ponds to evaporate. A proportion of this energy is used to make water vapour rise, against the gravitational pull of the Earth into the atmosphere, where it eventually condenses to form rain or snow. Therefore water at any height above sea level represents stored 'gravitational' energy [15].This energy is naturally dissipated by eddies and currents as the water runs downhill in streams and rivers until it reaches the sea. The greater the volume of water stored and the higher up it is, then the more available energy it contains. For example, water stored behind a dam in a reservoir contains considerable 'potential' energy. To capture this energy in a controlled form, some or all of the water in a natural waterway can be diverted into a pipe. It can then be directed as a stream of water under pressure onto a water wheel or turbine wheel. The water striking the blades causes the wheel (or turbine) to turn and create mechanical energy. [15]

The hydroelectric plants work by converting the kinetic energy from falling water into electric energy. This is achieved from water powering a turbine, and using the rotation movement to transfer energy through a shaft to an electric generator. [15]

The power capacity of a hydropower plant is primarily a function of two main variables of the water: *1) water discharge*, and *2) the hydraulic head*. Water discharge is the volume rate of flow with respect to time through the plant. Full gate discharge is the flow condition which prevails when turbine gates or valves are fully open. At maximum rated head and full gate, the maximum discharge will flow through the turbine. Rated discharge refers to a gate opening or plant discharge which at the rated head produces the rated power output of the turbine. [16]

Hydraulic turbines are machines that develop torque from the dynamic and pressure action of water. They can be grouped into two types. One type is an impulse turbine, which utilizes the kinetic energy of a high-velocity jet of water to transform the water energy into mechanical energy. The second type is a reaction turbine, which develops power from the combined action of pressure energy and kinetic energy of the water. Reaction turbines can be further divided into several types, of which the principal two are the Francis and the propeller. [16]

2.1.3 Hydropower terminologies

a) Firm energy

It is the energy that a plant can generate 95 per cent of the time. Firm flow required to generate the firm energy is the minimum flow that a hydroelectricity plant can operate. [17]

b) Secondary Energy

It is all the energy available in excess of firm power. Secondary energy is not guaranteed; therefore the price of secondary energy is lower than the firm energy [18] [19]

c) Heating value

This is a measure of energy released when a fuel is completely burned. Depending on the hydrogen composition of the fuel, the amount of steam in the combustion products varies. Higher heating value (HHV) is calculated assuming the combustion product is condensed and the steam is converted to water. Lower heating value (LHV) is calculated assuming the combustion product stays in a vapour form.

Higher heating value is typically used in Canada and USA, while lower heating value is used in the rest of the world. [19] Heating values are of importance in RETScreen since they are used in greenhouse gas (GHG) emission analysis.

d) Capacity factor

It is the ratio of the total amount of energy the plant produced during a period to the amount of energy the plant would have produced at full (nameplate) capacity. Typical values for hydro plant capacity factor range from 40 to 95% [19]

e) Firm flow

The firm flow is defined as the flow being available p% of the time, where p is a percentage specified by the user and usually equal to 95%. The firm flow is calculated from the available flow-duration curve.

f) Flow duration curve

A flow duration curve illustrates the percentage of time, or probability, that flow in a stream will equal or exceed a particular value. Flow duration curve analysis is a method involving the frequency of historical flow data over a specified period. Typically, low flows (flow during prolonged dry spells) are exceeded majority of the time, while high flows, such as those resulting in floods, are exceeded infrequently.

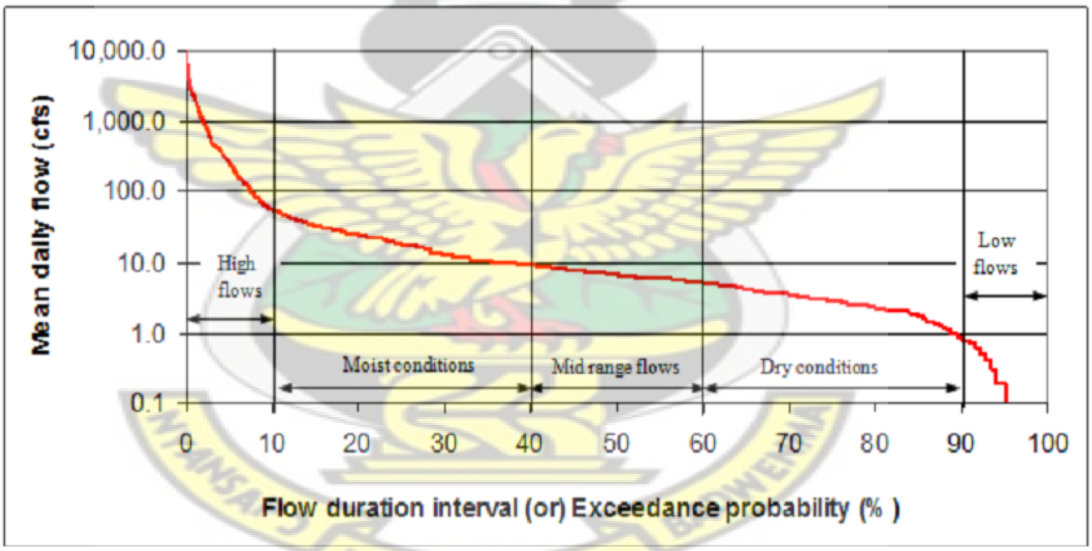

Figure 2.1: flow duration curve showing possible intervals

SOURCE: [20]

2.2 Hydropower Schemes in Africa

The following (*Table 2.2)* is a list of hydropower plants in Africa outside Ghana having a capacity below 500 MW.

Table 2.2:Selected hydropower schemes in Africa having a capacity below 500 MW

	Plant Name	Installed Capacity (MW)	Country
1	Kompienga Dam Hydroelectric Power Plant	14	Burkina Faso
2	Song Loulou Dam Hydroelectric Power Plant	398	Cameroon
3	Edea Hydrelectric Power Plant	264	Cameroon
4	Lagdo Hydroelectric Power Plant	72	Cameroon
5	M'Bali Hydroelectric Power Plant		
6	Djoue Hydroelectric Power Plant	365	Congo
7	Moukoukoulou Hydroelectric Power plant	74	Congo
8	Imboulou Hydroelectric Power Plant	120	Congo
9	Buyo Hydroelectric Power Plant	165	Cote D'Ivore
10	Taabo Hydrolectric Power Plant	210	Cote D'Ivore
11	Kossour Hydrelectric Power Plant	174	Cote D'Ivore
12	Ayame (Ayme) II Hydroelectric Power Plant	30	Cote D'Ivore
13	Ayame (Ayme) I Hydroelectric Power Plant	20	Cote D'Ivore
14	Inga I Hydroelectric Power Plant	351	DRC
15	Zongo Hydroelectric Power Plant	75	DRC
16	Nzilo Nydroelectric Power Plant	100	DRC
17	Nseke Hydroelectric Power Plant	260	DRC
18	Koni Hydroelectric Power Plant	36	DRC
19	Mwadingusha Hydroelectric Power Plant		DRC
20	Aswan Dam 1 Hydroelectric Station	322	Egypt
21	Aswan Dam 2 Hydroelectric Station	270	Egypt
22	Esna (Isna) Hydroelectric Power Plant	86	Egypt
23	New Naga Hamadi Hydroelectric Power Plant	64	Egypt
24	Tekeze Hydroelectric Power Plant	300	Ethiopia
25	Tis Abay I Hydroelectric Power Plant	11.4	Ethiopia
26	Tis Abay II Hydroelectric Power Plant	73.6	Ethiopia
27	Tana Beles Hydrolectric Power Plant	460	Ethiopia
28	Fincha Hydroelectric Power Plant	84	Ethiopia
29	Koka Hydroelectric Power Plant	43	Ethiopia
30	Melka Wakema Hydroelectric Power Plant	153	Ethiopia
31	Awash II and III Hydreoelectric Power Plant	64	Ethiopia
32	Masinga Hydroelectric Power Plant	40	Kenya
33	Kindaruma Hydroelectric Power Station	40	Kenya
34	Gitaru Hydroelectric Power Station	225	Kenya

35	Kiambere Hydroelectric Power station	168	Kenya
36	Kamburu Hydrolectric Power Plant	94.2	Kenya
37	Sondu Miriu Hydroelectric Power Plant	60	Kenya
38	Turkwel Hydroelectric Power Plant	106	Kenya
39	Kapichara Hydroelectric Power Plant	64	Malawi
40	Nkula Hydroelectric Power Plant	124	Malawi
41	Tedzani Hydroelectric Power Plant	92.7	Malawi
42	Manantali Hydrolectric Power Plant	200	Mali
44	Felou Hydroelectric Power Plant	62.3	Mali
45	Selingue Hydroelectric Power Plant	44	Mali
46	Sidi Said Maachou Hydro Power Plant	20.8	Morocco
47	Imfout Hydroelectric Power Project	32	Morocco
48	Daourat Hydroelectric Power Project	17	Morocco
49	Allal el Fassi Hydroelectric Power Project	240	Morocco
50	Al Wahda Dam Hydroelectric Power Project	240	Morocco
51	Oued El Makhazine Hydroelectric Power Plant	36	Morocco
52	Ahmed el Hansali Hydroelectric Power Plant	92	Morocco
53	Hassan I Hydroelectric Power Project	67.2	Morocco
54	Al Massisra Hydroelectric Power Project	128	Morocco
55	Mohamed V Hydroelectric Power Project	23	Morocco
56	Mansour Ed Dahbi Hydroelectric Power Project	10	Morocco
57	Bin El Ouidane Hydroelectric Power Plant	135	Morocco
58	Afourer Power Plant	84	Morocco
59	STEP Afourer I and II Power Project	465	Morocco
60	Idriss I hydroelectric Power Project	40	Morocco
61	Chicamba Hydroelectric Power Plant	38.4	Mozambique
62	Mavuzi Hydroelectric Power Plant	52	Mozambique
63	Corumana Hydroelectric Power Plant	16.6	Mozambique
64	Ruacana Hydroelectric Power Plant	240	Namibia
65	Bumbuna Hydroelectric Power Plant	50	Sierra Leone
66	Collywobbles Hydroelectric Power station	42	South Africa
67	Gariep Hydroelectric Power Station	360	South Africa
68	Second Falls Hydroelectric Station	11	South Africa
69	Vanderkloof Hydroelectric Power Station	240	South Africa
70	Palmiet Pumped Storage Hydroelectric Power Plant	400	South Africa
71	Sreensbras Pumped Storage Hydroelectric Power Plant	180	South Africa

SOURCE: [21,22]

2.3 Medium Scale Hydro projects in Ghana

2.3.1 The Kpong hydroelectric dam

This is a 160 MW dam which is about 24 km downstream of Ghana's major hydroelectric dam; the Akosombo dam located at Akosombo in the Eastern Region of Ghana [8], managed and owned by Ghana's Volta River Authority (VRA). The Kpong Dam operates as a run-of-the-river facility with minimal storage to re-turbine the Akosombo releases [23,24].

The main plant equipment in the combined intake and powerhouse structure includes the following:

- 12 wheeled intake gates (3 per unit), 6.40 by 13.50 m, stop logs and trash racks;
- 6 draft tube gates (2 per draft tube), 6.60 by 6.30 m;
- one powerhouse crane - 270-ton plus 25-ton auxiliary;
- 4 generating units of 40 MW each; 55,000 HP, 11.75 m head fixed-blade propeller turbines with concrete spiral casings, 7.50 m runners driving 44.6 MVA (at 0.9 p.f.), 13.8 kV, 62.5 RPM, 50 Hz umbrella type three-phase synchronous generators;
- Ancillary electrical and mechanical systems; and

i) Two 13.8/161 kV, 100 MVA forced cooled three-phase step-up transformers (two units per transformer).

2.3.2 The Bui hydroelectric dam

This is a power plant on the Black Volta in the Brong Ahafo region of Ghana. The development of this dam has been the subject of many studies; namely, detailed studies by J.S. Zhuk Hydroprojeckt of the USSR in 1966, a Feasibility Study by

Snowy Mountains Eng. Corp (SMEC) of Australia in 1976 and another Feasibility Study by Coyne et Bellier of France in 1995.

The 400 MW Bui hydropower scheme was considered to be the most technically and financially attractive hydropower site in Ghana after the Akosombo and Kpong hydro power plants [25,26,27] It consist of the following specifications:

Main Dam

Roller Compacted Concrete (RCC) Gravity Dam (1,000,000 m^3)

Crest length	492.5 m
Dam crest elevation	185.0 masl
Maximum dam height	108 masl
Dam crest width	7 m

Reservoir

Full Supply Level (FSL)	183.0 m
Reservoir Area at FSL	444 km^2
Storage Volume at FSL	12.57 x 10^9 m^3
Minimum Operating Level	168.0 m
Active Storage	7.72 x 10 m

Spillway

Five gated structure

Designed for 1 in a 10,000 year flood of 10,450 m^3 /s

Weir crest elevation 166.5 masl

Power House

Unit Type - 3 Francis Turbines/Generators of 133 MW each

Guaranteed Peak Efficiency > 94%

Installed Capacity 400 MW

Net Average long term energy production 969 GWh/yr

Transmission System

Power produced from the plant will be evacuated from the Bui Switchyard through 161 kV transmission facilities, which will be operated as part of the National Interconnected Transmission System. The transmission facilities to be constructed are:

Bui Switchyard

Bui - Teselima Two (2) lines - 18 km each

Bui - Kenyase transmission line - 170 km

Bui - Kintampo transmission line - 70 km

Kintampo Substation, by GRIDCo [28]

2.4 Hydropower Project Development

Development of a hydropower scheme is a challenging process, which needs great amount of time and money in addition to expertise in various disciplines. All the phases of a hydropower project are covered in *section 2.5*. The initial stages of the development require quick estimations of the energy output of the project using a resource such as a computer software.

2.4.1 Computer software for hydropower project development

Several computer software programs such as RETScreen, HES, Hydra are available to make initial financial analysis for a new hydro project. Utilization of such software shortens the time and money spent for conducting the initial financial assessments for the projects [14]. In addition, during the initial (pre-feasibility) studies preceding hydropower projects, computer software are necessary in accessing project capacities [29,30] thereby eliminating the waste of project study time and financial resources [31].

The objective of these software programs is to find a rapid and reasonably accurate means of predicting the energy output of a particular hydro scheme. These predictions involve establishing the 'head' or vertical distance that water can be dropped, and the incidence, in time and magnitude, of the quantity of water to be used. The first of these is a relatively simple matter of physical measurement together with some hydraulic loss calculations concerning pipe materials and water velocities, etc. The second is much more difficult and it is this part of the problem that is most intractable. There are two main approaches, the flow duration curve (fdc) and the simulated stream flow (ssf) methods [32].

Table 2.3 shows the features of some common hydropower project analysis software.

Table 2.3: Hydropower sofware and their features

Hydro power software		Features of Software					
software	Country of Application	Hydro logy	Power	Costing	Financi al Evaluat ion	Prelimi nary Design	access
HES®	USA	*					free
HydrA®	Europe	*					free
IMP®	Canada	*	*		*		free
# PEACH®	France	*		*		*	sold (comm ercial)
PROPHETE®	France	*	*		*		free
RETScreen®	Internation al	*	*	*	*		free
SMART mini-idro®	Internation al		*	*	*		free

SOURCE: [29]

RETScreen® has specifically been selected for analysis of this project because it a step ahead of the others in the following number of ways:

1. It is not limited geographically but it is international
2. It can be obtained free of charge
3. It has a very user-friendly manual and an online help; all of which come at no cost.
4. It has a cost analysis (financial evaluation) module, which some other packages do not have. Eg. HydrA, HES and PROPHETE

RETScreen® however falls short in one area – presentation of a preliminary plant design.

2.4.2 RETScreen® clean energy Analysis Package

RETScreen is a to analyse the viability of clean energy projects. However, it is also useful for planning, designing, implementing, and reviewing the viability of clean energy policies. RETScreen allows participants in the policy making process to consider the technology, business, and finance of clean energy in an integrated fashion, thus helping to develop appropriate – and ultimately, successful policies [19].

It is designed to help energy project proponents identify and evaluate, relatively quickly and at low cost, the most viable near-term opportunities for cost-effective RETs project implementation [32].

Hydrology

In RETScreen, hydrological data are specified as a flow-duration curve, which is assumed to represent the flow conditions in the river being studied over the course of an average year. The flow-duration curve is used to assess the anticipated availability of flow over time, and consequently the power and energy, at a site. The model then calculates the firm flow that will be available for electricity production based on the flow-duration curve data, the percent time the firm flow should be available and the residual flow.

Load

The RETScreen Small Hydro Project Model assumes that the daily load demand is the same for all days of the year and can be represented by a load duration-curve.

In this software, daily energy demand is calculated by integrating the area under the load duration curve over one day. A simple trapezoidal integration formula is used and the result expressed in kWh.

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 (load-duration curve), the gross head and the efficiencies/losses. The calculation involves comparing the daily renewable energy available to the daily load-duration curve for each of the flow-duration curve values.

Hydro turbine efficiency data can be entered manually or can be calculated by RETScreen. Calculated efficiencies can be adjusted using the *Turbine manufacture/design coefficient and Efficiency adjustment factor in the Equipment Data worksheet* of the model. Standard turbine efficiency curves have been developed for the following turbine types: kaplan, francis, propeller, pelton, turgo and Cross flow turbines. The type of turbine is selected based on its suitability to the available head and flow conditions. The calculated turbine efficiency curves take into account a number of factors including rated head (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 manufacturers efficiency curves for different turbine types, head and flow conditions.

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 between two turbines, and so on up to the maximum number of turbines selected. The turbine efficiency equations and the number of turbines are used to calculate plant turbine efficiency from 0% to 100% of design flow (maximum plant flow) at 5% intervals.

Renewable energy available is determined by calculating the area under the power curve assuming a straight-line between adjacent calculated power output values. Given that the flow-duration curve represents an annual cycle, each 5% interval on the curve is equivalent to 5% of 8,760 hours (number of hours per year).

The Small Hydro Project Model is unique among RETScreen technology models in that it offers two methods for project costing: the detailed costing method, or alternatively, the formula costing method. The formula costing method is based on empirical formulae that have been developed to relate project costs to key project parameters. The costs of numerous projects have been used to develop the formulae.

Validation

Numerous experts have contributed to the development, testing and validation of the RETScreen Small Hydro Project Model. They include small hydro modelling experts, cost engineering experts, greenhouse gas modelling specialists, financial analysis professionals, and ground station (hydrology) and satellite weather database scientists.

As a means of validation of the RETScreen software a turbine efficiency curve as calculated by RETScreen has been compared to manufacturer's efficiency data for an installed unit with the same characteristics. Also, the annual renewable energy delivered and plant capacities calculated by RETScreen are compared to values calculated by another software program, HydrA®. Project costs, as calculated by the

RETScreen® formula costing method has also been compared to the as-built costs of one small hydro project [33].

2.5 Hydropower Project Engineering Phases

There are normally four phases for engineering work required to develop a hydro project [34].

2.5.1 Reconnaissance surveys and hydraulic studies

This first phase of work frequently covers numerous sites and includes: map studies; delineation of the drainage basins; preliminary estimates of flow and floods; and a one day site visit to each site (by a design engineer and geologist or geotechnical engineer); preliminary layout; cost estimates (based on formulae or computer data); a final ranking of sites based on power potential; and an index of cost.

2.5.2 Pre-feasibility study

Work on the selected site or sites would include: site mapping and geological investigations (with drilling confined to areas where foundation uncertainty would have a major effect on costs); a reconnaissance for suitable borrow areas (e.g. for sand and gravel); a preliminary layout based on materials known to be available; preliminary selection of the main project characteristics (installed capacity, type of development, etc.); a cost estimate based on major quantities; the identification of possible environmental impacts; and production of a single volume report on each site.

2.5.3 Feasibility study

Work would continue on the selected site with a major foundation investigation programme; delineation and testing of all borrow areas; 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 project design earthquake and the maximum credible earthquake; design of all structures in sufficient detail to obtain quantities for all items contributing more than about 10% 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 a detailed cost estimate; and finally, an financial and financial evaluation of the project including an assessment of the impact on the existing electrical grid along with a multi-volume comprehensive feasibility report. System planning and project engineering This work would include studies and final design of the transmission system; integration of the transmission system; integration of the project into the power network to determine precise operating mode; production of tender drawings and specifications; analysis of bids and detailed design of the project; production of detailed construction drawings and review of manufacturer's equipment drawings. However, the scope of this phase would not include site supervision or project management, since this work would form part of the project execution costs [33] .

2.6 Hemang and the Pra River Basin

2.6.1 Location of Hemang

Hemang (a.k.a Sekyere-Hemang is located in the very southern part of the main Pra River basin (*Figure 2.2*). Its geographical co-ordinate is 5°10'60" N, 1°34'0" W. This is situated in the Mpohor/Wassa East district of the Western region on Ghana (Shown in *Figure 2.4*).

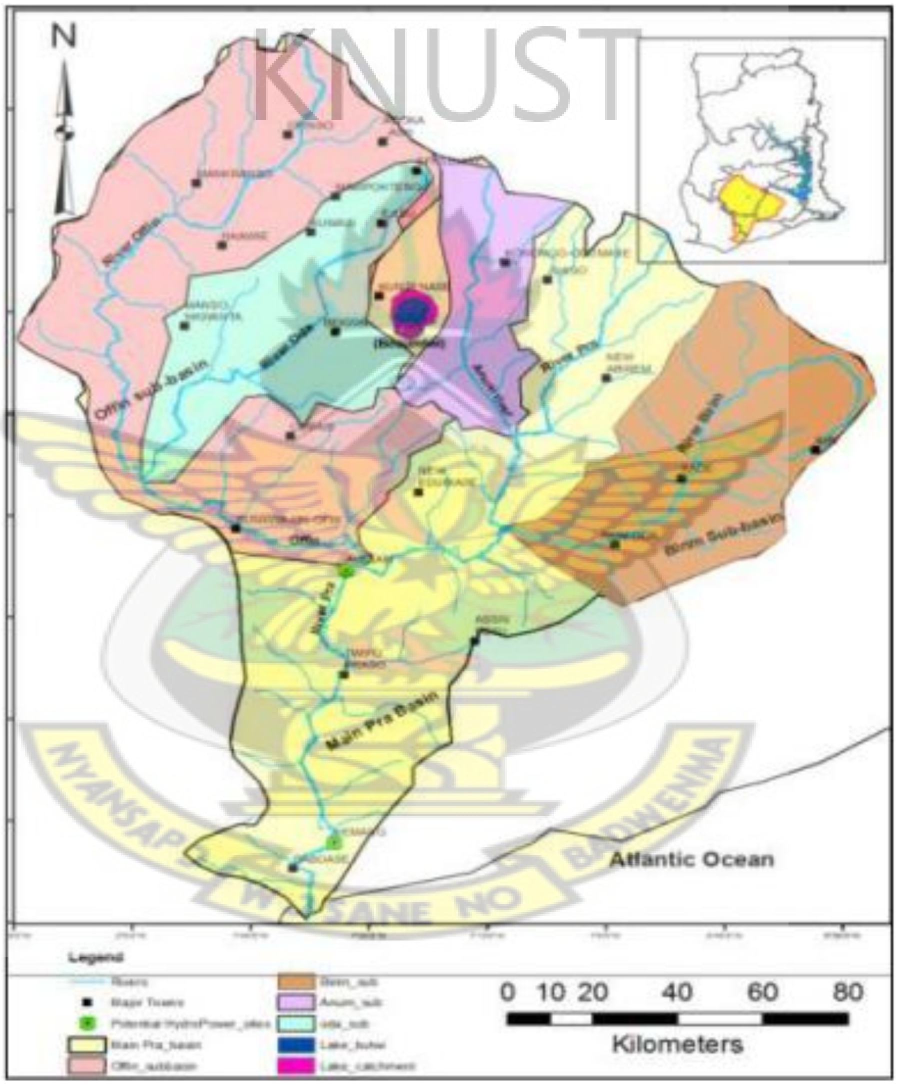

Figure 2.2: The Pra River Basin

Source: Ghana Water Resources Commission (2012) - Integrated Water Resources Plan of the Pra Basin.

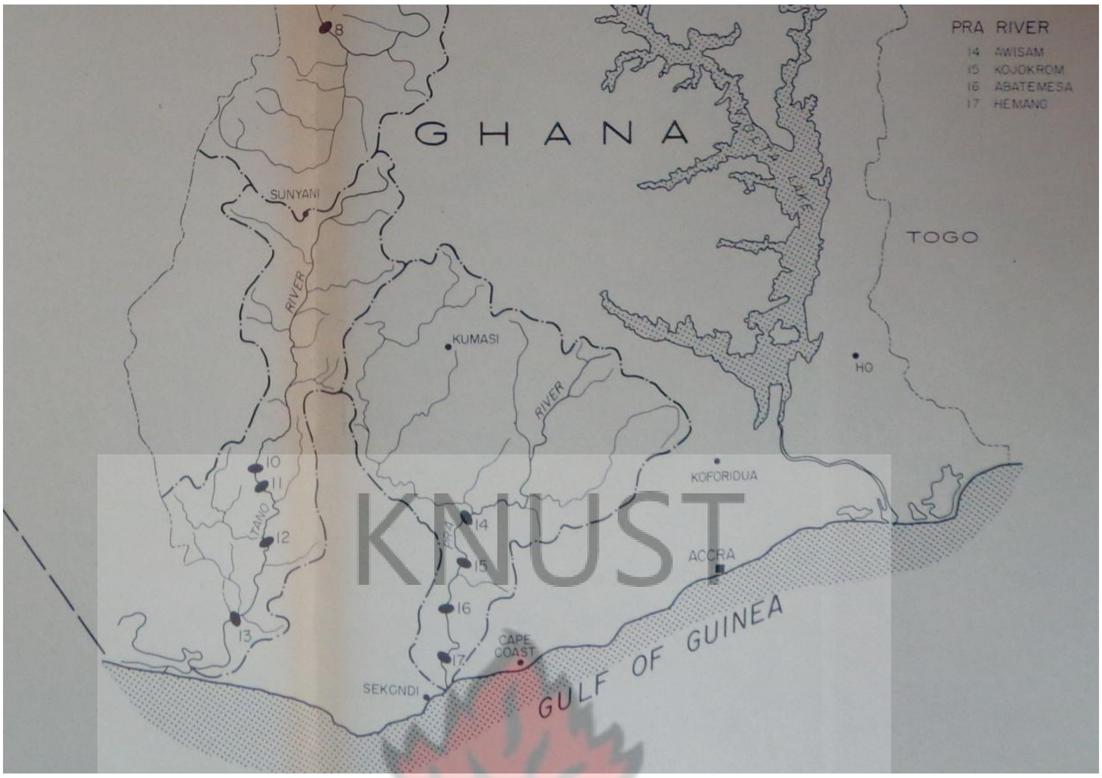

Figure 2.3: A map of southern Ghana showing potential hydropower sites on the Pra and Tano Rivers
Source: [7]

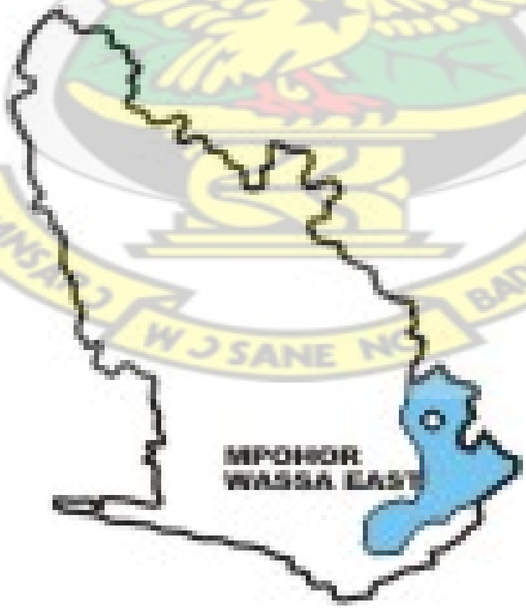

Figure 2.4: Western Region showing the Mpohor Wassa East District
Source: Ghana Districts Website (2006)

Figure 2.2 shows the whole Pra Basin. An inset of the regional map of Ghana. Hemang can be seen on the second southernmost part of the basin. An enlarged south -central part of the regional map clearly shows ***Sekyere Hemang***. *Figure 2.3* shows the Pra River Basin and other hydropower sites on it. *Figure 2.4* shows the district in which the study area (Sekyere Hemang) is located and the position of the district in Ghana's Western Region.

2.6.2 The Pra River.

The Pra River together with its tributaries forms the largest river basin of the three principal southwestern basins systems in Ghana (ie. Ankobra, Tano and Pra). Its total basin area of approximately 23,200 km² extends through almost 55% of Ashanti, 23% of Eastern, 15% of Central and 7% Western Regions (see Figure 2.2). The Pra River and its major tributaries–(Rivers Anum, Birim, Offin and Oda), originate from the eastern and north-western fringes and flows southwards. The main Pra River (on which Hemang is located at the southern part of the basin) takes its source from the highlands of Kwahu Plateau in the Eastern Region and flows for some 240km before entering the Gulf of Guinea near Shama in the Western Region. [35]

2.6.2.1 Mpohor Wassa East District

The Hemang site, Administration wise, falls under the Mpohor/Wassa East District located in the Western Region of Ghana (see *Figure 2.3*)

2.6.2.2 Topology & drainage

The district lies within the low-lying areas of the country with most parts below 150 metres above sea level. The landscape is generally undulating with an average height of about **70 metres.**

The highest elevation ranges between 150 and 200 metres above sea level. The drainage pattern of Mpohor Wassa East District is largely dendriatic. There are medium and small rivers and streams.

Most of them originate from the Akwapim ranges and flow southwards towards the coast. The main rivers in the district 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 rapids. [36]

2.7 Occupations and Economic Activities in the Hemang Area (Mpoho /Wassa East district) of the Pra Basin

2.7.1 Economy

On revenue and expenditure base, the sources of revenue for the District Assembly could be classified into internal and external. The internal sources consist of basic rates, property rates, stool lands, fees, fines and licenses. The external sources comprise grants in aid made up of DACF, donor assistance and funds from NGOs and others. Also included are salaries and wages paid on behalf of the assembly by central government. The employment levels and occupations in the district is very typical of a rural district. 8.1 % of the labour force is unemployed. Those employed are engaged in diverse activities. [37,38].

2.7.2 Agricultural sector

Subsistence and large-scale agriculture employs 71.5% of the workforce according to the 2000 population and housing census. The major staple food crops produced in the district include cassava, plantain, maize, cocoyam and vegetables. The output per yield is substantially low in the district due to traditional methods of farming with an average farm size of one acre per farmer.

The predominant cash crops are cocoa and oil palm and coffee in some cases. Cocoa is usually cultivated in small to medium sized plantations mostly by settler farmers. Oil palm is cultivated on a large-scale by Benso Oil Palm Plantation (BOPP) NORPALM and smaller companies like WAOPP and Ayiem Oil Mills.

Non-traditional crops like black pepper and pineapples which are cultivated in the district have high potential of becoming export crops if they are given serious attention in production and marketing. Other non-traditional crops that could do well in this district are citrus, cashew and banana.

About 98% of the farmers rely on traditional methods of farming using slash and burn, simple farm tools such as hoe, cutlass and relying on natural climatic conditions for cropping. These traditional methods lead to fast depletion of the soil nutrients and low production and productivity.

Most of the crops grown in the district are perishable in nature. Examples are plantain, cassava, vegetables and oil palm. There are virtually no arrangements to store these crops. Few farmers use some form of storage facilities and these could store only small quantities of produce for short periods [39].

2.7.3 Industrial Sector

The following are the large-scale industries in the district. Subri Industrial Plantation Limited (SIPL) in Daboase, Golden Star (Wassa mines) Limited in Akyempim, Benso Oil-Palm Plantation (BOPP) in Adum Banso and Norpalm Ghana Limited in Pretsea. (39)

The medium scale industries include Ayiem Oil Mills Limited in Mpohor and Wiriko Asubonteng Oil Mills Limited in Adum Banso. A number of small scale industries for agro processing can be found in most parts of the district. Specific locations include an oil palm processing facility in Adum Banso and Mpeasem and cassava processing in Kwabaa, Awiadaso, Akotosu, Adiembra and Abroadzewuram (39).

Small-scale mining activities are carried out in areas like Mpohor, Manso, Sekyere Krobo, Nsadweso and Ateiku. Again, there is prospecting for gold and in some parts of the district and iron ore in Adum Banso. [40]

2.8 Demographic Characteristics

According to the 2000 population census, the population of the district in 1970 was 27,573 and 55,801 in 1984. The total population in 2000 was 122,595 and estimated to be 143,876 in 2005 with an inter-censal growth rate of 3.2 %, which is the same as the regional growth rate. It is however higher than the national growth rate of 2.7 %. [37,41]

Males form 52.5 % of the total population (64,384) as against 47.5 % (58,211) for females. Children under fifteen years (0-14) account for 43.4 % (53,206) of the population compared with the national figure of 41.3 %, the economically active population (15-64 years) accounts for 50.6 % (62,033) as against the national figure of 53.4 % and the elderly or the aged (65 years and above) accounts for 6 % (7,356) of the total population compared to 5.3 % of the national figure in 2000. The population pyramid in figure 1.3 shows the detailed age and sex distribution of the population in the district. [37]

The analysis of the population structure reveals a high economically active population of 50.6 %, which indicates an immense human resource potential for development. This could be attributed to in-migration of labour to seek employment in the district agriculture and mining.

2.9 Previous Work on the Hemang Hydropower Site

A feasibility was conducted on the Pra river as part of Ghana Generation Study: a study conducted by ACRES International for the Volta River Authority (VRA) and published in 1985.

The studies found the Hemang Hydroelectric site to have a capacity of 75 MW with the following technical data:

Table 2.4: Some technical details of previous work on Hemang site

Technical detail	**magnitude**
Plant design efficiency	0.9
Plant capacity	75 MW
Annual energy output	308 GWh
Turbine type	Propeller (3 × 25 MW)
Gross Head	29.9 m

Information and knowledge obtained from literature are used to develop the methods and materials for this work and are presented in *Chapter 3.*

CHAPTER 3: METHODS AND MATERIALS

The methodology employed for this research work on the pre-feasibility study of the hydropower potential of the Hemang site is planned under three (3) main areas (technical, financial and environmental) and they are presented in the following sections.

3.1 Technical Analysis

The flow rate (discharge) and gross head are the most important information for planning a hydropower plant [42] [16]. Figure 3.1 explains the process used to obtain the performance characteristics of the most suitable turbine type for the Hemang hydropower site.

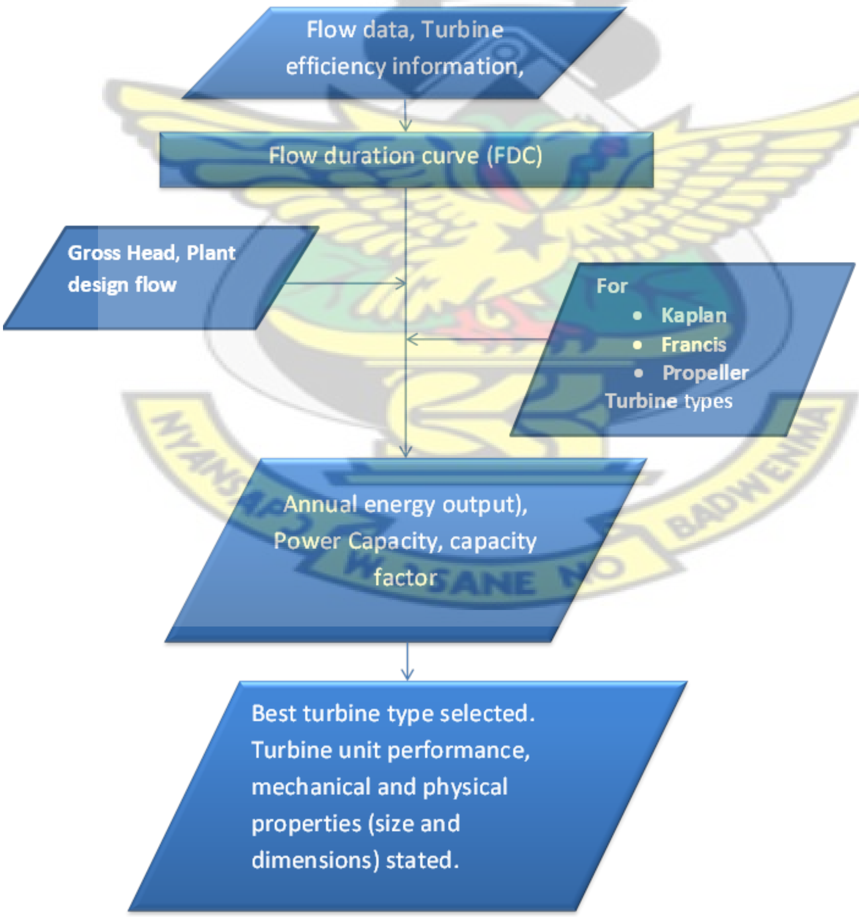

Figure 3.1: Flow diagram for technical analysis

From *Figure 3.1*, the flow data is processed to obtain the flow duration curve. *Subsection 3.1.1* explains how the flow data was obtained for this study. *Subsection 3.1.2* explains how the flow data is processed into the flow duration curve (FDC).

Applying the head of the site to the flow duration curve, the performance characteristics (annual energy output, power capacity and capacity factor) of the three types of turbines considered are then determined and the best turbine is selected for the plant (as presented in *Subsection 3.1.5*). The determination of physical characteristics of the selected turbine and other turbine unit components is explained in details in *Subsection 3.1.6*.

3.1.1 Flow rate data

Flow rate data used in this analysis consists of two sets of data (1944 – 1984; and 1980 – 2011) on the Pra River. These two sets of data were obtained by multiplying flow rate readings from gauge stations near the site by factor of **1.06**. This correction factor helped to translate flow rate reading at the gauge stations (Twifo-Praso) to the actual site where the hydro dam is being investigated at Hemang [7]. The 1944 – 1984 data and 1980 – 2011 data (monthly flow rates) are presented *in appendix B.* The flow rate data is used to obtain the flow duration curve as presented in the next subsection.

3.1.2 Obtaining the flow duration curve (FDC)

The daily mean flow data as presented in appendix B is used to generate a flow duration curve. The creation of a flow duration curve involves these four basic steps.

i) Acquisition of stream flow data,

ii) Arrangement of data (in descending order),

iii) Ranking[1] of flow data, and

iv) Obtaining frequency of occurrence (or exceedance probabilities).

Frequency of occurrence is obtained using the following formula:

$$F = 100\left(\frac{R}{N+1}\right)$$

Where, **F** is frequency of occurrence (expressed as % of time a particular flow value is equaled or exceeded), **R** is Rank and **N** is Number of observations [20].

Using the method explained at the start of this section (four basic steps used to obtain FDCs), the flow duration data is processed with exceedance values of 0% to 100% . The processed flow data (1944 – 1984) is shown in *appendix B1*. This data is used as input into RETScreen analysis. The processed 1980 – 2011 data is also shown in appendix B2. For the purpose of this study which focuses on recent data, entries in Table 3.1 below are extracted from the fully processed data in *appendix B2*.

Table 3.1: Exceedance probability for 1980 to 2011 Hemang site flow data.

flow (m^3/s)	rank	exceedance probability (%)
1022.763	1	0.00961
449.6796	521	5.006727
344.2954	1041	10.00384
271.307	1561	15.00096
216.1541	2082	20.00769
174.4463	2602	25.0048
141.5121	3122	30.00192
116.5216	3643	35.00865
96.87022	4163	40.00577
77.6556	4683	45.00288
61.58706	5203	50
50.6044	5724	55.00673
40.8736	6244	60.00384
35.83542	6764	65.00096
31.5986	7285	70.00769
27.89496	7805	75.0048

[1] Assigning of numbers to every single rate, from the largest flow rate to the least flow rate. The largest flow rate has a rank of 1.

24.433	8325	80.00192
21.43214	8846	85.00865
15.22902	9366	90.00577
7.23132	9886	95.00288
0.31694	10406	100

The entries of flow and exceedance probability from *Table 3.1* are plotted using Microsoft Excel® to give the daily flow duration curve shown in *Figure 4.1*. RETScreen® also has the capability of producing the same graph.

The data of *Table 3.1* and *Figure 4.1* is used to obtain the annual energy output of each turbine type, which is presented in *Section 4.1.1* of *Chapter 4*.

3.1.3 Gross head

The topography of the site suggests the gross head to be used for this analysis. This affects the site (land area) to be submerged by dam.

In reconnaissance or pre-feasibility studies, contour maps are used to determine the gross hydraulic head [16] [43]. From the detailed surveying at the Hemang site carried out by the Acres study (topographical map and River profile are shown in appendix D), a gross head of 29.9 meters was determined. This study maintains the same gross head of **29.9 m**, as per the ACRES study since not much has changed concerning the elevations of the area under study.

3.1.4 Turbine design flow

Design flow is taken to be 271.31 $\mathbf{m^3/s}$ (from Table 3.1). This occurs at 15% exceedance probability. This consideration is typical of plants which are meant to be peaking power plants[1] [44]. The power plant is being considered a peaking power plant because there are other three major hydro-power plants considered as base power plants namely Akosombo, Kpong and Bui dams.

[1] Peaking plants augment other main (base) power plants.

3.1.5 Annual energy output and power capacities.

The processed flow data (in the form of flow duration curve), the design flow, and the turbine efficiency information are used to find the most suitable turbine type (turbine type that can give the highest annual energy output and highest capacity factor) using the following steps:

i) Finding of all turbine types applicable at a head of 29.9 m. The turbine application chart in Figure 3.2 shows that 3 different turbine types (Francis, Propeller and Kaplan) are applicable at the head of 29.9 m.

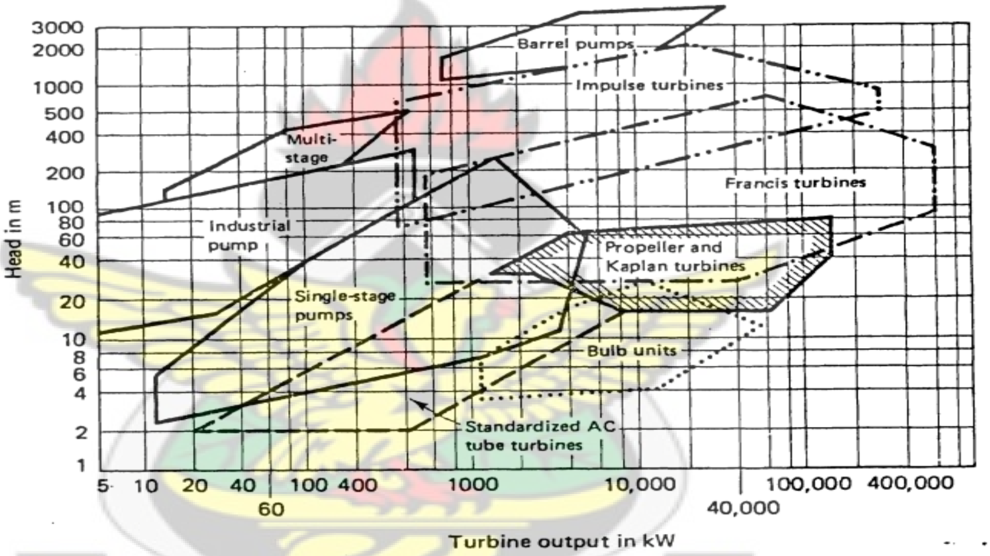

Figure 3.2: Conventional turbine application chart. SOURCE: Allis-Chalmers Corporation, in [44]

ii) Using the processed flow data to obtain annual energy output, capacity factor and power capacity for the three (3) different turbine types (Kaplan, Propeller and Francis) applicable at a gross head of 29.9 m using the RETScreen® energy module. This involves the following:

   a. Consideration of turbine efficiency (e_t) data applicable to the particular turbine type at different flows.

b. Calculating the power ($P_{0\%}$, $P_{5\%}$, $P_{10\%}$, $P_{15\%}$,... $P_{100\%}$) available as a function of flow (ie. Calculating power available for values of stream flow on the f.d.c at exceedance increments of 5% (i.e. $Q_{0\%}$, $Q_{5\%}$, $Q_{10\%}$, $Q_{15\%}$... $Q_{100\%}$)

c. Energy available (energy exported to grid) is determined by calculating the area under the power curve assuming a straight-line between adjacent power output values.

d. Capacity factor [45] is computed using the relation: $K = \frac{E_{dlvd}}{8760 \times P_{des}}$, where E_{dlvd} is annual energy delivered and P_{des} is capacity or name plate capacity.

iii) Comparing the performance of the turbine types using their capacity factors, power capacities and annual energy outputs.

iv) Selecting the turbine type that gives the highest annual energy output.

Engineering relations used by RETScreen energy module are listed in *appendix F.*

3.1.6 Sizing of turbine and other water passages

The purpose of this section is to be able to make a more exact selection of the price of the main water passages that will form a crucial part of the hydro installation by sizing them and inquiring their prices from their manufacturers. The characteristic dimensions of the turbine and various water passages were computed using Matlab® codes (m-file) written for this purpose using relevant equations (codes shown in *appendix A*). Even though RETScreen has a database of turbines and their manufacturers, the characteristic dimensions of the turbines are not given. This reason therefore necessitates the sizing of turbine and other water passages. All the dimensions obtained from this sizing are stated in *Chapter 4, Table 4.3, Table 4.4* and *Table 4.5*. The following sections describe details of the characteristic components of the hydropower units.

Turbine

The main turbine dimension for characterizing the turbine to be used in the pre-feasibility study is the outer propeller diameter, D_M. This is equal to the throat diameter minus the clearance [46,47,48]. The relation of *Equation 3.1* below is used to determine the propeller diameter.

$$D_M = (66.76 + 0.136N_s)\frac{\sqrt{H}}{n}$$ *Equation 3.1*

N_s *is turbine specific speed,* ***H*** *net head, and* ***n*** *is turbine speed in rpm. Other details of computing D_M are covered in Appendix A1.*

Penstock

Out of the various experience curves and empirical equations which have been developed for determination of economical size of penstocks, the equations which use very few parameters to make initial size determinations for purposes of a reconnaissance or pre-feasibility study [49] have been utilized. In this regard, the equations by Gordon and Penman (1979) and Sarkaria (1979) [49] was used to compute the diameter for the penstock of each of the plant's units. The penstock diameter can either be obtained from the rated flow rate or a combination of rated power and head information.

$$D_p = 0.72Q^{0.5}$$ *Equation 3.2*

Where D_p is penstock diameter in metres.

Q is water flow in m^3/sec

$$D = \frac{4.44p^{0.43}}{h^{0.63}}$$ *Equation 3.3*

Where, D is economical penstock diameter, ft. [1]

p is rated turbine power, horse power

h is rated net head, ft.

Matlab® is used to code the relations for penstock diameters. First, the two equations (*Equation 3.2* and *Equation 3.3*) are used and the larger diameter selected for the purposes of the preliminary design. The characteristics of the turbine are presented in *Table 4.3* in *Chapter 4*.

Scroll (spiral) Case

All the dimensions of the scroll are dependent on the turbine diameter, D_M obtained for the turbine as presented in previous section and the turbine specific speed, N_S . The dimensions to be determined are described in and shown in *Figure 3.3* below.

[1] The result obtained in feet is eventually stated in meters in the results (*Chapter 4*).

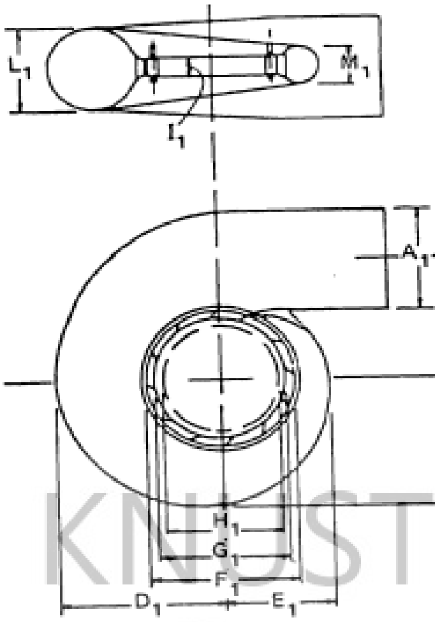

Figure 3.3: Scroll case (steel) characterizing dimensions

SOURCE: [50].

The dimensions of the parts of the draft tube shown by letters A_1, B_1, C_1, D_1, E_1, F_1, G_1, H_1, I_1, L_1, and M_1 are listed in column 2 of *Table 3.2*.

Table 3.2: Equations for sizing parts of Kaplan turbine steel scroll case

Equation #	Dimension name	Equation
1	A_1	$\frac{A_1}{D_M} = 0.40 N_S^{0.20}$
2	B_1	$\frac{B_1}{D_M} = 1.26 + 3.79\times10^{-4} N_S$
3	C_1	$\frac{C_1}{D_M} = 1.46 + 3.24\times10^{-4} N_s$
4	D_1	$\frac{D_1}{D_M} = 1.59 + 5.74\times10^{-4} N_S$
5	E_1	$\frac{E_1}{D_M} = 1.21 + 2.71\times10^{-4} N_S$
6	F_1	$\frac{F_1}{D_M} = 1.45 + \frac{72.17}{N_S}$
7	G_1	$\frac{G_1}{D_1} = 1.29 + \frac{41.63}{N_S}$
8	H_1	$\frac{H_1}{D_1} = 1.33 + \frac{31.86}{N_S}$
9	I_1	$\frac{I_1}{D_M} = 0.45 - \frac{31.80}{N_S}$
10	L_1	$\frac{L_1}{D_M} = 0.74 + 8.7\times10^{-4} N_S$
11	M_1	$\frac{M_1}{D_M} = \frac{1}{2.06 - 1.20\times10^{-3} N_S}$

Source: [16,50]

The third column of *Table 3.2* shows the relations for computing the named scroll-case parts. The dimensions are shown in the results of the Matlab® computation in *Table 4.4* (*Chapter 4*).

Draft tube

The turbine discharge diameter, D, and specific speed, N_s, are used as reference parameters for developing the appropriate controlling dimensions according to deSiervo and deLeva (1976) [44]. For this purpose, $D = D_M$. *Figure 3.4* shows all the dimensions (represented with letters) that describe the turbine's draft tube. *Figure 3.5* gives other draft tube types that may be considered.

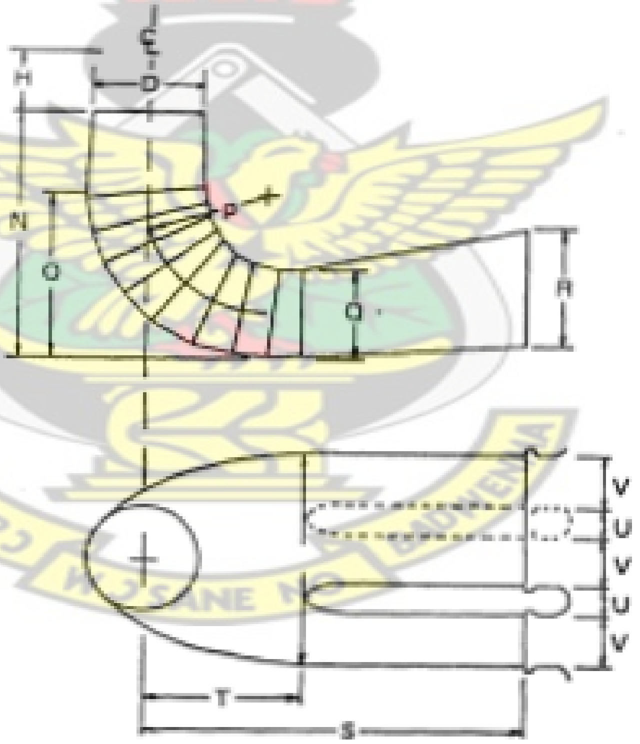

Figure 3.4: Draft tube characteristic dimensions

The corresponding relations to the draft tube parts that were used to determine the controlling dimensions are listed in *Table 3.3*.

Table 3.3: Equations for draft tube dimensions

Equation #	Dimension name	Equation
1	H_t	$\frac{H_t}{D_M} = 0.24 + 7.82\times10^{-5} N_S$
2	N	$\frac{N}{D_M} = 2.00 - 2.14\times10^{-6} N_S$
3	O	$\frac{O}{D_M} = 1.4 - 1.67\times10^{-5} N_S$
4	Q	$\frac{Q}{D_M} = 0.66 - \frac{18.40}{N_S}$
5	R	$\frac{R}{D_M} = 1.25 - 7.98\times10^{-5} N_S$
6	S	$\frac{S}{D_M} = 4.26 + \frac{201.5}{N_S}$
7	T	$\frac{T}{D_M} = 1.20 + 5.12\times10^{-4} N_S$
8	Z	$\frac{Z}{D_M} = 2.58 + \frac{102.66}{N_S}$

Source: [46]

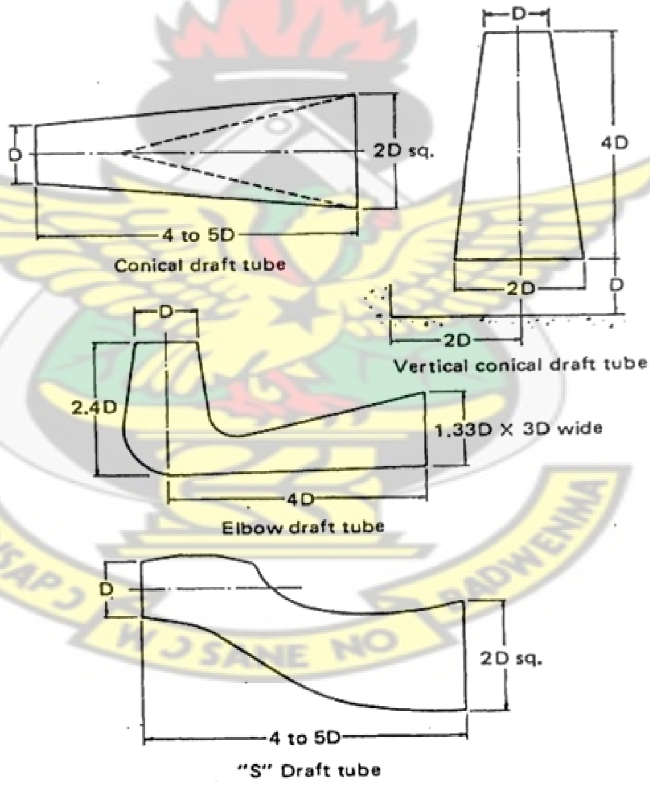

Figure 3.5: Relative dimensions for the different types of draft tubes.
SOURCE:(Allis-Chalmers Corporation) in [16].

The results of the relations in *Table 3.3* are presented in *Table 4.5* of *Chapter 4*.

3.2 Financial Analysis

Three project viability indicators are used for the financial analysis of this work. They are:

1. The net present value (NPV)
2. The equity payback time (EPBT) and
3. Internal rate of return (IRR).

The financial analysis considers the total investment cost as well as the operation and maintenance cost of the system and matches it against the revenue generated from the sale of electricity to the utility grid. *Figure 3.6* below is a flow-chart which summarizes the steps used for the financial analysis of this study.

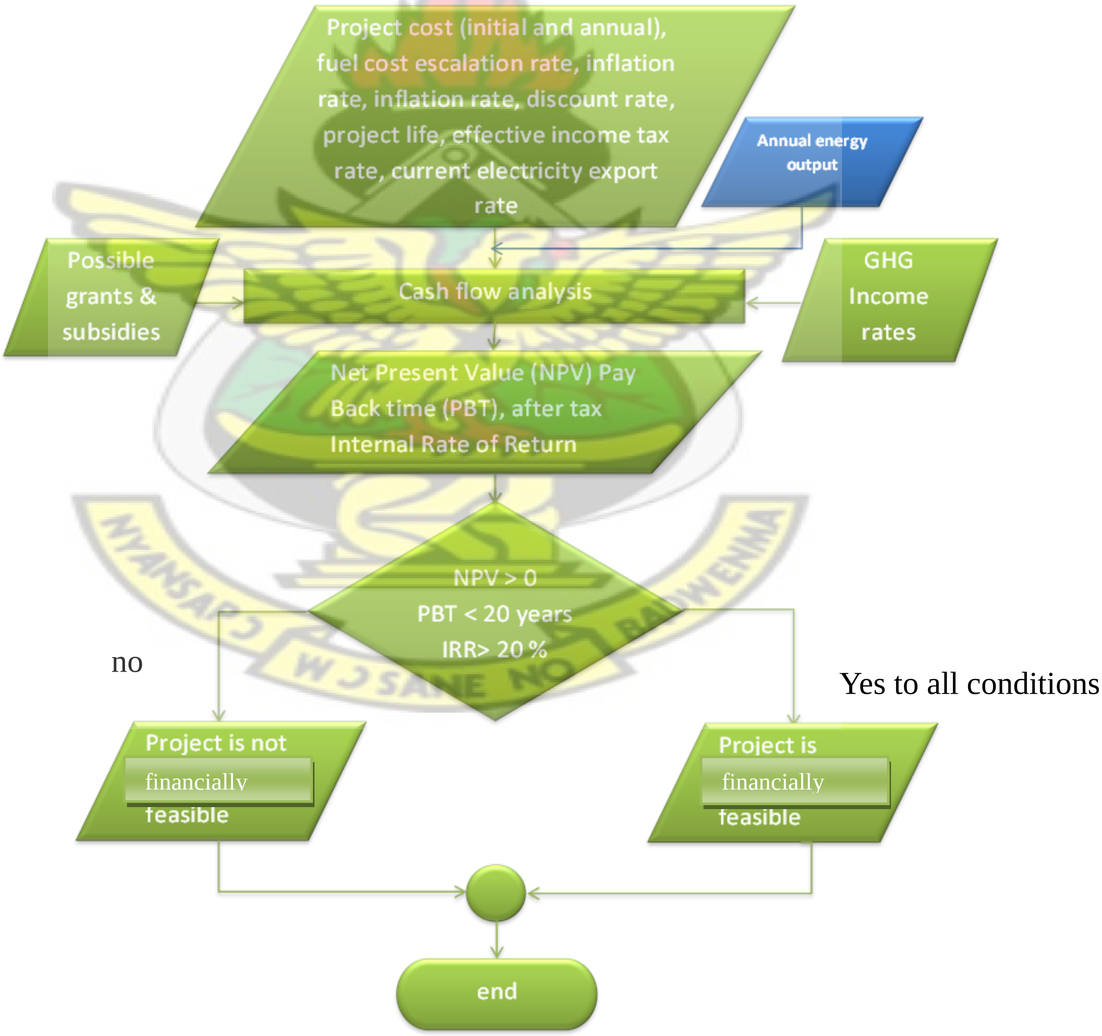

Figure 3.6: Flow diagram for financial assessment

Figure 3.6 shows information required to determine the financial viability indicators and the decisions needed to assess the financial viability of the project.

3.2.1 Net present value (NPV):

NPV is used in capital budgeting to analyze the profitability of an investment or a project. It is the difference between the present value of all revenues and the present value of all expenses, including savings, accrued during the life cycle of an investment. It is a standard method for long-term projects appraisal, which takes into account the time value of money. It measures the excess or shortfall of cash flows, in present value terms, once financial charges are met. Net Present Value (NPV) is determined as:

$$NPV = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t}$$ *Equation 3.4*

Where C_t = Net cash flow (revenue + savings – expenses)

r = Discount rate

t = Period (1, 2, 3…N)

N = Total number of periods in years.

Net Present Value is an indicator of how much value is added to an investment under the specified conditions of discount rate, r, and the financial life time of the investment, **N**. A positive NPV indicates the financial viability of an investment. The greater the value of the NPV, the more profitable the investment [51].

Explained below are the considerations backing the selection of particular independent variables for computing of NPV.

These same independent variables are used for finding the project's EPBT and IRR. Their values are summarized in the *Table 3.4*. The subsections below explain input required for the financial analysis.

Net cash flow

The net cash flow sums all **revenues**, **savings** and **expenses** of the project. The net cash flow term (C_t) is present in the expression for finding other project viability indicators (EPBT and IRR).

Revenue

The project's revenue is dependent on the following: The electricity export rate (selling price of energy generated from the Hemang plant) and the rate of inflation.

The selling price in this analysis has been set to range from US**$ 50 per MWh** to US**$ 150 per MWh.** This wide range was chosen considering the rapidly changing exchange rate of the Ghana Cedi.

This range however covers the **US$ 64.9 /MWh** (dollar equivalence of **22.7436 GHp/kWh** quoted by PURC in the "publication of feed-in-tariffs for electricity generated from renewable sources" document which took effect from 1ST September 2013. The effects of grants/subsidies and greenhouse gas credit financing on the project's present value is considered. The financial analysis takes the annual energy output (from technical analysis) as an input.

Savings

Savings in the life of the project may come in the form of Greenhouse gas (GHG) credits. The effect of different amounts of GHG credit (US $ 10 per tonne of $CO_{2,}$ US $ 20 per tonne of CO_2 and US $ 30 per tonne of $CO_{2)}$ as different levels of revenue on the project's NPV and other project viability indicators is investigated. The amount of GHG credit is based on minimum and maximum values of most likely credits quoted by RETScreen International [19]. The amounts of Grants and subsidies may also be obtained for the project in the form of tax holidays, etc. This analysis also investigates varying levels of grants (in the form of revenue) on the project's NPV and other project viability indicators and the results are presented in *Chapter 4*.

Expenses

The expenses of the project include the initial costs of the project (as a part of expenses in the first year). Operation and maintenance costs are included as a part of annual costs of the project (including corporate taxes to be paid). The determination of the initial cost of the project was done using three approaches:

Approach 1: *Finding the current value of the 1985 cost of the project (by ACRES).*

This method applies a dollar inflation rate to the 1985 cost of the project as estimated by ACRES International. By this approach, $1 in 1985 is equivalent to $2.18 in 2013 [52].

Approach 2: *Investment cost of US$3400 / kWp*

This method employs The European Renewable energy council's "Energy Revolution: A sustainable World Outlook" document's [53] initial cost assessment approach. The approach uses an investment cost of US$3400 / kWp for hydropower plants.

Approach 3: *Hall et al's equation:*

This method (Equation by Hall et al.) is used in the IPCC-SCREN report [53] [54].

$$Y = 3 \times 10^{6} \times C^{0.9}$$ *Equation 3.5*

where *Y* is project's initial cost in US$ and *C* is the project's power capacity in MW. The results obtained for these three approaches of determining the initial cost of the project is presented in *Chapter 4*.

Discount rate

The discount rate for high-risk (economic and political instabilities common to the West African sub region) projects is taken to be 10% [55].

Total number of periods (N)

The total number of periods (N) in the equation for computing NPV of the project is taken as the maximum amortization period given for energy projects heavily dependent on commercial loans from Asian governments and banks (e.g. China Exim Bank). For this study and most hydroprojects in Africa, N is usually forty years.

3.2.2 Equity payback time (EPBT):

EQPT is the length of time taken for the owner of a project to recoup his own initial investment (equity) out of the project cash flows generated. It considers project cash flows from its inception as well as the leverage (level of debt) of the project.

For the purpose of this analysis, the level of debt (also known as debt ratio) is taken to be 90%, which is typical of energy projects in Africa [55].

The project is profitable if the EPBT is less than or equal to the EPBT for similar renewable energy projects.

3.2.3 After-Tax Internal Rate of Return(IRR).

It is defined as the discount rate at which the present value of all future cash flow is equal to the initial investment or in other words, the rate **(r)** at which an investment breaks even. RETScreen calculates the IRR using:

$$\mathrm{NPV} = \sum_{t=0}^{N} \frac{C_t}{(1+r)^t} = 0 \qquad \textit{Equation 3.6}$$

The rate **(r)** in *Equation 3.6* at which NPV = 0 is the IRR.

It represents the true interest yield provided by the project equity over its life after income tax. It is calculated using the after-tax yearly cash flows and the project life. The higher a project's IRR, the more desirable it is to undertake the project. An IRR>20% for this project will make the project financially feasible. The IRR value of 20% is acceptable in some financial feasibility studies of some hydro projects in Africa. For instance the Kafue Gorge Lower dam project in Zambia [55].

All financial parameters used for the financial analysis are summarized in *Table 3.4* below.

Table 3.4: Financial analysis parameters

Parameter	**value**	**remarks**
Fuel (natural gas) cost escalation rate	**5%**	Fuel cost escalation in international energy markets. Used by IFC in other African hydropower project financial analysis. [55]
inflation rates	**2.50%**	inflation rate in dollars, IFC [55,56]
discount rate	**10%**	discount rate for high risk energy projects(IPCC-SREN), IFC [53] [55]
Project life	**40 years**	Chosen to exceed maximum known amortization period of a similar power project (Bui dam – 20 years).
Debt ratio	**90%**	Subjective. Most energy projects in Ghana are funded with loans from international organisations.

Debt interest rate	**5%**	Subjective, IFC [55]
Effective income tax rate	**25%**	Corporate tax rate in Ghana according to Price Waterhouse Coopers (taxation in Ghana). [56] [55]
Electricity export escalation rate	**2.50%**	same as inflation rate of the US dollar, IFC [55]
current electricity export rate (at average April 2014 dollar rate)	**64.9 USD/MWh**	From PURC renewable energy feed in tariffs [57]

The justification for selecting a particular financial parameter for this financial analysis has been stated in the remarks column of *Table 3.4 above*. The RETScreen package accepts the parameters in *Table 3.4* for finding the net cash flow and subsequently used to compute the project viability indicators.

The results from RETScreen's analysis are presented in *Chapter 4*.

3.3 Environmental Assessment (GHG analysis)

This section compares the amount of greenhouse gas (GHG) emitted annually by the Hemang project to a natural gas fired thermal power plant having the same power capacity. The comparison is based on the emission factors of the fluids used in both cases (natural gas and water) and the transmission and distribution losses in the Ghana's electric power distribution system (power grid). The assessment is summarized in *Figure 3.7* shown below.

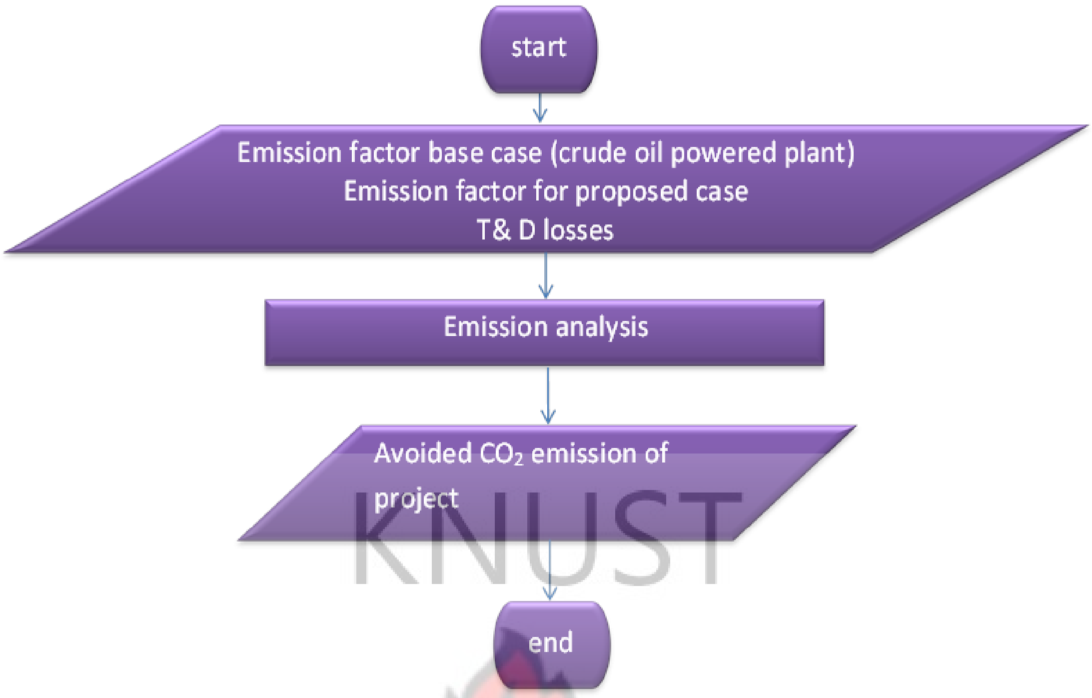

Figure 3.7: Flow chart of environmental analysis (GHG emission reduction)

The result of the environmental analysis is expressed in the form of avoided CO_2 effected by the Hemang hydroelectric project. It is reported in the results section (*Chapter 4*).

3.3.1 Emission factor

The emission factor is a representative value that attempts to relate the quantity of a pollutant (in this case tonnes of CO_2) released into the atmosphere with an activity (in this case, energy in MWh) associated with the release of that pollutant.

This analysis uses emission factor values for proposed (hydropower) and base (natural gas fuelled thermal plant) cases. The emission factors used are obtained from IPCC's GHG emission factor inventory. 0 tCO_2 per MWh for hydropower and 0.180 tCO_2 per MWh for natural gas [58].

3.3.2 Transmission and distribution losses

The transmission and distribution losses are taken to be 28.7% [2] for both cases [59].

Table 3.5: Green House Gas emission comparison

	Base Case (Natural Gas)	Proposed Case (Hydro Power Plant)
Emission factor	0.683	0
Transmission & Distribution Losses	28.7 %	28.7 %

CHAPTER 4: RESULTS AND DISCUSSIONS

The results for this study are presented in three sections: technical, financial and environmental analyses.

4.1 Technical Assessment

This covers the results of turbine selection, verification of some results and the results obtained for plant turbine and water passage sizes.

4.1.1 Results for turbine selection

The Hemang site flow data (1944 – 1984 and 1980 – 2011) are used to construct a flow duration curve, which is used to obtain the annual electricity that will be exported to grid. The flow duration curves are obtained using the steps explained in *Section 3.1.2*. of this study report. *Figure 4.1* shows a flow duration curve obtained using daily flow data of the Hemang site.

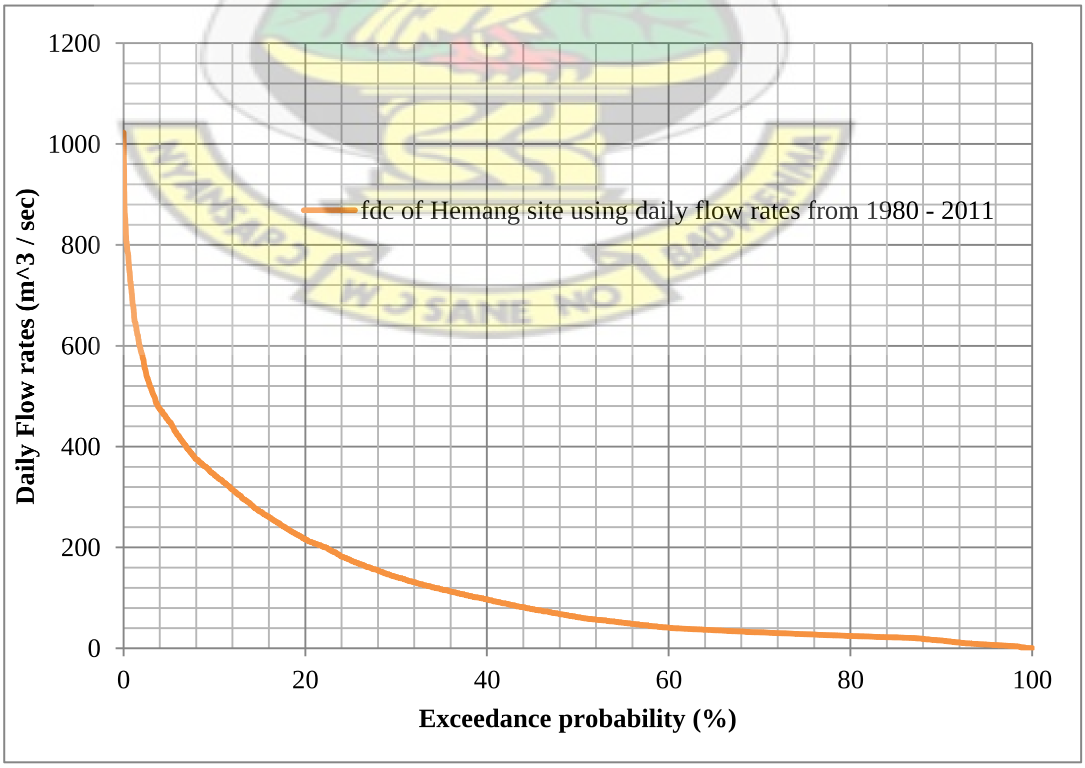

Figure 4.1: Daily flow duration curve at Hemang site using 1980 – 2011 flow data

The above f.d.c (from daily stream flow data) is used to obtain the power and energy (energy exported to grid) capacities of the Hemang site because it will give more accurate results as compared to f.d.c obtained using monthly stream flow data.

For the purposes of comparing the nature of stream flow data used by ACRES in the 1984 (1944 – 1984) study with the current (1980-2011) data, the f.d.c using monthly flow data from the two regimes are constructed and shown in *Figure 4.2* and *Figure 4.3* respectively.

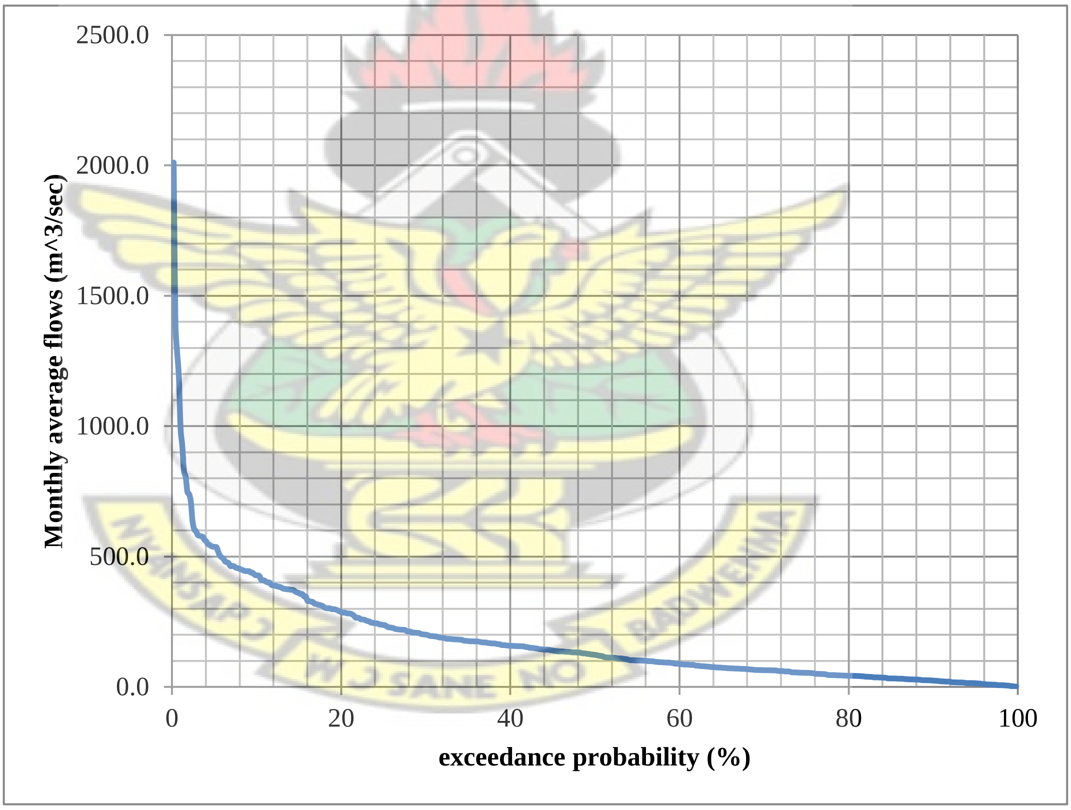

Figure 4.2: Monthly flow duration curve using 1944 - 1984 ACRES flow data

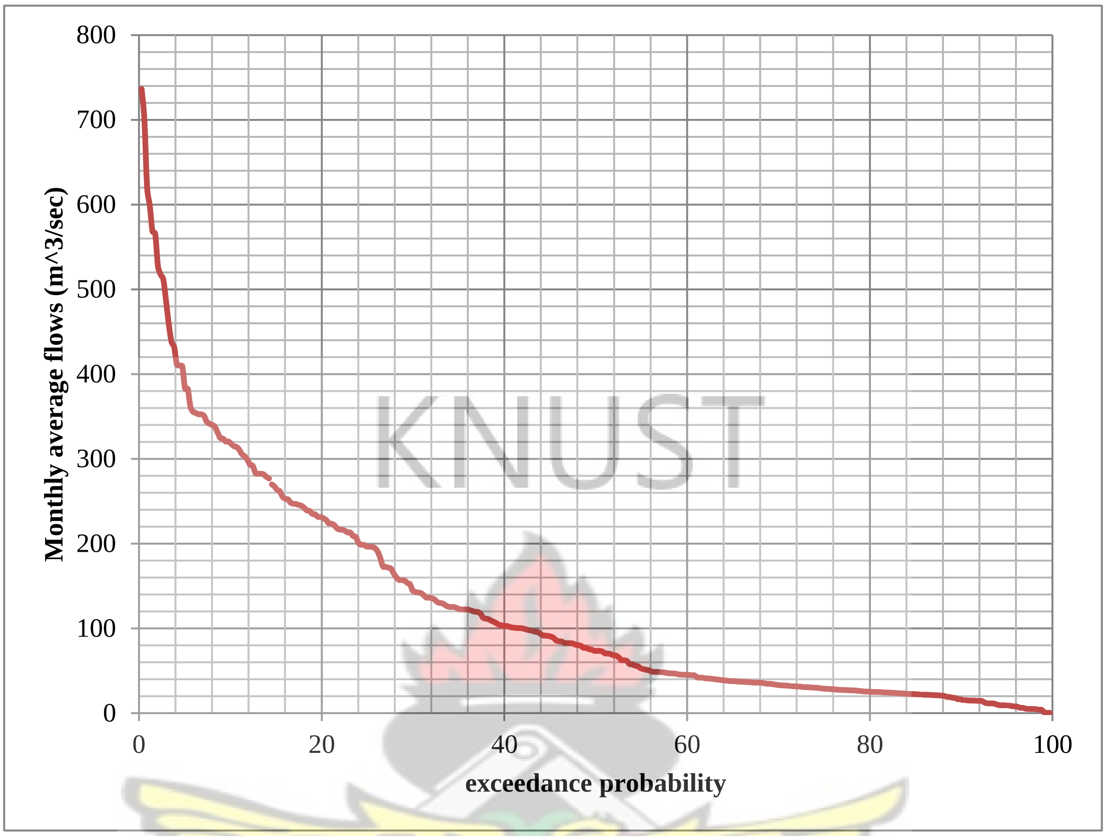

Figure 4.3: Monthly flow duration curve using 1980 - 2011 flow data

The above figures (*Figure 4.2* and *Figure 4.3*) show clearly the maximum stream flow available for electricity production. For example, for at least 0% exceedance probability (0% exceedance probability and above) , it is possible to obtain a stream flow of 1500 m^3/s according to the 1944 -1984 data and 736 m^3/s according to the 1980 – 2011 data. Also, finding a stream flow of 389 m^3/s using 1944 -1984 data and 230 m^3/s using 1980 – 2011 data will all occur at, at least 20% of the time.

Putting together the two (1944 – 1984 and 1980-2011) monthly f.d.c (shown in *Figure 4.2* and *Figure 4.3* above), we obtain a more detailed and more explanatory f.d.c shown in *Figure 4.4* .

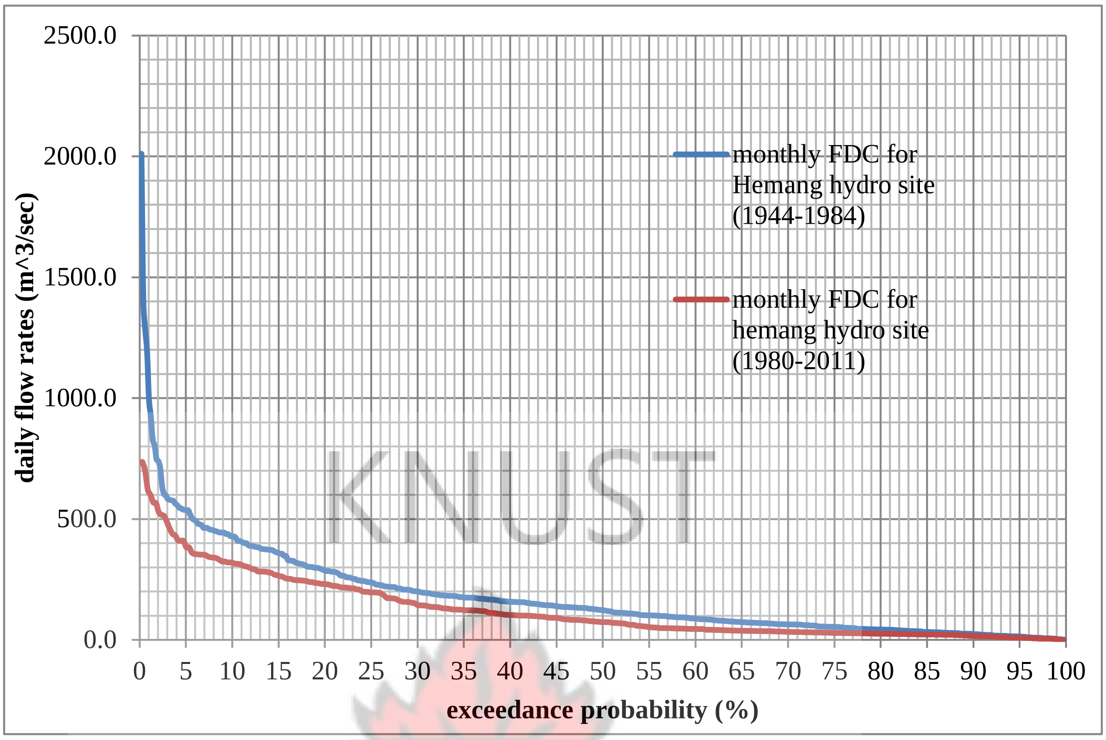

Figure 4.4: Comparison between f.d.c of 1944 - 1984 and 1980 – 2011using monthly flow rate data of both regimes

Figure 4.4 helps give an idea of (or better appreciate) how much the flow data of the Pra river at Hemang has changed when the former flow (1944 – 1984) rates are compared against the current ones (1980 - 2011). It makes it easy to compare flow rates at any exceedance probability for the two sets of flow rate data under consideration.

For the available head of 29.9 meters and design flow of 271.31 m^3/s, at the Hemang site, the characteristics of the plant for different turbine types processed by RETScreen using the two flow data, the turbine efficiency data (obtained for different rated flows), head losses, parasitic losses, generator efficiencies, transformer losses and constants (density and acceleration due to gravity) [61,45] are shown in *Table 4.1* and *Table 4.2* below. For details on how the different turbine parameters are obtained, see *Subsection 3.1.5*.

Table 4.1: Analysis for selection of turbine type using 1944 -1984 flow data

turbine type	power output (peak)	capacity factor	turbine peak efficiency	turbine efficiency at design flow	electricity exported to grid/MWh
kaplan	72.797	47.30%	95.70%	95.20%	302091
propeller	73.145	40.00%	95.70%	95.70%	256086
francis	67.51	46.30%	92.80%	88.30%	274079

Table 4.2: Analysis for selection of turbine type using 1980 – 2011 flow data

turbine type	power output (peak)	capacity factor	turbine peak efficiency	turbine efficiency at design flow	electricity exported to grid/ MWh
kaplan	70.524	36.5%	94.6%	94.2%	225346
propeller	70.846	30.1%	94.6%	94.6%	187070
Francis	65.515	34.9%	92%	87.5%	200533

Information on the main parameters which describe a power plant: power capacity, annual energy output and capacity factor are extracted from *Table 4.1* and *Table 4.2* and shown in and shown by *Figure 4.5*, *Figure 4.6* and *Figure 4.7* respectively.

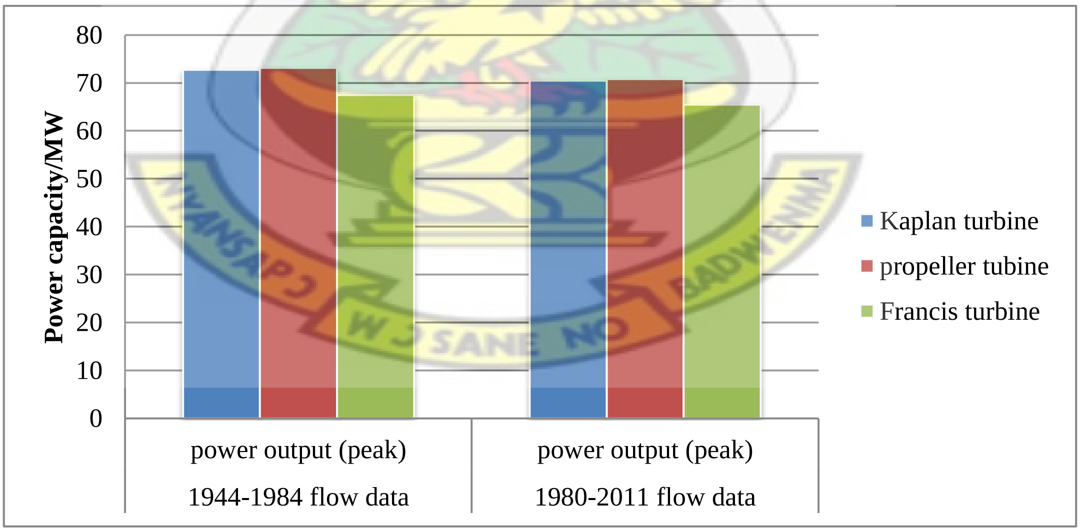

Figure 4.5: Plant power capacities using different turbine types

In *Figure 4.5*, it is observed that for the recent (1980 – 2011) flow data, the propeller turbine type will deliver a higher power at its peak efficiency followed by the Kaplan turbine and the Francis type turbine is observed to have the least power capacity of the three turbine types. For the old (1944 – 1984) flow data, it is observed that Kaplan turbine has the highest power capacity followed by the propeller and Francis type turbines. Deciding on a turbine type, however is not based on capacity only but also on the annual energy output and capacity factor.

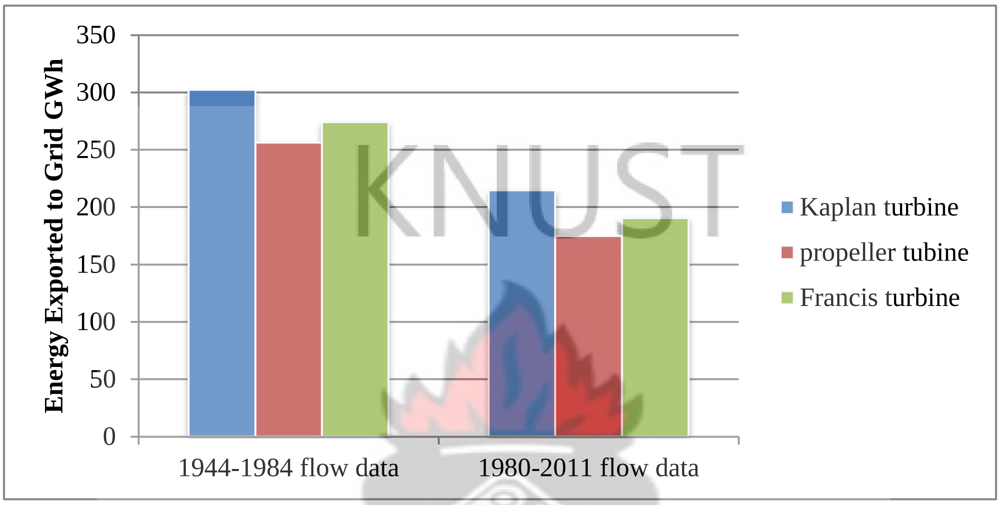

Figure 4.6: Plant energy output using different turbine types

Using the old (1944 – 1984) and recent (1980 – 2011) flow data, the annual plant energy output of the Kaplan turbine is the highest of the three turbine types. It is followed by the Francis and propeller turbine types This is attributed to the differences in the nature of the efficiency curves of the three turbine types.

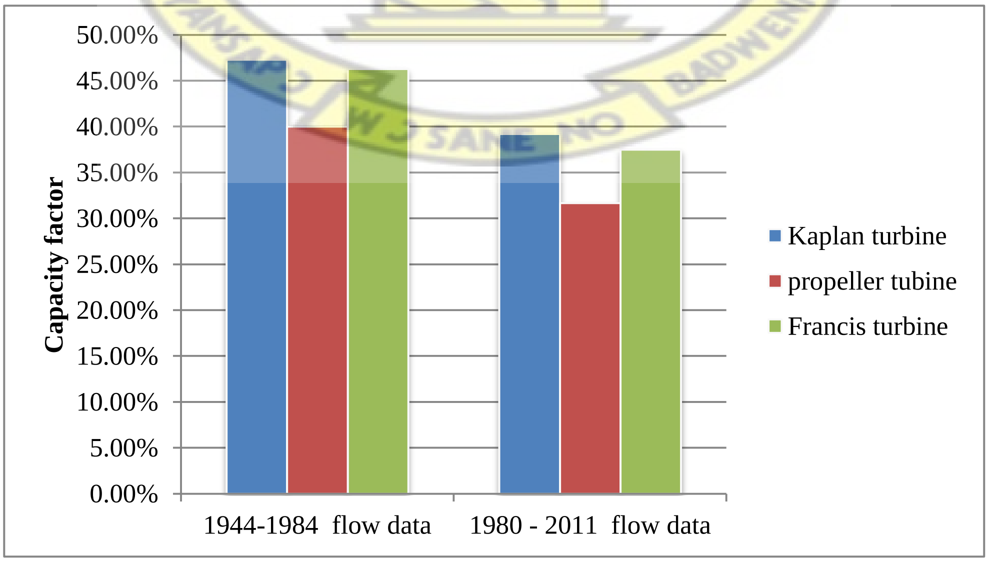

Figure 4.7: Plant Capacity Factors using different turbine types

In *Figure 4.7,* It can be seen that the highest capacity factor is associated with the Kaplan turbine when both old (1944 – 1984) and new (1980 – 2011). This implies that of all three turbines, the Kaplan turbine's actual annual energy output is closest to its highest possible annual energy output. Based on the total energy produced per year from the supposed plants and the capacity factors, it can be seen from *Table 4.2, Figure 4.5,Figure 4.6, and Figure 4.7* that a Kaplan type turbine will be the best choice for this site as it will deliver the largest amount of energy (i.e. about 225.35 GWh).

It is concluded that the Hemang site, using Kaplan turbines will have a power capacity of 70.524 and deliver an energy of 225,346.00 MWh (225.35 GWh) to the national grid.

4.1.2 Verification of results of technical analysis with SMART mini-idro® software

In verifying the power potential of the Hemang site, the Italian mini-hydro power software, SMART mini-idro® was used. It showed the site under study has a power potential of **75.221 MW**. This is a **6.66 %** increase in peak power when compared to the result obtained using RETScreen.

4.1.3 Results for water passages

Water passage sizes were obtained by writing a Matlab® codes (m-file) to evaluate the appropriate relations that describe the various parts of the proposed plant's water passages. The obtained size (dimensions) for turbine and other water passages are tabulated as follows (*Table 4.3, Table 4.4* and *Table 4.5*):

Table 4.3: Plant turbine unit details

parameter	Quantity/magnitude
Gross Head	29.9
Discharge	90.436 m^3/s
Unit efficiency	0.95
Rated unit power	23.476 MW
Runner speed	206.89 rpm
Specific speed	453.396
Diameter for Kaplan turbine runner	3.394 m

The dimension names in *Table 4.4* and *Table 4.5* are taken from *Figure 3.3* and under *Section 3.1.6* above.

Table 4.4: Controlling dimensions for Kaplan turbine scroll case

Dimension name	Dimension Size
A1	4.614 m
B1	10.110 m
C1	9.941 m
D1	14.23 m
E1	8.277 m
F1	5.462 m
G1	4.690 m
H1	4.074 m
I1	1.289 m
L1	2.541 m
M1	2.239 m

Table 4.5: Controlling dimensions for Kaplan turbine draft tube

Dimension name	Dimension Size
H	12.800 m
N	6.755 m
O	4.495 m
P	4.139 m
Q	2.102 m
R	3.015 m
S	15.967 m
T	4.861 m
Z	8.525 m

Below is how the Hemang hydro site using 1980-2011 flow data compares against the 1944-1984 flow data.

Table 4.6: Comparing technical analysis results using 1944-1984 and 1980-2011.

Technical detail	**magnitude**		**% change**
	1944-1984 flow data	***1980-2011 flow data***	
Plant design efficiency	0.9	0.94	+4.4
Plant capacity	75 MW	70.524 MW	-6.0
Annual energy output	308 GWh	225 GWh	-27

Clearly, the capacity of the Hemang site has reduced when compared to the 1984 study of ACRES study. Its annual energy potential (annual energy output) has also reduced by about a quarter.

4.2 Financial Assessment

The financial assessment uses variables stated in *Section* 3.2, *Table 3.4* above. In addition to those variables, the results obtained for the costs (fixed cost and annual costs) associated with the project are stated below:

Approach 1: *Finding the current value of the 1983 cost of the project (by ACRES).*

Using this approach, initial (fixed) project cost is found to be **US$ 472,602,997.20.** The breakdown of the estimates is found in appendix C.

Approach 2: *Investment cost of US$3400 / kWp*

Applying an investment cost of US$3400 / kWp to the 70,524 kW Hemang project (see *Subsection 4.1.1.1*) it results in an initial investment cost of **US$ 239,781,600.00**.

Approach 3: *Hall et al's equation:*

Using *Equation 3.5* of *Subsection 3.2.1*,

$$Y_{Hemang} = 3 \times 10^{6} \times C^{0.9}$$

$$= 3 \times 10^{6} \times 70.524^{0.9}$$

= US$ 138,237,062.90

Applying *Equation 3.5* the Bui hydroelectric project (estimated to cost US$ 622 million [28]),

$$Y_{Bui} = 3 \times 10^{6} \times C^{0.9}$$

$$Y_{Bui} = 3 \times 10^{6} \times 400^{0.9}$$

$$Y_{Bui} = US\$659{,}136{,}235.98$$

The cost of the Bui project using the Hall et al equation (*Equation 3.5*) shows a **5.97 %** increase from the actual cost of 622 million estimated at the start of the project.

Conclusion of project cost

Of all these approaches, the method of *Hall et al's equation* above gave the most accurate results because it gave the closest estimate to the actual estimated cost of the Bui Hydro project. The financial assessment, therefore, uses a project cost of **US$ 138,237,062.90.**

The financial assessment of the project is carried out using results of the three main financial viability indicators; namely net present value (NPV), equity payback time (EPBT), and internal rate of return (IRR). The effect of grants/subsidies on one hand and greenhouse gas(GHG) income on the other hand were considered in obtaining the results of the financial indicators as presented in the following sections:

4.2.1 Effects of grants and subsidies on project's NPV, EPBT and IRR at changing tariffs.

Grants and subsidies may come in from both governmental and non-governmental organizations, which have some interest in the project or its immediate and long-term effects on the community or the country's energy policy. All factors considered in analyzing the effects of grants and subsidies are explained in *Section 3.2* of *Chapter 3*. The results of the analysis are presented in the following subsections.

4.2.1.1 NPV

The results for the net present value at different levels of subsidies and grants are determined using the financial factors (*Table 3.4*) and presented in *Table 4.7* below:

Table 4.7: Effect of different levels of grants and subsidies on project's NPV.

Tariff / USD/MWh	NPV (USD)			
	no grants and subsidies	**10% grants and subsidies**	**20% grants and subsidies**	**30% grants & subsidies**
50	-6032438.00	7,698,916	21,430,270	35,161,623
60	15,695,177.00	29,426,531	43,157,885	56,889,238
70	37,422,792.00	51,154,146	64,885,499	78,616,853
80	59,150,407.00	72,881,761	86,613,114	100,344,468
90	80,878,022.00	94,609,375	108,340,729	122,072,083
100	102,605,637.00	116,336,990	130,068,344	143,799,698
110	124,333,252.00	138,064,605	151,795,959	165,527,313
120	146,060,866.00	159,792,220	173,523,574	187,254,928
130	167,788,481.00	181,519,835	195,251,189	208,982,543
140	189,516,096.00	203,247,450	216,978,804	230,710,157
150	211,243,711.00	224,975,065	238,706,419	252,437,772

For the purpose of explanation, the results of *Table 4.7* is shown in *Figure 4.8.*

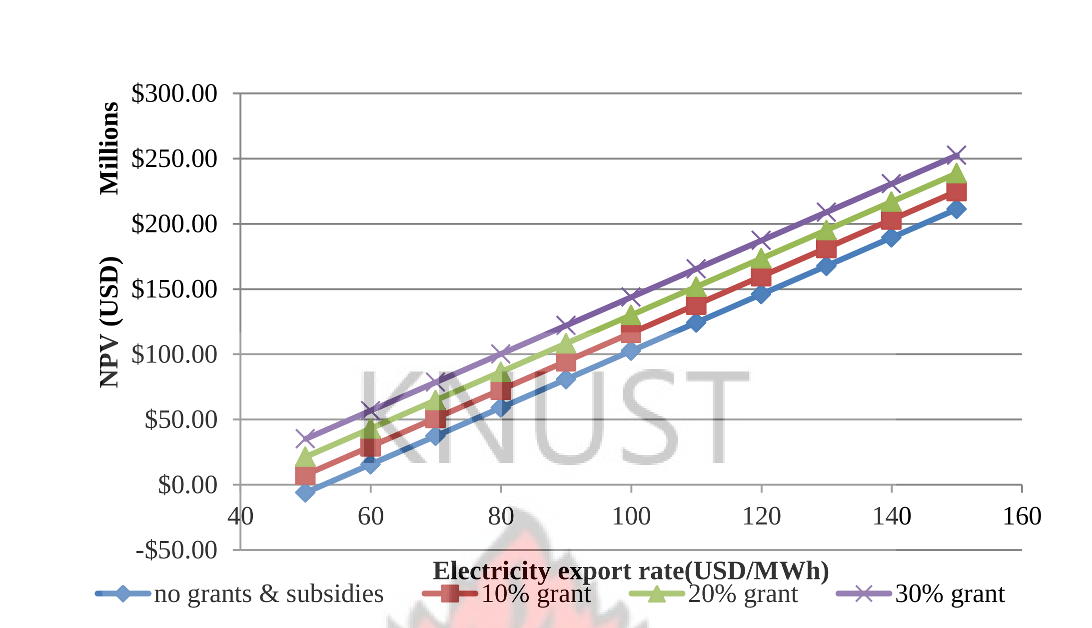

Figure 4.8: Effects of different levels of grants and subsidies on project's NPV

The results show that the project makes financial sense for every value of electricity export rate considered above 50 USD/MWh only. Export rates ≤ 50 USD/MWh (at no grants & subsidies) give negative NPVs.

For a realistic electricity export rate of 64.9 USD/MWh (according to PURC's "Publication of feed-in-tariffs for Electricity Generated from Renewable Energy Sources" document), however, the resulting NPV indicates the project is profitable.

4.2.1.2 EPBT

The equity payback time gives an idea of how fast the project's equity can be recouped. It will make it possible to compare the profitability of this project to other projects that an investor may be interested in. In the preceding results section, the NPV has proven the project is profitable with current electricity export rate of 64.9 USD/MWh. The effects of different levels of grants/subsidies and changing electricity export rate on EPBT is shown in *Table 4.8.*

Table 4.8: Effect of different levels of grants/subsidies on project's EPBT

Tariff / USD/MWh	equity payback / years			
	no grants and subsidies	10% grants and subsidies	20% grants and subsidies	30% grants and subsidies
50.0	16.9	15.7	0	0
60.0	14.3	13.3	0	0
64.9	13.4	12.4	0	0
70.0	12.5	11.6	0	0
80.0	11	10.2	0	0
90.0	9.3	0	0	0
100.0	5	0	0	0
110.0	3.2	0	0	0
120.0	2.3	0	0	0
130.0	1.8	0	0	0
140.0	1.5	0	0	0
150.0	1.3	0	0	0

For the purpose of explanation the results of *Table 4.8* is shown in *Figure 4.9* below.

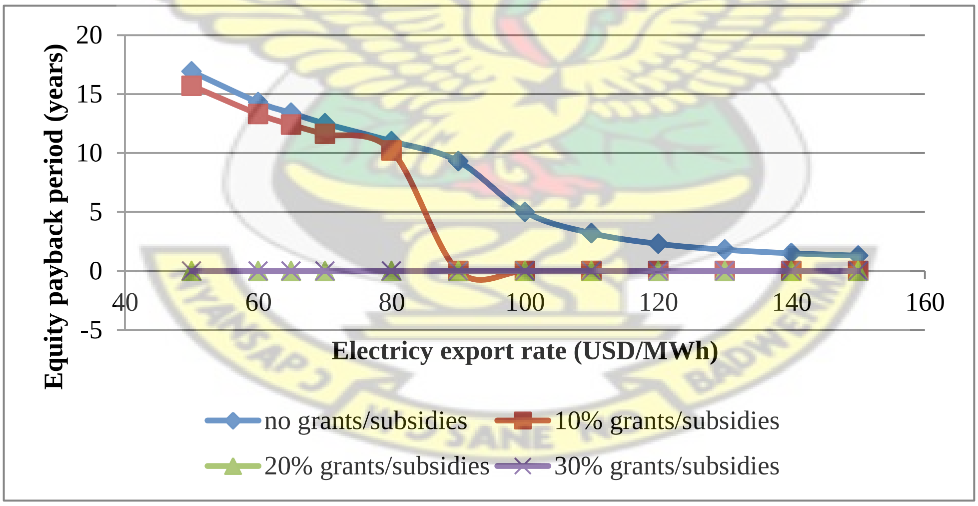

Figure 4.9: Effects of different levels of grants/subsidies on project's EPBT

The instances of 0 years of EPBT (in *Figure 4.9*) indicate the project's investments are recovered in the same year of the project's commissioning. At the lowest export tariff of 50 USD/MWh and without any grant/subsidy, the project's investments will be recovered after 16.9 years which is appreciable considering the project has a life of 40 years (EPBT<Project life). This payback time however is uncompetitive considering similar projects, which usually have EPBT of around 5 – 11 years [55]. At the same export rate of 50 USD/MWh, the project however sees an EPBT of 15.7 years when there is a grant of 10% (of project cost) available for the project.

It can be deduced that, at a realistic export rate of 64.9 USD / MWh and 0% grants/subsidies, the project is profitable but highly uncompetitive as its equity payback time of 13.4 years falls outside the 5 – 11 years range accepted by the International Finance Corporation (IFC). At the same prevailing export rate of 64.9 USD/MWh and 10 % grants/subsidies an EPBT of 12.4% will be realized.

4.2.1.3 IRR

The project's after tax internal rate of return on equity also measures how fast profits are made by the project.

The effect of different levels of grants and subsidies on project's IRR is presented in *Table 4.9* below.

Table 4.9: Effects of different levels of grants and subsidies on project's IRR

Tariff / USD/MWh	**IRR (%)**	
	no grants and subsidies	10% grants and subsidies
50	9.20	11.30
60	12.10	15.60
64.9[1]	13.70	18.4
70	15.50	22.20
80	19.50	36.60

[1] This tariff is used because it was the prevailing tariff at the time of the writing of this report.

For the purpose of explanation, the results of *Table 4.9* is shown in *Figure 4.10*

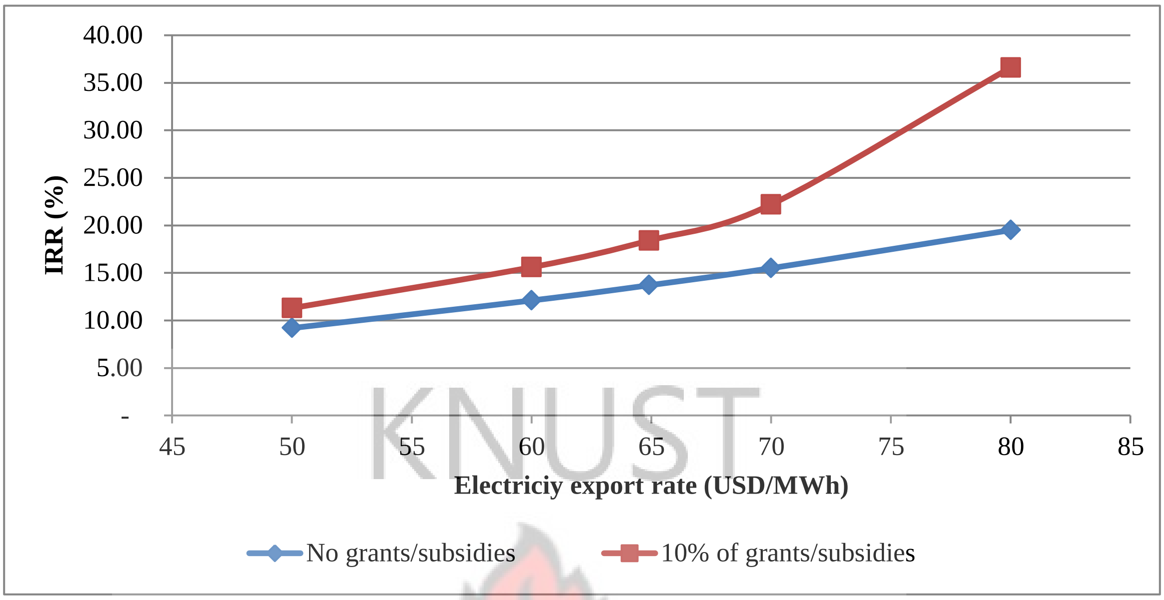

Figure 4.10: Effect of different levels of grants/subsidies on project's IRR

As observed from Figure 4.10, without any grants/subsidies, at 64.9 USD/MWh, the project did not attain the 20% required level of IRR indicated by the IFC on hydropower projects. From electricity export rates of USD 70 per MWh, with 10% of project funded by grants, the project is able to attain an IRR 22.2 %. This means for the project to be competitive and profitable at the same time with other hydro projects in Africa, it should benefit from grants and subsidies up to a level of about 10% of initial project cost and the feed in tariff (electricity export rate) must be a little above the current rate of about 64.9 USD/MWh.

4.2.2 Effects of GHG credit financing on project's NPV, EPBT and IRR

Hydroelectric power plants are solely carbon free and have the capability of attracting greenhouse gas (GHG) reduction credit depending on the amount of GHG the hydro-plant is able prevent from being released when compared with a natural gas fuelled power plant having the same capacity. Using RETScreen® emission model for analysis, it is determined that with the 70.524 MW project being analyzed, 109,739 tonnes of CO_2 (shown in appendix D4: Emission model D: RETScreen Input) will be saved from being released into the air. Greenhouse gas reduction credit rates depend on factors such as how the credit are generated and distributed, whether the emissions are mandatory or voluntarily reduced private or public purchase of credits and the type of greenhouse gas technology used. Typical GHG reduction credit rates range between US$ 1 to US$ 35 per tonne. The effects of different GHG reduction credit rates on the project NPV, EPBT and IRR are given in the following sections. All factors considered in analyzing the effects of GHG credit financing is explained in *Section 3.2* of *Chapter 3*.

4.2.2.1 NPV

The effects of GHG credit prices (rates) on the project's NPV are presented in *Table 4.10 below*.

Table 4.10: Effects of different levels of GHG credit prices on project's NPV

Tariff / USD/MWh	NPV (USD)			
	No GHG income	USD 10 per tonne of CO2	USD 20 per tonne of CO2	USD 30 per tonne of CO2
50	-6,032,438	9,825	6,052,087	12,094,350
60	15,695,177	21,737,440	27,779,702	33,821,965
70	37,422,792	43,465,055	49,507,317	55,549,580
80	59,150,407	65,192,669	71,234,932	77,277,194
90	80,878,022	86,920,284	92,962,547	99,004,809
100	102,605,637	108,647,899	114,690,162	120,732,424
110	124,333,252	130,375,514	136,417,777	142,460,039
120	146,060,866	152,103,129	158,145,392	164,187,654
130	167,788,481	173,830,744	179,873,006	185,915,269
140	189,516,096	195,558,359	201,600,621	207,642,884
150	211,243,711	217,285,974	223,328,236	229,370,449

For purposes of explanation, the result of *Table 4.10* above are presented in *Figure 4.11*.

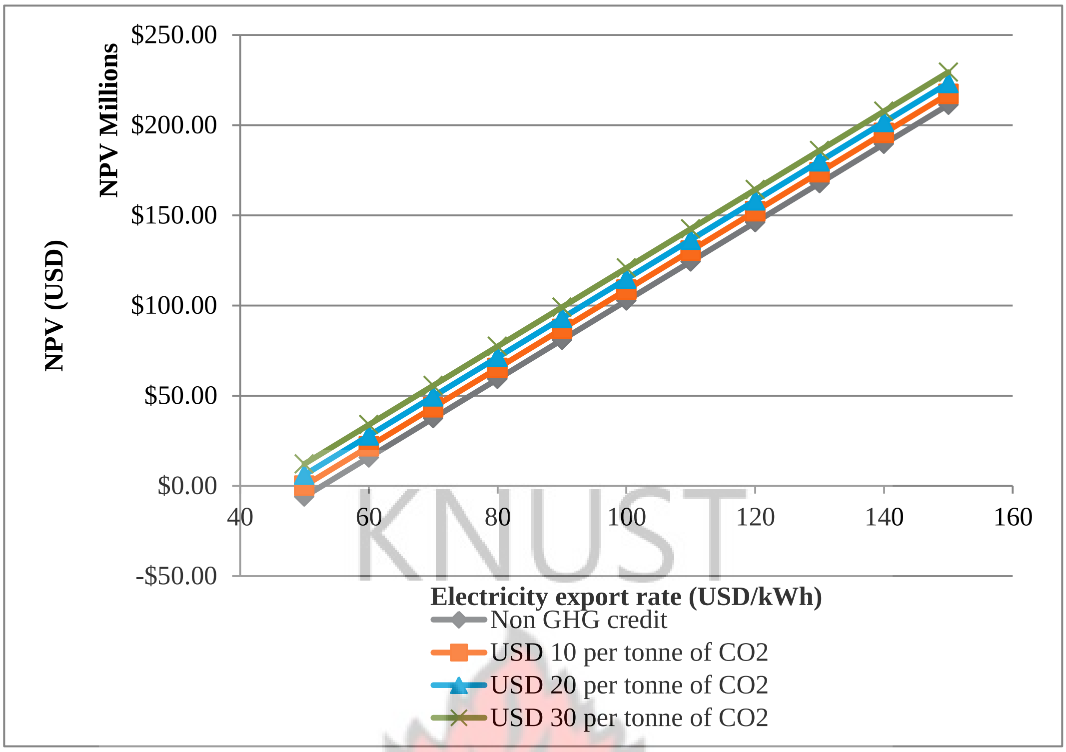

Figure 4.11: Effect of different GHG credit prices on project's NPV

It can be observed in *Figure 4.11* that at a level of no GHG income (0 USD per tonne of CO_2), the project is profitable except for feed-in-tariffs (electricity export rates) of 53 USD/MWh and below. This is because the project's NPVs at electricity export rates of 53 USD/MWh and below are all negative when there is no GHG income. NPVs for export rates above 53 USD/MWh however are all positive.

For a realistic electricity export rate of 64.9 USD/MWh (according to PURC's "Publication of feed-in-tariffs for Electricity Generated from Renewable Energy Sources" document) however, the resulting NPV indicates the project is profitable.

4.2.2.2 EPBT

The effects of different levels of GHG credit price (rates) on the project's EPBT are shown in *Table 4.11*.

Table 4.11: Effects of different levels of GHG credit prices on project's EPBT

Tariff / USD/MWh	equity payback / years			
	No GHG income	USD 10 per tonne of CO_2	USD 20 per tonne of CO_2	USD 30 per tonne of CO_2
50	16.9	16.2	15.4	14.6
60	14.3	13.7	13	12.4
70	12.5	11.9	11.3	10.7
80	11	10.5	9.7	4.9
90	9.3	6	4.2	3.2
100	5	3.6	2.8	2.3
110	3.2	2.6	2.1	1.8
120	2.3	2	1.7	1.5
130	1.8	1.6	1.4	1.3
140	1.5	1.3	1.2	1.1
150	1.3	1.1	1	1

For purposes of explanation, the result in *Table 4.11* above are presented in *Figure 4.12.*

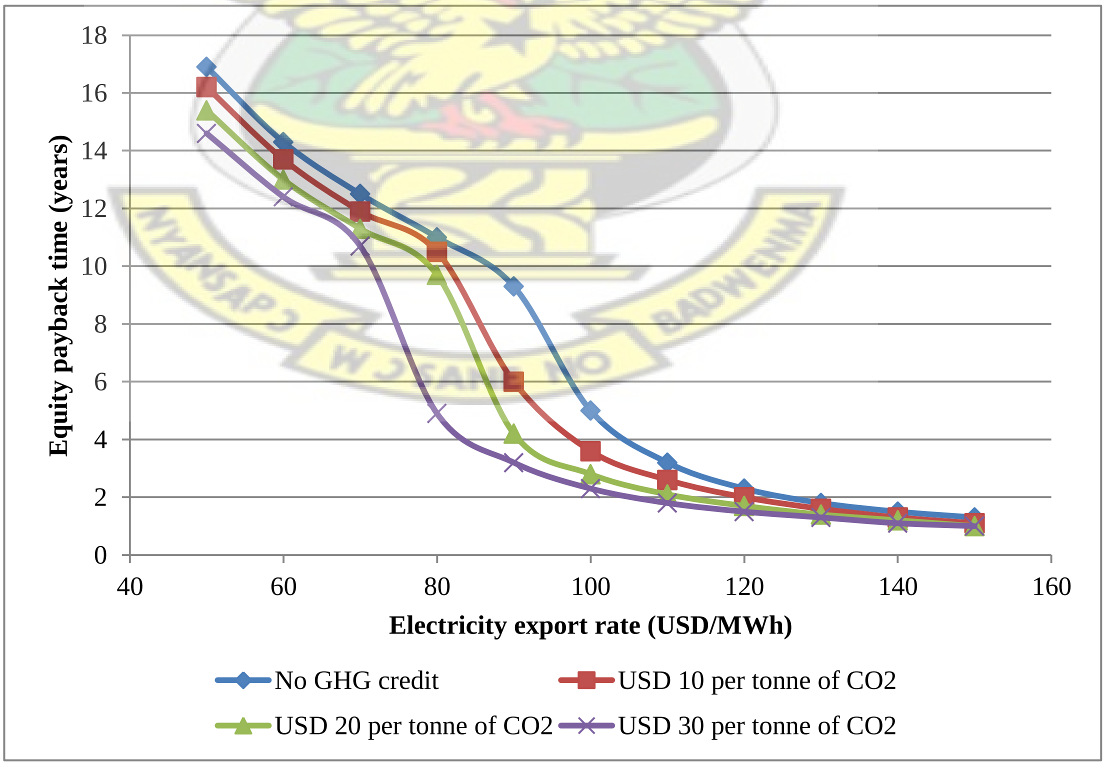

Figure 4.12: Effects of different GHG credit prices on project's EPBT

It can be observed that pay back times are very favorable (between 1 and 11 years), resulting in EPBTs lesser that 40 years (project life) especially with GHG credit financing and with electricity export rates above **USD 80 MWh**.

For the real export rate of 64.9 USD /MWh and with no GHG income, EPBT from *Figure 4.12* is observed to be about 12.4 years. With a 30 USD per tonnes CO_2, however, the EPBT realized is 10.5 years. It can therefore be concluded that though the project has some profitability, an EPBT of 13.4 years without GHG income makes the project financially uncompetitive. In order for the project to look attractive to an investor there has to be GHG income above 30 USD per tonnes of CO_2 or the project's energy has to be exported at a rate of above 80 USD / MWh.

4.2.2.3 IRR

The effects of different levels of GHG income on the project's internal rate of return is shown in *Table 4.12* below.

Table 4.12: Effects of different levels of GHG credit prices on project's IRR

Tariff / USD/MWh	IRR (%)			
	No GHG income	USD 10 per tonne of CO2	USD 20 per tonne of CO2	USD 30 per tonne of CO2
50	9.20	10	10.9	12
60	12.10	13.2	14.5	16.1
64.9	13.70	15	16.5	18.5
70	15.50	17	18.9	21.4
80	19.50	21.7	24.6	28.2
90	24.50	27.8	31.9	37
100	31.00	35.5	41.1	47.6
110	39.20	45	51.7	59.1
120	49.00	55.9	63.3	71.2
130	59.90	67.5	75.4	83.5
140	71.50	79.5	87.6	95.9
150	83.60	91.7	100	108.4

For the purpose of explanation, the results of *Table 4.12* above are presented in *Figure 4.13*.

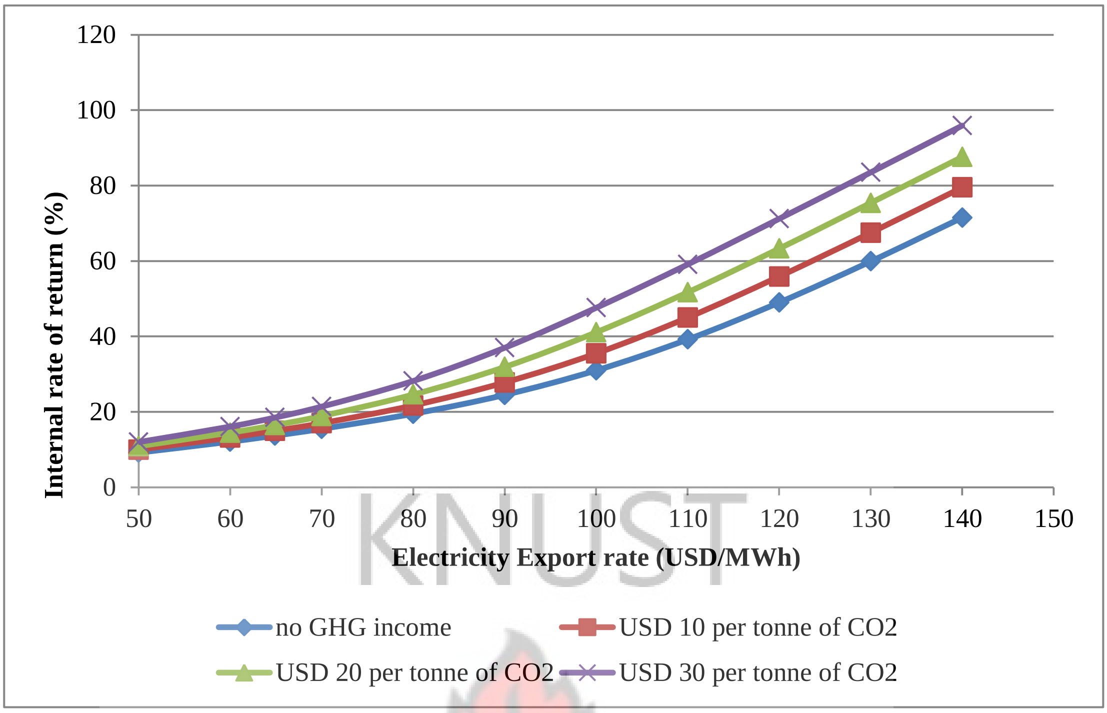

Figure 4.13: Effects of different GHG credit prices on project's IRR

The results as shown in *Figure 4.13* clearly show that income from GHG credits will make a significant change on the project IRR. Moreover, the actual credit, which may be received for the project, is very likely to be less than the USD 30 per tonne of CO_2 used in this analysis. This is because the maximum GHG credit attainable is USD 35 tCO_2 [19], and renewable energy projects in Ghana are not known to receive any GHG incomes yet.

At electricity export tariffs of 90 USD/MWh with no GHG financing, the IRR realized is 24%, which is above IFC's 20% rate for similar projects. In addition, at a lower tariff of 80 USD / MWh, the IFC's 20% IRR can be attained only with GHG credit financing.

At an export rate of **USD 64.9/MWh**, however, with GHG credit rate of USD 30 per tonne of CO_2, the IFC's 20% IRR is not achieved for the project. The only way this is possible is with GHG credits at export rates above **USD 70/MWh**. It is also possible for the project to have the required IRR with electricity export rates above **USD 80/MWh** without GHG credits.

Summarizing the financial prefeasibility study, the project is financially profitable but not competitive at the current prevailing electricity export rate of 64.9 USD / MWh with no grant and subsidies or GHG income.

For the project to be financially competitive at no GHG income and no grants, the feed-in-tariff (electricity export rate) will have to be increased to over **USD 80/MWh** by the Ghana PURC**.**

4.3 Environmental Assessment (GHG emission reduction)

The environmental analysis as presented in *Section 3.3* will result in an annual GHG savings of **109,739 tonnes** of CO_2 annually as computed from the RETScreen emission module simulation (appendix D4).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Ghana has a large hydro-electric potential considering all the small and medium scale hydro sites spread across the country.

The method used in this study can be applied in studying the technical and financial potentials of the other medium and small scale hydro sites in the country.

Four hydro sites along the Pra river were considered prior to the start of this study, however, only the Hemang hydro-electric site was fully studied in this work as it turned out to be the most viable (with the highest power capacity).

It is observed from this study that the current flow rates (1980 -2011) of the Pra River at the Hemang site have decreased when compared to 1944 – 1984 readings.

The technical analysis using the RETScreen software showed that the Hemang hydro-site has a capacity of 70.524 MW and an annual energy generation capacity of 255,346 MWh (255 GWh) at a turbine peak efficiency of 94.6%, at a design flow of 271.31 m^3/s using the Kaplan type turbine. The Kaplan type turbine was selected on the basis of the fact that it has the largest capacity factor and energy output when compared to other turbine types (propeller and Francis) suitable for the flow and head at the site. Sizing of water passages including the turbine was carried out using MATLab® resulting in a turbine runner diameter of 3.4 m.

The project is estimated to cost about USD **138,237,062.90**. At an electricity export rate of USD 64.9/MWh and without any form of grants and GHG financing, the project, taken to be financed 90% by loan will have finished paying its debt after 13.4 years of the project's life and have an NPV of USD 26,341,708.00. An IRR of

13.7% however, makes the project financially uncompetitive when compared with similar energy projects, which have an IRR of 20%.

5.2 Recommendations

Based on the results obtained for this study, the following recommendations are made:

1. For the project to be financially competitive at prevailing energy feed-in-tariffs, there has to be grant (or subsidy) greater than 10%.
2. If there is no grant or GHG income for the project, the feed-in-tariff (electricity export rate) will have to be adjusted upwards to about **USD 80.0 per MWh** in order for the project to be both profitable and competitive.
3. There should be an environmental impact assessment to evaluate the impact of damming on the surrounding communities of the Hemang hydro site.
4. There should be other studies which should include the optimizations of the dam's capacity.

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APPENDICES

A: Matlab® Codes

A1

function apprxmt_ns_prptbn(H,G,etha) is the Matlab® command that computes the specific speed (Ns) and outlet diameter (d3) of a Kaplan turbine using net head, unit efficiency, and rated discharge. Using Ns and d3, other turbine, scroll case and draftube characterizing dimensions and economic penstock diameters are computed as well.

```
function apprxmt_ns_prptbn(H,Q,etha)
%H is net head in metric units
%ns is specific speed
%Q is volumetric flow rate
%etha is assumed efficiency
disp(' ')
disp('INPUT')
disp(['net head = ',num2str(H)])
disp(['discharge = ',num2str(Q)])
disp(['efficiency = ',num2str(etha)])
disp(' ')
ns1 = 2419/(H^0.489);

%computing power
%disp('input volumetric flow rate "Q" in m^3/s')
rho = 1000;                      % since for this project we have only water with
density=1000
g = 9.81;
P = rho*g*Q*H*etha/1000;     %power in kW

%Solving for N1, approximate rotational speed of turbine runner
N1 = (ns1*(H^1.25))/sqrt(P);%the value of power is divided by 1000 since
                            %the value of power is in killowats in the specific speed
relation

%Computing number of poles, Np
f = 50; %f is frequency of electric current or voltage
Np = 120*f/N1;
Np = round(Np);
%computing actual speed, N2
N2 = 120*f/Np;

%computing actual specific speed Ns2
Ns2 = N2*(P^0.5)/(H^1.25);

%calculating runner diameter using equation 4.32
Dm = (66.76 + 0.136*Ns2)*((sqrt(H))/N2);


%calculating characteristic dimenstions for kaplan steel-scroll case
A1 = Dm * (0.4 * (Ns2^0.2));

B1 = Dm * (1.26 + 3.79 * 0.001 * Ns2);

C1 = Dm * (1.46 + 3.24 * 0.001* Ns2);

D1 = Dm * (1.59 + 5.74 * 0.001* Ns2);

E1 = Dm * ( 1.21 + 2.71 * 0.001* Ns2);

F1 = Dm * (1.45 + (72.17/Ns2));

G1 = Dm * (1.29 + (41.63/Ns2));

H1 = Dm * (1.13 + (31.86/Ns2));

I1 = Dm * (0.45 - (31.80/Ns2));
```

```
L1 = Dm * (0.74 + 8.7 * 0.001);

M1 = Dm * ( 1/(2.06 - (1.20 *0.001* Ns2)));

disp ('OUTPUT')
disp (['guess specific speed, ns1      = ',num2str(ns1)])
disp (['rated turbine power,   P       = ',num2str(P),' kW'])
disp (['approximate runner speed, N1   = ',num2str(N1),' rpm'])
disp (['number of poles for gen., Np   = ',num2str(Np)])
disp (['actual runner speed, N2        = ',num2str(N2), 'rpm'])
disp (['actual specific speed, Ns2     = ',num2str(Ns2)])
disp (' ')
disp ('characteristic dimensions for Kaplan turbine runner')
disp (['turbine diameter, Dm           = ',num2str(Dm),' m'])

disp (' ')
disp ('controlling dimensions for kaplan spiral case')
disp (['A1                             = ',num2str(A1),' m'])
disp (['B1                             = ',num2str(B1),' m'])
disp (['C1                             = ',num2str(C1),' m'])
disp (['D1                             = ',num2str(D1),' m'])
disp (['E1                             = ',num2str(E1),' m'])
disp (['F1                             = ',num2str(F1),' m'])
disp (['G1                             = ',num2str(G1),' m'])
disp (['H1                             = ',num2str(H1),' m'])
disp (['I1                             = ',num2str(I1),' m'])
disp (['L1                             = ',num2str(L1),' m'])
disp (['M1                             = ',num2str(M1),' m'])

%computation of economic diameter of penstock
%Dg is economic penstock diameter using the Gordon and Penman Relation
Dg = 0.72 * Q ^ 0.5;

%Ds is economic penstock diameter using Sarkaria's equation
P = 1.341 * P;  % converting the power from kW of previous calculation to horsepower
H = H * 3.281;  % converting the net head from in previous calculation from m to ft
Ds = (4.44 * (P ^ (0.43)))/(H^0.63);%sarkaria's formula
Ds = Ds/3.281;  %converting diameter back to a value in meters

if Dg > Ds
    Dp = Dg;
else if Ds > Dg
        Dp = Ds;
else Dp = Dg;
    end
end
 disp (['penstock economic diameter = ',num2str(Dp),' m'])

 %dimenstions describing Kaplan turbine draft tube
 disp(('dimensions describing Kaplan turbine draft tube'))

H = Dm * ( 0.24 + 7.82*0.001*Ns2);
N = Dm * (2 - 2.14 * 0.00001*Ns2);
O = Dm * (1.4 - 1.67*0.0001*Ns2);
P = Dm * (1.26 - (18.4/Ns2));
Q = Dm * (0.66 - (18.4/Ns2));
R = Dm * (1.25 - 7.98*0.0001*Ns2);
S = Dm * (4.26 + 201.5/Ns2);
T = Dm * (1.20 + 5.12*0.0001*Ns2);
Z = Dm * (2.58 + 102.66/Ns2);


 disp (['H                             = ',num2str(H),' m'])
 disp (['N                             = ',num2str(N),' m'])
 disp (['O                             = ',num2str(O),' m'])
 disp (['P                             = ',num2str(P),' m'])
 disp (['Q                             = ',num2str(Q),' m'])
 disp (['R                             = ',num2str(R),' m'])
 disp (['S                             = ',num2str(S),' m'])
 disp (['T                             = ',num2str(T),' m'])
 disp (['Z                             = ',num2str(Z),' m'])
```

B: Flow data and Exceedance probabilities

B1: processed monthly flows from 1944 – 1984. Source: ACRES International

Flow/ CMS	Rank	Exceedance probability	Flow/ CMS	Rank	Exceedance probability	Flow/ CMs	Rank	Exceedance probability
212.1	139	28.19473	166.9	186	37.72819	132.9	233	47.26166
208.1	140	28.39757	166.8	187	37.93103	132.5	234	47.4645
208.1	141	28.60041	166.6	188	38.13387	132.5	235	47.66734
207.8	142	28.80325	165.3	189	38.33671	131.9	236	47.87018
207.1	143	29.00609	163.9	190	38.53955	131.8	237	48.07302
206.6	144	29.20892	163.7	191	38.74239	131.6	238	48.27586
203.1	145	29.41176	160.6	192	38.94523	129.1	239	48.4787
201.9	146	29.6146	160.4	193	39.14807	128.5	240	48.68154
201.0	147	29.81744	160.1	194	39.35091	128.4	241	48.88438
200.3	148	30.02028	159.0	195	39.55375	126.4	242	49.08722
198.7	149	30.22312	158.1	196	39.75659	126.4	243	49.29006
196.4	150	30.42596	157.7	197	39.95943	124.6	244	49.4929
195.1	151	30.6288	157.6	198	40.16227	124.1	245	49.69574
194.7	152	30.83164	157.0	199	40.36511	123.3	246	49.89858
193.5	153	31.03448	156.9	200	40.56795	122.6	247	50.10142
193.5	154	31.23732	156.3	201	40.77079	121.1	248	50.30426
190.9	155	31.44016	156.2	202	40.97363	119.4	249	50.5071
189.5	156	31.643	156.2	203	41.17647	118.6	250	50.70994
188.7	157	31.84584	155.8	204	41.37931	117.6	251	50.91278
188.2	158	32.04868	155.7	205	41.58215	114.1	252	51.11562
186.7	159	32.25152	153.1	206	41.78499	113.2	253	51.31846
184.5	160	32.45436	152.8	207	41.98783	112.6	254	51.5213
184.4	161	32.6572	150.9	208	42.19067	112.3	255	51.72414
183.8	162	32.86004	149.8	209	42.39351	112.1	256	51.92698
183.3	163	33.06288	149.7	210	42.59635	112.0	257	52.12982
182.7	164	33.26572	148.7	211	42.79919	111.5	258	52.33266
182.2	165	33.46856	147.6	212	43.00203	110.7	259	52.5355
182.0	166	33.6714	146.9	213	43.20487	109.1	260	52.73834
181.8	167	33.87424	145.2	214	43.40771	109.1	261	52.94118
180.8	168	34.07708	144.5	215	43.61055	109.0	262	53.14402
180.4	169	34.27992	143.7	216	43.81339	107.8	263	53.34686
177.4	170	34.48276	143.1	217	44.01623	107.1	264	53.5497
177.0	171	34.6856	143.0	218	44.21907	106.1	265	53.75254
176.3	172	34.88844	142.9	219	44.42191	104.3	266	53.95538
175.2	173	35.09128	141.9	220	44.62475	102.4	267	54.15822
175.0	174	35.29412	140.3	221	44.82759	102.4	268	54.36105
174.9	175	35.49696	139.4	222	45.03043	102.2	269	54.56389
174.6	176	35.6998	138.0	223	45.23327	101.7	270	54.76673
174.5	177	35.90264	137.6	224	45.43611	101.5	271	54.96957
174.4	178	36.10548	136.4	225	45.63895	101.4	272	55.17241
173.3	179	36.30832	136.3	226	45.84178	101.1	273	55.37525
171.6	180	36.51116	136.2	227	46.04462	100.9	274	55.57809
170.8	181	36.714	136.1	228	46.24746	100.5	275	55.78093
170.4	182	36.91684	135.0	229	46.4503	100.1	276	55.98377
170.3	183	37.11968	134.6	230	46.65314	99.4	277	56.18661
168.5	184	37.32252	134.4	231	46.85598	98.8	278	56.38945
168.1	185	37.52535	134.0	232	47.05882	98.6	279	56.59229

Flow/ CMS	Rank	Exceedance probability	Flow/ CMS	Rank	Exceedance probability	Flow/ CMS	Rank	Exceedance probability
98.4	280	56.79513	71.0	327	66.3286	52.2	374	75.86207
97.2	281	56.99797	70.5	328	66.53144	50.2	375	76.06491
96.0	282	57.20081	70.2	329	66.73428	50.2	376	76.26775
95.9	283	57.40365	70.2	330	66.93712	49.9	377	76.47059
94.9	284	57.60649	69.5	331	67.13996	49.5	378	76.67343
94.7	285	57.80933	69.2	332	67.3428	49.4	379	76.87627
94.2	286	58.01217	69.2	333	67.54564	49.0	380	77.07911
93.5	287	58.21501	68.9	334	67.74848	48.2	381	77.28195
93.5	288	58.41785	67.9	335	67.95132	46.1	382	77.48479
93.2	289	58.62069	67.8	336	68.15416	45.4	383	77.68763
93.0	290	58.82353	66.9	337	68.357	45.4	384	77.89047
91.9	291	59.02637	66.4	338	68.55984	45.3	385	78.09331
91.3	292	59.22921	65.7	339	68.76268	45.3	386	78.29615
89.1	293	59.43205	64.8	340	68.96552	44.7	387	78.49899
88.9	294	59.63489	64.8	341	69.16836	44.3	388	78.70183
88.6	295	59.83773	64.8	342	69.3712	44.2	389	78.90467
87.3	296	60.04057	64.5	343	69.57404	43.9	390	79.10751
87.3	297	60.24341	64.4	344	69.77688	43.5	391	79.31034
85.8	298	60.44625	64.1	345	69.97972	43.3	392	79.51318
85.6	299	60.64909	64.0	346	70.18256	43.1	393	79.71602
85.6	300	60.85193	64.0	347	70.3854	42.7	394	79.91886
85.5	301	61.05477	63.9	348	70.58824	42.7	395	80.1217
84.4	302	61.25761	63.9	349	70.79108	42.6	396	80.32454
84.3	303	61.46045	63.4	350	70.99391	42.3	397	80.52738
84.2	304	61.66329	63.4	351	71.19675	42.3	398	80.73022
82.1	305	61.86613	63.1	352	71.39959	42.0	399	80.93306
81.3	306	62.06897	61.7	353	71.60243	41.7	400	81.1359
81.1	307	62.27181	60.9	354	71.80527	41.5	401	81.33874
79.8	308	62.47465	60.8	355	72.00811	40.6	402	81.54158
79.6	309	62.67748	60.7	356	72.21095	40.3	403	81.74442
79.2	310	62.88032	59.5	357	72.41379	39.4	404	81.94726
78.4	311	63.08316	59.3	358	72.61663	38.9	405	82.1501
78.1	312	63.286	59.3	359	72.81947	38.8	406	82.35294
77.3	313	63.48884	58.8	360	73.02231	38.3	407	82.55578
76.6	314	63.69168	56.1	361	73.22515	38.1	408	82.75862
75.7	315	63.89452	55.6	362	73.42799	36.7	409	82.96146
75.7	316	64.09736	55.5	363	73.63083	36.6	410	83.1643
74.9	317	64.3002	55.4	364	73.83367	36.6	411	83.36714
74.5	318	64.50304	54.9	365	74.03651	36.2	412	83.56998
74.2	319	64.70588	54.5	366	74.23935	35.9	413	83.77282
74.0	320	64.90872	54.4	367	74.44219	35.8	414	83.97566
73.0	321	65.11156	54.1	368	74.64503	35.2	415	84.1785
73.0	322	65.3144	54.0	369	74.84787	35.0	416	84.38134
72.4	323	65.51724	53.9	370	75.05071	32.9	417	84.58418
71.6	324	65.72008	53.7	371	75.25355	32.7	418	84.78702
71.6	325	65.92292	53.4	372	75.45639	32.5	419	84.98986
71.1	326	66.12576	52.4	373	75.65923	32.4	420	85.1927

Flow/ CMS	Rank	Exceedance probability	Flow/ CMS	Rank	Exceedance probability
32.4	421	85.39554	14.3	468	94.92901
32.2	422	85.59838	13.6	469	95.13185
31.5	423	85.80122	12.9	470	95.33469
31.4	424	86.00406	12.9	471	95.53753
31.3	425	86.2069	11.3	472	95.74037
31.2	426	86.40974	10.9	473	95.9432
30.1	427	86.61258	10.6	474	96.14604
30.0	428	86.81542	9.5	475	96.34888
29.1	429	87.01826	9.3	476	96.55172
29.0	430	87.2211	9.3	477	96.75456
28.8	431	87.42394	8.5	478	96.9574
28.7	432	87.62677	8.5	479	97.16024
28.4	433	87.82961	8.2	480	97.36308
28.2	434	88.03245	7.1	481	97.56592
27.7	435	88.23529	6.6	482	97.76876
27.5	436	88.43813	6.6	483	97.9716
26.0	437	88.64097	6.4	484	98.17444
25.8	438	88.84381	6.2	485	98.37728
25.6	439	89.04665	5.3	486	98.58012
25.6	440	89.24949	5.3	487	98.78296
25.4	441	89.45233	4.3	488	98.9858
25.1	442	89.65517	3.0	489	99.18864
24.6	443	89.85801	3.0	490	99.39148
24.0	444	90.06085	1.3	491	99.59432
23.6	445	90.26369	1.3	492	99.79716
23.4	446	90.46653			
22.5	447	90.66937			
21.5	448	90.87221			
21.2	449	91.07505			
21.0	450	91.27789			
20.4	451	91.48073			
20.3	452	91.68357			
20.3	453	91.88641			
18.7	454	92.08925			
17.7	455	92.29209			
17.6	456	92.49493			
17.3	457	92.69777			
17.2	458	92.90061			
16.9	459	93.10345			
16.9	460	93.30629			
16.6	461	93.50913			
15.9	462	93.71197			
14.9	463	93.91481			
14.7	464	94.11765			
14.7	465	94.32049			
14.7	466	94.52333			
14.6	467	94.72617			

B2: processed monthly flows from 1980 – 2011. Source: Ghana Hydrological Services department

Flow/ CMS	Rank	Exceedance Probability	Flow/ CMS	Rank	Exceedance Probability	Flow/ CMS	Rank	Exceedance Probability
694.763	1	0.296736	254.704	49	14.54006	148.029	97	28.78338
660.756	2	0.593472	252.437	50	14.8368	147.649	98	29.08012
585.359	3	0.890208	248.584	51	15.13353	145.04	99	29.37685
564.952	4	1.186944	246.888	52	15.43027	143.37	100	29.67359
536.165	5	1.48368	240.845	53	15.727	136.515	101	29.97033
533.71	6	1.780415	238.626	54	16.02374	134.988	102	30.26706
497.575	7	2.077151	237.985	55	16.32047	134.388	103	30.5638
488.232	8	2.373887	234.168	56	16.61721	133.786	104	30.86053
482.61	9	2.670623	233.197	57	16.91395	131.479	105	31.15727
458.677	10	2.967359	232.788	58	17.21068	128.762	106	31.45401
433.209	11	3.264095	231.796	59	17.50742	128.739	107	31.75074
413.532	12	3.560831	230.781	60	17.80415	128.044	108	32.04748
407.351	13	3.857567	228.466	61	18.10089	126.713	109	32.34421
387.924	14	4.154303	225.649	62	18.39763	123.854	110	32.64095
386.952	15	4.451039	225.072	63	18.69436	122.733	111	32.93769
386.005	16	4.747774	221.771	64	18.9911	122.231	112	33.23442
361.192	17	5.04451	221.387	65	19.28783	120.361	113	33.53116
360.973	18	5.341246	218.54	66	19.58457	118.753	114	33.82789
340.932	19	5.637982	218.378	67	19.88131	118.254	115	34.12463
335.423	20	5.934718	217.118	68	20.17804	118.204	116	34.42136
334.124	21	6.231454	215.299	69	20.47478	117.46	117	34.7181
332.683	22	6.52819	211.474	70	20.77151	115.993	118	35.01484
332.679	23	6.824926	210.973	71	21.06825	115.628	119	35.31157
330.93	24	7.121662	209.416	72	21.36499	115.543	120	35.60831
324.439	25	7.418398	205.944	73	21.66172	115.536	121	35.90504
322.226	26	7.715134	204.401	74	21.95846	114.846	122	36.20178
320.891	27	8.011869	204.199	75	22.25519	113.851	123	36.49852
318.805	28	8.308605	203.096	76	22.55193	112.961	124	36.79525
312.587	29	8.605341	201.139	77	22.84866	112.69	125	37.09199
306.282	30	8.902077	201.099	78	23.1454	110.747	126	37.38872
305.69	31	9.198813	197.165	79	23.44214	106.2	127	37.68546
302.473	32	9.495549	196.103	80	23.73887	105.292	128	37.9822
302.383	33	9.792285	189.526	81	24.03561	104.575	129	38.27893
299.884	34	10.08902	187.537	82	24.33234	102.865	130	38.57567
297.228	35	10.38576	187.356	83	24.62908	101.642	131	38.8724
296.343	36	10.68249	185.485	84	24.92582	99.972	132	39.16914
293.219	37	10.97923	185.451	85	25.22255	98.347	133	39.46588
288.301	38	11.27596	184.972	86	25.51929	97.669	134	39.76261
285.98	39	11.5727	183.882	87	25.81602	97.234	135	40.05935
282.103	40	11.86944	180.28	88	26.11276	96.946	136	40.35608

276.454	41	12.16617	172.988	89	26.4095	95.891	137	40.65282
275.258	42	12.46291	163.408	90	26.70623	95.311	138	40.94955
267.318	43	12.75964	162.945	91	27.00297	94.929	139	41.24629
266.635	44	13.05638	161.994	92	27.2997	94.811	140	41.54303
266.517	45	13.35312	160.817	93	27.59644	94.689	141	41.83976
265.82	46	13.64985	155.469	94	27.89318	94.06	142	42.1365
263.156	47	13.94659	151.002	95	28.18991	93.12	143	42.43323
261.254	48	14.24332	148.212	96	28.48665	92.362	144	42.72997
91.826	145	43.02671	45.589	193	57.27003	30.073	241	71.51335
90.781	146	43.32344	45.257	194	57.56677	30.026	242	71.81009
90.277	147	43.62018	44.704	195	57.8635	29.737	243	72.10682
88.608	148	43.91691	44.429	196	58.16024	29.603	244	72.40356
86.61	149	44.21365	44.305	197	58.45697	29.188	245	72.7003
86.416	150	44.51039	44.075	198	58.75371	29.009	246	72.99703
85.969	151	44.80712	43.261	199	59.05045	28.911	247	73.29377
85.287	152	45.10386	42.934	200	59.34718	28.78	248	73.5905
83.83	153	45.40059	42.918	201	59.64392	28.51	249	73.88724
80.873	154	45.69733	42.725	202	59.94065	28.373	250	74.18398
80.196	155	45.99407	42.515	203	60.23739	27.98	251	74.48071
79.742	156	46.2908	42.344	204	60.53412	27.594	252	74.77745
78.101	157	46.58754	42.128	205	60.83086	27.214	253	75.07418
78.013	158	46.88427	39.862	206	61.1276	27.212	254	75.37092
77.92	159	47.18101	39.656	207	61.42433	26.842	255	75.66766
77.739	160	47.47774	39.537	208	61.72107	26.713	256	75.96439
76.328	161	47.77448	38.899	209	62.0178	26.47	257	76.26113
75.729	162	48.07122	38.788	210	62.31454	26.122	258	76.55786
75.047	163	48.36795	38.509	211	62.61128	26.059	259	76.8546
72.848	164	48.66469	38.104	212	62.90801	25.81	260	77.15134
72.721	165	48.96142	37.557	213	63.20475	25.781	261	77.44807
71.318	166	49.25816	37.359	214	63.50148	25.65	262	77.74481
70.777	167	49.5549	36.811	215	63.79822	25.468	263	78.04154
69.473	168	49.85163	36.551	216	64.09496	25.433	264	78.33828
69.441	169	50.14837	36.273	217	64.39169	25.092	265	78.63501
69.437	170	50.4451	35.832	218	64.68843	24.757	266	78.93175
68.625	171	50.74184	35.736	219	64.98516	24.428	267	79.22849
66.557	172	51.03858	35.7	220	65.2819	24.111	268	79.52522
66.449	173	51.33531	35.209	221	65.57864	24.099	269	79.82196
65.77	174	51.63205	35.17	222	65.87537	23.782	270	80.11869
64.576	175	51.92878	35.035	223	66.17211	23.778	271	80.41543
64.137	176	52.22552	34.743	224	66.46884	23.732	272	80.71217
62.131	177	52.52226	34.692	225	66.76558	23.636	273	81.0089
59.064	178	52.81899	34.284	226	67.06231	23.47	274	81.30564
59.025	179	53.11573	34.184	227	67.35905	23.163	275	81.60237
58.156	180	53.41246	34.077	228	67.65579	23.14	276	81.89911

54.72	181	53.7092	34.03	229	67.95252	22.863	277	82.19585
54.597	182	54.00593	33.678	230	68.24926	22.862	278	82.49258
52.987	183	54.30267	33.189	231	68.54599	22.561	279	82.78932
52.354	184	54.59941	32.743	232	68.84273	22.279	280	83.08605
50.213	185	54.89614	32.709	233	69.13947	22.152	281	83.38279
49.204	186	55.19288	32.237	234	69.4362	22.002	282	83.67953
48.481	187	55.48961	31.774	235	69.73294	21.721	283	83.97626
47.94	188	55.78635	31.312	236	70.02967	21.445	284	84.273
46.569	189	56.08309	31.105	237	70.32641	21.383	285	84.56973
46.044	190	56.37982	30.881	238	70.62315	21.314	286	84.86647
46.037	191	56.67656	30.77	239	70.91988	21.173	287	85.1632
45.861	192	56.97329	30.457	240	71.21662	20.906	288	85.45994
20.774	289	85.75668	14.56	305	90.50445	8.602	321	95.25223
20.639	290	86.05341	14.177	306	90.80119	7.994	322	95.54896
20.544	291	86.35015	14.117	307	91.09792	7.601	323	95.8457
20.381	292	86.64688	14.073	308	91.39466	7.341	324	96.14243
20.128	293	86.94362	13.924	309	91.69139	6.124	325	96.43917
20.112	294	87.24036	13.675	310	91.98813	6.073	326	96.73591
19.879	295	87.53709	13.619	311	92.28487	5.218	327	97.03264
19.634	296	87.83383	11.833	312	92.5816	4.791	328	97.32938
19.389	297	88.13056	11.092	313	92.87834	4.705	329	97.62611
18.253	298	88.4273	10.978	314	93.17507	4.698	330	97.92285
18.108	299	88.72404	10.954	315	93.47181	4.538	331	98.21958
17.341	300	89.02077	10.287	316	93.76855	3.92	332	98.51632
17.054	301	89.31751	9.213	317	94.06528	3.792	333	98.81306
15.744	302	89.61424	8.952	318	94.36202	0.901	334	99.10979
15.561	303	89.91098	8.886	319	94.65875	0.517	335	99.40653
14.624	304	90.20772	8.774	320	94.95549	0.5	336	99.70326

B3: Monthly flow data on the Pra River at the Hemang site for 1944 – 1984 (unprocessed)

Source: [7]

	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec	ANNUAL AVERAGE
1944	69.2	30.0	102.4	43.9	66.4	136.4	302.2	94.7	207.1	285.0	134.4	88.9	130.1
1945	32.5	20.3	10.6	17.7	53.9	87.3	143.0	85.8	183.8	424.8	239.1	94.9	116.1
1946	28.4	14.3	53.4	25.6	21.5	121.1	134.6	66.9	14.7	251.2	186.7	40.3	79.9
1947	14.6	21.0	21.2	65.7	102.2	242.9	201.9	309.0	557.7	481.0	326.1	131.8	206.3
1948	36.2	24.0	43.3	64.8	147.6	388.9	193.5	59.3	50.2	176.3	201.0	79.8	122.1
1949	24.6	8.2	28.7	59.5	77.3	182.0	563.7	237.0	400.3	502.5	237.4	132.9	204.5
1950	54.0	29.1	16.9	23.4	126.4	145.2	98.8	63.9	63.9	182.2	170.4	85.5	88.3
1951	38.9	31.4	69.2	54.1	140.3	159.0	129.1	76.6	170.3	537.8	547.2	97.2	170.9
1952	31.5	28.8	119.4	93.5	174.5	455.6	376.2	195.1	285.3	579.8	402.7	131.9	239.5
1953	63.4	35.0	91.9	111.5	84.4	450.6	496.5	184.5	177.4	427.7	208.1	70.2	200.1
1954	42.3	64.8	146.9	228.2	246.2	273.3	298.2	78.4	157.6	380.1	355.8	156.2	202.3
1955	58.8	45.4	88.6	89.1	196.4	326.9	437.8	160.4	177.0	444.3	443.8	128.4	216.4
1956	49.9	38.3	109.1	208.1	184.4	438.1	124.1	45.3	98.6	297.3	218.8	113.2	160.4
1957	32.9	28.2	42.6	71.1	112.3	370.3	805.4	194.7	265.9	463.3	384.1	257.7	252.4
1958	101.1	64.0	71.6	104.3	346.8	582.7	118.6	41.7	36.7	110.7	126.4	85.6	149.2
1959	38.1	31.2	55.4	101.5	427.8	431.1	346.6	139.4	137.6	409.4	329.1	143.7	215.9
1960	64.8	50.2	74.0	219.6	94.2	372.3	478.1	153.1	132.5	535.6	281.1	85.6	211.8
1961	43.5	38.8	35.2	63.1	43.1	298.4	575.2	160.1	148.7	359.9	173.3	70.2	167.5
1962	29.0	25.6	49.0	74.2	171.6	597.6	924.6	281.8	99.4	149.7	217.9	163.9	232.0
1963	67.9	64.4	72.4	93.0	124.6	304.1	711.1	603.4	739.4	1191.6	372.5	144.5	374.1
1964	155.8	112.6	166.6	158.1	181.8	288.7	258.6	136.1	170.8	175.0	163.7	135.0	175.2
1965	61.7	60.8	107.8	132.5	166.9	301.7	826.9	318.0	374.3	516.9	264.3	157.7	274.1
1966	93.2	40.6	79.2	174.6	174.9	391.1	747.0	410.2	329.6	445.3	295.2	131.6	276.0
1967	44.7	45.3	60.7	67.8	128.5	463.9	365.0	81.3	152.8	200.3	142.9	73.0	152.2
1968	27.7	30.1	49.5	91.3	134.0	577.2	1283.8	994.5	2010.8	1399.9	544.7	183.3	610.6
1969	100.9	60.9	64.5	138.0	156.2	536.2	454.4	228.7	175.2	282.0	448.8	122.6	230.7
1970	73.0	42.3	100.1	168.5	203.1	232.8	136.2	52.4	141.9	383.0	314.2	78.1	160.5
1971	55.6	26.0	54.9	101.7	95.9	168.1	222.2	188.7	174.4	246.5	84.2	54.5	122.7
1972	18.7	10.9	32.4	155.7	206.6	457.9	226.8	136.3	109.0	165.3	98.4	44.2	138.5
1973	27.5	11.3	12.9	46.1	32.4	71.6	100.5	157.0	312.5	243.9	150.9	32.7	99.9
1974	13.6	4.3	23.6	64.0	189.5	220.4	278.2	219.2	399.7	319.5	190.9	55.5	164.9
1975	25.1	48.2	32.2	69.5	123.3	198.7	463.5	112.1	71.0	207.8	102.4	75.7	127.5
1976	16.9	14.9	35.9	59.3	114.1	386.1	156.3	56.1	42.7	101.4	180.4	42.0	100.5
1977	17.2	6.6	6.4	8.5	25.8	149.8	45.4	12.9	36.6	254.9	63.4	25.4	54.4
1978	6.2	7.1	15.9	84.3	160.6	491.4	74.9	35.8	107.1	193.5	117.6	41.5	111.3
1979	17.6	9.5	6.6	17.3	52.2	315.5	355.9	259.3	474.8	634.5	291.8	93.5	210.7
1980	39.4	22.5	53.7	70.5	143.1	407.5	180.8	301.3	443.7	539.2	213.1	82.1	208.1
1981	31.3	20.3	54.4	75.7	225.9	243.8	374.3	221.3	284.6	265.6	156.9	49.4	167.0
1982	20.4	8.5	36.6	44.3	87.3	188.2	388.6	74.5	64.1	109.1	79.6	16.6	93.2
1983	5.3	1.3	3.0	9.3	14.7	212.1	68.9	81.1	112.0	166.8	106.1	42.7	68.6
1984	5.3	1.3	3.0	9.3	14.7	212.1	361.7	182.7	252.3	376.0	239.1	96.0	146.1
Mean Flow	43.3829268	31.17805	56.13902	86.78439	135.9366	314.1122	361.68537	182.6976	252.2927	376.0146	239.1341	95.9878	181.2787805
Standard deviation	30.4462469	22.47081	39.20273	56.91731	84.23124	143.273	269.81554	173.9423	321.6539	256.9307	123.3821	49.49431	94.37419675

C: Cost Estimation Sheets

C1: original project cost estimates by ACRES international, 1985 and present values

capacity					Quantity	Units	Unit Price	present unit price	amount			present value of 1985 estimates
73.145												
Power System												
Infrastructure	access roads	new pavement roads	coastal way to site		2	kilometres	150,000.00	327000	300,000.00			654000
		main bridge			-	LS	-	-	500,000.00			1090000
		construction site roads			10	kilometres	50,000.00	109000	500,000.00			1090000
	construction and camp power	DIESEL POWER SYSTEM			-	LS	-	-	3,000,000.00			6540000
	construction camp and townsite				-	LS	-	-	30,700,000.00			66926000
							subtotal		35,000,000.00			76300000
						contingency	0.25		8,925,000.00			19456500
							subtotal+contingency		**43,925,000.00**	subtotal 0	43,925,000.00	95756500
												0
												0
reservoire Clearing	reservoire clearing				650	hectors	2,000.00	4360	1,300,000.00			2834000
							subtotal		1,300,000.00			2834000
						contingency	0.30	0.654	390,000.00			850200
							subtotal+contingency		**1,690,000.00**	subtotal 1	1,690,000.00	3684200
												0
Diversion and spill way structure	Civil works	Cofferdam	fill		25000	cubic metres	10.00	21.8	250,000.00			545000
			Dewatering		-	LS	-		75,000.00			163500
		Escavation	common		275000	cubic metres	3.00	6.54	825,000.00			1798500
			Rock -open cut		90000	cubic metres	20.00	43.6	1,800,000.00			3924000
		Rock bolting and support	Rock -bolting and support			LS	50,000.00	109000	50,000.00			109000
		Grouting & Pressure relief	Drilling		600	metres	70.00	152.6	42,000.00			91560
			Grout		75000	Kilos	1.20	2.616	90,000.00			196200
			Pressure relief		200	metres	60.00	130.8	12,000.00			26160
		Concrete	Diversion		30000	cubic metres	300.00	654	9,000,000.00			19620000
			Piers & Rollway		29000	cubic metres	425.00	926.5	12,325,000.00			26868500
			Retaining walls		17000	cubic metres	350.00	763	5,950,000.00			12971000
			Plug diversion ports		5000	cubic metres	275.00	599.5	1,375,000.00			2997500
		Spillway decks & Miscelaneous				LS			250,000.00			545000
							subtotal		31,794,000.00			69310920
						contingency	0.25		7,948,500.00			17327730
							subtotal + contingency		**39,742,500.00**			86638650
								0				0
	Electro Mechanical works	Diversion stoplog guides			-	LS	-		575,000.00			1253500
		Diversion stoplogs			-	LS	-		2,200,000.00			4796000
		diversion crane			-	LS	-		300,000.00			654000
		spillway guides			-	LS	-		590,000.00			1286200
		spillway stoplogs			-	LS	-		900,000.00			1962000
		spillway radial gates			-	LS	-		1,585,000.00			3455300
		spillway hoists & gantry crane			-	LS	-		1,650,000.00			3597000
							subtotal		7,800,000.00			17004000
						contingency	0.15		1,170,000.00			2550600
							subtotal + contingency		**8,970,000.00**			19554600
								0		subtoatal 2	48,712,500.00	0
								0				0
Dams	Main Dam	cofferdams	upper stream coffer dam	Rockfill	53000	cubic metres	3.00	6.54	159,000.00			346620
				Sand & Gravel	47000	cubic metres	10.00	21.8	470,000.00			1024600
				Slurry Trench & cutoff wall	5700	cubic metres	120.00	261.6	684,000.00			1491120
				Drainage wells	200	metres	250.00	545	50,000.00			109000
			downstream coffer dam	Rockfill	29000	cubic metres	3.00	6.54	87,000.00			189660
				Sand & Gravel	21000	cubic metres	10.00	21.8	210,000.00			457800
				Slurry Trench & cutoff wall	5000	cubic metres	120.00	261.6	600,000.00			1308000
				Drainage wells	240	metres	250.00	545	60,000.00			130800
			Dewatering and pumping		-	litres	-	-	100,000.00			218000
		Escavation	River Bottom escavation		85000	cubic metres	5.00	10.9	425,000.00			926500
			Embankment common		21500	cubic metres	5.00	10.9	107,500.00			234350
		Foundation preparation	below core		7000	square metre	10.00	21.8	70,000.00			152600
			below rockfill		30000	square metre	2.00	4.36	60,000.00			130800
		Drilling and grouting	drilling		6100	metres	50.00	109	305,000.00			664900
			grouting		450000	kilos	1.00	2.18	450,000.00			981000
		Dam fills	Impervious core		87000	cubic metres	5.00	10.9	435,000.00			948300
			filters		49000	cubic metres	15.00	32.7	735,000.00			1602300
			rockfill shells		490000	cubic metres	12.00	26.16	5,880,000.00			12818400
			riprap		8700	cubic metres	20.00	43.6	174,000.00			379320
		Instrumentation			-	litres	-	-	100,000.00			218000
	Saddle dam	Escavation	common		150000	cubic metres	3.50	7.63	525,000.00			1144500
		foundation preparation	below cores		5500	square metres	10.00	21.8	55,000.00			119900
			below rockfill		22500	square metres	2.00	4.36	45,000.00			98100
		Drilling and grouting	drilling		5000	metres	50.00	109	250,000.00			545000
			grouting		500000	kilos	1.00	2.18	500,000.00			1090000
		fills	Impervious		39000	cubic metres	5.00	10.9	195,000.00			425100
			flters		26000	cubic metres	15.00	32.7	390,000.00			850200
			rockfill		75000	cubic metres	12.00	26.16	900,000.00			1962000
			riprap		7500	cubic metres	20.00	43.6	150,000.00			327000
							subtotal		14,171,500.00			30893870
						contingency	0.25		3,542,875.00			7723467.5
							subtotal + contingency		**17,714,375.00**	subtotal 3	17,714,375.00	38617337.5
												0

C2: original project cost estimates by ACRES international, 1985 and present values (continued from C1)

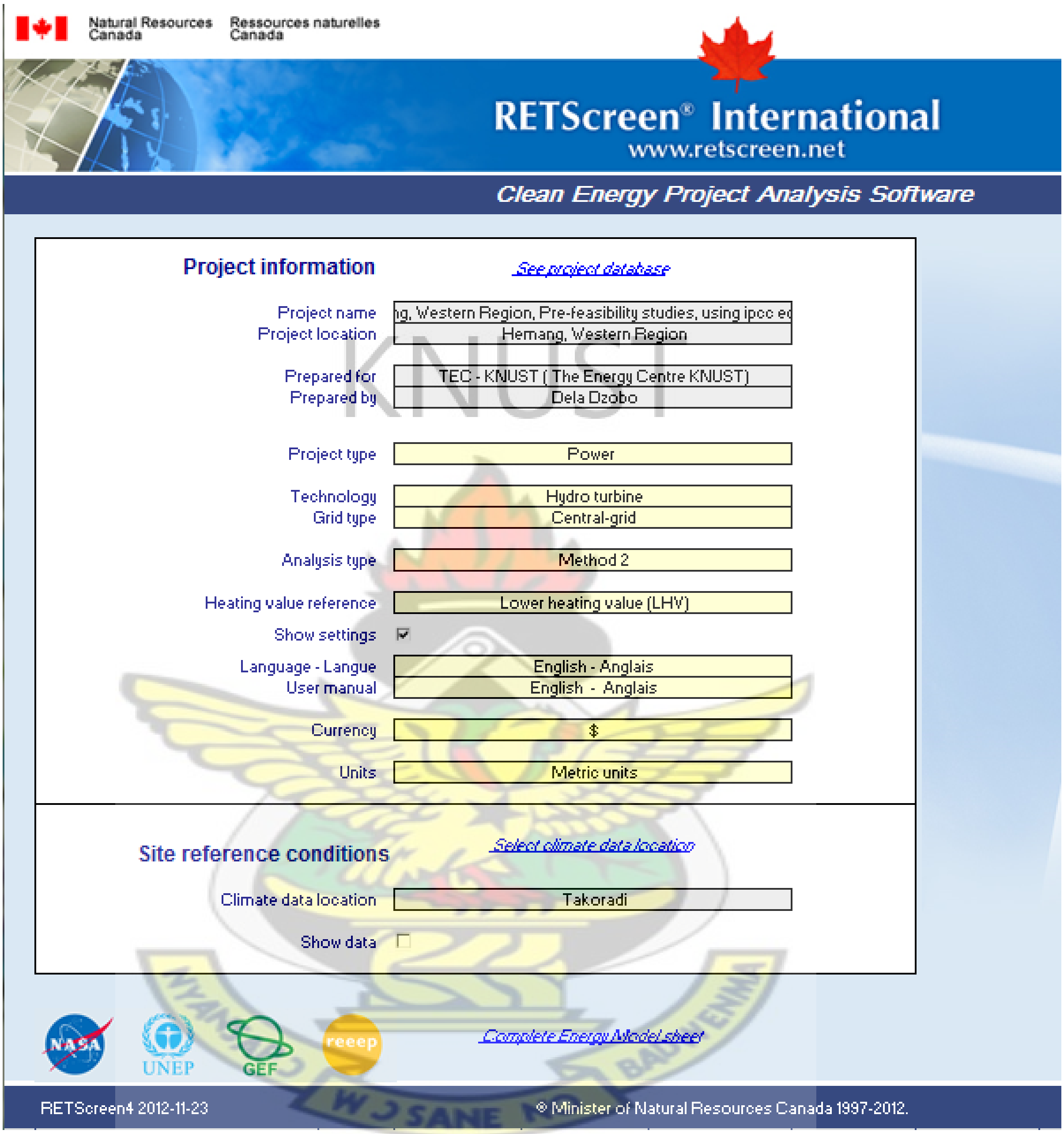
												0
Concrete bulkheads	excavation	common			34000	cubic metres	5.00	10.9	170,000.00			370600
		rock			2600	cubic metres	25.00	54.5	65,000.00			141700
	drilling and grouting	grout curtain drilling			1700	cubic metres	70.00	152.6	119,000.00			259420
		grouting			150000	kilos	1.20	2.616	180,000.00			392400
		pressure relief drains			500	metres	60.00	130.8	30,000.00			65400
	concrete				47000	cubic metres	300.00	654	14,100,000.00			30738000
	deck & miscelaneos				-	LS	-	-	400,000.00			872000
							subtotal		15,064,000.00			32839520
						contingency	0.25		3,766,000.00			8209880
							subtotal + contingency		**18,830,000.00**	subtotal 4	18,830,000.00	41049400
								0				0
Headworks & Powerhouse	Civil works	excavation	common		39000	cubic metres	5.00	10.9	195,000.00			425100
			rock		12300	cubic metres	20.00	43.6	246,000.00			536280
			rockbolting and support		-	litres	-		100,000.00			218000
		Grouting & pressure Relief	drilling		700	metres	70.00	152.6	49,000.00			106820
			grout		70000	kilos	1.20	2.616	84,000.00			183120
			pressure relief		200	metres	60.00	130.8	12,000.00			26160
		reinforced concrete	headworks		10500	cubic metrers	425.00	926.5	4,462,500.00			9728250
			powerhouse		11700	cubic metrers	475.00	1035.5	5,557,500.00			12115350
		embeded conduit/piping			-	cubic metrers	-		250,000.00			545000
		superstructure & architectural			12600	cubic metrers	75.00	163.5	945,000.00			2060100
							subtotal		11,901,000.00			25944180
						contingency	0.25	0.545	2,975,250.00			6486045
							subtotal + contingency		**14,876,250.00**			32430225
								0				0
	electrical and mechanical equipment	electrical	generators & exciters		3	EA	3,000,000.00	6540000	9,000,000.00			19620000
			power transformers		-	LS	-		900,000.00			1962000
			P/H auxilliary electrical		-	LS	-		2,400,000.00			5232000
		mechanical	guides, gates and hoists	draft tube guides	-	LS	-		140,000.00			305200
				draft tube gates	-	LS	-		140,000.00			305200
				draft tube mondrail hoist	-	LS	-		50,000.00			109000
				headworks (intake guides)	-	LS	-		1,200,000.00			2616000
				trashracks	-	LS	-		275,000.00			599500
				trash rake	-	LS	-		150,000.00			327000
				bulkhead gate	-	LS	-		180,000.00			392400
				service gates	-	LS	-		650,000.00			1417000
				headworks hoists	-	LS	-		500,000.00			1090000
			turbines and governors		3	EA	4,500,000.00	9810000	13,500,000.00			29430000
			powerhouse crane		-	LS	-		400,000.00			872000
			powerhouse mechanical services		-	LS	-		3,500,000.00			7630000
							subtotal		32,985,000.00			71907300
						contingency	0.10		3,298,500.00			7190730
							subtotal + contingency		**36,283,500.00**	subtotal 8	51,159,750.00	79098030
												0
Tail Race	excavation	common			157000	cubic metres	5.00	10.9	785,000.00			1711300
		rock			7400	cubic metres	25.00	54.5	185,000.00			403300
							subtotal		970,000.00			2114600
						contingency	0.26	0.5668	250,066.00			545143.88
							subtotal + contingency		**1,220,066.00**	subtotal 9	1,220,066.00	2659743.88
								0				0
Switchyard	Civil works	civil works and foundations			-	LS	-		200,000.00			436000
							subtotal		200,000.00			436000
						contingency	0.25		50,000.00			109000
							subtotal + contingency		**250,000.00**			545000
												0
	elecrical	161-KV switchyard equipment			-	LS	-		1,600,000.00			3488000
							subtotal		1,600,000.00			3488000
						contingency	0.10		160,000.00			348800
							subtotal + contingency		**1,760,000.00**	subtotal 10	2,010,000.00	3836800
												0
transmission	transmission lines				30	kilometres	65,000.00	141700	1,950,000.00			4251000
	line breakers & substation				-	LS	-		800,000.00			1744000
							subtotal		2,750,000.00			5995000
						contingency	0.20		550,000.00			1199000
							subtotal + contingency		**3,300,000.00**	subtotal 11	3,300,000.00	7194000
												0
Land/Resettlement	provisional sum				-	LS	-		3,000,000.00			6540000
									3,000,000.00	subtotal 12	3,000,000.00	6540000
												0
TOTAL CONSTRUCTION COST (0 T0 12)									**191,561,691.00**			417604486.4
												0
Engineering and construction management							0.10		**19,347,730.79**			42178053.12
owner's costs							0.03		**5,880,943.91**			12820457.73
												0
						Total Estimated Cost of Project			**216,790,365.70**			472602997.2

C3: Project cost estimates regrouped for entry into RETScreen® cost analysis sheet (see Figure 3.8)

Power system	quantity	unit price	present unit price	total		comment/constituents
hydro turbine	73144.65	184.5657885	402.3534189	13,500,000.00	29,430,000.00	turbines
road construction	12	108333.3333	236166.6667	1,300,000.00	2,834,000.00	access roads
transmission line	30	91666.66667	199833.3333	2,750,000.00	5,995,000.00	total for transmission
substation	1	2010000	4381800	2010000	4,381,800.00	switchyard costs(subtotoal for 10)
energy efficiency methods					0.00	none
					0.00	
					0.00	
Balance of system miscellaneous					0.00	
clearing	650	2000	4360	1300000	2,834,000.00	reservoir clearing
earth excavation	761,500.00	3.292843073	7.178397899	2,507,500.00	5,466,350.00	sum all common and river bed excavations all in blue
rock excavation	112300	21.33570793	46.51184328	2,396,000.00	5,223,280.00	rock and open cut. All in blue
concrete dam	142300	307.8988053	671.2193956	43,814,000.00	95,514,520.00	in yellow
earth fill dam				13,114,000.00	28,588,520.00	in deep blue
spillway				8,569,000.00	18,680,420.00	in pink
powerhouse civil				10,415,000.00	22,704,700.00	
building and yard construction				33700000	73,466,000.00	infrastructure
					0.00	
others				42,475,943.91	92,597,557.73	

D: RETScreen Input and Output display screens

D1: Start page



D2: Energy model

RETScreen Energy Model - Power project

☑ Show alternative units

Proposed case power system

Technology		Hydro turbine		
Analysis type		○ Method 1 ◉ Method 2		

Resource assessment

Proposed project		Reservoir			
Gross head	m	29.9	ft	98.1	
Maximum tailwater effect	m	0.00	ft	0.0	
Residual flow	m³/s	0.000	ft³/s	0.000	
Percent time firm flow available	%	95.0%			
Firm flow	m³/s	7.23	ft³/s	255.36	

Hydro turbine

Design flow	m³/s	271.310	ft³/s	9,581.222	
Type		Kaplan			See product database
Turbine efficiency		Standard			
Number of turbines		3			
Manufacturer		Alstom			
Model		Kaplan			
Design coefficient		6			
Efficiency adjustment	%	0.0%			
Turbine peak efficiency	%	94.6%			
Flow at peak efficiency	m³/s	203.5	ft³/s	7,185.9	
Turbine efficiency at design flow	%	94.2%			Show figure

%	Flow m³/s	Turbine efficiency	Number of turbines	Combined efficiency
0%	1022.76	0.00	0	0.00
5%	449.70	0.00	1	0.08
10%	344.29	0.00	1	0.79
15%	271.31	0.08	1	0.93
20%	216.15	0.43	1	0.95
25%	174.45	0.66	1	0.95
30%	141.51	0.79	1	0.95
35%	116.52	0.87	2	0.94
40%	96.87	0.91	2	0.95
45%	77.66	0.93	2	0.95
50%	61.59	0.94	2	0.95
55%	50.60	0.95	2	0.95
60%	40.87	0.95	2	0.95
65%	35.84	0.95	2	0.94
70%	31.60	0.95	3	0.95
75%	27.90	0.95	3	0.95
80%	24.43	0.95	3	0.95
85%	21.43	0.95	3	0.95
90%	15.23	0.95	3	0.95
95%	7.23	0.95	3	0.95
100%	0.32	0.94	3	0.94

Show figure

Maximum hydraulic losses	%	2.0%
Miscellaneous losses	%	1.0%
Generator efficiency	%	97.0%
Availability	%	96.0%

Summary

			Firm		
Power capacity	kW	70,524	85		
Available flow adjustment factor		1.00			
Capacity factor	%	36.5%			
Electricity exported to grid	MWh	225,346			
Electricity export rate	$/MWh	64.90		$/kWh	0.065

D3: Project cost model

◉ Method 1 ○ Method 2

◉ Notes/Range ○ Second currency ○ Cost allocation

Notes/Range: None

Initial costs (credits)	Unit	Quantity	Unit cost	Amount	Relative costs
Feasibility study					
Feasibility study	cost	1	$ 214,820	$ 214,820	
Subtotal:				**$ 214,820**	0.2%
Development					
Development	cost	1	$ 333,386	$ 333,386	
Subtotal:				**$ 333,386**	0.2%
Engineering					
Engineering	cost	1	$ 46,241,077	$ 46,241,077	
Subtotal:				**$ 46,241,077**	33.7%
Power system					
Hydro turbine	kW	70,524.18	$ 454	$ 32,004,077	
Road construction	km	12	$ 258,917	$ 3,107,000	
Transmission line	km	30	$ 258,917	$ 7,767,500	
Substation	project	1	$ 4,803,900	$ 4,803,900	
Energy efficiency measures	project			$ -	
User-defined	cost			$ -	
				$ -	
Subtotal:				**$ 47,682,477**	34.7%
Balance of system & miscellaneous					
Spare parts	%	3.0%	$ 47,943,400	$ 1,438,302	
Transportation	project	36	$ 1,000	$ 36,000	
Training & commissioning	p-d	30	$ 10,000	$ 300,000	
User-defined	cost	1	$ 17,236,200	$ 17,236,200	
Contingencies	%	20.0%	$ 113,482,262	$ 22,696,452	
Interest during construction	1.00%	20 month(s)	$ 136,178,715	$ 1,134,823	
Subtotal:				**$ 42,841,777**	31.2%
Total initial costs				**$137,313,537**	100.0%

Annual costs (credits)	Unit	Quantity	Unit cost	Amount
O&M				
Parts & labour	project	40	$ 16,000	$ 640,000
User-defined	cost	1	$ 200,000	$ 200,000
Contingencies	%	10.0%	$ 840,000	$ 84,000
Subtotal:				**$ 924,000**

Periodic costs (credits)	Unit	Year	Unit cost	Amount
User-defined	cost			$ -
				$ -
End of project life	cost			$ -

Go to Emission Analysis sheet

D4: Emission model

RETScreen Emission Reduction Analysis - Power project

Emission Analysis

- (•) Method 1
- ( ) Method 2
- ( ) Method 3

Base case electricity system (Baseline)

Country - region	Fuel type	GHG emission factor (excl. T&D) tCO2/MWh	T&D losses %	GHG emission factor tCO2/MWh
Ghana	Oil (#6)	0.683		0.683

☐ Baseline changes during project life

Base case system GHG summary (Baseline)

Fuel type	Fuel mix %	Fuel consumption MWh	GHG emission tCO2/MWh	GHG emission tCO2
Electricity	100.0%	225,346	0.683	153,911.1
Total	100.0%	225,346	0.683	153,911.1

Proposed case system GHG summary (Power project)

Fuel type	Fuel mix %		T&D losses	Fuel consumption MWh	GHG emission tCO2/MWh	GHG emission tCO2
Hydro	100.0%			225,346	0.000	0.0
Total	100.0%			225,346	0.000	0.0
Electricity exported to grid	MWh	225,346	28.7%	64,674	0.683	44,172.5
					Total	44,172.5

GHG emission reduction summary

	Base case GHG emission tCO2	Proposed case GHG emission tCO2	Gross annual GHG emission reduction tCO2	GHG credits transaction fee %	Net annual GHG emission tCO2
Power project	153,911.1	44,172.5	109,738.6		109,738.6

Net annual GHG emission reduction 109,739 tCO2 is equivalent to 20,099 Cars & light trucks not used

D5: Financial analysis model

RETScreen Financial Analysis - Power project

Financial parameters

General		
Fuel cost escalation rate	%	5.0%
Inflation rate	%	2.5%
Discount rate	%	10.0%
Project life	yr	40
Finance		
Incentives and grants	$	0
Debt ratio	%	90.0%
Debt	$	123,502,103
Equity	$	13,731,354
Debt interest rate	%	5.00%
Debt term	yr	10
Debt payments	$/yr	16,004,450
Income tax analysis		
Effective income tax rate	%	25.0%
Loss carryforward?		No
Depreciation method		Declining balance
Half-year rule - year 1	yes/no	Yes
Depreciation tax basis	%	
Depreciation rate	%	
Tax holiday available?	yes/no	No

Annual income

Electricity export income		
Electricity exported to grid	MWh	225,346
Electricity export rate	$/MWh	64.30
Electricity export income	$	14,624,333
Electricity export escalation rate	%	2.5%
GHG reduction income		
Net GHG reduction	tCO2/yr	153,311
Net GHG reduction - 40 yrs	tCO2	6,156,443
GHG reduction credit rate	$/tCO2	0.00
Customer premium income (rebate)		
Other income (cost)		
Clean Energy (CE) production income		

Project costs and savings/income summary

Initial costs			
Feasibility study	0.2%	$	214,020
Development	0.2%	$	333,306
Engineering	33.7%	$	46,241,077
Power system	34.7%	$	47,602,477
Balance of system & misc.	31.2%	$	42,041,777
Total initial costs	#####	$	#########
Annual costs and debt payments			
O&M		$	324,000
Fuel cost - proposed case		$	0
Debt payments - 10 yrs		$	16,004,450
Total annual costs		$	16,328,450
Periodic costs (credits)			
Annual savings and income			
Fuel cost - base case		$	0
Electricity export income		$	14,624,333
Total annual savings and income		$	14,624,333

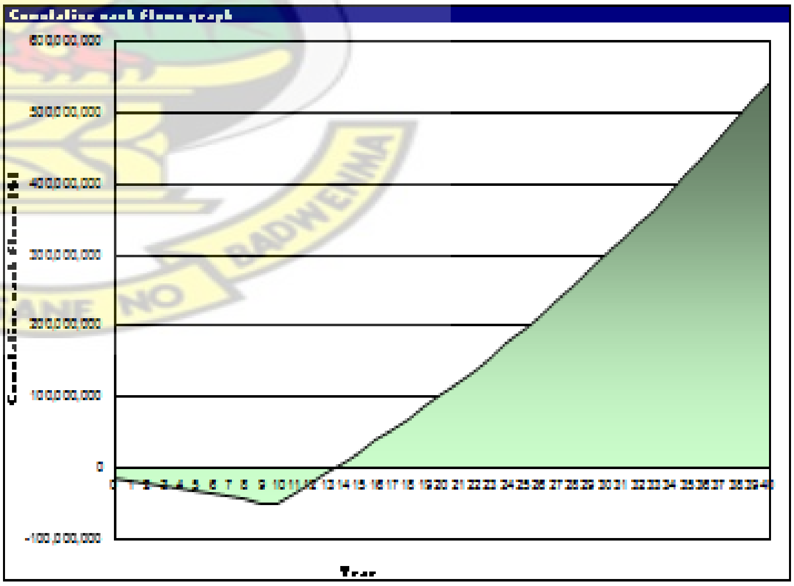
Financial viability

Pre-tax IRR - equity	%	13.7%
Pre-tax IRR - assets	%	7.2%
After-tax IRR - equity	%	13.7%
After-tax IRR - assets	%	5.2%
Simple payback	yr	10.0
Equity payback	yr	13.4
Net Present Value (NPV)	$	26,341,700
Annual life cycle savings	$/yr	2,693,600
Benefit-Cost (B-C) ratio		2.32
Debt service coverage		0.00
Energy production cost	$/MWh	52.70
GHG reduction cost	$/tCO2	(40)

Yearly cash flows

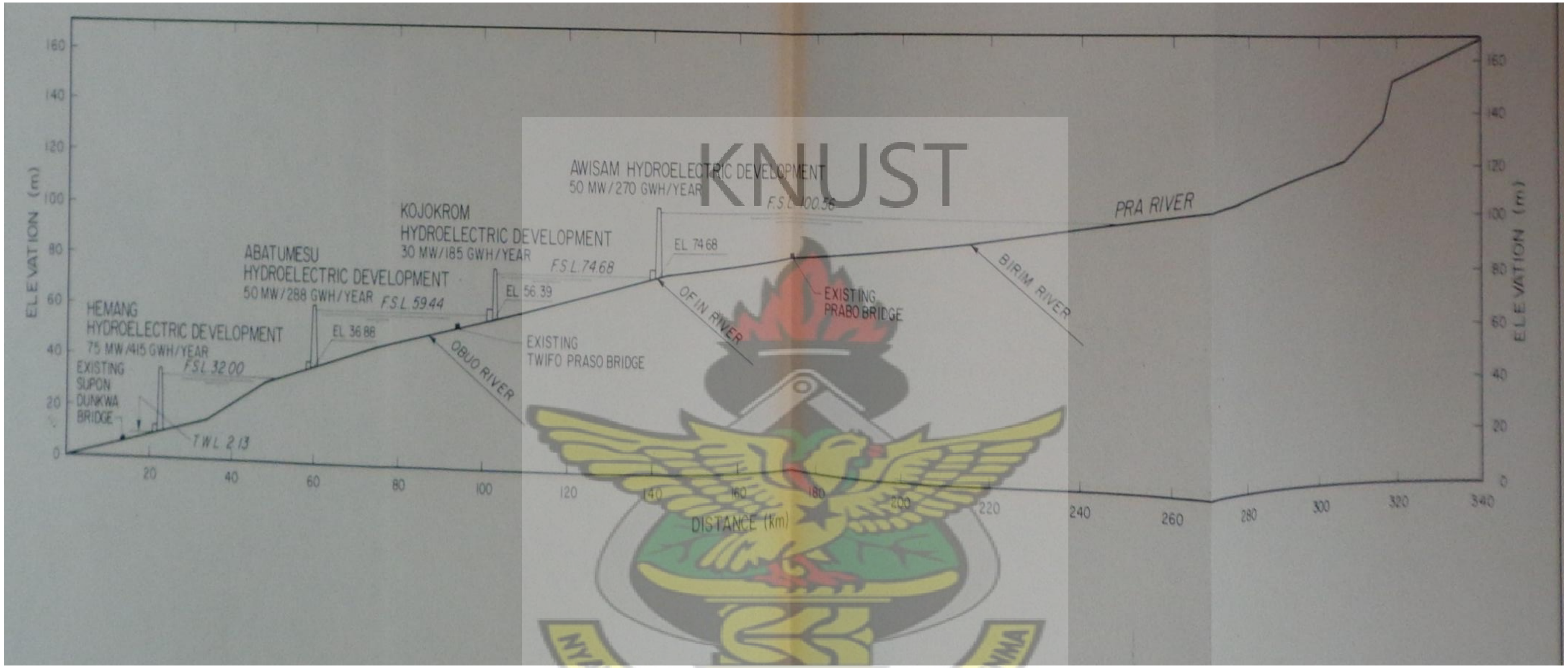
Year	Pre-tax	After-tax	Cumulative
#	$	$	$
0	-13,731,354	-13,731,354	-13,731,354
1	-4,361,002	-3,927,083	-17,658,442
2	-4,603,316	-3,786,531	-21,445,033
3	-1,250,052	-3,645,651	-25,030,604
4	-001,132	-3,504,411	-28,595,035
5	-503,110	-3,363,026	-31,350,121
6	-115,576	-3,221,660	-35,173,701
7	201,646	-3,000,433	-30,260,274
8	600,730	-2,333,715	-41,133,303
9	1,106,130	-2,733,532	-43,333,520
10	1,533,034	-2,660,165	-46,653,605
11	17,376,011	13,402,600	-33,177,076
12	10,426,231	13,013,674	-13,357,403
13	10,006,007	14,165,165	-5,132,237
14	13,353,053	14,513,235	3,327,057
15	13,043,036	14,002,277	24,203,334
16	20,333,112	15,254,334	33,463,660
17	20,047,530	15,635,632	55,033,360
18	21,360,773	16,026,505	71,125,345
19	21,302,333	16,427,243	07,553,134
20	22,450,574	16,037,330	104,331,424
21	23,011,030	17,250,073	121,650,003
22	23,507,134	17,630,351	133,340,354
23	24,176,013	10,132,603	157,472,363
24	24,701,233	10,505,325	176,050,000
25	25,400,764	13,050,573	135,103,460
26	26,035,703	13,526,037	214,636,237
27	26,606,677	20,015,000	234,651,305
28	27,353,044	20,515,303	255,166,603
29	20,037,630	21,020,260	276,134,356
30	20,730,633	21,553,374	237,740,331
31	23,457,030	22,032,024	313,041,755
32	30,133,526	22,645,144	342,406,033
33	30,340,364	23,211,273	365,630,172
34	31,722,073	23,731,555	303,403,727
35	32,515,125	24,306,344	413,076,071
36	33,320,003	24,336,002	430,072,073
37	34,161,203	25,620,302	464,432,375
38	35,015,233	26,261,425	430,754,400
39	35,030,614	26,317,361	517,672,361
40	36,707,073	27,530,310	545,263,270

Cumulative cash flows graph



E: Topographical Map and River profile

E1: Topographical map showing elevations around the Hemang hydropower site



E2: The profile of the Pra River showing other hydro sites on the river course and water levels on the Hemang size

F: RETScreen Computation relations

Power Capacity determination

Item	Designation	Formula
Design flow (maximum flow used by generating station) in m^3/s	D_q	User defined
Specific speed adjustment to peak efficiency	$\hat{}e_{nq}$	$\hat{}e_{nq} = \left[(n_q - 170)/700\right]^2$
Runner size adjustment to peak efficiency	$\hat{}e_d$	$\hat{}e_d = (0.095 + \hat{}e_{nq})(1 - 0.789d^{-0.2})$
Turbine peak efficiency	e_p	$e_p = (0.905 - \hat{}e_{nq} + \hat{}e_{nq}) - 0.0305 + 0.005R_m$ R_m is turbine manufacturing co-efficient (2.8 to 6.1; default 4.5)
Peak efficiency flow	Q_p	$Q_p = 0.75Q_d$
Efficiency at flows above and below peak efficiency flow	e_q	$e_q = \left[\left(\frac{Q_p - Q}{Q_p}\right)^6\right]e_p$
Hydraulic loss	h_{hyd}	$h_{hyd} = H_g l_{hydr,\max} \frac{Q^2}{Q_{des}^2}$
Tail water effect	h_{tail}	$h_{tail} = h_{tail,\max} \frac{(Q - Q_{des})^2}{(Q_{\max} - Q_{des})^2}$
Design power	P_{des}	$P_{des} = \rho g Q_{des} H(1 - l_{hyd}) e_{t,des} e_g (1 - l_{trans})(1 - l_{para})$ $\rho = Density = 1000\frac{kg}{m^3}$, $g = Acceleration\ of\ gravity = 9.81\frac{m}{s^2}$ H_g = *Gross head*, H_{hyd} = *hydraulic losses*, h_{tail} = *Tailrace effect associated with flow*, e_t = *turbine efficiency*, e_g = *generator efficiency*, l_{trans} = *transformer losses*, l_{para} = *parasitic losses*